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SECTION ONE
INTRODUCTION

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of Multipurpose Trees

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METHODOLOGY FOR THE EXPLORATION AND ASSESSMENT OF MULTIPURPOSE TREES (MPT'S)

Prepared by the International Council for Research in Agroforestry (ICRAF) in part in co-operation with the Commonwealth Forestry Institute, U.K. (CFI)

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Editor's Note

These source materials have been written and compiled, as far as possible to point out how the exploration and assessment of multipurpose trees differs from, or needs special emphasis in relation to, parallel activities with agricultural or industrial forest species. It is assumed that the reader has access to other manuals covering the basic concepts and practical guidelines for agricultural and forestry plant collectors and field researchers. In particular 'A Manual of Species and Provenance Research with Particular Reference to the Tropics, Burley, J. and P.J. Wood, 1976. Trop. For. Papers No. 10. Commonwealth Forestry Institute, Oxford, U.K. - as well as standard texts on experimental design and statistics.

In its present form this material is still largely "in draft" and comments and suggestions for improvement are welcomed. Citations may be made and they should designate individual parts and their author/s as well as the work as a whole. None of the materials may be reproduced or copied in any way without the express permission of ICRAF and/or the authors concerned.

A MANUAL OF METHODOLOGY FOR THE EXPLORATION AND ASSESSMENT OF MULTIPURPOSE TREES (MPT's)*

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* including Fast-Growing Nitrogen-Fixing Trees (FGNFT's).

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- remainder being drafted -

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A MANUAL OF METHODOLOGY FOR THE EXPLORATION AND ASSESSMENT OF MULTIPURPOSES TREES*

- SYNOPSIS -

Please refer to the individual Parts when quoting authorship.

Figures 6, 7, 8, 9,and 10 are reprinted from Wright, H. L. and I.A, Andrew, Principles of Experimental Design in Burley, J. and P.J. Wood (Eds) *A Manual on Species and Provenance Research with Particular Reference to the Tropics*. Tropical Forest Papers No. 10 pp. 226. Commonwealth Forestry Institute, University of Oxford, UK.

This manual on multipurpose trees assumes that the reader has access to the basic information concerning research on forest tree species such as that contained in the CFI manual quoted above.

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* including Fast-Growing Nitrogen-Fixing Trees.

Introduction and General Considerations

Part 1A

Summary statements

Multipurpose trees/shrubs (including Fast-growing Nitrogen-fixing species) can be useful in many types of land use systems where they may be grown as communities or as wide spaced specimens either alone or with other types of woody perennials, herbaceous crops and grasses.

Key questions:

1. What is it about the ways that MPT's may be used and managed that demands a somewhat different kind of investigative approach to that normally undertaken by a forester or an agriculturalist? and 3A

2. More particularly, what factors should be taken into consideration with regard, not only to the technical, but also the managerial and socio-economic constraints that may be imposed? and 6A

- We still know relatively little about many MPT species, especially with regard to their ecozone and/or site adaptability, their capacity to promote sustainability, and the ways in which they can best be managed, especially so as to share environmental resources in crop mixtures.

  Parts 3E
  4A
  4B
  4C app 1-3
  6B

- In view of the large number of questions that need to be answered research programmes should be carefully planned so as to produce information as quickly and as cost effectively as possible.

  1B
  3A

- The factors listed in Table 1 are intended as an aide memoire covering most points that need to be considered in evaluating MPTs for agroforestry landuse of one kind or another.

- see also 6C 'A Glossary of Terms'

Table 1. SOME CHARACTERISTICS OF TREES (AND OTHER WOODY PERENNIALS) FOR CONSIDERATION IN AGROFORESTRY.

Technical	*Managerial*	*Socio-economic*
GERMPLASM		
• Is this species outbreeding and the germ plasm therefore hetero-zygous?	- Does a mixture of genotypes matter? - Is germplasm easily and cheaply available? And through what sources?	Can the land user collect and/or distribute his own seed? Or does he have to buy it?
• Are there seed viability problems? If so, does it pay and are there facilities to investigate them?	Will someone have to carry out seed testing? If so, are the necessary skills and equipment available?	Can a farmer easily store seed? Does this put up the cost of seed?
• Are there seed dormancy problems? If so, does it pay and are there facilities to investigate them?	Is any special equipment or technology required to break seed dormancies?	Does this hinder adoption?
• Are seeds commonly attacked by pests and/or diseases?	Are special storage facilities or conditions required?	Will this be a major hindrance to issuing farmers with seed?
• Are there specific seed-borne diseases?	- Is any special treatment of the seed required? - Will the land user have to watch out to eradicate these diseases or treat young seedlings?	Will the land user need special help or advice? And will this be effective and/or costly?
• If tree seeds are not the best or most convenient method of propaga-tion, then what other materials can be tried?	Are the skills and equipment avail-able for collecting and storing propagules (cuttings, bud wood, etc.). Will there be problems asso-ciated with using clones, for example, viruses?	What are the comparative costs? And does the farmer already have experience in handling cuttings etc.? (And see next section.)

Table 1 continued

Technical	*Managerial*	*Socio-economic*
PROPAGATION		
• What methods of propagation are available? (And see above.) Seeds; cuttings; budding and grafting; tissue culture, etc.	- What facilities are there for establishing nurseries and distributing plants? - What types of nursery are best? Central, village schools, commercial, etc. - What skills/labour/materials are there for setting up nurseries and distributing plants? And what national organisations and/or infrastructure can help?	- What are the relative cost advantages of direct planting vs using nurseries (transplants and container grown plants)? - What propagating method best suits the land user? - What will the costs be of using different methods?
• What are the specific environmental requirements for germinating seeds and/or rooting cuttings, etc., and for early seedling growth?	Are the facilities (labour and skills) available?	Will the land user easily understand the requirements?
• Are there requirements for seed inoculation (rhizobium, mycorrhizal fungi)?	Will this be done 'on-farm' or for issued seeds?	Will seed be sown in time, and with care, so that inoculation is effective?
• Are there specific pests and diseases in the nursery phase?	Are special procedures involving materials and skills required?	Will the land user suffer severely from a failure to control these properly?
• What is the likely (and optimum) duration of the nursery phase?	Can the nurseries supply plants - when the farmer wants them, and	What are the costs of seedlings? What are the costs of maintaining unsold/undistributed plants?

Table 1 continued

Technical	*Managerial*	*Socio-economic*
	- for as long as he wants them in sufficient quantities and of a type which will survive the distribution and planting systems available?	
PLANTING OUT		
• What are the soil/environmental conditions needed? What is the best season? And are there special soil conservation requirements in this phase?	What site preparation problems are there?	How does it fit in with labour availability and other family needs?
• What is the optimum plant size, and condition, at planting out? (See also above.)	Are proper handling facilities available, and the necessary skills?	Can the necessary care be given?
• Is shelter/support required for the young plants?	What is the easiest to arrange? For example, what local materials are available?	Will the farmer bother? Can he afford it? Will he maintain and manage it and finally remove it?
• Do the young plants need watering, fertilizing or mulching?	Can it be provided?	What is the cost and likelihood of the land user adopting these procedures?
• Are pests/diseases/weeds likely to be a problem (and animals/birds)?	Are special chemicals or protective methods needed?	What cost? How does it fit with labour requirements and available skills?

Table 1 continued

Technical	*Managerial*	*Socio-economic*
JUVENILE PHASE		
• - What is the morphology and early growing habit of the species? - How does it respond to training/pruning, and what growth responses are there from buds of different kind?	- Does this affect crops growing nearby? What are the tree/crop interactions? - What training is possible and desirable? - Are plant training skills available?	Will the land-user understand what is required? What are the costs of training vs not training?
• Is the species slow or fast growing in its early stages? (See also above.)	If slow growing will this increase the burden of management operations?	Will a slow growing species be acceptable, however useful and productive later?
• What are the rooting characteristics of the tree species?	- How does this affect management practices (watering, weeding, fertilizing)? - Do early, deep-rooting characteristics affect associated crops and what are the tree/crop interactions at below-ground level? - Will this affect choice of site?	Is the land user prepared to allocate a special site to the trees if needed?
• Is the tree palatable? What is the need for animal protection?	- Are there any effects on animal production if browsing is restricted? - Are people, methods, etc., available for animal protection measures?	- What are the land user's habits with regard to his (or others') browsing animals? - What are the 'costs' of protecting the trees from animals?

Table 1 continued

Technical	*Managerial*	*Socio-economic*
• What are the plants' requirements and responses to shade/shelter, watering, fertilizing, weeding?	What materials, labour and skills are available?	- What are the costs/benefits? - What is the likelihood of adoption of these techniques? What will happen if this is not done?
• What is the duration of the time to flowering/fruiting? (Is the species being grown for fuits?)	What management procedures can be adopted to induce early flowering?	How does this affect incentives to plant?
• How susceptible is this tree species to pests and diseases?	What materials and skills are required?	Will a failure to control these end in disaster?
• What is the phenology of this species? How does this affect the associated crop plants?	How do the time-of-planting restraints and/or other management factors affect the overall management plan, especially with regard to the associated agricultural crop?	How does all this fit with labour availability and social needs?
MATURE GROWTH PHASE AND PERIOD OF MATURITY		
• - What are the morphology and branching habit? - What is the phenology? · shoot dormancies and growth regulation · leaf flush/leaf fall sequences · flowering and fruiting cycles · general source - sink relationships	- Are skills/labour available to deal with training/pruning? - What are the tree/crop interactions implicit in the trees' morphology/phenology and cropping sequences?	- Are there any land user preferences? - What effects are there on the land user's immediate environment (does he want shade/shelter)?

Table 1 continued

Technical	*Managerial*	*Socio-economic*
• Competitiveness (from morphology, etc., above).	What possible operations (for example, lopping) might reduce this and what are the timings?	- What does the land user see as his needs to 'control' the tree? - What are the costs/benefits of doing so?
• Harvestability (single, terminal harvest/sequential harvests).	How does this fit into the pattern of farming operations?	How does this fit into social requirements or market opportunities?
• Needs for weed control.	- Is the necessary labour/equipment available? - How does this fit in with weed control timing and methods for the agricultural crop?	- What methods are best suited? - Will the land-user adopt some form of weed control? - What is the cost/benefit to him?
• Soil management and soil conservation.	- Is the necessary labour/equipment available? - How does this fit in with weed control timing and methods for the agricultural crop?	- Does the land user perceive a need? - Will the land user adopt the appropriate soil management? - What is the cost/benefit to him?
• Pests and/or diseases	- Is the necessary labour/equipment available? - How does this fit in with weed control timing and methods for the agricultural crop? - Can advice be obtained?	- Does the land user perceive a need? - Will the land user adopt the necessary control measures? - What is the cost/benefit to him? - Will there be a disaster if he neglects pest control with these species combinations?

Table 1 continued

Technical	*Managerial*	*Socio-economic*
• Biennial (seasonal) bearing - for fruiting crops.	Are the necessary skills and understanding available to obviate this?	To what extent do variations in seasonal output affect the land-user/markets?
SENESCENCE AND REPLANTING PREPARATIONS		
• What is likely time of onset of ageing/senescence?	What decisions have to be taken on how to remove trees?	How will the land-user perceive the need to remove trees?
• What is the duration of this phase and its effects?	Especially on associated agricultural crops and farm management?	- What are the effects of declining productivity? - Is there a need for credit/help or alternative sources of income?
• What are the options for technical solutions to final harvesting sequences and/or tree removal?	What are the effects on adjacent crops and on the soil?	Are there alternative choices of how to dispose of the trees?
• Are there pests/diseases associated with cutting down trees (including general and specific replant problems)?	Is the knowledge of what to look for available?	Is there a willingness to take care?
• What land preparation is required for replanting?	- What place does this occupy in the whole farming programme? - What is the availability of labour for this?	- What costs are there? - Are there any social implications?
• What crop/soil management is required in the transition period before replanting trees?	What labour/resources are needed, especially for soil conservation in this period?	- Is there a willingness to adopt a sound plan? - Are there any extra costs?

The choice of MPT's, their exploration and collection

Part 2A

Summary statement

The choice of MPT's rests on their ultimate end use and biophysical requirements. see also 4B

The objective of exploration is to sample along ecological gradients (and to take into account any other kind of selection pressure), so as to obtain properly documented, source-identified reproductive material and information for the evaluation phase.

Trees for industrial use are typically pioneer species, wind pollinated, outcrossing and heterozygous. By comparison much less is known of the breeding systems and genetic structures of MPT's, which probably include inbred as well as outcrossed populations.

Key questions

1. If we are to avoid gene loss what kind of sampling procedures should we adopt?

2. Exactly what do we need to know about MPT's, bearing in mind that the range of such information will be greater than when selecting industrial species? 1B 3A 4A

3. Sampling and evaluation is a re-iterative process, but exactly what is entailed at the sampling/collection stage?

(see also CFI Sections 2 & 3)

- Genetic adaptation should be assessed within the geographical range and particularly with regard to sites which are "difficult", ecologically extreme, or where there has been some consistent selection pressures by man, animals, insect pests fire etc. Note that for any particular characteristic selection can be dysgenic (e.g. harvesting the best samples and leaving the poorest to interbreed or eugenic (disposing of poorer specimens in a population).

- Distinct "land races" (i.e. separate interbreeding populations) may have evolved where the new environment has exerted selection pressure on an introduced species.

- The following information is required both from the field and from documental sources such as are found in herbarium, forestry department etc.

  - daylength precipitation (pattern, distribution, amount), and mean and extreme temperatures;

  - soil extremes: salinity/alkalinity, impended drainage;

  - the incidence of fires, floods;

  - details of the phenology of the species and, in particular, pollination and seed maturation/ dispersal times.

- Site selection is a reiterative process. Stratified site selection may be used where no prior knowledge exists, to be modified as the status of the species, the results of trials, and special roles for trees and shrubs in land use systems become better known.

see also 2A app.11

Data specifically required for each seed lot Part 2A

- In addition to the basic collection site information (above) the following is required:

  - date of collection and personnel involved;

  - specific location and comments on access;

  - altitude;

  - relief, including aspect, forest-hollows, position on a slope etc.;

  - soil characteristics at the site and any indication of soil conditions (water table, plant rooting depth, geological formation and forest materials etc;

- Tree characteristics

  - capacity for production of identified outputs/benefits;

  - variability as an indication of inter- and intra-specific relationshops.;

  - characteristics relevant to multiple cropping, including possible allelopathy and competition for water and light;

  - details of any specific phenophases (particularly if different from adjacent species);

  - associated vegetation;

- Collect also, as needed,

  - good photographs (an efficient way of recording much information);
  - herbarium specimens;
  - live root specimens and/or soil to examine for organisms;
  - gums, resins etc.;
  - wood samples.

. information on local management practices;

. status regarding genetic conservation;

. information on fodder potential (but there are great seasonal variations in foliar nutrients and other chemicals affecting digestibility and palatability of leaves. (and see 3E)

- Within any one site (or group of sites) seed or other forms of propagules should be collected so as to cover:

  . clinal genetic variability

  . any outstanding individuals (for selected characteristics)

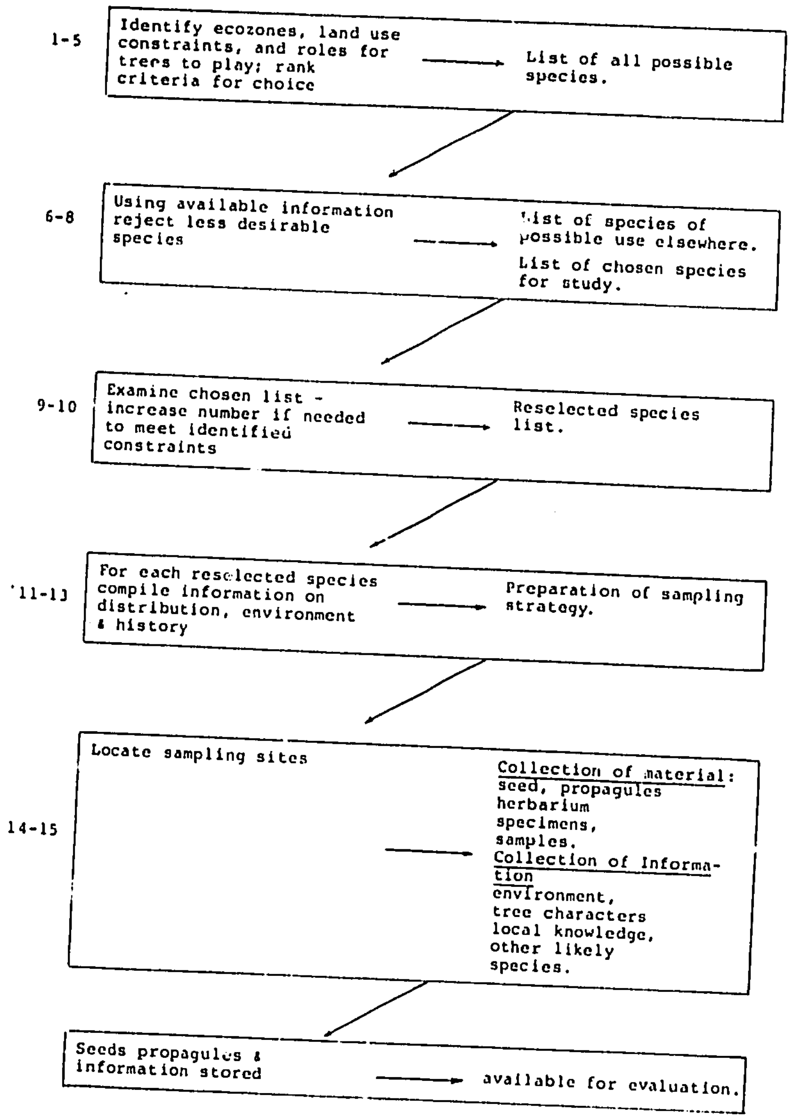
- The number of parent trees in each seed lot must be noted (for a provenance this would ideally be 25-50). If possible individual tree collections should be kept separately.

- Great care is needed in *labelling* containers, inside and out; use ventilated containers unless seed is really dry and apply insecticides fungicides, as appropriate.

Figure 1 gives an outline of the main stages in the choice, exploration and collection of MPT's. see flowchart in 2A

Figure 1: OUTLINE OF MAIN FLOWCHART SEQUENCES FOR SELECTION/COLLECTION OF MPT'S

Steps — Process — Results



Guidelines for Collecting Root Nodules

Part 2C

- The exceptional performance of a leguminous tree in a particular ecological niche may be because of an effective match between the tree host and a specific strain of *Rhizobium*.

- Both when collecting leguminous tree germplasm and when introducing it and assessing it in new areas the presence and/or need for this symbiosis should be borne in mind.

- Nodule *(Rhizobium)* collection should be undertaken as a routine procedure by all germplasm collectors.

  The following are some guidelines:

  - Preparation for the collecting trip

    . select time of vegetative growth and adequate soil moisture (this may entail a seperate expedition - so specify accurate site location);

    . for short trips samples can be stored in polythene bags, for up to 2-week trips collecting bottles.

  - Collection procedures

    . for a selected tree look for nodulated roots in any surface litter, or on adjacent seedlings;

    . otherwise retrieve a sample of soil (10-20 g);

    . check in literature whether species has been reported to nodulate (or is a new record).

- excavate nodulated root together with adhering soil and pack firmly in a polythene bag or (for longer trips) take a nodulated root segment temporary in a plastic bag with moist soil and transfer to a nodule collecting container;

- deliver sample to laboratory (on same day if possible)

- on mature trees nodules will be found on fine roots (sometimes a long way from the trunk), dig for them do not pull roots out of the soil but excavate to them gently;

- sample only fresh, firm nodules

- when taking nodulated root segments cut (with a sharp knife or scissors) about 0.5cm on either side of the nodule, pulling the nodule off will damage it and allow contaminants in;

- if washed blot off excess water;

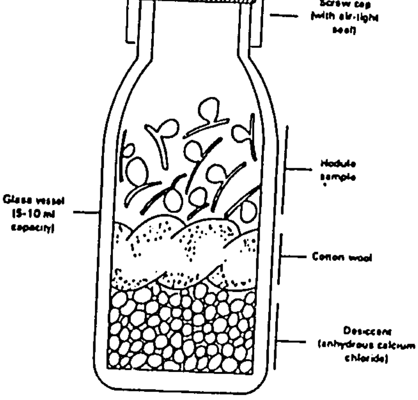
- put all nodules from same tree in a separate container and label; (Figure 2)

- surface sterilize the *outside* of sealed containers with nodule samples before delivering them to a laboratory (they would have been sterilized inside before taking them to the field)

- Documentation

  - similar to that for collecting seeds and see 5B

Figure 2:



Vessel for storing nodules.

General Considerations for Evaluation of MPT's

Part 3A

Summary statement:

There are many species of MPT's that are potentially useful, but little is known about the ecozones and site adaptability of many, or about the best ways to manage them for the production of selected outputs.

Key questions:

1. How can such information be obtained as quickly as possible, and in a cost-effective way? 1B

2. What steps are needed in planning a research programme to evaluate MPT's? see flowchart in 3A

Apart from the usual steps to be taken in formulating and implementing any sound programme of investigation, research work with multipurpose trees requires special considerations of the following points:-

- Where little information is available about a species every attempt should be made to obtain data in the Exploration Stage that will be useful later during assessment. — and 2A 2B

- Stages in research planning that are of particular importance are:

  - A review of existing literature which for many species, may be extremely scanty.

  - A choice of species and/or provenances to test; for woody species with multiple outputs which may be grown with other kinds of crops this requires careful thought. There should be a careful check on the taxonomy and the validity of the germplasm acquired for assessment. — and 1B 3A 4B 4C

  - Because of the long time scales involved a plan for the whole investigation is needed that assembles information from various sources. These should include simple field trials and experiments each of which has relatively easily-achieved goals. These steps must be dealt with in sequence but they can overlap to some extent so as to shorten the time needed for obtaining the information that is sought.

  - Because of the increasing interest in MPT's for a wide range of production and services functions research objectives have to be very closely associated with national and/or regional requirements.

- see also Table 2

Part 5A deals with the ways that controlled (or modified) environments can assist with field or nursery investigations.

Design of Experiments

Stating the objectives

1 Have you stated clearly and explicitly the objectives of the experiment and the reasons for undertaking it?

2 Have you translated these objectives into precise questions that the experiment can be expected to answer?

Defining the population about which inferences are to be made

3 Have you defined carefully the population about which you are seeking to make inferences from the results of the experiment?

4 Is the site or location of the experiment representative of that defined population?

5 If not, what do you need to do to find a representative site?

6 Is the experimental material to be used in the experiment, e.g. plants, animals, soil, water, etc., representative of the defined population?

7 If not, how can representative material be obtained?

8 If either the location or the experimental material is not representative of the population about which you wish to make inferences, is it worth doing the experiment at all?

Selection of experimental treatments

9 Have the experimental treatments been defined sufficiently precisely for them to be applied correctly by the experimenter or by those wishing to repeat the experiment, and are they realistic?

10 If the "treatments" consist of species, varieties, or strains of organisms, are they representative of some defined population of organisms?

11 Can the experimental treatments be expressed as "factors", that is as groups of treatments at two or more levels?

12 If so, can all combinations of factors be achieved and are these combinations realistic?

13 Is the number of levels within each factor restricted to two or three?

14 If not, is there any real advantage in using more than three levels to determine the shape of the response curve?

15 Do the levels of any one factor change by a constant amount or in a constant ratio?

16 If not, is there a good reason for departing from linear relationships, or relationships which can be made linear by an appropriate transformation?

17 Is the number of factorial combinations so large that there would be some advantage in considering only some of those combinations, perhaps sequentially?

18 Is there a naturally defined control treatment which should be included in the experiment?

1

Plot shape and size

19 Is the plot size for the experiment defined by the nature of the experimental material or the site?

20 If not, will the proposed plot size enable the treatments to be applied and allow the desired records to be made?

21 Is the plot shape defined by the nature of the experimental material or treatments?

22 If not, will the proposed plot shape enable the treatments to be applied and allow the desired records to be made?

23 Are the experimental plots all of the same size and shape?

24 If not, are you aware of the problems that may be encountered during the analysis of the results of the experiment?

25 Is there likely to be interaction between the individual plots of the experiment?

26 Can this competition be reduced by increasing the space between plots, or surrounding each plot by a buffer zone?

27 Are the plots of the experiment of the smallest size consistent with the other constraints?

Number of replications

28 Do you have any preliminary estimates of the precision likely to be achieved by the experiment (expressed as a coefficient of variation, for example)?

29 Is it possible to conduct a pilot experiment to determine the coefficient of variation likely to be encountered, and to test the experimental procedures?

30 Have you determined the size of the difference between treatment means which you would regard as of practical importance, if such a difference were to exist?

31 Have you calculated the number of replications that would be necessary to match the size of the differences likely to be detected as significant with the size of differences you regard as of practical importance?

(E.g. $N = (\frac{c}{s})^2$

where N = number of replications
c = coefficient of variation
s = standard error of means)

32 If there is insufficient land or experimental material for the number of replications required to give significant differences of practical importance, is it worth doing the experiment at all?

33 Do the controls need to be replicated more or less frequently than the other treatments, in order to place greater emphasis on particular comparisons?

Layout of the experiment

34 Is it possible to divide the site of the experiment or the experimental material into blocks within each of which there will be less variation than over the experiment as a whole?

35 Is the size of these blocks sufficiently large to contain at least one plot of each treatment and controls?

2

Table 2 Statistical Checklist "Design of Experiments" by J.N.R Jeffers. Institute of Terr.Ecology U.K.

36 Have you considered the advantages of robustness and ease of analysis of a randomized block design?

37 If the blocks are not large enough to contain at least one plot of each treatment and controls, is there some way of allocating the treatment replications so that the important comparisons are estimated with the greatest precision?

38 If the treatment comparisons are not orthogonal, do you know how the data can be analysed, and will that analysis answer the questions the experiment is designed to pose?

39 Are there any regular trends across the experimental site or material? If so, are these trends in one or both directions?

40 Have you considered the use of row and column designs to remove the effects of one or two-way trends?

41 Is there likely to be any advantage in the use of a split plot design?

42 If so, are the treatments applied to the sub-plots the ones for which the greatest precision is required?

43 Will confounding of treatment factors or interactions with block differences improve the efficiency of the design?

44 Have you planned to use the blocks of the experiments to absorb as much as possible of the extraneous variation in the execution and conduct of the experiment?

45 Is it possible that plots may be lost through accidents or mishaps?

46 If so, does your choice of experimental layout allow for a meaningful interpretation of the results?

Randomization

47 Have the treatments and controls been allocated to the plots of the experiment by an explicit randomizing procedure?

48 Was a separate randomization carried out for each block or row of the experiment?

49 Were the constraints on the randomization correctly applied?

50 Were you tempted to re-randomize any part of the allocation of treatments and controls to plots because of apparently unfortunate coincidences?

51 If so, do you have some knowledge of variation in the site or experimental material which has not been incorporated into the design of the experiment?

52 Does a plan exist, showing the allocation of the treatments and controls to the individual plots?

Recording of results

53 Does each plot of the experiment have a clear number or designation, linking it unambiguously to the plan of the experiment?

54 Have you defined the time intervals at which assessments of the experimental results are to be made?

55 Have you defined the variables or attributes to be counted or measured at each assessment?

56 If so, are the measurements meaningful and relevant to the objectives of the experiment?

57 Are any of the assessments to be made from samples of the experimental plot rather than from the whole plot?

58 If so, has the efficiency of the sampling been tested?

59 Are any of the assessments to be used as covariates to correct for unavoidable but measurable differences between the plots?

60 If so, will these assessments need to be made before any of the experimental treatments are applied, or can take any effect?

61 Have you planned to use the blocks or rows of the experiment to absorb any unwanted variation in assessment, e.g. different observers, assessments on different days or at different times of the day?

62. Have you designed a record form which will ensure that all assessments are complete and are recorded against the correct plot?

63 Have the assessors been trained to measure and count the variables or attributes efficiently and accurately?

64 Is there space on the record forms for observations to be recorded of unexpected changes or effects, and have the assessors been encouraged to look for these effects?

Planning for analysis

65 Have the hypotheses to be tested in the analysis of the results of the experiment, and their alternatives, been defined *a priori*?

66 Are these tests expressed, as far as possible, as null hypotheses?

67. Have any special contrasts to be tested or estimated in the analysis been defined in advance of a first inspection of the results of the experiment?

68 Do you understand the methods of analysis that will need to be used for this experiment and made arrangements for the computations to be done on a computer, or elsewhere?

69 If the computations are to be done on a computer, does the necessary program exist, and do you understand the constraints that the program places on the data set?

70 If not, have you obtained advice from a qualified statistician on the analysis and interpretation of the results, preferably before starting on the experiment?

The final (and most important) question

71 If you are in doubt about the purpose of any of the questions in this checklist, should you not obtain some advice from a statistician with experience of your field of research before continuing with the experiment?

There is usually little that a statistician can do to help you once you have committed yourself to a particular experimental design

Table 2 Statistical Checklist " Design of Experiments". by J.N.R Jeffers. Institute of Terr. Ecology U.K. (cont')

Assessment of Experimental Sites

Summary statement

Because any MPT species will be grown over a wider range of sites and management situations then other plantation species, the selection of sites needs especial care. They must be representative of areas where MPT's are to be used, it must be possible to correlate environmental conditions with the performance of the germplasm under test, and the number and kind of sites chosen must permit extrapolation of conclusions reached to other unplanted sites.

Key questions

1. What is known about the classification of land systems in the chosen area? And do we know enough to select sites for testing MPT's so as to cover all the major ecozones? and 2A app.11

2. Are resources available to undertake any further land and soil surveys and/or climatic measurements that may be needed?

3. Will the site permit the testing of any special management techniques required for MPT's?

(see also CFI Section 3)

Location and number of sites

Each proposed experimental site should be selected in terms of the detailed land classification for the area which will consist of *land systems* ("an area, or group of areas throughout which there is a recurring pattern of topography,soils and vegetation") and *land units* or *land facets*("an area of land with characteristics combination of soil topographic, climatic and biotic factors"). The latter is a unit whose size and characteristic depends on the variability.

Ideally, a trial should be established in each of the land unit or land facet categories. However, facilities seldom exist for such comprehensive coverage. The following criteria should be used to establish priorities.

- Choose only the most widely occurring categories of units
- Select categories of units which are representative of areas where trees are expected to provide the most significant benefits.
- Selected categories of units from as wide a range of eco-climatic situations as possible.
- It may be advantageous to have trial sites close to existing climate recording centres, and sites where frequent environmental and performance measurements are to be made *must* be readily accessible.

Environmental factors

Classification and interpretation is based on the following environmental parameters:

- climate
- relief, including position on slope
- rooting depth in soil
- soil parent material
- existing vegetation

also see 2A app. 5 & 6 and 3E

Alterations of site management

It is important to record changes of site through the establishment or affects of:

- micro-catchments
- terracing
- drainage
- irrigation
- cultivation
- weeding
- mulching
- fertilizers, manure
- pesticides, herbicides.

The Scope and Design of Field Trials

Part 3C

Summary Statement:

Multipurpose Trees can fulfil both production and service functions. Because they produce multiple outputs their selection and assessment demand a more complex series of experimental tests than plant species grown for a sole product or purpose.

Key questions to be answered:

1. In planning field trials is the objective to study free-standing or community-grown plants?

2. What information can be obtained by first studying single tree specimens?

3. With space-demanding plants such as MPTs how should control over experimental site variability best be managed?

and see 3C
supplement 1
supplement 2
(CFI Section 4,5&6)

Points to note

- Most genera of MPTs, with the exception of a few (e.g. *Leucaena*) are outcrossing and, therefore, their germplasm is highly heterozygous This implies that the number of plants selected for study must be adequate. and 1B 2A app.10 4B

- For investigations on survival/ adaptability and even vigour/ phenology the *extent* of variability is an important factor to assess. Single tree plots may be suitable (or small numbers of well-spaced trees in lines, as long as community-imposed stresses are not to be tested. (These may be looked into later in combination with management variables e.g. lopping, pruning).

- On-station trials can usually be better supervised and assessed, but on-farm trials often offer a wider choice of sites. They also incorporate farmer evaluation, and some early opportunities for testing adoptability - both aspects of importance with newly-introduced species. 3C app.4

- For MPT trials the usual ways of dealing with locational variability and plot size are valid. It is especially necessary to reduce variability as much as possible by:

  - choosing a homogeneous site

  - considering the genetic diversity of the germplasm, the types of treatments to be imposed, and whether juvenile (more variable) or mature (less variable) stages are to be examined

  - considering the management to be applied and the resources available

  The 49 tree plots frequently used by foresters may well contain too few plants considering the likely variability of the germplasm.

- Guard rows may need especial consideration because of the size and geometry of mature trees and, especially where management treatments (spacing, fertilizer application etc) can affect adjacent plots.

Table 3 lists the types of field trials related to the different stages in a full investigation with MPT's

Figure 3 Outlines the steps for implementing a whole programme

Table 4 Indicates the choices available for selecting actual field layouts for any stage of the investigation.

(Part 5C gives some information on herbicides for use with MPT's)

Steps	Forestry Trial Phases: Nomenclature	Forestry Trial Phases: Scope	Multipurpose Tree Trial Phases: Nomenclature	Multipurpose Tree Trial Phases: Scope
10	Species elimination trials and Range-wide provenance sampling trials	Mass screening in small plots or lines - short-term	Elimination trials	Mass screening in small plots - short-term
11	Species testing trials and Restricted provenance sampling trials	Reduced number of promising accessions only, in larger plots - longer-term	Vigour/phenology trials	Reduced number of promising lines of anything from single tree plots up. Especially to study plant behaviour with a view to helping assess potentials for selection (later) of plant management techniques and for preliminary assessment of output potentials ("multipurpose" traits).
12	Species proving trials and Provenance proving trials	Few selected accessions, large plots and long-term	Performance/management trials	Few selected accessions in either: a) single tree plots (if for wide-spaced systems) and/o. b) Small to large plots (if for "crop" situations)
16	Not strictly applicable except, perhaps, trials on suitability of taungya-type plantation establishment methods	-	Screening intercropping trials	Tree/crop interface trials
			Management intercropping trials	Full scale plot trials with intercrops.

TABLE 3 APPROXIMATE EQUIVALENCE OF TERMS USED TO DESCRIBE CONVENTIONAL FORESTRY FIELD TRIALS AND MPT FIELD TRIALS AS DESIGNATED IN THIS MANAUL)

Figure 3 OUTLINE OF MAIN FLOWCHART SEQUENCES
(see back of this chapter for the flowchart itself)

Steps	Process		Results
1 - 5	Information and germplasm acquisition	→	Selected choice of indigenous and exotics.
6 - 9	Decide on experimental objectives and match to available resources	→	An experimental plan
10-12	Commence field trials to test HPT species and provenances in a logical and properly phased manner	→	Sufficient research information concerning survival, adaptability vigour and productivity in relation to site and chosen levels of management
13	Evaluation of the HPT information and experimental evidence to data	→	Decision to go on to mixed cropping trials or acquire more information about the HPT's first.
14-17	Examine and update, if necessary, information about other crop components and likely between plant component interactions. Carry out screening trials with mixtures, then more detailed management trials	→	Determination of suitable HPT/crop species mixtures and a knowledge of how to manage them so as to optimize required outputs
18	Feasibility and acceptability trials with landuse systems	→	Leading to adoption

Table 4 Selection of approaches for MPT trials of various kinds.

Degree of control over local environment variation	Type of study requires: Single plants	Type of study requires: Community-grown plants
None *or* Minimal	Well-spaced fully randomised (individual or lines)	Simple replicated plots *or* systematic designs
Definitely required	Single tree plots	Multiple tree plots
	arranged in: • Randomized complete blocks • Latin squares • Rotating designs (e.g. Augmented layouts) Consider raising efficiency and/or effectiveness by the use of: • Partial replication (e.g. Lattice designs) • Split plots/factorial arrangements • Covariance/Nearest neighbour analyses	

This is discussed below:

Briefly:

- Well-spaced fully-randomized individuals are:

  - useful for elimination/ survival trials and where local environmental variation is minimal; 3C app.5

  - very cost effective to observe growth and phenology of newly-introduced species;

  - not suitable where there are marked differences in plant size and/or form or locational variability;

  - flexible statistically. - see Fig.4 and Table 5

- Simple replicated plots (or lines) are:

  - good for handling limited amounts of plant material and may have advantages for demonstration purposes;

  - otherwise, similar to above.

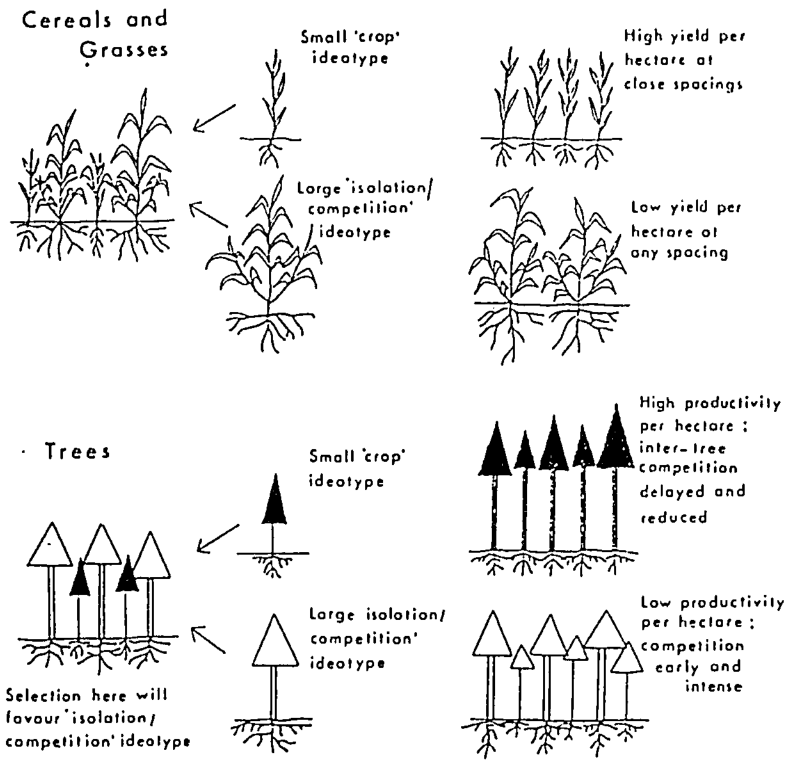
- Single *versus* multiple tree plots very space-saving but:

  - choice depends on purpose of trial and nature of plant material, valuable for studying plant behaviour but no use to assess yields of a MPT "crop"; - see Fig.4

  - single tree plots are useful with clones (or in-breeding species), less so for out-breeders when a greater number of replication are needed, anyway.

- Randomised Complete Blocks/Latin Squares -see Fig. 6,7,9 and 10 and Table 5.
  - can help account for spatial variability, differences due to time-imposed factors (e.g. planting-out), or in source material (e.g. graded seedlings), but only if these are known and allowed for in blocking (or in the two-way assemblage of rows and columns in a Latin Square, or some other row and column design).

Figure 4.



Possible differences in the performance of various ideal plant types (ideotypes) as spaced individuals (centre), in mixtures (left) and in stands (right) (after Donald 1968; Donald & Hamblin 1976). Note that (a) relationships between individual plant performances and per hectare productivity after canopy closure can be negative (Hamblin & Powell 1975), (b) 'isolation/ competition' ideotypes may tend to be selected if the criterion is plant size, and (c) selection for 'isolation/competition' ideotypes may lead to a desirable early spread in tree size frequency distributions.

From Cannell, M.G.R. (1978).

Figure 5

Fully Randomized Layouts

(with or without equal sample numbers)

Either as multi- or single-tree plots this can be a very flexible layout to use with MPT's, especially in early testing of species and/or provenances. There needs to be minimum spatial variability (e.g. in soil fertility) over the experimental area, but the design can handle samples of different sizes.

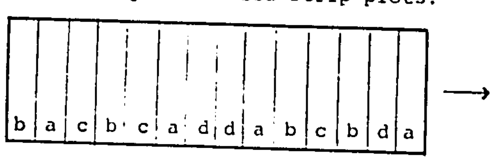
Replicates

5 a's
8 b's
7 c's
9 d's
7 e's
10 f's
5 g's
9 h's

Single trees

a	g	h	b	f	c	e	d	b	f	b	e
b	f	d	c	e	b	f	f	a	g	c	d
f	g	a	h	f	g	h	c	e	b	f	a
d	c	h	d	h	a	f	d	g	d	c	e
d	h	c	h	e	h	b	h	b	e	f	d

or fully randomized strip plots.



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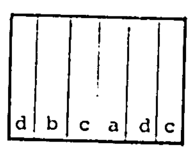

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Table 5

A comparison of simple experimental designs

Feature of the experiment	Fully random design	RCB	Latin square
Number of replications	Need not be the same for all species	The same for all species	The same for all species
Number of treatments (species and provenances) possible	Unlimited, except that a very large number may lead to much variability	If too many the advantage of blocks may be lost	Effectively limited to between 5 and 10 Below this the layout is insensitive, above this, unwieldy
Laying out the trial	Easy	Fairly easy but the blocks are of fixed size and must be carefully laid out according to the site	Design is fixed and little flexibility is possible
High variability between plots	No account can be taken of this in the	Can take care of variation in one or more directions depending on layout of the blocks	Particularly good if variation is in two directions
Missing plots	No difficulty in analysis	Little difficulty but some loss of efficiency	May entail much loss of efficiency and complex analysis
Residual degrees of freedom for	Maximum number available	Number reduced by number of blocks	Number reduced both for rows and columns
Differences in treatment	Whole area must be treated uniformly	Blocks may be treated differently	Whole area must be treated uniformly if two way effectiveness is not to be reduced

Figure 6

A possible randomization of four populations in a randomized complete block design with four replicates

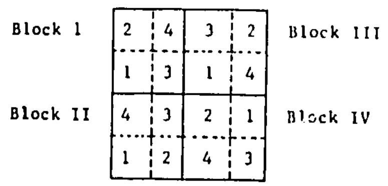


Figure 7

Plot layout for a field trial of four complete blocks of four populations. The site varies systematically in the direction of the arrow and there are rock outcrops as indicated.

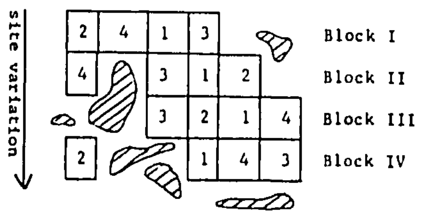


Table 6

APPLICATION OF AUGMENTED DESIGN IN FIELD CROP EXPERIMENTS[1]

James L. Brewbaker
Professor of Horticulture
University of Hawaii

Tropical crop investigations often involve treatments or varieties at two distinct stages of inquiry. Some treatments will be at a fairly advanced level of inquiry, and extensive replication is desired. Other treatments are preliminary in nature, and it may be unnecessarily expensive and time-consuming to include them in all replications at all locations of the experiment. An experimental design that conveniently incorporates both types of treatments is the "Augmented design" of Federer (Federer, 1956; Federer and Raghavarao, 1975; Federer and Searle, 1976 Neely, personal communication, 1978).

The augmented design was first applied to varietal trials of sugarcane, where it was desired to compare new seedling varieties with older, well-adapted varieties (Federer, 1956). Plots were large and experimental expenses and errors were both high. As Federer pointed out, however, the design has wide applicability where both advanced and preliminary varieties or treatments are studied. This seems especially true for tropical crop experiments, such as those involving multiple cropping, soil amelioration, new varieties or new control measures. It is widely used in Hawaii for Statewide corn yield trials, involving about 20 old, standard hybrids and about 40 new hybrids, with 4 reps in 8 experiments annually.

A simplified example is given here of an augmented randomized block I have borrowed freely from Dr. Federer's papers,[1] and acknowledge his authorship of the design and statistical notation used here.

AN EXAMPLE OF THE AUGMENTED RCB DESIGN

All calculations and interpretations apply to the following set of data, from a randomized complete block (RCB) design with 3 treatments (t_r) in 3 reps. The design was augmented by the inclusion in each replication of 2 unreplicated treatments (t_u).

Table

Treatments:

	Replicated				Unreplicated				
Rep	A	B	C	Sub-total					Rep totals
I	3	6	12	26	(D)	4	(E)	6	36
II	9	5	9	23	(F)	13	(G)	10	46
III	12	8	13	33	(H)	10	(I)	8	51
Total	29	19	34	[illegible]		27		24	133

[1]The author acknowledges with thanks review and criticism of the manuscript by Dr. W.T. Federer, Biometrics Unit, Cornell University, Ithaca, New York, and by Dr. Douglas Neely, formerly of ORD, Suweon, Korea.

Figure 8 Possible field layout of three replicates of a 3 x 4 rectangular lattice design

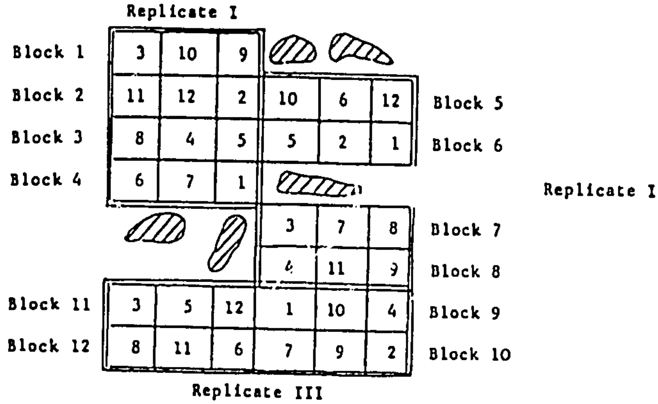


Figure 9 A latin square design for five populations

Column

	1	2	3	4	5
Row 1	A	C	B	E	D
2	B	D	A	C	E
3	C	A	E	D	B
4	D	E	C	B	A
5	E	B	D	A	C

Figure 10 A family block design for four provenances of each of three species.

Replicate I

B_1 (Species B) (Prov 1)	A_2	C_2
B_3	A_4	C_1
B_1	A_3	C_4
B_4	A_1	C_3

Repl .ate II

C_3	B_4	A_3
C_1	B_2	A_2
C_4	B_3	A_1
C_2	B_1	A_4

(For illustration only two replicates are shown)

- may involve an inefficient use of space unless plot size and the need for guard rows (internal and external) are considered.

- fairly robust designs; straightforward statistical analyses, and missing plots can be accounted for.

- check against other methods of controlling or accounting for environmental variations (see Pearce, 1980 e.g. covariance, including adjustment by neighbouring plots).

- Augmented (rotational) designs - see Table 6

  - useful for comparing some "extra" or "preliminary" treatments (e.g. species or provenances) within a trial in which major, more precise, comparisons are being undertaken. 3C app.6

  - statistical comparisons involve a calculation of an average mean square for error which excludes unreplicated ("preliminary treatment") plots.

- Increasing layout efficiency or effectiveness

  - partial replication as "incomplete blocks" if some information is not required e.g. "lattices" -see Fig.8 3C app.7

  - factorial (including split-plot) designs are especially useful when interactions between treatments are to be studied, but they can take much space with MPTs, especially if internal guard rows are needed 3C app. 9 -see Table 7 and Fig.11

  - confounding can help reduce the size of experiments if the two factors confounded are relatively unimportant (e.g. by assigning, say, separate species to individual blocks which are, themselves, replicated because enough is already known about them 3C app.8

Table 7

Factorials

Using a randomised block design each block will contain *all* the combinations and levels of treatments. These can be assembled most easily by drawing a small table. (see below)

For example, if there were 4 species of MPTs (ABCD) each to be subjected to one of 3 lopping regimes (1,2, and 3) to be carried out at one of two seasons (early or late = x or y) i.e. a 4x3x2 factorial.

Species	Lopping Regime 1		2		3	
	x	y	x	y	x	y
A	Ax1	Ay1	Ax2	Ay2	Ax3	Ay3
B	Bx1	By1	Bx2	By2	Bx3	By3
C	Cx1	Cy1	Cx2	Cy2	Cx3	Cy3
D	Dx1	Dy1	Dx2	Dy2	Dx3	Dy3

When these are tabulated they provide 24 plots with all the various combinations of treatments to supply 1 replication (block).

An advantage of factorials is their ability to test interactions, and this can be particularly useful in exploratory work when one is not aware if the main effects are additive or not. Factorials also contain a high degree of "internal replication" and are therefore efficient designs.

Figure 11

Split-plot designs

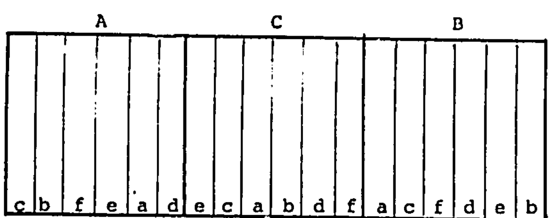
Example. A randomised complete block layout with:

3 main plot treatments - randomised throughout each block (each block contains all 4 treatments

6 sub plot treatments - randomised throughout each main plot, and

4 replicates (blocks)

Main plot treatments Block 1



Split plot treatments

- covariance analysis can be used to increase experimental accuracy where the effects of unwanted influences are measured, and these can then be eliminated from the statistical analysis. 3C app.11

- Systematic designs

  - useful in the early stages of investigations when a treatment may be of interest over a wide range of levels (e.g. spacing) and plant responses and yields are likely to be markedly affected by it and/or it will interact highly with other kinds of treatments; 4F

  - individual replications take up little space but are difficult to lay out and must be maintained meticulously, statistical analysis is usually confined to regression parameters, systematic designs make very useful demonstrations.

Objectives and Designs for Four Different Type of Field Trials with MPT's

Some suggested objectives and designs are noted in Table 8 below, followed by some brief notes.

TABLE 8: OBJECTIVES AND DESIGNS FOR FOUR DIFFERENT TYPES OF FIELD TRIALS WITH MPT'S

Types of trial	Objectives	Suggested design(s)	Comments
1. Nursery	To explore the ways of optimising the plant-raising conditions of selected species using relevant nursery practices.	Fully-randomized plants, or plots; or randomized complete block design.	May also involve separate direct-sowing trials, if appropriate. (Studies on biosystematics, juvenile-mature correlations, seed source identification and specific physiological/microbiological responses would be treated as separate experiments).
2. Elimination/ Survival (= "species elimination" or "Range-wide provenance trials")	To test, in the short-term (2 to 4 years, maximum) the ability of any interesting species (and/or range-wide provenances) to establish and flourish.	Fully-randomized single plants or *small* plots (no guards needed). Split into several experiments if needed to obviate local environmental variation.	The inclusion of some, known well-adapted species is useful in order to have a 'controlled' estimate of potential growth in view of year-to-year climatic variations over the short term of these trials.
3. Vigour/Phenology (="Species testing or "Restricted provenance trials")	To re-evaluate, and critically compare the growth performance of apparently adapted *selected* species (or provenances), and to obtain information concerning plant behaviour.	Depending on whether a) single plant b) community grown assessments are required: a) Fully-randomized or lattice designs or b) Augmented design in randomised blocks.	Species (or provenances) of very different structure should not be included in the same 'community-grown' trial. The repetition of trials in both space and time at this phase will enable GxE evaluation to be started.

...../2

TABLE 8 Cont.

Types of trial	Objectives	Suggested design(s)	Comments
4. Early management ("species or provenance proving")	To compare a selected range of management techniques for one or more chosen species (or provenances) with a view to obtaining *extrapolatable* information on how best to optimize chosen outputs (products and/or services) in a range of practical situations.	Fully-randomized for single-plant studies. Randomized complete blocks (possibly with split-plots or a full factorial arrangement) for community-grown studies. Systematic designs where spacing is a prime variable.	See the 'Evaluation' flow diagram. As more is known about the species (or provenance), and the land use system for which it is destined, then increasingly complex management trials will be required. At this stage vegetatively propagated material can help cut down unwanted variability.

Nursery trials

On occasion direct sowing trials may be used.

- Variables to test or to standardize may include:

  - seed pre-treatment;
  - germination medium;
  - germination method;
  - choice of sowing, germination, planting-out sequence;
  - choice of seedbed or container method;
  - choice of growing medium;
  - additional treatments of interest (undercutting, topping, shoot pruning etc.);
  - type of container (if used)
  - choice of seedling watering and shading methods;
  - plant nutrition;
  - pest and disease control
  - (and seed treatment, time and manner of sowing if for direct sown plants).

- Layout considerations

  - Will locational variability be contained by one of the methods already noted (blocking, etc.), or by moving containers around (if used)?

  - Is the intention to use blocks in the nursery to provide plants for associated blocks in the field?

  - Does spacing have to be adjusted as the seedlings grow?

Elimination / survival trials

- Considerations are:

  - on-farm or on-station?

  - layout could suitably be minimum 5-tree lines fully randomized 5x5 plots), with tree spacing 1x1 to or 2x2 meters.

- at what plant size should planting out be done, and how?

- are young plants to be protected from animals?

Vigour/Phenology trials

- These are to obtain comparisons of growth performance and plant behaviour of selected species and/or provenances and, if possible, of G x E interactions by using a range of experimental sites;

  - the duration may be some 4-6 years and so plant spacing should allow for this (e.g. 2x2 or 3x3 meters , but half this if early community-stress is wanted, with thinning later);

  - some inputs (fertilizers, water) may be desirable at planting out so as to ensure a good establishment;

  - there may be a case for some very simple management treatments (perhaps on guard rows) even at this early stage to give indications of plant responses, especially phenological information;

  - will trees be allowed to fruit or not? A non-synchronized attainment of maturity (flowering or fruiting) will cause considerable within-species variability in growth and vegetative development.

- Layouts

  - for wide-spaced trials, fully randomised layouts, or balance lattice designs;

  - for community-stressed trials, an augmented design may be suitable.

Early management trials

- Will utilize a selected range of management techniques for a *few* chosen species and/or provenances in order to ascertain how best to optimize particular outputs.

  - survival and adaptability will have already been tested;

  - if destined for mixed agro-forestry land use some indications of the trees' potential as an intercrop with herbaceous plants can be looked into;

  - the kind and degree of management variables imposed will be far-ranging; thus the options for the type of trial to be undertaken will be large (see Table 9);

  - these trials may be relatively long-term (8-10 years).

and see Part 3C
Supplement 1
Supplement 2

66

Early management trials with MPT's are likely, depending on local circumstances, to be concerned with some of the lines of investigation listed in Table 3. The type of layout suitable in designated (FR) = fully-randomized; (RCB) = randomized complete blocks, (S) a systematic design; and simple observational (O).

TABLE 9: Subjects of investigation for early management trials and MPT's

Type of investigation	Comments	Type of layout suitable
Plant management		
Spacing	For all kinds of MPT,s. Consider not only suitable plant populations but also rectangularity and plant arrangement. (See Part 4E)	(S) for exploratory trials followed by (RCB) once "target" spacings identified.
"Lopping"	May include cutting back (coppicing, pollarding) or just the removal of leafy shoots - or combinations of these. For fodder, mulch, fuelwood species. Consider age treatment starts, seasonal timing, plant parts, removal intensity (frequency x amount) and total amount of dry matter removed each year in relation to annual increment. All trials should include a 'control' treatment in order to compare the yield response and phenology of untouched plants.	(FR) for initial trials followed by (RCB) once main treatments identified.
Spacing x lopping	To discover the optimum combination to maximize yield of parts required and to maintain sustainability.	(S)

TABLE 9 cont.

Type of investigation	Comments	Type of layout suitable
Soil aspects		
Soil management options	Cultivations (or zero/ minimum tillage) Mulch Water collection/water spreading	(RCB) - using split plots or full-factorial.
Micro-site enrichment	Important to obtain such information so as to compare relative value of species - but trial may have to run 8 - 10 years, at least	(FR) (RCB) (O)
Soil conservation	Looking into plant numbers required, planting arrangement and how best to manage.	(O)
Innoculation experiments	Normally, this would follow nursery (or glasshouse) screening trials Comparing local strains (any natural infection by *Rhizobium*) with strains obtainable from Niftal.	(FR) or (RCB)
Special suitability		
For example for: . Shelter (wind-breaks) . Dune fixation . Slope stabilization . Swamp drainage . Land reclamation . Planted fallow . Browse resistance . Drought resistance etc.	All of these would involve some selection of appropriate management treatments. For example: . planting-out techniques . spacing . early training . harvesting	All (O)

Raising plants for field experiments

Part 3D

Summary statement

The objective is to produce the right number of uniform, good quality trees at the planting site. In most cases seed is used to raise plants in a nursery, but direct sowing at the trial site is also possible. Seed testing (germination tests) should be done under international rules, and research may be needed on storage and germination methods.

Key questions

1. How to ensure as much uniformity as possible on the planting stock so as to minimize unexplained variability in the field plots?

2. How to make possible the use of direct sowing in the field?

The answers to these questions lie in giving attention to the following considerations.

Germination testing

This should be done under the ISTA (International Seed Testing Association) rules. These cover:

- Germination tests under controlled conditions
- Biochemical tests
- Seed health

Plant raising

This involves decisions on the numbers of plants needed for planner experimental designs. The need is for standard, good quality, uniform material.

Research may be needed on:

- Seed variability under various storage and chemical treatment
- Germination conditions - depth of sowing etc.
- Seedling management - soil mixture (compost), shading, watering, nutrition.

The purpose of the nursery work is to produce information on:

- Germination percentage
- plant percent i.e. number of plants for planting as a percentage of number of seeds sown
- actual planting stock for field trials
- Information on juvenile characters
- Information for late use for juvenile/ mature correlations

Direct sowing in the field

This is of great potential importance for MPT's to be used by farmers. Research may be needed on:

- When to sow
- Soil treatment moisture relation (e.g. micro catchments)
- Seed pelleting or fertilizer addtions
- Inoculation with rhizobia etc.

Nursery technology

Standard techniques are normally used, though research may be needed to identify optional plant production systems covering

- Complete plants
  - bare rooted
  - in containers
- Incomplete plants (e.g. /stumps")
- Soil mixtures
- Fertilizers
- Reproductivity of system
- Pests and diseases
- Watering and shading regime
- Selection of plants for uniformity

Definitions of plant quality

These cover:

- Root system (e.g. preferably fibrous)
- "Hardenup off"
- Suitable root-shoot ratio
- Plant form
- Freedom from pests and diseases
- Incidence of nodulation etc.

Planting out

Standard planting methods, optimise the following, through research if necessary:

- Land preparation
- Water conservation techniques
- Uniform treatment in planting
- well planned irrigation methodology how much and when
- Suitable soil inputs if needed
- Cultivation as necessary
- Good records of all activities.

- Inoculation of seed of leguminous species with a selected strain of *Rhizobium* may, in some circumstances provide more effective nodulation and, perhaps, more effective di-nitrogen fixation, than where native rhizobia are relied upon.

- Generally, the *need* for inoculation should be established before *Rhizobium* strain-selection programmes are undertaken and these may then be focussed on, for example, effectiveness in di-nitrogen fixation and host-specificity, competitive ability in nodule formation (persistence in the soil may be of less importance with trees/bushes), or specific characteristics such as tolerance of low pH (e.g. with *Leuceana* inoculants). However, there is little detailed knowledge about nodulation and N_2-fixation for many FGNFT species and field experimenters might wish to inoculate seed of exotic and displaced indigenous species as a matter of course, using whatever strain is available.

- Information about whether or not a particular species (including non-leguminous symbiotic N_2-fixers have been found to fix nitrogen can be obtained from:

The Niftal Project and Mircen
(Dr. J. Halliday)
College of Tropical Agriculture and Human Resources
Department of Agronomy and Soil Science
University of Hawaii
P.O. Box 0, Paia
Hawaii 96779
USA.

or

The Nitrogen Fixing Tree Association
P.O. Box 680
Waimanalo
Hawaii, 96795
USA.

(and see Part 5B for Rhizobium Resource Centres)

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- Inoculants are prepared by adding pure cultures of the appropriate *Rhizobium* strain to a finely ground carrier base material such as peat or other organic materials. Clean washed seed (free of fungicides and other chemicals) is treated according to the instructions received with the inoculant. Usually this entails mixing the peat-based inoculant with water and a "sticker" such as casein (or milk), gum arabic and sucrose before applying it to the seeds by shaking together in a beaker and then allowing the seeds to air-dry in the shade.

  - for example, for small samples of seed (e.g. 100-150g) use 150ml of milk plus 15 g sucrose plus 30g of peat-based inoculum (but the exact amount of the latter will depend on the concentration of *Rhizobium* in it)

  - for precise investigations of strain-host effects the seeds should first be surface-sterlized (thoroughly wetted for 3 minutes in a solution of 0.2 per cent mercuric chloride) and then thoroughly washed (at least 3 rinses of 3 minutes each).

Points to note are:

- obtain a well-prepared inoculant from a known source;

- keep it in cool storage until used (note any expiry date);

- ensure that the seed has not previously been treated with any chemical (or, if it has, wash until it is all removed);

- sow as soon as possible after inoculation and keep the seed cool and in shade until then;

- do not mix inoculated seed with fertilizer

- in some cases, e.g. where the soil is acid, and fast-growing acid producing strains are to be used, lime-pelleting may provide better nodulation.

- In some cases, inoculation with *Rhizobium* and a mycorrhizal organism (e.g. *Glomus* sp) has been shown to improve nodulation, growth, reproductive capacity and yield (of leguminous herbaceous crop species) as compared with rhizobial inoculation alone. It may, therefore be as well, for indigenous tree species, to mix some soil into the nursery compost from a local stand of the species concerned.

Plant Assessment

The plant characters measured and recorded, and the method used, will depend on the experimental objectives. Adequate data (i.e. not too few or too many) are required and much depend on the levels of resources and skills that are available.

The following is a check list of the kinds of attributes that might be included, taken from a much expanded version of the Manual.

and Part 5D gives guidelines on general purpose photography

Leaves

Morphology Anatomy	For taxonomic purposes, and in relation to response to environment
Phenology or state	Leaf flushing times/durations and leaf longevity
Chemical composition	Soil nutrient availability; food, fodder, mulch values, taxonomy, physiological condition
Physical	Weight; leaf temperatures, light reflectance/ transmission for physiological studies
Microbiological	Phyllosphere
Pests and diseases	Identification of causal organisms

Crown/Canopy

Morphology	Size and shape ref. species and environment; community form
Phenology or state	Seasonal changes and effects on light distribution, throughfall etc.

Physiological	Water loss estimates, radiation (light distribution) measurements, light interception.
Pests and diseases	Whereabouts in crown

Buds

Morphology	Type and characteristics
Anatomy	Of axillary and series, and in relation to plant form
Phenology or state	Dormancies and growth flushes pollination/fertilization, fruit drop etc.
Physiological	Bud temperatures, water potentials, hormones - for growth regulation studies; plastochron/phyllochron for growth and flowering behaviour
Pests and diseases	Special pests (e.g. thrips) birds and some plant diseases.

Stems

Morphology	Diameter at base/breast-height/top to estimate taper and volume; form (straightness); forking/branching; bark; thorns.
Antomy	Of wood (for taxonomy); fibre length etc; texture; grain indication; figure; heartwood; sapwood.
Phenology or state	Linear changes; season of bark formation; branch-shedding; production of extractives
Chemical composition	Extractives and exudates (including quality); carbohydrate reserves; analysis of major and minor elements.

Physical and physio-mechanical properties	Colour/density; calorific value; fuelwood properties; strength properties; processing properties; finishing and preservation characteristics; veneer and pulp paper properties; fire resistance (in the field); weight
Physiological	Water potentials; sap studies
Miscellaneous	Epiphytes
Pests and diseases	Stem cankers, galls, wood borers etc. Resistance to termites.

Fruits and Seeds	*(Flowers may be important taxonomically)*
Morphology	Size, shape, colour, surface characteristics; variability
Anatomy	Ovule development; fruit growth (parts); seed characteristics and relation of seed to fruit growth during development
Phenology or state	Time of flowering and fruit set; pollination time; duration of fruit maturation period; site of fruiting points source / sink relationships and environment); affects of weather; size of fruiting load.
Chemical composition	Standard analyses for nutrient composition, total carbohyd-rates, oils and fats, fibre, vitamins
Physical	Seed storage requirements
Physiological	Growth rates
Microbiological	Mycotoxins
Miscellaneous	(Permits for movement)
Pests and diseases	Will include mammalian and avian pests, as well as insects such as bruchids etc.

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Roots

Morphology	Rooting habit and type of roots
Phenology or state	Evidence of root elogation and of root death and decay
Chemical composition	Carbohydrate analysis of main root tissue; extractives
Physical	Weights (but cleaning roots is is difficult), distribution of roots of different kinds can be useful.
Physiological	Root activity: by observation of live, fine roots in soil cores; soil water profiles; radio-isotope techniques
Microbiological	Seasonal occurence of root nodules (from soil cores); estimates of N_2-fixation using ethylene reduction technique; net increase/decrease in nitrogen in topsoil (given only partial balance); total N-balance using radio-isotopes; cuvettes, detailed soil/plant N-status, samples for free-living N_2 fixers; micorrhizas (plant samples).
Pests and diseases	Sampling for soil borne pests pathogens and diseases roots (if symptoms apparent); weed allelopathy.

Measurements can be local or distance-recording, instantaneous or continuous (and, hence, integratable with time through the use of data loggers). All intruments need calibrating and checking frequently. Careful choice of representative site for measurements is critical.

Temperature and heat flux

General	Take as instantaneous measurements or integrated with time ("day-degrees")
Instruments	Differential expansion thermometers (liquid in glass, liquid in metal, bimetallic strips); electrical resistance thermometers, thermocouples heat flux plates, diodes and transistors; katathermometers; radiation measurements (for surface temperatures) chemical transformations (involving sugars and polarimetry).

Air humidity

General	Expressed as vapour pressure, saturation vapour pressure, relative humidity, saturation deficit, mixing ratio, or as dew point (a temperature). - see definitions in glossary.
Instruments	Hygroscopy; water vapour sensors; hygrographs; psychrometers; wet and dry bulb thermometers (ventilated or unventilated); absorption methods; electrolytes or substances which change electrical resistance/capacity.

Sunshine and radiation

General

(a) short wave radiation (light) 0.3 - 4.0nm; (b) photosynthetically active radiation ('PAR') 0.4 - 0.7nm approx.45% of (a) (c) terrestrial radiation (4-100nm) for water balance studies; (d) total radiation (0.3 -100nm), seldom needed.

Instruments

Sunshine sensors ("Campbell-Stokes), gives "duration of hours of bright sunshine," not solar radiation; radiation sensors for (a) above e.g. metallic or thermopile actinographs (exposed black and shaded, or black and white surfaces) such as the Kipp or Eppley "Solarimeters"; the Gunn-Bellani pyranometer measures accumulated distillate along a heat gradient. Net radiometers (for energy balance studies) use heat flux sensors with thermocouples.

Precepitation

Geneal

Measured as depth. Representative site often difficult to select

Instruments

Non-recording or recording (the latter are well-worth the expense); totallising raingauges (plastic) are read at relatively long intervals; dew gauges (hypgroscopic plate or paper); wetness recorders.

Wind

Used in Penman estimates of potential evapotranspiration measured as "wind run", wind speed and direction

Instruments

(Freely exposed site essential.) Wind vane (direction); anemometers e.g. cup, propeller vane, pitot tube, hot wire etc.

Evaporation

General	Water loss from a surface depends on air humidity, turbulence, surface roughness (etc.) temperature, radiation and atmospheric pressure. Is expressed as a depth of water evaporated.
Instruments	Direct measurements: evaporimeter (qualitative); evaporation pans (can be continuous recording); lysimetry and evaporimeters. Indirect measurements: can also be estimated by the use of various empirical equations e.g. Penman, Blaney and Criddle, Monteith etc.

Monitoring soil changes

- It is essential to determine the soil conditions at the start of a trial.

- The growth of trees normally has favourable effects on soils. These arise from the well-developed root system. The protection from raindrop impact by the canopy, and above all the addition of organic matter and nutrients from the leaf litter.

- It is clear that different species vary in their potential to provide such ameliorating effects. Monitoring of the soil changes under trial sites can contribute to building up a body of information on this important subject.

- Measurement of soil biological and chemical changes.

  - techniques for this are relatively simple, consisting essentially of a systematic programme of soil sampling and analysis, repeated annually (or at 3-year intervals) for the duration of the trial;

  - sampling: do it prior to vegetation clearance, if possible;

    design: topsoil (0-20cm) and at least one lower horizon (45-55 cm is recommended). Sample according to a grid (dimension depends on variability and size of area/plots) composite samples essential (over a 10m radius around grid points);

  - Analysis. Organic C and/or total organic matter;

    properties of the exchange complex (e.g. pH, CEC etc.)
    Available P (state method).

- Measurement of soil physical changes. Techniques are more specialized, requiring special sampling methods.

  - dry bulk density (undisturbed cores, special auger);

- infiltration capacity (field test, double ring infiltrameter);
- water status: field capacity and wilting point, soil available water capacity (indirectly, using gravimetric sampling, electrical resistance blocks, tensiometers or neutron probe: (construction of soil moisture tension curves enables tension in relation to water status to be evaluated, and *vice versa*) or directly by undisturbed cores in special rings.

- Monitoring of soil erosion; requires specialized installations. This is desirable in regions and trials where potential for erosion control is considered important.
  - run-off plots
  - wash traps

- Soil description and classification: Note the following:
  - soil surface (e.g. stoniness)
  - soil profile, topsoil (0-20cm) and subsoil (50cm) specifying:
    . colour
    . motting
    . texture
    . stones and gravel
    . organic matter
    . laterite
    . nodules
    . other secondary materials (calciam carbonate etc.).
  - also, as a whole:
    . drainage class
    . effective depth
    . soil class (according to FAO, US Taxonomy or ORSTOM).

Evaluation and Assessment - with special Reference to Mixed Cropping

Part 4A

(and see 6A for economic considera-tion:
- and 6B on evaluat-ing agroforestry system.

Summary statement:

When MPTs are used in species mixtures, in some way or another, they often involve a change in dimensions of both space and time, and an increase in the range of the diversity of such dimensions, as compared with those usually found in agriculture.

Even foresters, concerned with mixtures of tree species of various structures and life durations are not usually involved in optimizing productivity from the lower or ground stories. This has implications for intercropping and other forms of mixed cropping research with MPT's.

Key questions

1. How do we set about making initial choices of trees and crops for possible associations in particular landuse systems? — see also 4B

2. How can we best study the ways of optimizing tree/crop association? — and 4C, 4D

3. What experimental procedures are available for testing any particular tree/crop combination and comparing it with others? — and 4D, 4E 4F

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- Before starting work with tree/crop mixtures it is assumed that there is sufficient knowledge about the agricultural crop component and that the MPT species has at least been tested for adaptability and general behaviour (phenology, growth characteristcs etc) and 4C

- In species mixtures objectives may not be merely to maximize overall yields. The exact objectives must, therefore be clearly stated before any experiments are planned. and 1B

- Very large numbers of variables (and levels are involved in mixed cropping trials. In order to limit the size of an experiment it is often tempting to assemble "packages" of treatments which appear to have direct practical relevance, rather than to study the underlying causal environmental and managemental factors. The former procedure may sometimes be expedient but treatments are usually highly - confounded and their interactions, being strongly site-regulated, limit the value of the results.

- Thus experimental programmes may need to be broken down into a few, relatively simple field experiments, or trials, if the problem is to be contained within the resources available. In particular, if work is concentrated on studying the "tree/crop interface", the information obtained can readily be extrapolated to hypothesize about any kind of landuse system using the same plant components, whether as a mixture or as a zonal arrangement. and 4D

- Another important decision for the researcher is whether it is better, at the experimental stage reached, to try to compare actual yields, or to test plant responses, or both. Quantitative estimates of the effects of treatments on yields may often require fairly substantial resources in mixed cropping trials whereas plant response tests occupy less space (although measurements are taken) and they can sometimes be adequate to predict yields.

- All this points to a series of small trials that are planned so as to provide a continuing output of information that will, ultimately, provide all that is necessary without having to wait many years. and see 3A

- In evaluating intercropping experiments the extent to which interference between plots results is mutual inhibition, mutual co-operation or some form of compensation depends on:

  - the extent to which the individual genotypes influence the basic "aggressivity" of each species.

  - the general level of environmental resources under which the test is being carried out.

  - site and season -imposed restraints on environmental resources, in so far as these are different from the mean.

  - the overall level of plant density stress involved (including the "intimacy" of the mixture.

- Agriculturists use the "land equivalent ratio" to describe the yield results of intercropping trials with plants of a similar or comparable stature, i.e.

$$LER = La + Lb = \frac{Ya}{Sa} + \frac{Yb}{Sb}$$

Where La and Lb are the LERs for the individual crop species in the mixture, Ya and Yb are the actual yields of the intercrops, and Sa and Sb are their yields as sole crops.

There are problems in relating this to tree crops (which occupy the land continuously and not seasonally), where canopy (or root) spread are more relevant than plant numbers per unit of land in some cases, and where the sole crop yields (for any particular product output) will be affected in different ways by a change in plant density.

- A "Competitive Ratio" has recently been proposed to serve as a more universal measure.

$$CR = \frac{\text{Actual yield of (a) when intercropped}}{\text{Expected yield of (a) when intercropped}} \div \frac{\text{Actual yield of (b) when intercropped}}{\text{Expected yield of (b) when intercropped}}$$

Again, it does not take crop duration into account, or ways of handling the different forms of harvesting periods. "Aggressivety" may also be affected, at different times by the phenophases being undergone by the woody species. Thus a relatively "simple" index, or measure, to interpret the results of intercropping with trees grown with low-stature, short duration crop mixtures needs careful consideration. This is a further arguement for trying to evaluate species *responses* as much as possible, in order to draw some conclusions about the general behaviour of them in a mixture, for both design prediction and management selection, even if the results are not as precisely quantitative as one would wish at this stage.

and see 4A supplement

Optimizing tree/crop combinations

and 4C

- An initial agronomic/sylvicultural choice.

Once a selected list of potentially-suitable tree/shrub and agricultural crop species has been defined for a particular area (or site), a final selection can be made by checking against the points listed in Figure 12. Starting first with one of the agricultural crop species, and then a woody one listing the good and bad points as they occur, until the choices become clearer, and so on with another pair.

For agricultural crops a selection of genotype (crop duration) and time-of-planting is critical, for trees/shrubs their phenology and the ways in which they can be manipulated (trained or pruned) are fundamental issues. The inforamtion obtained as sole crops has then to be tested in mixtures.

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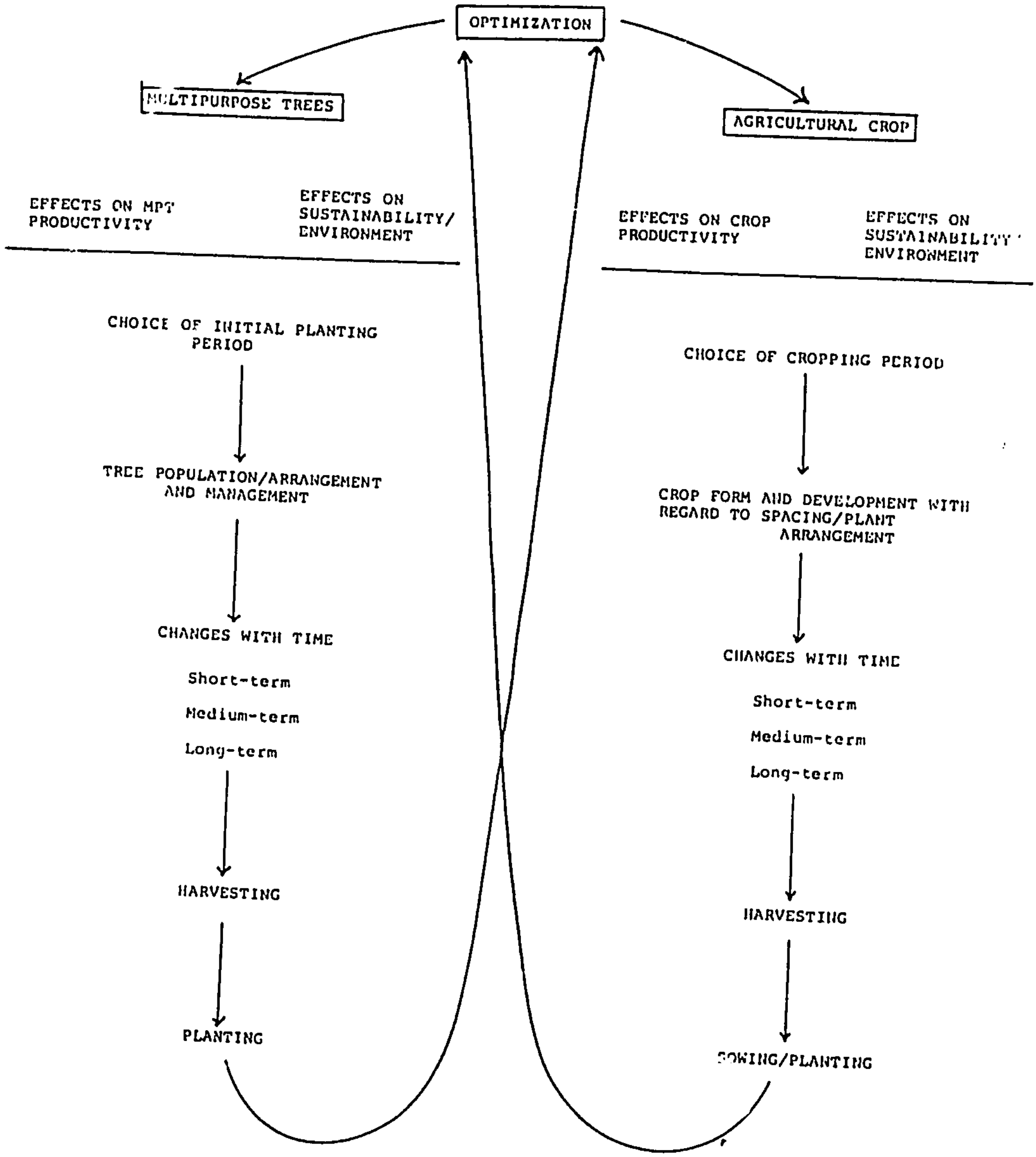
FIGURE 12



FLOWCHART SHOWING STEPS TO CONSIDER WHEN ATTEMPTING TO OPTIMISE MPT/AGRICULTURAL CROP COMBINATIONS THROUGH A GENERAL AGRONOMIC/SYLVICULTURAL APPROACH.

Pairs of tree/crop selections can be considered at any one time, treating these successively if there are more than two plant components. Start with the agricultural crop and then "match" the MPT as well as possible, reiterating the process as necessary.
The steps are described more fully in the text that follows.

(revised version of an ICRAF in-house paper by P.A. Huxley, June 1979).

The tree/crop interface - or simplifying the biological/environmental study of mixed croppings agroforestry systems

Part 4D

Briefly, the study of a complex multistoried agroforestry system (shown in plan in Figure 13) may best be attempted by breaking it down into its several "interfaces" (Figure 14 and 15) between the different plant species (tree/tree, tree/crop, tree/grass etc), and examining the results of environmental resource-sharing along a transect through the points where interference no longer occurs (Figure 16). This might be done using sophisticated instrumentation or just by critical observations, depending on what is available and to what detail the information is required.

Similarly, the interface approach can be used with an investigation of a MPT species at the stage where it is necessary to know how well or badly it will associate with other species, using simple field layouts (geometric designs, systematic designs), or the opportunities presented by appropriate mixtures in plots in some more conventional layout.

Table 10 shows how "tree/crop interface" studies may fit with other steps in the investigation of MPT, and Table 11 the type of information to be collected from a "tree/crop Interface" transect.

and see 4A & 4C

and 4G for the use of multivariate techniques investigating agroforestry system.

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Table 10 Steps in understanding the biological/ environmental complexities of agroforestry land use systems.

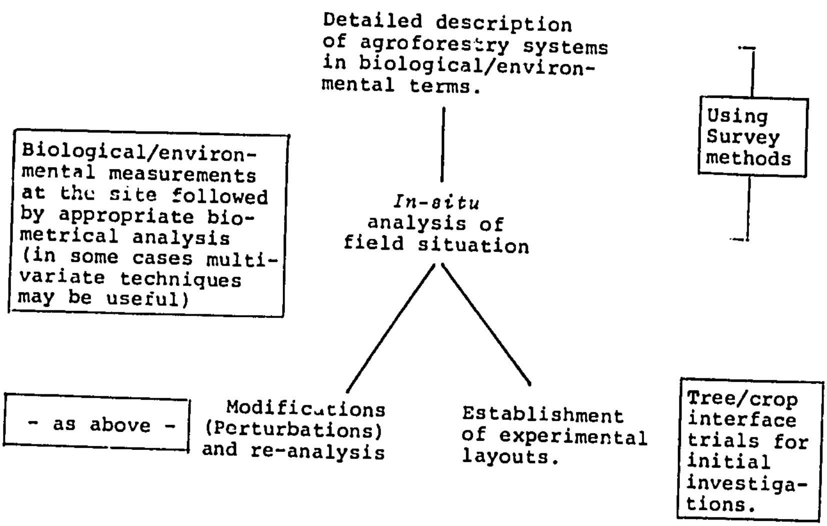

TABLE 11 INFORMATION TO BE COLLECTED FROM A TREE/CROP INTERFACE TRANSECT

VR = Visual Records - (see also Appendix for complete list)

Type of information	How obtained	Comments
1. Plant characteristics (less important items in brackets)		
Morphology - mainstems - branching - habit - vegetative growth flushes - leaf fall	Visual/photographic records and tape measure	Weekly notes and/or measurements are sufficient
Development - flowering - time(s) of flowering - fruit set - fruit/seed size/ numbers	Visual/photographic records plus simple weighing equipment	Sample branches/ plants can be labelled at the start.
Stress/shelter effects - water stress - (water conservation) VR - shading - nutrient deficiencies	Soil/plant water potential equipment light meters plant analysis/ fertilizers	Some water measuring equipment is highly desirable - otherwise visual records of plant and soil conditions (by digging) will have to serve.
General - yield/biomass (of agric. crop) - plant condition VR - pest/diseases VR - management records	Drying ovens/balances written notes	
2. Environmental changes		
Short-term - (wind - (humidity/dew) - rain dispersion VR - topsoil water status VR - (soil temperatures) - light distribution - total intercepted light.	- hand anemometers - dew gauges - small collecting rain gauges - soil water measuring equipment - soil thermometer - light measurement - integrating light measurement	May help clarifying plant responses and visual records will certainly help Will reflect canopy changes This should be attempted if at all possible
Long-term - soil fertility changes - soil less/compaction - (Soil fauna)	- Litter traps, O.M. analysis Physical/chemical soil analysis percolation rate - levelling pegs/bulk density - samples for identification	Essential to compare tree and agric.crop effects on soil

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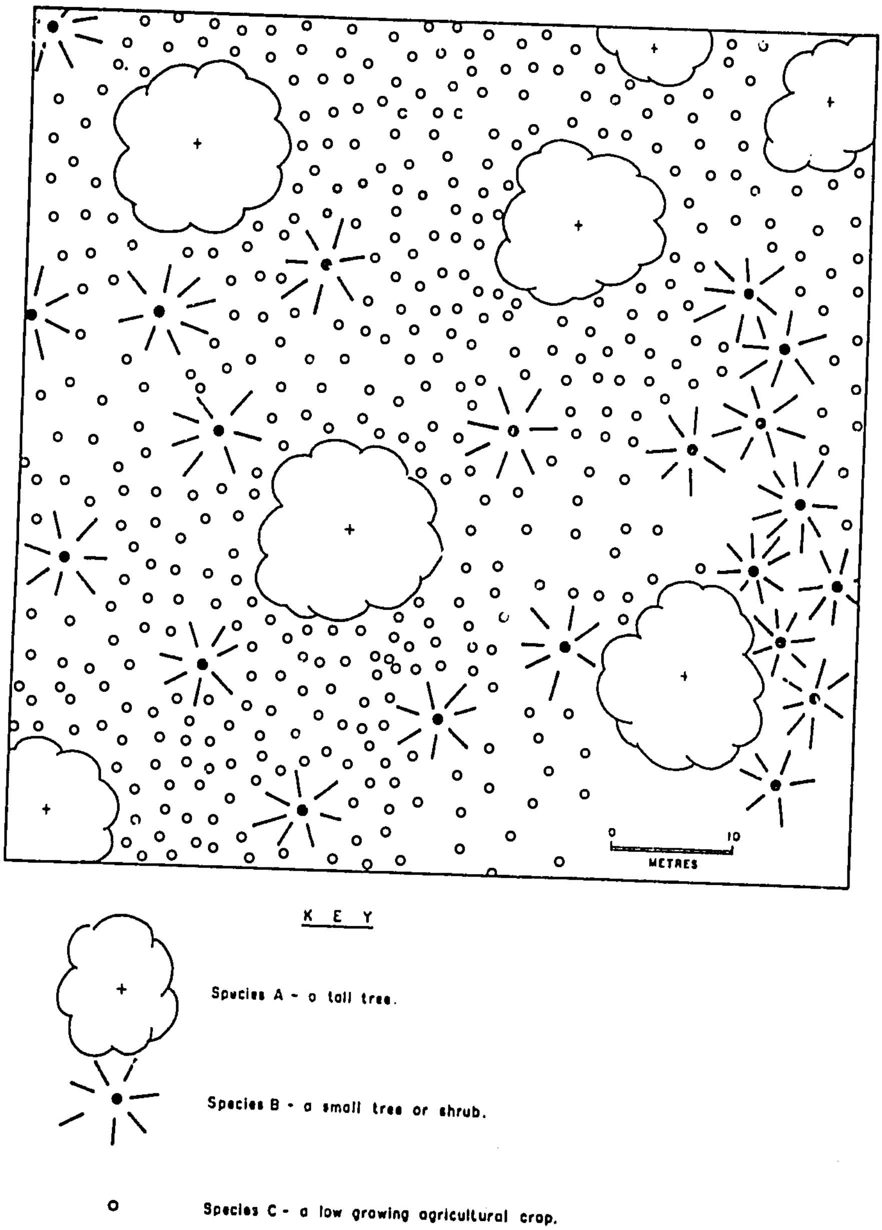
Figure 13 Plan view of a 3-component, multistoried system. Varying distances are involved between the same species and between any two component species in this relatively complex form of land use.



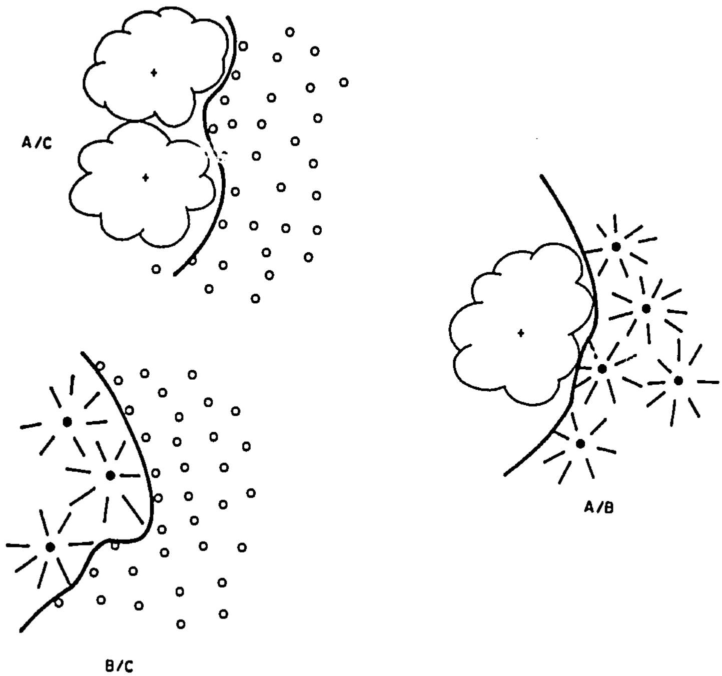
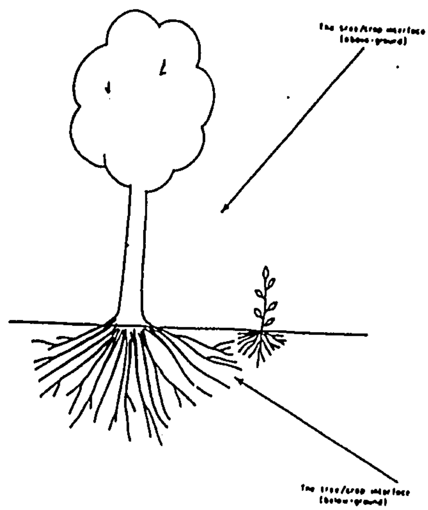
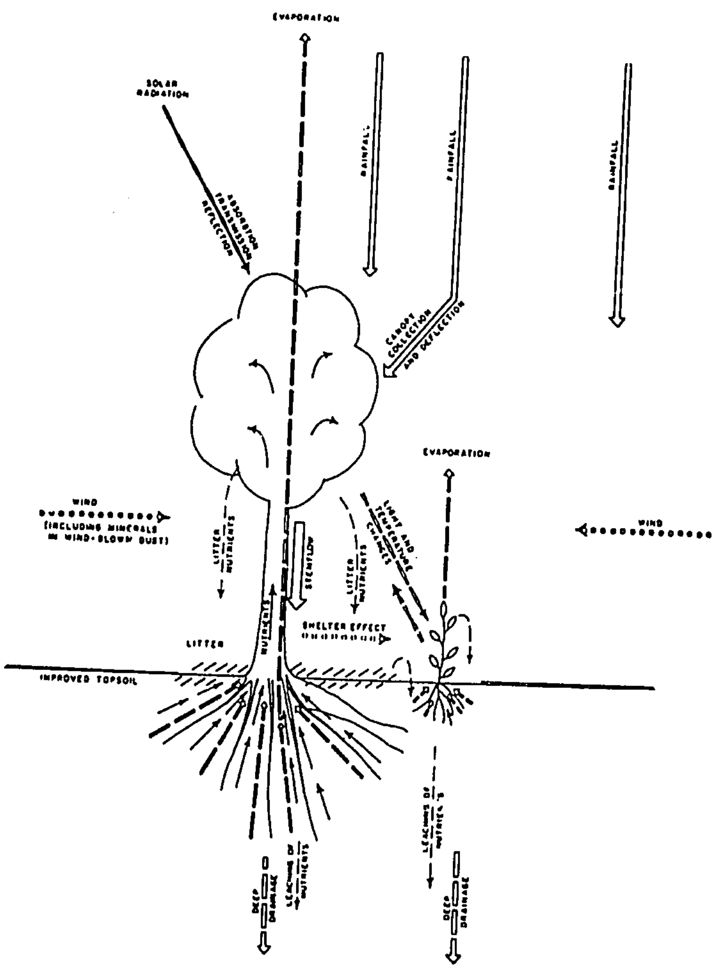


Figure 14: The key to understanding the complex agroforestry system shown in Figure 1 - the interfaces between pairs of component species. It may also be of interest to examine the sole crop interactions (A/A, B/B and, certainly, C/C).

Figure 15: A tree crop interface

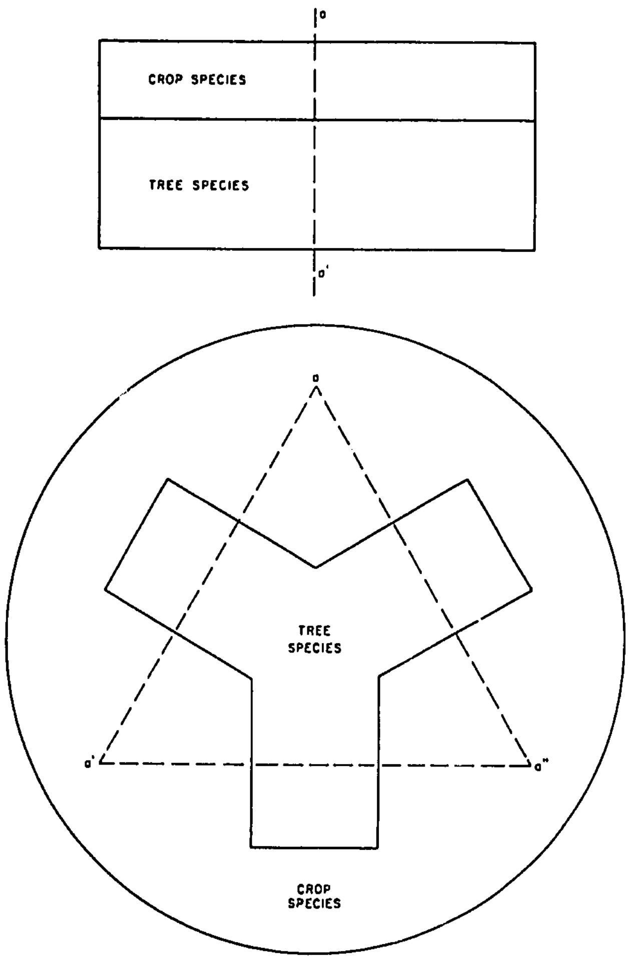


(a) at its simplest



(b) showing some of the complex environmental processes

Figure 16 Two simple geometic designs. In either the tree/crop interface can be studied along transects a to a' (a"). The circular design takes into account bias introduced by orientation (sun angles, prevailing winds etc).



Systematic designs

Systematic designs can be useful in the following circumstances when investigating the effects of changes in density stress during preliminary tests with a MPT species; when this factor needs to be considered in relation to management treatments (e.g. pruning or lopping); and also when the relative spacings of tree/crop mixtures need to be looked into.

Such designs are particularly useful in studying plant responses and they will usually be followed by further focussed trials using more robust designs.

Advantages as compared with conventional designs

- Systematic designs occupy a much smaller space than randomised block or other conventional layouts.
- Relatively fewer plants will be needed (but this saving may not be as great as expected due to the higher population densities usually being tested).
- The percentage effective experimental area is proportionally much greater than in conventional layouts that include spacing as a variable, as these ave to incorporate multiple internal guard rows.
- The range of levels of the experi-variable under test (for example, spacing) can be greater than in a conventional layout, and it can easily incorporate extremes so as to obtain a better appreciation of plant responses to "density stress", or any other imposed management factor.
- Systematic designs can provide an easily observable response to a treatment, so that they are useful as demonstrations.

Disadvantages as compared with conventional designs

- Systematic designs required a greater level of skill to layout in the field.

- Each plot must be sited on an area that is environmentally very uniform (not so difficult as they each can take up only a limited space).

- Thev are susceptible to damage and need consistent care and attention so as to maintain a high level of management (e.g. weed control) throughout the plot.

- Although they can, and should, be adequately replicated (preferably using different compass oritentations) the data is basically evaluated only by regression analysis (for example yield on plant population).

- Unwanted variability will occur if either:

  - the genetic material used is itself variable, or

  - extreme care is not taken at planting, together with early and proficient gapping-up.

In addition, particular rows or parts of rows in a systematic spacing layout may sometimes show a degree of unexpectedly dominant or suppressed growth. Any such effects can be obviated by displaying the data in the form of running means.

- All the outer rows of plants in systematic design are usually discarded as "guards" but, especially in spacing trials, the area of high plant density will require several additional guard rows in order to eliminate any "edge effects". Or the design should incorporate a number (5 or 6) of additional 'dense' steps which are not required.

Figure 17 shows an example of a parallel row design with management treatments (A-K) superimposed and Figure 18 a double, superimposed parallel row layout for obtaining information, simultaneously, about the effects of plant density on a MPT, an agricultural crop, and their mixture. In Figure 19 a simpler type of systematic layout is illustrated that might be useful 'on-farm' trials and demonstrations.

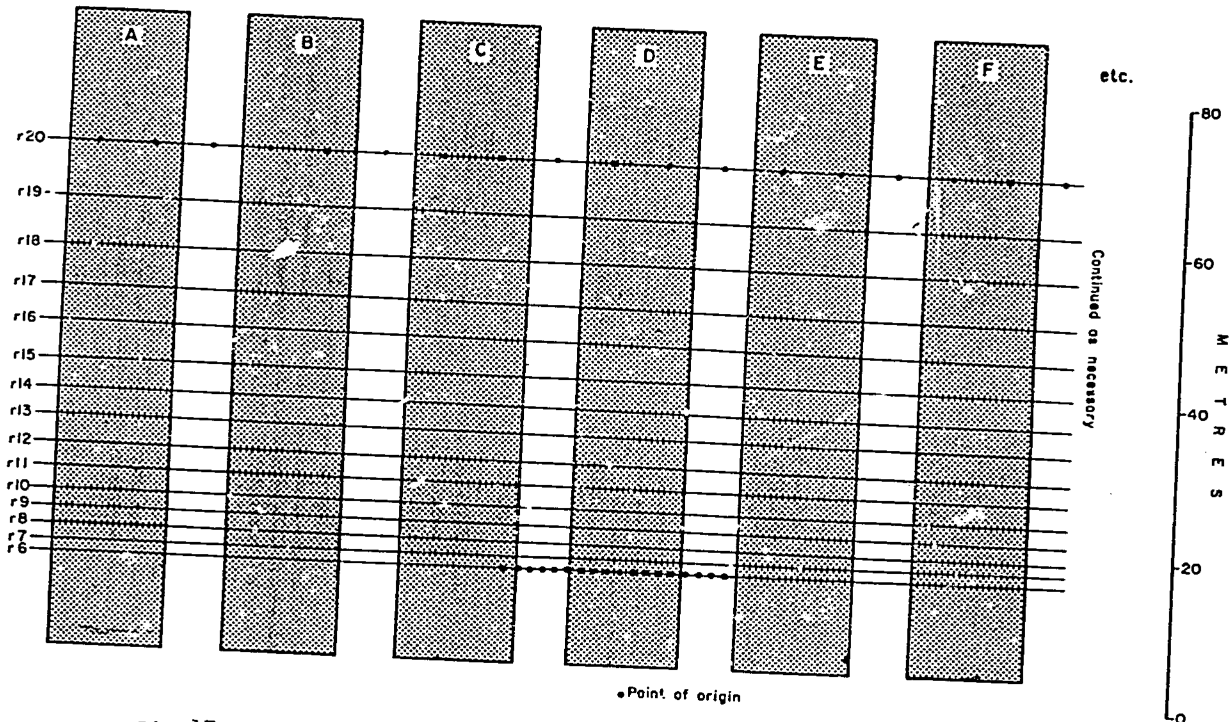


Fig.17: Experimental treatments (e.g. lopping, pruning etc) superimposed on a parallel row design. The treatments could also be different crop species (at standard spacings) for investigating mixed cropping combinations.

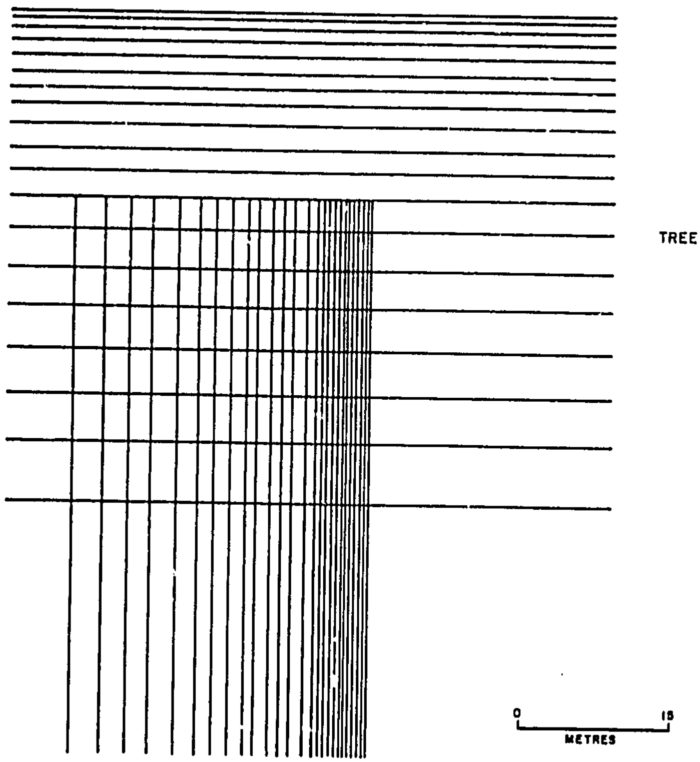
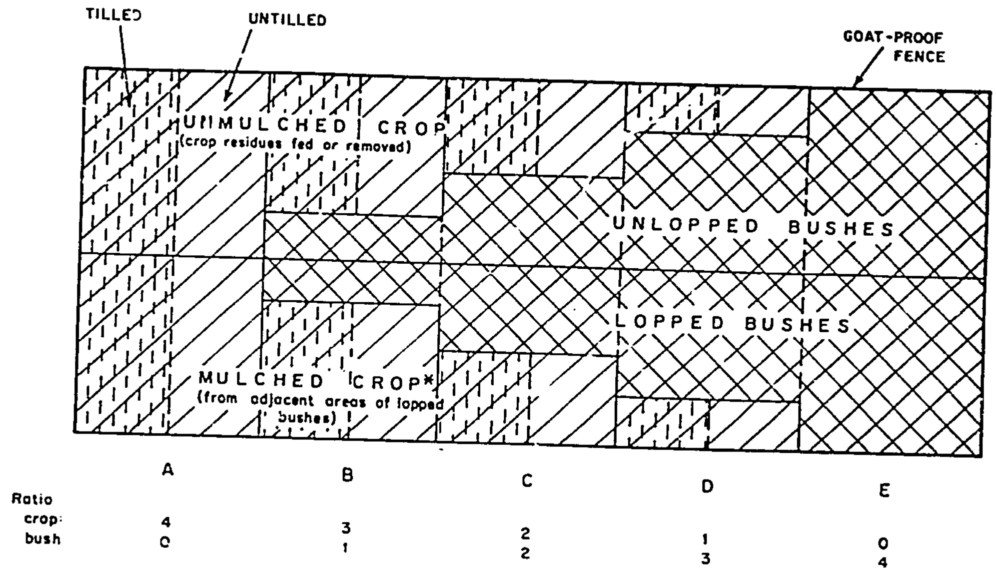


Figure 18 Two superimposed pa~allel row designs for testing the effects of simultaneously changing plant density in both a tree and a crop species. If the tree parallel row is extended a second crop layout could be fitted in.



(*in plot A no mulch available, but crop residues should be left)

Figure 19: A systematic design for an on-farm trial to investigate the effects of woody model on tilled (hoed) and untilled land. The different areas of bush provide varying amounts of mulch material to their adjacent cropped plots (from Huxley, 1980).

Considerations when Experimenting with Changing in Plant Spacing

Part 4E

- Crop yields and the yield of tree products are all highly dependent on plant density (plant population per unit area of land). Two other underlying variables are "Rectangularity" (the ratio of between- to within-row spacing) and "Plant Arrangement" (e.g. the positions of plants within a row in relation to those in adjacent rows).

- The resource-sharing capacity of woody perennials can change markedly with age (they may be 'dominated' plants when young and 'dominant' plants when mature).

- Spacing on its own is only one factor by which the intimancy of a crop mixture can be altered. Others are management (pruning, lopping) of the tree component and manipulation of time-of-planting of the crop, together with the selection of cultivars with appropriate crop durations.

- The manipulation of rectangularity in row-cropping situations (Figure 20) can be a powerful tool to obtain productive species mixtures involving a MPT and an agricultural crop. "Alley cropping" is an extreme example of this.

and see 4C & 4F

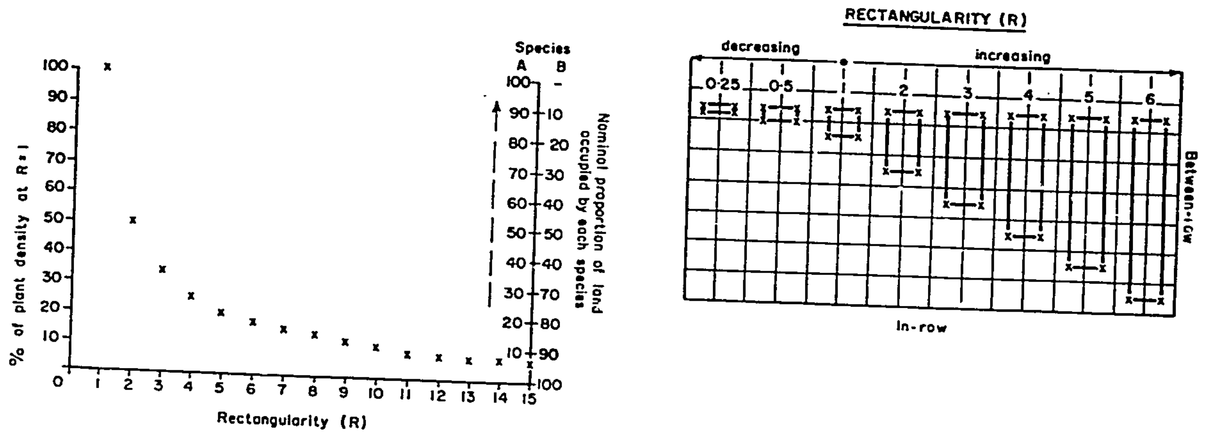


Figure 20 Different rectangularities (right) and the way in which plant population per unit area changes with a change in rectangularity if the in-row spacing remains the same (left). Changes in the nominal allocated area (assuming the species A is a tree and it occupies all the land at its optimum plant density at rectangularity 1) are shown on the right-hand axis, but the actual area utilized by each species will be more in the direction of the dotted arrow as the tree matures and its canopy and roots spread to the between-row space.

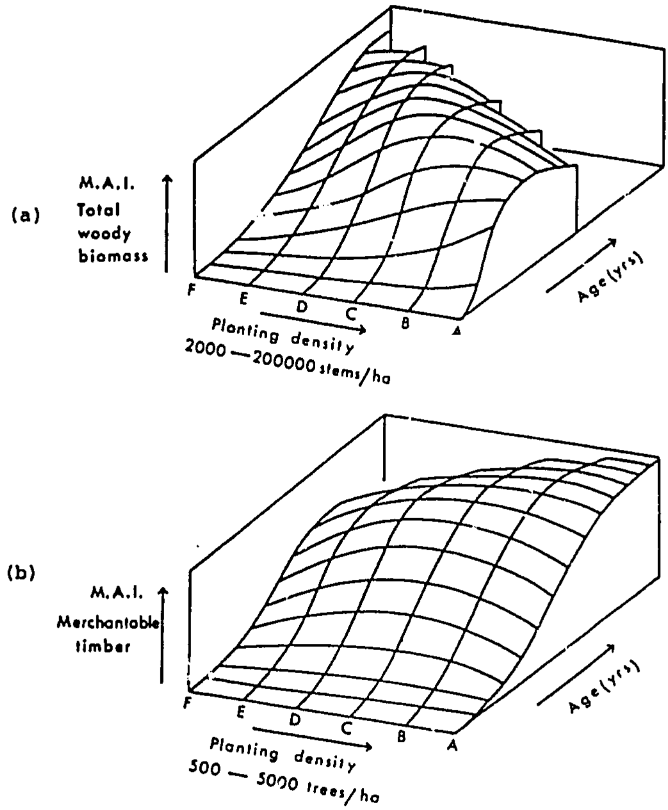


Figure 21 Effects of planting density on the mean annual increment (MAI) of trees grown for woody biomass (a) (branches and stems of any diameter) and merchantable timber (b) stems above a given diameter). Note that there is an optimum density for woody biomass as well as timber production, and that thinning will move the population in the direction A to F. Remember that closely spaced trees will be small in diameter, but not necessarily height, and that, in unthinned stands, the number of trees at harvest will be less than at planting owing to self-thinning. From Cannell, M.G.R. 1983. Plant population and yield of trees and herbaceous crops, pp. 489-502 in P.A. Huxley (Ed) "Plant Research and Agroforestry", ICRAF. Nairobi.

Figure 23 Changes with time of total biomass accumulation per unit area of land for different plant densities of a woody perennial species. Eventually the net annual increment due to carbon fixation and mineral uptake will be exceeded by losses (parts shed, total respiration and this will happen sooner at high plant densities.

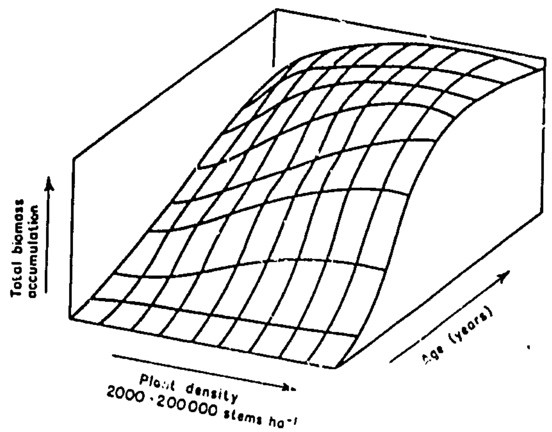
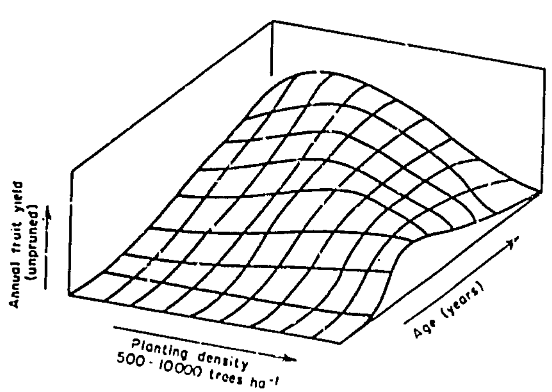


Figure 24 Changes in annual fruit yield with time for a woody perennial species planted at different densities. Small amounts of fruit per plant can give substantial yields per unit area at very high plant populations early on, but increasing densities (and the development of pests and diseases) can make such unpruned stands rapidly unproductive. Mid-level



populations will attain maximum yields per unit area later but possibly become unproductive less quickly. Low levels of plant population will give longer individual tree yields but too wide a spacing will limit yield per unit area (although it may make management easier). Pruning at any time will shift the response to the left.

- Plant density greatly affects the size of individual plant parts.

- The reciprocal yield equation can usefully describe both the asymptotic (total biomass) and parabolic (plant part) yield relationships which are density-dependent.

$$\frac{1}{w}\theta = a + bx$$

where w = mean weight of an individual plant
x = plant population per unit area
a&b = a constanst and a coefficient, respectively

$\theta = 1$, when the yield response is asymptotic
$\theta < 1$, when the yield response is parabolic

Figure 21 shows the two basis yield/density relationships, Figures 21b and c the effects of increasing the rectangularity, and Figure 21d the likely changes due to changing plant stress factors (soil and climate).

- The distribution of dry matter within the plants density and, as MPTs are grown for various product outputs, it is useful to know how yields of various kinds will be changed with time in this respect. Figures 22, b, 23, 24 and 25 give hypothetical examples that can help in research planning. Table 12, similarly provides a means of calculating in- and between-row spacing when maintaining equal, or any stated fraction, of a chosen maximum plant density, while changing the rectangularity (and the reverse).

- Finally, Figure 26 shows the steps to be taken in making decisions about plant density, rectangularity and arrangement when planning experiments involving such changes.

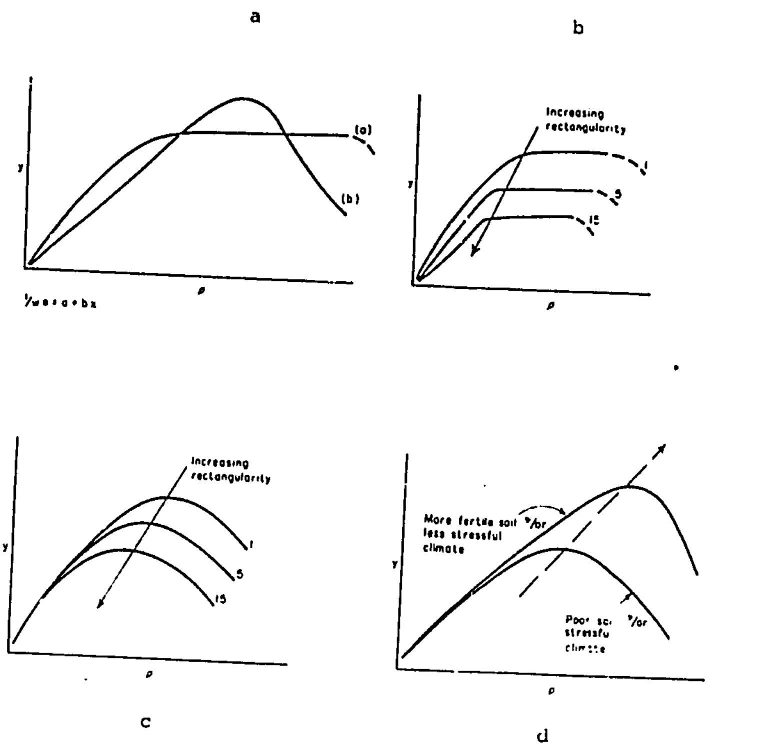


Figure 21 (a) Basic yield per unit area (y) plant density (P) relationships
(b) (c) The effects of increasing rectangularity on an asymptotic and parabolic relationship, respectively.
(d) The general trend in a parabolic yield/density relationship brought about by changing soil fertility and climatic stress.

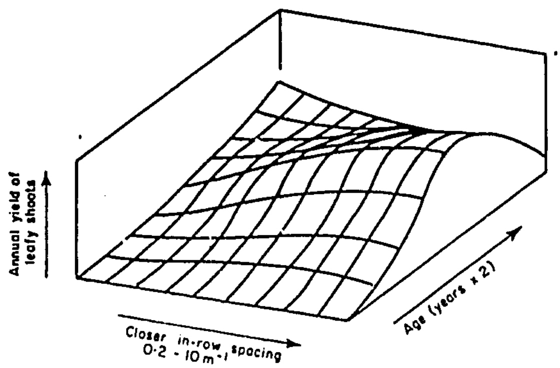


Figure 25 Changes with age in the yield of leafy shoots in hedgerows with different within-row spacing. Assuming no over-browsing or excessive lopping and that hedge height is restricted to that achieved after 4-5 years. A decline in the numbers of active vegetative buds available may sometimes occur with some species (e.g. tea) after continued pruning of leafy shoots.

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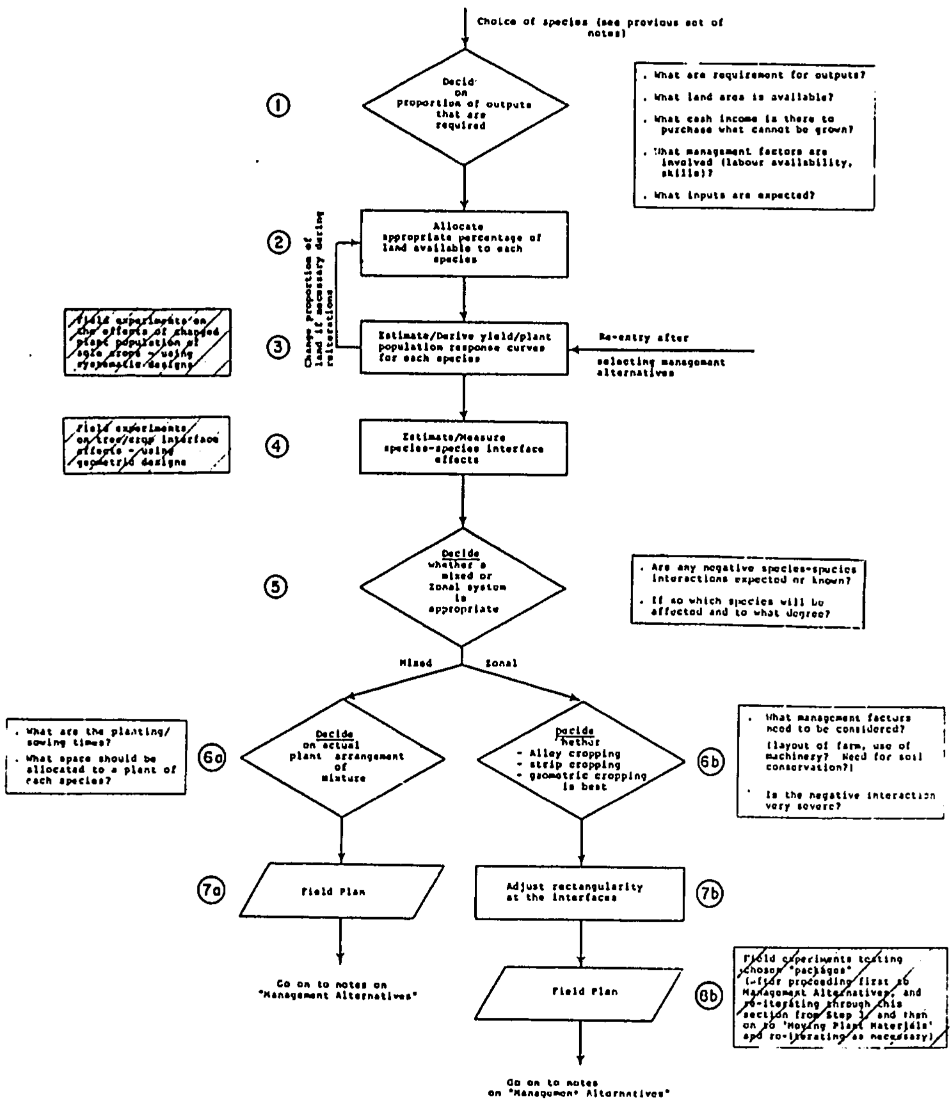
MAXIMUM NO. OF PLANTS PER HECTARE = 1
MAXIMUM RECTANGULARITY 12
MINIMUM RECTANGULARITY 1

FRACTIONS OF DENSITY USED 1/ 10
STEPS OF RECTANGULARITY USED .5

RHO	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00
1.000	1.000	0.816	0.707	0.632	0.577	0.535	0.500	0.471	0.447	0.426	0.408	0.392	0.378	0.365	0.354	0.343	0.333	0.324	0.316	0.309	0.302	0.295	0.289
1.000	1.000	1.225	1.414	1.581	1.732	1.871	2.000	2.121	2.236	2.345	2.449	2.550	2.646	2.739	2.828	2.915	3.000	3.082	3.162	3.240	3.317	3.391	3.464
0.900	1.054	0.861	0.745	0.667	0.609	0.563	0.527	0.497	0.471	0.449	0.430	0.413	0.398	0.385	0.373	0.362	0.351	0.342	0.333	0.325	0.318	0.311	0.304
0.900	1.054	1.291	[illegible]	1.667	1.826	1.972	2.108	2.236	2.357	2.472	2.582	2.687	2.789	2.887	2.981	3.073	3.162	3.249	3.333	3.416	3.496	3.575	3.651
0.800	1.118	0.913	0.791	0.707	0.645	0.598	0.559	0.527	0.500	0.477	0.456	0.439	0.423	0.408	0.395	0.383	0.373	0.363	0.354	0.345	0.337	0.330	0.323
0.800	1.118	1.369	1.581	1.768	1.936	2.092	2.236	2.372	2.500	2.622	2.739	2.850	2.958	3.062	3.162	3.260	3.354	3.446	3.536	3.623	3.708	3.791	3.873
0.700	1.195	0.976	0.845	0.756	0.690	0.639	0.598	0.563	0.535	0.510	0.488	0.469	0.452	0.436	0.423	0.410	0.398	0.388	0.378	0.369	0.360	0.352	0.345
0.700	1.195	1.464	1.690	1.890	2.070	2.236	2.390	2.535	2.673	2.803	2.928	3.047	3.162	3.273	3.381	3.485	3.586	3.684	3.780	3.873	3.964	4.053	4.140
0.600	1.291	1.054	0.913	0.816	0.745	0.690	0.645	0.609	0.577	0.550	0.527	0.506	0.488	0.471	0.456	0.443	0.430	0.419	0.408	0.398	0.389	0.381	0.373
0.600	1.291	1.581	1.826	2.041	2.236	2.415	2.582	2.739	2.887	3.028	3.162	3.291	3.416	3.536	3.651	3.764	3.873	3.979	4.082	4.183	4.282	4.378	4.472
0.500	1.414	1.155	1.000	0.894	0.816	0.756	0.707	0.667	0.632	0.603	0.577	0.555	0.535	0.516	0.500	0.485	0.471	0.459	0.447	0.436	0.426	0.417	0.408
0.500	1.414	1.732	2.000	2.236	2.449	2.646	2.828	3.000	3.162	3.317	3.464	3.606	3.742	3.873	4.000	4.123	4.243	4.359	4.472	4.583	4.690	4.796	4.899
0.400	1.581	1.291	1.118	1.000	0.913	0.845	0.791	0.745	0.707	0.674	0.645	0.620	0.598	0.577	0.559	0.542	0.527	0.513	0.500	0.488	0.477	0.466	0.456
0.400	1.581	1.936	2.236	2.500	2.739	2.958	3.162	3.354	3.536	3.708	3.873	4.031	4.183	4.330	4.472	4.610	4.743	4.873	5.000	5.123	5.244	5.362	5.477
0.300	1.826	1.491	1.291	1.155	1.054	0.976	0.913	0.851	0.816	0.778	0.745	0.716	0.690	0.667	0.645	0.626	0.609	0.592	0.577	0.563	0.550	0.538	0.527
0.300	1.826	2.236	7.582	2.887	3.162	3.416	3.651	3.873	4.082	4.282	4.472	4.655	4.830	5.000	5.164	5.3.3	5.477	5.627	5.774	5.916	6.055	6.191	6.325
0.200	2.236	1.826	1.581	1.414	1.291	1.195	1.118	1.054	1.000	0.953	0.913	0.877	0.845	0.816	0.791	0.767	0.745	0.725	0.707	0.690	0.674	0.659	0.645
0.200	2.236	2.739	3.162	3.536	3.873	4.183	4.472	4.743	5.000	5.244	5.477	5.701	5.916	6.124	6.325	6.519	6.708	6.892	7.071	7.246	7.416	7.583	7.746
0.100	3.162	2.582	2.236	2.000	1.826	1.690	1.581	1.491	1.414	1.348	1.291	1.240	1.195	1.155	1.118	1.085	1.054	1.026	1.000	0.976	0.953	0.933	0.913
0.100	3.162	3.873	4.472	5.000	5.477	5.916	6.325	6.708	7.071	7.416	7.746	8.062	8.367	8.660	8.944	9.220	9.487	9.747	10.000	10.247	10.488	10.724	10.954

Table 12 Factors for [illegible] in-row distance and (b) between-row distance of plants in order to achieve selected plant densities and rectangularities. Procede by chosing the [illegible] plant population required per unit area then calculate the in-row/between-row spacing (x) in metres, for a square plant for that plant density (i.e. R = 1, ρ = 1). For other arrangements multiply x by the appropriate factors given in the table. Note that the between-row factors for alternate columns (R) for any one plant population level (ρ) are multiples of 2; this can be useful in selecting combinations of ρ and R [illegible] layout having multiples of a common unit for between-row dimensions.

FIGURE 26 IMPLEMENTATION FLOWCHART FOR DECIDING ON PLANT POPULATION, RECTANGULARITY AND ARRANGEMENT (Follows "Choice of species flowchart" and continues on to "Management Alternatives"



SECTION ONE

PART 1B

Introduction

C O N T E N T

Some General Considerations

1. *The species*

The genera and species of woody perennials that we are concerned with in this type of study are very diverse in habit, growth characteristics and phenology. Many of them, unlike the trees grown solely, or principally, for roundwood timber production, are of small or medium height and have a branching habit; some are bushes.

2. *Management*

In many land management systems the woody perennial components may be grown, although still on the same unit of land, either separately from the crops, or intermixed in some way with them. In the former case they may be managed quite differently from the normal ways in which conventional "forestry" species are handled silviculturally. They are likely to have a different plant habit and they will be managed so as to encourage a range of outputs. If they are to be separated from the crop species, in time for example if we are using them in the form of a tree fallow, then factors such as site enrichment, and even of clearing, become especially important to consider.

When intermixed intimately with crop species or grasses there will be additional constraints on the management of woody perennials involving, for example, training, lopping or pruning so as more closely to regulate their growth, habit and development in conformity with the needs of the crop, or crops, with which they are closely associated. The agricultural crop species and/or grasses may also need to be selected so as to optimize their production under the changed environmental conditions imposed by the woody perennials.

This possible high level of interaction with crops, and the compromises that ensue with regard to management, imply that the field evaluation of multi-purpose woody species will logically involve four stages: elimination trials (survival); vigour/phenology trials undertaken so as to select appropriate genetic types for specific locations, and involving minimal management; performance/management trials; and then the evaluation of selected species together with their relevant management in appropriate land use systems.

In practice, there may have to be some overlap because of the considerable pressures obtaining to provide "best-bet" technology for urgent development schemes. Procedures for such trials will follow those already well established by foresters

and tree crop specialists. But a number of additional characteristics will need to be measured

The final trials of woody perennial components within a systems context involves a much wider range of research complexities (in terms of choice of associated crop, the geometry of the system, etc), and a basic implication is that this type of investigation has, at as early a stage as possible, to be carried out under conditions which relate to those found on cultivated lands range/pasture lands/degraded lands etc.

3. *Multiple outputs*

One further important issue is that the outcome of comparative species and provenance trials will depend, to a large extent, on the exact requirements that they are expected to fulfil in any land use system. Indeed, this has to be borne in mind from the start of the exploration stage onwards. Unlike the selection for a single-output character (e.g. timber of some specified quality) the multiple output function of most species of interest implies a more complex selection process. Thus the "best" species (or provenance) will depend not only on vigour, growth characteristics, resistance to pests and diseases, and those attributes which enhance the selection fitness to the site, but also on some combination of characteristics such as palatibility and nutritional status of the foliage and/or fruits, density and calorific value of the wood, nutrient re-cycling capacity, and shelter attributes etc. In other words its "productivity" with regard to a *whole range of outputs*. This aspect will demand attention not only in the kinds of measurements made but in the very design and layout of the field trials themselves. Furthermore, there has to be some logical basis for analysing the trial data in a way that will assist the selection process.

4. *Yield and management*

Selection is made even more difficult by the fact that certain management options may drastically effect the yield of particular plant parts in a way that individual species will respond to differently. For example, grown at wide spacing and left unpruned or unlopped Species A may appear to be the best yielder of fuelwood for a particular site. Grown at closer spacing and lopped sequentially it may be much lower in the ranking order of species being tested. Again if two species being compared can be utilized for animal feed, but one provides mainly pods and the other

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palatable foliage, the trial layout and selection procedures become even more involved. These two examples serve to indicate some of the problems, and they highlight the need to plan species and provenance trials in a phased manner and with very clearly established objectives.

In general, much more will be known about the productive potential and management of the agricultural crop (or grass) components which it is intended to include in trials which involve any combinations of woody species and agricultural crops, at least in term of their responses as sole crops. This is a situation which is likely to persist for a few years to come.

Certainly, much information needs to be obtained about the performance and response to management of any woody species *before* it is brought into an evaluation stage within a selected agroforestry system, or systems. This may entail the inclusion of small "satellite" investigations in the first phase of comparative trials which are designed to provide as rapidly as possible some basic information about the growth, development and responses to management of the species involved. Such simple investigations could start with single tree plots and, although replicated, these need not lay undue emphasis on statistical evaluation but, rather, be regarded as providing useful indicative information where little or none was previously available.

These comments emphasize a requirement to revise and evaluate our whole approach to the collection and acquisition of "MPT" germplasm and its subsequent examination in the field.

Before going into details we may remind ourselves briefly, in the following two sections, of some underlying concepts which are basic to our understanding of the part played by woody perennials in agroforestry land use systems, and of our perception of their various roles. Of course MPT's will also be required in land use systems which are not strictly agroforestry i.e. for fuelwood plantations, for anti-desertification or soil erosion programmes, and so on.

Land Development and Agroforestry Research

1. *Trees in the landscape*

Agroforestry is concerned with "Trees in the landscape" and it involves the more or less intimate association, temporally or spatially, of different plant components, always including woody ones, on the same unit of land. When plant components are sharing space they can be arranged zonally or in mixtures but in either case they will be associated closely enough to interact with one another in some way, either through environmental processes or through management (e.g. the transfer of material or litter from one zone to another). Thus agroforestry is concerned with "trees" not with forests, and the many roles which these trees (or woody perennials in general) can play on individual plots and in the landscape as a whole.

Where agroforestry research is to be effectively problem-oriented the objectives of the investigations require careful definition in terms not only of their value in overcoming restraints, or of taking advantages of potentials, but bearing in mind the level of scale at which they can intervene. Conceptually we need only three components: two different plant species (one at least woody) and man. In practice any small patch of land with these three which is providing multiple outputs (products and/or environmental benefits) may be considered the basic agroforestry unit for purposes of study. Animals may be involved in some systems.

Next in the hierarchy is the complete management unit, a holding or farm; then any aggregation of land-use systems with some common feature (a complete watershed, for example); and finally the region or, better still, agro-ecological zone.

The problems and potentials of agroforestry will require attention at all four of these levels and there is no reason why, from the farm or plot up, agroforestry should be considered a sole solution to any existing land use problem. It is merely one logical option which may or may not be valid, depending on the circumstances.

Although there will be many agroforestry research activities which arise from commonly perceived needs - for example, technology development relating to the raising and planting out procedures for multi-purpose trees, or ecozone adaptability and site assessment programmes - much of the work is likely to arise, and be prioritized on the basis of diagnostic field evaluation of the situation in specific agrforestry land use systems. Despite the high level of site- specificity many common problems will emerge which demand

attention in terms of the appraisal of existing technologies, or the development of new ones.

2. *Site specificity*

The high level of local-problem site-specificity with regard to much of agroforestry requires especial attention in agroforestry research planning. This is because, at this "farm" level, the collaboration of the land users themselves may well be essential. This applies not only to the joint implementation and evaluation of simple "on-farm" trials, but even to the extent of involving the farmer in their planning phase (e.g. consulting over choice of treatments). The need to avoid an imposed perception of the producer's problems is often as important to the successful outcome of such experiments as the type of field layout, or the ways in which measurement data are obtained.

The necessary close association of agroforestry research activities with agroforestry field practices must be based on a critical evaluation of the relevant agroforestry system or systems. And this is even more essential than in agriculture or forestry. This is because of the *multiple output* nature of all agroforestry systems. In addition the successful outcome of any experimentation depends upon producing results in a form which is meaningful to the range of practical options required. In agroforestry the wide range of plant components and management procedures which could be available, for a specific site within a particular ecozone, have to be perceived by and evaluated through the researcher/landuser combination. In practice, they then have to be combined in such a way as to result in a sustainable and suitably productive agroforestry system which fulfils the particular needs of any *one* land user. For social and economic reasons these needs can do very considerably, even within the same local area.

All this imposes a requirement for research programmes to provide information of a kind, and in such a form, that is highly *extrapolatable* within the appropriate sccial and economic contexts.

3. *The land development cycle*

Figure 9 illustrates the basic stages in the land development cycle. Proposals for research will logically be engendered through involvement in this cyclic process of "Diagnosis"-"Technology Appraisal"-"Design"- "Diagnosis" etc. "Diagnosis" implies a process of data collection and evaluation whereby the potentials and restraints of the systems under considerations are evaluated. Because the whole process is re-iterative it also implies a *comparative* diagnostic procedure (comparing the second time solutions with the existing state, and so on).

"Technology Appraisal" will expose technological gaps, or opportunities and it is from these that specific proposals for technological field research will emerge. The "Design" stage, like "Diagnosis", requires a development of methodology. And comparative designs of whole systems, or sub-systems, may eventually be tested in the field. However, such elaborate investigations are likely to be considered a luxury at the present time and simpler, quicker and more expedient methods of drawing conclusions about possible ways of appropriately testing the combinations of plant components and management features are discussed later.

4. *MPT technology development*

In practice it would be foolish just to ignore the vast amount of existing development of technologies which has been undertaken by different kinds of tree crop specialists, and which we know can already suggest various areas for research. A long list of topics is given in the Annex to this Section ("Some Characteristics of Woody Perennials") which can serve as an 'Aide memoire'. The *actual* set of research priorities will then depend on what is already known about a particular MPT(FGNFT) species, what is thought to be clearly an obvious restraint to promulgating its general use, and the outcome of any studies of its potential value in specific land development studies.

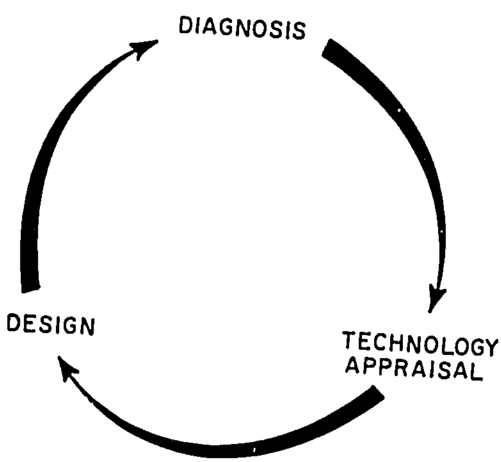

Figure 1: The Land Development Cycle in its simplest form

Specific Problems in Agroforestry Research - by Peter A. Huxley

Because many of the species we are concerned with will be used in agroforestry systems it is relevant to consider some specific problems before going any further. It may be useful to list a few of the *usual* questions facing those designing field experiments and then to note what added dimensions agroforestry may give to them.

1. Are we dealing with plant species which have an extensive range of germplasm available, or is this still to be collected and evaluated?

   - *In agroforestry the agricultural crops involved may well be in an advanced stage of selection or breeding (at least for sole cropping situations) but the woody species may not have been examined in any detail at all. Furthermore, they are likely to be out-breeding and therefore strongly heterozygous. Thus the research programme may need to be phased so that an initial supplementary investigation is made to screen the within-species range of MPT ideotypes available.*

2. Designs for field investigations may be simple or complex but they can always be made to yield more information if ancillary data are collected There is now, certainly, a strong case to obtain some simple basic crop physiological information in order to help explain *how* yields have been obtained. The kinds of data to be collected have to be chosen with great discrimination, if the burden of work is not going to be excessive, especially as they usually have to be collected over a number of consecutive seasons.

   - *In mixed cropping agroforestry systems these remarks apply with additional force as the key to productivity lies in the kinds and levels of plant interactions which are to be found. Depending on climatic variability, the number of experimental seasons required before any firm statements can be made about the response of the agricultural crop or crops components has to be considered very carefully. The "yield" from woody components may take even longer to evaluate and then there are still the long-term effects on the environment to consider. All-in-all agroforestry experiments cannot be expected to yield information, other than of an interim nature, for a number of years.*

3. When experimenting with agricultural crops "time-of-sowing" is important as there is now considerable evidence for many tropical crops that late sowing can seriously reduce yields. When we come to consider mixed cropping schemes there may be a complex and staggered series of sowing times. The reasons for this can be many:

it may be because of the ways in which the growth and development of the individual species are related to seasonal changes in climate; it may be moderated by farmers' preferences for planting food before cash crops, or for obtaining the harvest of a particular species at an appropriate time in his social life; or it may be decided by labour peaks, etc. etc.

- *In agroforestry systems a further consideration may be the phenology of the woody perennial component. There is very wide range of plant behaviour with regard to flushing and leaf fall and, as the activity of the woody species is very relevant to the success or failure of any herbaceous crop (or grass) sown beneath it, this is an important factor to consider. Additionally, many trees and shrub species have seed dormancy and/or acute viability problems. Agricultural crops are not encumbered with such problems as they have been eliminated to a large extent in breeding and selection programmes.*

4. In mixed cropping experiments with agricultural crop species the yield of any plant component in the system may depend very much on what happens to it in its early stages of growth.

   - *In agroforestry systems some species of trees and shrubs may have an extended juvenile phase. If such species are to be utilized for their fruits or seeds then the management of the system during the early stage may affect this. Furthermore, if more than one woody species is used in this way, and they have different juvenile periods, full comparisons will not be possible until they have all matured and come into even bearing. Even at this stage "bi-ennial bearing" may add greatly to the year-to-year variability of experiments.*

   There may well be a case, therefore, to split agroforestry experiments so that one set of investigations looks into what is happening in the early stages of growth and another set compares mature plants.

   If the woody species are to be used for fruits and seeds then the nature of the breeding system and the possibility of incompatibility mechanisms has to be borne in mind.

5. Mixed cropping systems are often stated to confer benefits in terms of pest management.

   - *Pest management, especially of weeds, may*

be very difficult in mixed cropping systems with a "permanent" woody component. Generally speaking herbaceous weeds will be less of a problem the more dense the canopy of the woody plant component in the system. However, this approach is self-defeating if there is an agricultural crop being grown beneath from which a regular high yield is expected.

Woody perennial species tend to build up their insect pest and disease problems with time and these are more difficult to control chemically because of the plant habit and form. Interactions between woody and annual plant species in terms of pest management seems to be a field in which there is, as yet, very little experience. Devising adequate measures of control at the start of an agroforestry experiment, when the problems have not even been defined, is something of a challenge.

6. Harvesting is nearly always more difficult in mixed cropping systems unless individual plants are very widely spaced.

   - *Where woody species are involved, and these are to be lopped or felled at regular intervals, then the problems of harvesting may be greatly intensified.*

7. In field experiments it is usually desirable to keep the variability within each treatment roughly equal. Indeed the premises on which the analysis of variance is based demand that this is so. Even if transformation of the data can be undertaken so as to achieve homogeneity of variances there can well be problems in mixed cropping experiments. Especially where one plant component is environmentally less well-suited than the others, or it is subjected to a treatment which may adversely affect its growth.

   - *Woody perennial species are commonly highly variable in almost all characteristics during their early stages of growth. This applies with even more force to the onset of fruiting and the development of yield when, with some species, extreme variability can be experienced. There may be, therefore, no sensible comparisons to be made for some years in some agroforestry experiments, until the woody species has "settled down".*

8. The different species in a mixed cropping system may represent a considerable measure of diversity in size and form. If this is so it has to be taken into account when considering plot size

and guard areas, which may need to be greater than is usual in agricultural experiments.

- *The problem of using adequate guard rows in agroforestry experiments is mentioned in detail later but additionally it is common practice with woody species in forestry and horticulture to carry out sequential thinning. In agroforestry experiments the question of maintaining a standard plant arrangement (as distinct from plant population and rectangularity) is a fact of considerable importance with regard to equalizing the interactions with an agricultural crop. If thinning is envisaged it must therefore be done so as not to affect plant arrangement, or there must be some means by which it can be taken into account if it does so.*

9. In mixed cropping there is a need for both, or all, crops to be adapted to the environmental conditions, as modified by the cropping system itself.

   - *The component plants in a mixed cropping system complete for light, moisture, nutrients and rooting space. Woody perennials can have both negative and positive effects upon intercropped annuals. Negative effects include shading, and possibly priority demains for moisture and nutrients arising from their established root system. Positive effects include improvement of the microclimatic conditions for annuals, nitrogen fixation, and soil enrichment by litter. According to the design of specific systems, in specific environments, the net effects may be negative or positive.*

Experimental Approaches to Studying Multi-purpose Trees

Types of investigation

A whole range of problems will emerge when investigating the potential role for woody perennial species. But the issues which have been raised so far emphazise that these can only be resolved by adopting a wide range of experimental approaches. Because agroforestry researchers will come from a variety of backgrounds it may be well to remind ourselves of the broad types of investigations that can be useful. They are dealt with in more detail later.

Type of investigation	*Comment*
1. Existing-data appraisal	Very little actual data are available about agroforestry systems themselves but a wealth of data and information is readily available which relate to forestry, agriculture, horticulture, ecology, range management etc. Much of this is in a form which requires adaptive thinking to make it directly relevant to agroforestry systems, however.
2. Evaluation of ecological situations. This can be approached in two ways.	This can be particularly useful where existing stands of mature species are immediately available
a) *The use of simulation to design agroforestry systems.*	Particularly refer to the work of Oldeman
b) *Use of multivariate techniques and pattern analysis to obtain information about the most important variables and interactions.*	This could be made more useful if modifications to existing stands are made e.g. by adding agricultural crop species.
3. Studies of single-tree plots	Our knowledge of the plant components in any agroforestry system may be at quite different levels. For example, the agricultural crop will usually be well studied often with a wide range of selected germplasm to choose from.

The trees or shrubs, particularly if these are newly introduced multi-purpose species, will be much less explored and even just a close examination of single trees will often be extremely useful.

4. Species elimination trials and survival/ vigour field trials	Mainly for testing the survival, adaptability, vigor and pest and disease resistance of individual species and provenances and, through the use of numerous sites in different eco-zones, GxE interactions.
5. Performance/management field trials	Using geometric, systematic, or conventional layouts and appropriate management variables and including any necessary additional measurement data.
6. Experiments with agroforestry systems.	a) whole system comparisons b) perturbation trials

Staging and Phasing

Woody perennials may often be the dominant partner when mature, because they are usually overstorey species. For this reason, and because we know much less about the "new" multipurpose tree/shrub species than we do about common agricultural crops, it is likely that any research effort will start by studying the role of the potential woody components. There will also be a need to look into a number of growth stages: seedling, juvenile, mature, involving plant raising. It may also be relevant to consider senescence and final harvesting/re-planting as these can pose special problems.

The types of experimental procedures relevant to tree-raising (involving planting out techniques) are likely to follow closely these which are well known to foresters and tree-crop horticulturalists. Experiments covering the juvenile stage can, clearly, be newly established and yet produce results in from 3 to 5 years, in most cases, depending on the species of multipurpose tree under trial. However, if we want to investigate, for example, aspects of growth, yield or the effects of particular management practices on the mature stage of even fast growing trees, there is no choice but to wait the necessary time (5-15 years?); especially if the species/provenance is just newly introduced. If it is indigenous then much can be learnt about it through the study of existing stands. Although, again, if new systems (or sub-systems) are to be designed and tested incorporating such species, the necessary time lag for conclusive experimental

results is unavoidable. What is vital in order to achieve any set of objectives is that the experimental plan fully takes the time factors into account. See Table 1.

The "Sherlock Holmes" approach

From what has been stated so far it is clear that agroforestry field investigations must sometimes resort to expedients in order to save time and cost, without sacrificing a reasonable level of security against drawing hasty or incorrect conclusions. It may therefore, be necessary to "fit together" information drawn from a number of different but reliable sources, and perhaps arrived at in a number of different ways, rather than embark immediately upon overlarge and complex field experiments which attempt to test all levels of all variables at one and the same time. The size, cost and duration of such large, long-term experiments will often be quite unacceptable.

If this general thesis is accepted then any programme of investigation on multipurpose trees will have to be phased; although such phases can overlap to some extent. Table 1 shows a series of phases (A to E) covering selected aspects of investigating the suitability of selected species/provenances of trees or shrubs for inclusion in some chosen agroforestry systems - which themselves are eventually to be compared (F).

TABLE 1 Different phases of field research for studying trees/shrubs suitable for agroforestry systems.

POSSIBLE OBJECTIVE	TYPE OF EXPERIMENT	TYPE OF LAYOUT	PROJECTED TIME SCALE
A. Appraisal of environment-related factors which affect growth and yield of different species already in natural or suitably-modified associations.	Survey of plant associations and environmental characteristics on a seasonal basis.	Multivariate techniques	Over 1 - 3 years.
B. To determine if the plant species are adapted and to select those which establish and grow well.	Elimination trials for: a) establishment and b) adaptation - providing *minimum* management such as fertilizer for the planting hole and/or *minimum* irrigation at planting.	Replications of: Well spaced-plants *and* close-placed plants (hedgerows)	4 - 7 years
C. To determine the phenology and the influence of management on growth (perhaps of the *single* plant).	Vigour/phenology trials Single-tree plots, fully randomized. Plants may be subjected to a range of different but very simple management treatments.	Fully randomized plots	4 - 7 years
D. Performance/management trials. Either on *single* plants or on plots containing *groups* of plants of any one species. a) without animals so as to optimize productivity	For community studies these would be especially to establish the interactions of spacing and management treatments.	a) Parallel row designs *or* factorial experiments with fixed/variable inter row populations.	All these trials might be laid out so as to investigate the juvenile phase (1-5 years) or the adult phase (6 years onwards) separately.

OBJECTIVE	TYPE OF EXPERIMENT	TYPE OF LAYOUT	PROJECTED TIME SCALE
D b) with animals, if appropriate i.e. if the species have a browse function and so as to investigate the plant-animal interactions.	(note that feeding trials with animals kept separately could be carried out if sufficient materials are available from this type of experiment, or any of the proceeding ones).	b) Randomized blocks with plots arranged to facilitate grazing or very simple systematic designs for farmer evaluation trials.	as above
E To test a selection of viable alternative components or sub-systems based on the information from proceeding experiments (A-D).	a) Tree/crop interaction trials. b) Large plot investigations using only *highly selected* treatment combinations. Also to include economic assessments such as labour, costs, etc. etc.	Geometric designs (to study the tree/crop interface). Randomized block layouts with or without internal guards and with provision for thinning of the woody component/s.	4-7 years (if trees newly planted or 2 or 3 seasons (if mature trees used).
F Evaluation of complete systems	Large area investigation to appraise a combination of technical, ecological, social and economic factors	Replication difficult	Very long term

International Co-operation and Central Co-ordination

An agroforestry research programme will range from the original choice of woody perennial species through "tree" and agricultural crop management to crop harvesting and processing. The most important of these fundamental decisions is the choice of the woody perennial species. Even where a strong national research agency exists, there is often little experience with the choice and evaluation of trees for multiple uses and international cooperation is desirable for several reasons.

The information available in one country may be limited to its indigenous species. Yet exotic species from remote countries or continents may be more suitable in terms of site adaptability, growth rate or the multiplicity of benefits achieved. Indications of potential species for particular sites or purposes are published by centralised agencies and further information, advice or seed can often be supplied by the centralized agency.

Many species occur naturally over a wide geographic range encompassing several "donor" countries. For a "recipient" country wishing to plant a given species, it would be administratively, economically and politically difficult to arrange a seed collecting expedition to each of the natural origins. Also, if many recipient countries are interested in a species it would clearly be inefficient for each one to collect its own seed independently of the others.

Further, in some donor countries, the species may be of little interest, or staff resources may be limited, so that there would be no reason or possibility to collect seed for the benefit of other countries. Even if seed were collected there would be no incentive to collect the associated site data and herbarium material that are so essential for the subsequent interpretation of experimental results and the description of patterns of natural variation.

For these reasons there is justification for a centralized agency to conduct the exploration phase in the donor region on behalf of *all* participating recipients. The stages of this "exploration" phase are described in the next section. They include, principally, seed collection supported by taxonomic material and, possibly, wood samples; and collection of information on the climate, soil and vegetation of each of the natural sites of origin of the species.

While the centralized agency studies this natural distribution and variation of each species and uses the information to interpret results of subsequent comparative seed source trials, it can also provide seed for the participants in these international trials and, where requested, it may supply the experimental designs and recommends standard managerial and evaluation methods. It may also assist with field evaluation In relation to the process of evaluation, while each participant's trial is his own, it should be clear from the outset that the data will be made available to the coordinator for combined analysis over all sites; information on site x origin interaction is critical in the selection of populations for new sites.

The CFI manual* for the conduct of tree species and provenance research combines guidelines for all these activities with industrial plantation species and it has been an early model for the present manual on multipurpose species. The concept of a central coordinator has been fundamental to the CFI's highly successful programme of international provenance trials of tropical pines (some 20 populations of two species tested on 400 sites in 50 countries). However, in the FAO/IBPGR programme for arid zone species, while FAO is the coordinator, it is leaving the collection of seed, herbarium material and site data to various institutions in the donor countries where the species are indigenous. (see Appendix 2). This will reduce the comparability and make subsequent interpretation more difficult.

These comments and suggestions about international co-operation and central co-ordination, especially with regard to germplasm collection and distribution, lead us to the next section of this manual which is concerned with the details of the "exploration" stage. When considering the factors involved in a national strategy for multipurpose tree exploration the considerable advantages of undertaking the exercise jointly, and with some effective form of central co-ordination, should

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* J. Burley and P. Wood (1976) "A manual on Species and provenance research with particular reference to the tropics. Comm. For. Inst. Trop. For. Papers No. 10. pp.226. CFI Oxford.

REFERENCES

Especially during the last few years a great deal has been written about agroforestry landuse systems and agroforestry research. The reader is referred to ICRAF's "Selected Bibliography of Agroforestry" (available, free, on request) for a broad coverage of the subject. Plant research topics are also covered in "Plant Research and Agroforestry" (Ed. P.A. Huxley) price US$15.00 available from ICRAF.

SECTION ONE

ANNEX

Appendix 1: Some Characteristics of Woody Perennials.

Some Characteristics of Woody Perennials

In designating MPT research objectives there is paramount need to relate the purely technical aims to the management and socio-economic backgrounds pertaining to the systems under study. Otherwise the results of the investigations are likely to be of little practical use. Most agroforestry field research being undertaken in the immediate future is likely to be highly problem-oriented.

In the table that follows some *technical* problems relating to trees/bushes have been listed in the form of questions and, accompanying them, are others which immediately arise with regard to *management practices,* and *socio-economic restraints.* Without any doubt it will pay the researcher to have this wider picture in mind when planning this experiments.

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GERMPLASM

Technical	Managerial	Socio-economic
a) Is this species outbreeding and the germplasm therefore heterozygous?	1. Does a mixture of genotypes matter? 2. Is germplasm easily and cheaply available? And through what sources?	Can the land user collect and/or distribute his own seed? Or does he have to buy it?
b) Are there seed viability problems? If so, does it pay and are there facilities to investigate them?	Will someone have to carry out seed testing? If so, are the necessary skills and equipment available?	Can a farmer easily store seed? Does this put up the cost of seed?
c) Are there seed dormancy problems? If so does it pay and are there facilities to investigate them?	Is any special equipment or technology required to break seed dormancies?	Does this hinder adoption?
d) Are seeds commonly attacked by pests/diseases?	Are special storage facilities or conditions required?	Will this be a major hinderance to issue farmers with seed?
e) Are there specific seed-borne diseases?	1. Is any special treatment of the seed required? And will the land user have to watch out to eradicate these diseases (or treat) young seedlings?	Will the land user need special help or advice? And will this be effective/costly?

	Technical	Managerial	Socio-economic
	f) If tree seeds are not the best or most convenient method of propagation, then what other materials can be tried?	Are the skills and equipment available for collecting and storing propagutes (cuttings, bud wood etc. Will there be problems associated with using clones (e.g. vines)?	What are the comparative costs. And does the farmer already have experience in handling, cuttings etc? (and see next section).
PROPAGATION			
	a) What methods of propagation are available? (and see f above) - seeds/cuttings/budding and grafting/tissue culture etc.	1. What facilities are there for establishing nurseries and distributing plants? 2. What types of nursery are best? (central, vilage schools, commercial etc.) 3. What skills/labour/materials are there for setting up nurseries and distributing plants? And what national organisations and/or infrastructure can help.	1. What are the relative cost advantages of direct-planting versus murseries? (transplants and container grown plants)? 2. What propagating method best suits the land-user? 3. What will the costs be of using different methods?
	b) What are the specific environmental requirements for germinating seeds and/or rooting cutting etc. and for early seedlings growth?	Are the facilities (labour and skills) available?	Will the land-user easily understand the requirements?

	Technical	Managerial	Socio-economic
c)	Are there requirements for seed innoculation *Rhizobium, Mycorrhizal fungi*	Will this be done "on-farm" or for issued seeds?	
d)	Are there specific pests and diseases in the nursery phase?	Are special procedures involving materials and skills required?	Will the land-user suffer severely from a failure to control these properly?
e)	What is the likely (and optimum) duration of the nursery phase.	Can the nurseries supply plants • When the farmer wants them? and, • For as long as he wants them in sufficient quantities and of a type which will survive the distribution and planting systems available?	What are the costs of seedlings? What are the costs of maintaining unsold/ undistributed plants?

PLANTING OUT

	Technical	Managerial	Socio-economic
a)	What are the soil/ environmental conditions needed? What is the best season? And are there special soil conservation requirements in this phase?	What site preparation problems are there?	How does it fit in with labour availability and other family needs?
b)	What is the optimum plant size, and condition, at planting out? (see also 'e' above).	Are proper handling facilities available, and the necessary skills.	Can the necessary care be given?

	Technical	Managerial	Socio-economic
c)	Is shelter/support required for the young plant?	What is the easiest to arrange? For example what local materials are available?	Will the farmer bother? Can he afford it? Will he maintain and manage it and finally remove it?
d)	Do the young plants need watering, fertilizing or mulching?	Can it be provided?	What is the cost and likelihood of the land-user adapting these procedures?
e)	Are pests/diseases/weeds likely to be a problem (and animals/birds)	Are special chemicals or protective methods needed?	What cost? How does it fit with labour requirements and available skills?

JUVENILE PHASE

	Technical	Managerial	Socio-economic
a)	1. What is the morphology and early growing habit of the species?	1. Does this affect crops growing nearby? What are the tree/crop interactions?	Will the land-user understand what is required?
	2. How does it respond to training/pruning, and what growth responses are there from buds of different kinds?	2. What training is possible and desirable?	What are the costs of training versus not training?
		3. Are plant training skills available?	
b)	Is the species slow or fast-growing in its early stages? (see also a above)	If slow-growing will this increase the burden of management operations?	Will a slow-growing species be acceptable, however useful and productive later?
c)	What are the rooting characteristics of this tree species?.	1. How does this affect management practices (watering, weeding fertilizing?).	

	Technical	Managerial	Socio-economic
		2. Does an early, deep-rooting characteristics affect associated crops and what are the tree/crop interactions at below-ground level?	
		3. Will this affect choice of site	Is the landuser prepared to allocate a special site to the trees if needed?
d)	Is the tree palatable? What is the need for animal protection?	1. Are there any effects on animal production if browsing is restricted? 2. Are people, methods etc. available for animal protection measures?	1. What are the land-users' habits with regard to his (or others) browsing animals? 2. What are the "costs" of protecting the trees from animals?
e)	What are the plants' requirements and responses to shade/shelter, watering, fertilizing, weeding.	What materials, labour and skills are available?	1. What are the costs/benefits? 2. What are the likelihood of adoption of these techniques? and what will happen if they are not done?
f)	What is the duration of the time to flowering/fruiting (is the species being grown for fruits?)	What management procedures can be adopted to induce early flowering?	How does this affect incentives to plant?
g)	How susceptible is this tree species to pests and diseases?	What materials and skills are required?	Will a failure to control these end in disaster?

	Technical	Managerial	Socio-economic
h)	What is the phenology of this species - how does this effect the associated crop plants.	How do the time-of-planting restraints and/or other management factors effect the overall management plan especially with regard to the associated agricultural crop?	How does all this fit with labour availability and social needs?

MATURE GROWTH PHASE AND PERIOD OF MATURITY

	Technical	Managerial	Socio-economic
a)	1. What is the morphology and branching habit? 2. What is the phenology? . Shoot dormancies and . growth regulations . leaf flush/leaf-fall sequences . flowering and fruiting cycles . general source-sink relationships.	1. Are skills/labour available to deal with training/pruning. 2. What are the tree/crop interactions implicit in the trees morphology/phenology and cropping sequences.	1. Are there any land-user preferences? 2. What effects are there on the land-users' immediate environment (does he want shade/shelter?).
b)	Competitiveness (from (a) above	What possible operations (e.g lopping) might reduce this and what is their timing.	1. What does the land-user see as his needs to "control" the tree? 2. What are the cost/benefits of doing so?
c)	Harvestability (single, terminal harvest/sequential harvests?)	How does this fit into the pattern of farming operations.	How does this fit into social requirement? or market opportunities?

Technical	Managerial	Socio-economic
d) Needs for weed control	1. Is the necessary labour/ equipment available? 2. How does this fit in with weed control timing and methods for the agricultural crop?	1. What methods are best suited? 2. Will the land-user adopt some form of weed control? 3. What is the cost/ benefit to him?
e) Soil management and soil conservation	1. Is the necessary labour/ equipment available? 2. How does this fit in with weed control timing and methods for the agricultural crop?	1. Does the land-user perceive a need? 2. Will the land-user adopt the appropriate soil management? 3. What are the cost/ benefits to him?
f) Pests/diseases	1. Is the necessary labour/ equipment available? 2. How does this fit in with weed control timing and methods for the agricultural crop? 3. Can advice be obtained?	1. Does the land-user perceive a need? 2. Will the land-user adopt the necessary control measures? 3. What is the cost/benefit to him? 4. Will there be a disaster if he neglects pest control with these species combinations.
g) Biennial (seasonal) bearing? (for fruiting crops)	Are the necessary skills and understanding available to obviate this?	To what extend do variations in seasonal output affect the land-user/ markets.

	Technical	Managerial	Socio-economic
a)	What is likely time of onset of ageing/senesence	What decisions have to be taken on how to remove trees?	How will the land-user percieve the need to remove trees?
b)	What is the duration of this phase and its effects?	Especially on associated agricultural crops and farm management?	1. What are the effects of declining productivity? 2. Is there a need for credit/help? or alternative sources of income?
c)	What are the options for technical solutions to final harvest sequence and/ or tree removal?	What are the effects on adjacent crops and on the soil?	Are there alternative choices of how to dispose of the trees?
d)	Are there pests/diseases associated with cutting down trees (including general and specific re-plant problems?).	Is the knowledge of what to look for available?	Is there a willingness to take care?
e)	What land preparation is required for re-planting?	1. What place does this occupy in the whole farming programme. 2. What is the availability of labour for this?	1. What costs are there? 2. Are there any social implications?
f)	What crop/soil management is required in the transition period before replanting trees?	What labour/resources are needed, especially for soil conservation in this period?	1. Is there a willingness to adopt a sound plan? 2. Are there any extra costs?

SECTION TWO

THE EXPLORATION STAGE

PART 2A

CONTENTS

ACKNOWLEDGEMENTS

Many of the basic concepts of an exploration strategy have already been discussed by various authors in J. Burley and P.J. Wood (1976). This contribution is concerned with expanding and elaborating the subject with special references to multipurpose tree species. Mr. C.E. Hughes of the Commonwealth Forestry Institute, Oxford, has provided useful comments.

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Introduction

Some basic considerations

The whole process of exploration, evaluation, conservation and utilization of a species depends on having, or obtaining, a knowledge of the taxonomy, natural breeding system, natural range and evolutionary history of the population of the species. It is variously called "seed study", "provenance research", "biosystematics", "genecology" or "experimental taxonomy".

For most industrial plantation tree species the natural populations may have been selectively or completely logged once, but there will have been no deliberate eugenic or dygenic disturbances of the population genotype that evolved under the natural selection of the local environmental factors. The industrial species are typically pioneers; wind-pollinated, outcrossing and heterozygous. Consequently seed source studies can usually detect any ecological gradients that may exist. For example, geographical, topographical or climatic variations in the clinal or ecotypic distribution of population means, in patterns of habitat-correlated characters or, indeed, of gene frequencies within populations e.g. by isozyme or terpene analysis.

Compared with timber species, however, less is known of the breeding system and the genetic structure of many multipurpose tree species. However, such genera as *Acacia* and *Prosopis* probably contain self pollinated and wind pollinated types, so that both inbred lines and outcrossed, heterozygous, populations are likely to exist. (See Appendix 2.10)

Of more importance, however, is the fact that, in many countries, quite a number of these species have been genetically manipulated through both deliberate and unconscious selection. Thus "land races" or local populations have developed that will be genetically distinct from the original population that would have existed naturally at the location in the absence of human interference. This can be expected in *Acacia*, *Cedrela*, *Cordia* and *Prosopis* species, and many others. It must be borne in mind that selection for a character, or a group of characters of value in one location may, commonly, and through genetic association or linkage, cause either an improvement or a decline in other traits that would be of value elsewhere. For example, it is possible that selection for, say, fodder yield could increase stem wood volume but decrease wood density and overall calorific yield. Or, again, selection of fast growing or dominant trees might concurrently select for aggressiveness and/or less nutrient efficient plants.

The implications of these natural characteristics and artifical historical events for the patterns of genetic variation are varied. Although large scale patterns of clinal variation are still likely to exist for some tree characteristics (e.g. physiological adaptation to specific temperature ranges or photoperiod), for other patterns of variation (e.g. fruit size, flowering/ fruiting propensity, branchiness) even strongly clinal patterns may be masked by a random network of local variants. However, where genetic material has been introduced from areas which experience different ecological conditions, even the genetic patterns of adaptation to strong clinal environmental variations which may have occured amongst the original populations can become masked. Consequently interpolations between sampled populations may not be possible for some characteristics, and intensive field sampling and recording may be necessary. In a centrally coordinated international programme provision *must* be made for the conservation of representative material from all the sampled populations.

The implementation flow chart which follows attempts to cover all these considerations. Furthermore, it starts with considerations about the ecozone *and* ultimate uses to which the species chosen are to be put. With industrial tree species, grown for roundwood, selection for ecozone is clearly important, but the issue of "what product" is hardly a relevant question. However, with multipurpose trees the production characteristics and role in a designated land use system have to be chosen and clearly defined *right from the start.*

The aims of data and material collection

Before going into details, it is useful to review what we are trying to do at the exploration stage. This can be summarized as follows:

- To provide, as efficiently and cost-effectively as possible, reproductive material for the evaluation phase. And to do this so that the most suitable species and provenances can, as far as possible, be rationally identified for particular user/site conditions and functions. The aim here should be to include as broad a spectrum of potentially useful genetic variation as possible.

- To provide information on the selection of potential management practices for the species provenance at the evaluation stage.

- Similarly to provide information which can help in the interpretation of results from the evaluation stage.

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- To provide information on the status of particular populations thereby indicating conservation needs.

As far as multipurpose trees are concerned there is a need to undertake a more comprehensive approach than would normally be the case for single-purpose industrial plantation species, as listed below.

- A greater *range* of information needs to be taken into account to select the sites at which populations should be sampled.
- More *intensive* sampling is likely to be necessary.
- Information derived from a first-stage sampling is also likely to indicate *further* changes in the sampling locations for any necessary subsequent second-stage within-species population sampling. It may also indicate a need to examine *additional* species whose attributes could be particularly useful for specific output purposes.

Factors related to sampling-site selection

Some of the criteria which have been used in the past for the selection of sampling sites for single purpose trees may be inappropriate for multipurpose trees. For example, as compared with species grown solely for roundwood timber production more emphasis might be given to collecting germplasm from particularly 'difficult' sites. Then again, normal criteria may be inadequate because the patterns of likely or possible man-made selection pressures must be taken into account as major criteria by which sites for sampling some multipurpose tree species are selected.

The extent of the availability of the information required for more detailed sampling will vary for each species concerned. Each step of the process needed for a rational selection of sites is therefore included here although, clearly, for some species some of the steps may be quickly dealt with. For example, if the species is known *not* to have been affected by man.

Intensity and location

Apart from its pattern (or patterns) of distribution both natural and exotic, it is necessary to determine, or predict, the following in order to decide on the intensity and location of sampling for each species.

- The factors that are likely to have led to genetic adaptation within the natural geographical range.
- The extent to which human influence may have influenced the genetic make-up of any population within the natural range of species.
- The degree to which populations of a species which have been introduced as exotics may have different characteristics from those in their natural range.

These are each now briefly discussed in turn.

Genetic adaptation to environment

It is assumed, based on past experience with several industrial plantation species, that the variation in broad envrionmental conditions found over the natural range of a species will have given rise to genetic adaptation to such variation.

Hence the species should be sampled at regular systematic intervals, or by following a stratified pattern along gradients of the major climatic parameters:

- daylength (latitude)
- precipitation
- temperature (altitude)

Where possible, sampling should be carried out also in locations where specific environmental conditions are likely to have led to an appropriate genetic adaptation to:

- frequent fires
- periodic flooding
- high salt concentration in the soil
- very alkaline or acid soils.

The greatest degree of adaptation to such specific conditions is likely to be found:

- In the centre of the area concerned and in the case where there is an unbroken distribution of the species and where the population is in contact genetically with populations experiencing different conditions.

- In populations which are genetically isolated from populations which experience different conditions. Here the factors which need to be taken into account to assess the degree of effective isolation are: distance between populations; ecophysical conditions of the areas which occur between the populations; breeding strategy of the species; mobility of the pollinators; seed dispersal strategy of species; and mobility of the seed dispersal agents.

- Where isolation has been effective for a long time. This influences the degree to which genetic differences may have evolved. There is a possibility that populations which have been isolated from each other for a considerable time have evolved particular features (non clinal variation) which may be of considerable importance in provenance trials.

Influence of man

The genetic make-up of any population may have been directly influenced by man, but the way in which it has been influenced depends on the degree of selection for particular characteristics and associated genes. Also on whether such characteristics are selected for and promoted in new generations (eugenic selection), or whether the characteristics are selected against in so far as the residual population contributes an increasing proportion of offspring lacking these characteristics (dysgenic selection). The degree of influence on the gene pool depends on the intensity of selection for or against the particular characters and associated genetic material. For some multipurpose tree species of interest in agroforestry we might expect that some form or another of utilization by man and his animals has modified the gene pool to a greater or lesser extent in areas where the interaction has been lengthy and/or intense.

Exotic species

Naturalized species which have been introduced originally as exotics may have different characteristics from those in their natural range. This may be because the individuals from which reproductive material was collected were unrepresentative of the original population in terms of genetic make-up. Or, again, because man-induced or natural selection in the new environment is likely to have further altered the genetic make-up in ways which did not occur in the original populations.

Information required for selecting sampling sites

The most efficient way of collecting information about any species will vary from country to country and, indeed, from species to species according to what is already known.

The form in Appendix 2.1 is an *aide memoire* of the kind of information which one would ideally aim to have for each species for the different locations in which it occurred.

In trying to get this information it should be remembered that knowledge about the distribution of a species (past and present), about specific site factors, and flowering and fruiting times may already be available from:

- floras
- expendition reports
- scientific papers in journals
- travel records
- herbaria
- forest management plans
- forest inventories

Care must be taken to check records for the species under the various synonyms which may have been previously used. In many countries for species which may have not traditionally been regarded as important timber species there may be more information available from:

- Botanical Survey records
- Botanical Research Institutes
- Medicinal Plant Departments
- National Parks or Wildlife Conservation Departments
- Range Management Institutions.

In order to gather up as much information as possible it may be desirable to send a questionnaire, along the lines of the form in Appendix 2.1, to government personnel in the field such as professional forest officers or engineers. Also to technical officers where a District covers either a large area, or a topographically and vegetationally complex one. The information supplied from such a questionnaire would be particularly useful for some of the phenological information (for example, fruiting times and intervals), and for information which would help in deciding on suitable sites for more intense exploration and seed

collection (for example, size of natural stands, likelihood of dysgenic selection, historical distribution where this was known to be different from the present pattern.

Information on climate and some of the information on other specific site factors may be more efficiently obtained from central, national or regional organisations than from the field. Climatic records may be scarce and cover only a few points within considerable ranges of climatic variation (for example, in areas which have a varied climate over short distances, such as in mountains).

There are some particular difficulties that may emerge. For some species, for example, particularly amongst the legumes, there may be considerable difficulty in even locating populations. In Latin America, for instance, *Prosopis juliflora* and *Senna atomaria* (syn. *Cassia emarginata*) occur in scattered populations of only a few individuals, partly due to environmental factors but also to human interference. The frequent lack of knowledge on breeding systems and dispersal mechanisms (pollen, seed) may often make it difficult to assess the degree of genetic isolation of different populations. Further, in reality, there may be many difficulties in trying to assess certain aspects of the past history of a species which have a bearing on the genetic make-up of different populations. For example in the following cases:

- Where it is difficult to judge whether a species is native or exotic. For example *Parkinsonia aculeata* and *Gliricidia sepium* in Latin America, *Salix* and *Populus* spp. in South Central Asia.

- Where it may be impossible to decide if a stand is derived from only a few, or even one parent. For example, *Gliricidia sepium* in Latin America.

- Where it is not known whether planted trees, for example in fence lines, represent the original natural populations in terms of genetic composition, an example being *Caesalpinia eriostachys* in Central America.

Actual Selection of Sites for Sampling

The ideal

For wide ranging provenance tests, one would wish to sample the species and collect reproductive material according to the following principles:

- Collect seed samples at regular spatial intervals, or according to a stratified pattern, over the ranges of altitude, latitude and longitude, so that temperature, radiation and rainfall variations are accounted for, as far as possible.

- Collect on sites where the species shows the particular desired characteristics. For example:

  - Where there are population with genetically determined and different leafing or flowering times for fodder or bee-forge uses, respectively.

  - Where there is obvious adaptation for particularly difficult or extreme conditions such as black cotton soils, saline and/or highly alkaline soils, waterlogged sites etc.

This is especially desirable if the populations concerned have been genetically isolated for sometime.

- Collect wherever populations are threatened, and information indicates that such populations are likely to be genetically different from the other sampled populations.

The compromise

In practice a compromise has to be reached between what is feasible and what is ideally desirable. Any provenance research should be viewed as a *reiterative process* whereby the sampling intensity for reproductive material increases, and the sampling locations become more precise, as more information is obtained about the following points:

- The status and distribution of a species' populations, and the site characteristics in the areas of occurance.

- What subsequent trials help identify potentially as more useful areas of origin.

- When the diagnoses of problems in particular land use systems identify specific roles to be performed by tree/shrubs.

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In some cases we may have to collect wherever the opportunity arises.

- In the case of species about which little or nothing is known concerning natural distribution and/or location of population

- For species which occur only as remnants because of the depleted state of their genetic resource.

This has been the situation with collection for several arid and semi arid species in Central and South America recently.

Seed* Source Data and Collection of Ancillary Samples

The collection of data and material has four main functions.

- To ensure that the site can be located *exactly* in later years by anyone wishing to obtain more material or data.
- To supply information about potential end uses or functions of a species. For example an *initial* selection of species or provenances may be desirable for the evaluation stage based on the likely primary desirable functions of trees in a particular area (for example dune fixation, dry season fodder), and on the specific constraints likely to be encountered (for example heavy grazing pressure, highly saline soil).
- To provide the information needed to help interpret the results of studies and experiments at the provenance trial stage.
- To suggest possible management and cultural practices aimed at achieving specific objectives (for example, maximization of fodder yield, minimization of root competition).

Some examples of forms for recording information, a checklist of material to be collected and a checklist of the equipment required are given in the Appendix.

Location of collecting site

(See Appendix 2.2, Form I).

Details concerning the location of the collecting site are required *along with information on access*. It is essential that records are kept together with the seed collection during its subsequent distribution and utilization (trials, plantations etc.). These records must specify the exact location and the date of the collection. Thus a site number and a seed collection number are required which can be used, for example, at the primary seed store,

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* In this chapter the word "seed" is used to imply any propagule.

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herbarium or at any other institutions handling the material for analysis, storage, testing or distribution.

*Environment at the collecting site - general comments**

An adequate description of the collecting site environment is required for the following reasons :

- It may help explain some of the phenotypic variation of the trees at the collection site.

- Variations in performance both of species and particularly of different provenances at the evaluation stage will be better understood, especially where the trials are located at various sites.

The kind of environmental variables about which it is important to have information are those which are likely to have induced marked genetic adaptation, in particular those which tend to show most correlation with growth, development, or some other useful plant character responses at the evaluation stage in an exotic environment. If the responses *do* indicate a clinal pattern of adaptation, rather than random or ecotypic adaptation, then the planning of the subsequent seeds and other ancillary samples for further evaluation and breeding can be made more efficiently, given a knowledge of the appropriate environmental variables at the sites where the species is likely to be planted. Concentrating on these, the areas in which it would be worth selecting further sampling sites can be more precisely located.

The precise level of detail required in the environmental description of the site or microsite is that which will facilitate the following.

- Any phenotype - environment correlations which can be made at the site of collection,

- Any genotype - environment correlations which can be made at the site of evaluation.

It must, however, be remembered that a species or provenance does not always perform best under environmental conditions which are similar to those of the original habitat.

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* Details of a computerized environmental database (for microcomputers) is available from A. Young, ICRAF.

- see Appendix 2.11

Form 2.2 in Appendix 2.2 concentrates, therefore, on environmental variables which have been shown to have a significant influence of genetic adaptation. The many studies in forestry research which have sought correlations between growth and environmental variables have often shown that the following, in decreasing order, are the most important.

- Climate
- Relief factors
- Rooting depth in soils (a measure of soil water availability)
- Soil parent material or nutrient status.

Soil parent material, as an indication of nutrient status, has often been shown to account for only a rather small variation in the growth rates of forest trees. This may, however, be particularly true only for the subtropical and temperate regions, where most such investigations have been carried out, but not for the tropics where low soil fertility is more commonly a greater problem. Furthermore, extensive and detailed work with a number of commodity tree crops in the tropics (cocoa, tea, rubber, coffee etc) has shown considerable response to improvements in soil fertility either from micro-site variations or the application of appropriate fertilizers. These responses are also often found to be paralleled in product quality.

A. *Climate*: Mean monthly precipitation and mean monthly temperatures are important for estimates of the length and intensity of periods of water stress. The mean daily maximum temperature of the hottest month is important because species are known not to perform well above certain temperatures however much water is available for transpiration. The incidence of frost is particularly important in limiting the distribution of many species; although it may be more difficult to detect patterns of adaptability which follow a frost related cline since there may be considerable variation in the risk of frost from year to year, which enable trees to become established in some years but not in others. Moreover trees can vary in susceptibility to frost with age.

Klimadiagrams are useful to illustrate the range of mean monthly rainfall and temperature regimes

experienced by each provenance (see Appendix 2.3) A klimadiagram is not the most accurate way of illustrating water balance from a site, however, Penman's method is widely accepted as a most reliable approach but it requires meteorological data which may not be available at the exploration phase.

It is, therefore, first necessary to predict in some way the monthly temperature and rainfall regime likely to be experienced at the actual collecting sites from that found at meteorological stations. Consistently high correlations are found for several areas of the globe between mean annual temperature, or mean monthly temperature, and altitude and latitude. For several Central American countries, Greaves (1976) suggested an adjustment of 0.56°C in monthly temperature for every 100m change in altitude. Webb *et al* (1980) suggested that the temperature lapse rate throughout the zone between 30°N and 30°S in all three continents varies between 0.3 and 0.6 degrees for every rise in 100m* ; the lapse rate averages 0.15 degrees for every one degree of latitude from the temperature equator (located between 7 and 10 degrees north in all continents). Appendix 2.4 gives the mean annual temperature for sites at various altitudes and latitudes.

Likely changes in precipitation cannot be predicted so readily. The same precipitation as that found at a nearby meteorological station cannot therefore be accepted unless the topography is fairly uniform between the station and the collecting site and there is no large feature (a mountain or lake) nearby. Otherwise, local knowledge and experience may suggest the possible extent of likely variation given prevailing wind directions during the rainy season(s).

Notes on the vegetation (physionomy and species composition) may help to give further indications of local climatic conditions. If a particular vegetation type is known to indicate particular climatic conditions in a region, the appropriate local method of vegetation description should be used. Form IIIa (Appendix 2.2) describes Kuchler

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* This does not apply to the arid land mass of Africa north of Latitude 15°N, or Australia south of latitude 15°S.

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scheme of vegetation description. However, human interference or natural hazards (e.g. hurricanes, fires, etc) may alter the vegetation in such a way that it is no longer a good indicator of climatic conditions. The effects on climate of large nearby geographical features will be felt not only in their general influence on temperature and rainfall, for example, but sometimes on the occurence of unfavourable climatic events - e.g. high winds, infrequent frosts, dust storms, salt winds etc. Evidence, records or hearsay evidence of such information should be recorded if possible.

B. *Relief*: The angle of the slope and its orientation, the location of the site on the slope in relation to the top and bottom and the shape of the slope at the site (convex or concave) can often give good indications of soil depths, water retention capacity, drainage capacity etc. for given climatic conditions. Other site morphology information can give indications concerning exposure, insolation etc.

Even relatively small slopes can have significantly different topoclimates at the top and bottom which affect plant growth. Combined with soil changes down a slope the overall influence on vegetation generally, and the growth of plants individually, can be quite marked. In tropical regions the climatic factors most affected by position on a slope are night temperatures (lower at the bottom due to cold air drainage) and dew occurrence.

Exposure in relation to orientation can effect both young and adult stages of plant growth, seedlings being particularly affected by hot dry winds and taller stages by gales or hurricanes etc. which, even if they occur at infrequent intervals, can have a devastating (and selective) effect on the taller plants in an association. Salt sprays on slopes exposed to the sea will have a selective influence on vegetation exposed to or protected from it.

C. *Soil Characteristics*: A detailed description of the soil, including nutrient analysis, is not necessary at the exploration phase unless there are peculiarities about the site. However, a general soil description will be useful including texture, depth and colour of the rooting zone, possible cause of rooting impediment (indurations, anaerobic zones), drainage, parent material and perhaps pH of the upper layers of the profile. In some areas regular soil catenas might follow topographical change and they should be identified and any correlation with vegetation noted.

As most woody perennials are sensitive to the effects of shallow or indurated soils some attempt to obtain information about this is often worthwhile, even if the number of sites at which auger holes can be made is relatively few. The samples from the holes can be used for the general descriptions mentioned above and to identify root restricting layers. In addition, a crude estimate of the water availability throughout the profile can be obtained by using some general relationships about the interactions between soil texture and soil water holding capacity. (See Appendix 2.5).

Soil parent material can be only a general guide to the nutrient status of soils derived from it because of the many other important pedogenic factors concerned. This aspect would assume greater importance where a MPT species was seen to be confined to locational sites related to specific types of soil.

Little can be done to estimate soil nutrient status properly without an organised soil sampling and testing procedure. Indirect methods such as obvious signs of poor growth and nutrient deficiency in the associated vegetation during the growing season can give indications only where it can be ascertained that soil water is not also limiting. Indicator species can help as long as they have been identified as such, and a search through the ecological records for such information could be well worthwhile.

Where MPT's are to be used in agroforestry land use systems, they will be expected, in virtually all cases, to play a key role in maintaining the *sustainability* of those systems. To obtain information about their potential values in this respect will therefore be most useful. A major aspect of this is their capacity for micro-site enrichment of the topsoil. When collecting reproductive material it will, therefore, be useful to look for any evidence of this e.g. depth of litter, evidence of flourishing growth of understorey plants, or characteristics of the topsoil beneath and away from the canopy.

A full analysis of the natural situation will require very detailed studies of both soil and

plant nutrient status and more detailed examination of soil physical and chemical characteristics (e.g. levels and nature of soil organic matter in the profile, cation exchange capacity measurements etc. Appendix 2.6 gives further information.

D. *Other factors*: Other notes on the frequency of occurrence of fires, flooding and human exploitation (e.g. charcoaling) can often be useful.

Tree characteristics

The tree characteristics (stand or individual trees) about which it is important to have some information are those which may give some indication of the following:

- Capacity for production of desired outputs.
- Service functions
- Inter and intra-specific relationships
- Dysgenic or eugenic selection.
- Characteristics relevant to multiple cropping.
- The type and timing of phenological development which may have bearing on
  - suitability of the species for specific purposes
  - management of the species
  - future collection efficiency

Form IV in Appendix 2.2 includes the kinds of information which it is possible to obtain for these purposes by direct observation, as well as some which can only be obtained by careful interpretation of observations. Clearly, while for most information observations are best evaluated in unaffected stands for some characteristics (e.g. coppicing propensity) the observations need to be obtained from stands or trees which have been utilized in some way.

Although a thorough and concientious set of information can be obtained at any one site during a single visit there are still some problems to be borne in mind :

- Will the species being collected present a different appearance if visited at other times of the year, and to what extent can this be forecast?

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- Is it possible to predict the pattern of plant behaviour for the species to be collected in relation to seasonal climatic changes? What will be the sequence of various phenophases such as bud development, flowering, fruiting, leaf fall?

- Will there be any major changes in the *associated* vegetation which can give further useful information, for example the nature and times of occurrence of competition from associated ground cover, understorey, companion or overstorey plant species?

If a sequence of visits (two or three) timed to concide with major seasonal changes are not possible then local informants can sometimes provide some general comments which should be recorded. Unlike most herbaceous plants woody perennials in the tropics often undergo growth and development patterns which are both more complex and, in the case of some species, or on some sites, may not be the same as those experienced by other members of the the species growing in different ecozones. Neither is it easy with some to relate their phenology to individual seasonal climatic parameters. These considerations are discussed more fully elsewhere in this manual but any information that can be gathered whilst in the field among natural populations is likely to be extremely useful, however fragmentary it may be.

Again some of the *direct* observations required can be very hard to make without considerable time and effort being taken. For example observation on seasonal rooting activity, or on the presence or absence of nitrogen fixing nodules. Furthermore results may be inconclusive if adequate sampling both in time and space is not possible.

Other direct observations provide information about characteristics which may be significantly influenced by site or management. For example tree crown shape may vary with stand density; and tree crown density or depth may in some cases vary with differences in the nutrient status of the tree. Therefore, potential tree development may be difficult to predict. Photographs of the range of tree shapes and sizes within the stand, and of tree parts (branches, flowers, fruits etc) all with reference scales, are a useful way of recording information for later study.

The validity of *derived* information will obviously depend on the correct interpretation of observations made on only one (or a few) occasions. It is, therefore, less valid. Indeed, patterns will be explainable by a whole range of alternative factors. Seed dispersal mechanisms are usually a key to ecological success and an understanding of, for instance, a lack of seedlings of the species concerned under the canopy of its parent could be due to many factors including:

- Allelopathic influences either
  - from its own parent or
  - from another species in the under/overstorey;
- Competition for moisture either
  - through root uptake, or
  - canopy interception by the parent or another species.
- If the site has been influenced by man and livestock and soil compaction has taken place, the root radicle may not be able to penetrate the soil surface; or seedlings may have been grazed.
- Infrequent good fruiting years combined with a shade intolerant seedling may lead to very few or no seedlings being present.
- Flowering and fruiting intensities and intervals can be influenced by pollarding and pruning patterns.

These examples are only some of many which will become apparent in the field.

An indication of the within-population variation for specific characteristics is certainly desirable. But because it expresses only phenotypic variations it cannot do more than provide clues as to possible genetic heterogeneity concerning such characters.

Nevertheless, it may sometimes be possible to suggest where an obvious environmental factor is most likely the cause (a larger tree and bigger leaves where growing in a hollow as compared with raised ground). Otherwise the mere presence of such variation must, at least, suggest the need for a careful scrutiny of such plant characters during the evaluation stage.

Species utilization and function

Appendix 2.2 Form V gives a list of some possible uses of trees and shrubs and their functions in an agroecological context.

These can be divided into indigenous, home based use and industrial or commercial utilization; the latter information derived from hearsay or literature. A further subdivision can be made according to the quality of the species for particular end uses in relation to the timing of the cropping for such uses, both within the yearly cycle and within the life cycle of the individuals of the species.

Under the heading "agroecological", the functions of the species should be divided into those appreciated locally under the broad environmental conditions defined by the site assessment, and those functions appreciated in other areas. In the latter the relative qualitative and quantitative differences in perceived functions may be due both to different site conditions (which are not recorded during a first stage exploration phase), and to the presence of other species which alter the ranking order of usefulness or undesirability of the species for specific functions. It is accepted that, under the heading agroecological, people may attribute a particular perceived effect of a tree on an associated crop or pasture to the wrong cause or combination of causes. This may mask site specificity thereby not allowing reliable prediction of the relative value of a species on a different site. For instance the allelopathic influences of *Eucalyptus camaldulensis* Dehn. on annual herb species in California has been shown to vary widely in space and time depending on soil type and on the particular rainfall pattern prevailing in any year.

Ancillary material needed to support seed or vegetative collections

Rhizobia/mycorrhizas: Following advice from a specialized institution it may be desirable to collect nodules or roots for rhizobial and mycorrhizal isolates from the natural habitat. These would be cultured for possible reinoculation of the associated species in the exotic environment (subject to quarantine regulations). And this may well improve the performance of the species outside its natural habitat. A discussion of the subject is given in Section 5B.

Herbarium specimens: Samples of leaves, fruits, seeds, flowers are essential to support the collections of fruits/seeds; enough material should be collected to represent the range of characteristics found in parent plants. Notes and photographs can usefully supplement herbarium material and, if seed extraction is carried out on the site, a photograph of a collection of fruits can be useful to illustrate the range of variation. Photographs are particularly useful as they show the form of trees very well, and can be analysed in the office.

Other Materials for scientific investigation: Because of the high cost of access to areas visited during the exploration phase, the opportunity should be taken to collect other material which could be of value to research and to indicate patterns of genetic variation (e.g. taxonomic research using biochemical characteristics - terpenes in conifers, phenolics in eucalyptus), or of value in indicating potential valuable products (e.g. gums, medicinal properties, etc) which may have already been mentioned by local inhabitants. However, special equipment is required for collecting and storing such material including specimen bottles, storage solutions, refrigerated or insulated containers.

Wood samples may be desirable for preliminary testing for a number of purposes (timber properties, calorific value) and present no problems of storage.

Some species may produce gums or other exudates which, again, are easily sampled, and it is worth seeking advice on collection, storage and analysis from specialists.

The collection of leaves at the exploration phase for foliar analysis of various nutrients and compounds in the hope of, for example, obtaining an indication of their potential value for fodder is likely to provide fragmentary or actually misleading information, unless it can be done throughly. There can be considerable variation in concentrations of foliar nutrients over time, im different parts of the canopy, and even along a branch. Individuals of the same species on the same site and at the same time will give varying results. Further, compounds which inhibit digestion (e.g. tannins, flavinoids, alkaloids) are also known to vary over time.

Collection and Storage of Reproductive Materials

The main objectives of material collection are as follows

- The propagation of the species/provenance:
  - for evaluation purposes
  - for subsequent distribution for development.
- To enable the identity of the population to be checked.

Additional objectives may include the collection of material of value for scientific research and to provide data on the potential value of the products.

Appendix 2.2 Form VI provides a checklist of the information which should be recorded during material collection, and Appendix 2.7 provides a list of the equipment which may be needed for the collection of material.

Planning of a seed collection*

The objectives behind seed collection may be varied and lead to collecting the following.

- A maximum *quantity* of seed
- The widest *range* of provenances possible.
- Seed from *single* identified, *parent* trees

Where the purpose is to evaluate multipurpose trees the objectives of seed collection, in the first instance, should be to collect material so as to be aware of the between-and within-population range of variation in *performance*. That is, rather than with regard to purely taxonomic characters. Hence, seed collection should initially concentrate on two main sources :

- Populations which are distributed in such a way as to be likely to provide information on the extent of (clinal) genetic variability
- From individuals which show outstanding examples of selected characteristics within-populations.

In this way it may be possible to discover some measure of the variation in performance attributed to within-population genetic differences.

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* Again the term "seed" here is used both to describe actual seeds as well as other types of propagules.

Planning should start as early as possible. For species suitable for agroforestry it is likely that much information already exists, so that the first step is a literature search. The best sources for up-to-date information on international priorities and activities are: "Forest Genetic Resources Information" and "Plant Genetic Resources Bulletin" - both from FAO.

Factors in the planning process then include consideration of information about the following:

- The distribution of the species
- Probable flowering and fruiting times
- The likelihood of different seed yields in different years
- Weather (also in relation to conditions of roads, etc)
- Distance to collection sites (with regard to available transport)
- Any seed collections by other organisations.

It is also necessary to prepare for any legal or official documentation that may apply in the country or district of collection or use. These include import and export licences, plant quarantine certificates, seed source certificates, and permission to enter or collect from governmentally or privately owned land.

Background information for seed collections

If collection is planned sufficiently far ahead, people in the field can be asked to keep regular records of phenology, and to note likely seed sources. In addition to learning about possible seed yields, the timing of seed collections within the overall programme can be planned more effectively by acquiring such local information.

Timing and tactics of seed collection: The timing of the seed collection operations depends upon the information available. In abundant seed years it is clearly easier to obtain larger quantities of seed from the desired parent trees or populations. If seed production is unreliable, prior correlations of actual seed production with flowering patterns can be a most valuable planning aid.

In situations where important populations of plants

are threatened with destruction, it is clearly important to give these priority, and to plan to raise these seed sources in conservation plantations for further seed production.

Tactics also include the organisation of field workers, transport, handling requirements, temporary storage and preliminary testing (see below). Although seeds will be the most usual propagules, vegetative material may be desirable in some situations (e.g. stem cuttings, root cuttings or material for micro-propagation).

Selection of parent plants: The natural occurrence of the species being collected has a strong bearing on what *can* be collected. A widespread tree species such as *Acacia tortilis* lend to range-wide collection of different populations for provenance testing. *Cordeauxia edulis*, on the other hand, is geographically and ecologically much more restricted.

For adequate sampling of a whole range of genotypes, regular or systematic sampling may be best to ensure that clines or regular patterns are detected. Where a species is represented by widely spaced individual specimens espcially where there are marked differences visible between them, individual tree collections, kept separate, will be strongly desirable. It is, however, though not always feasible to maintain individual tree identities even in seed collections which are made specifically for research.

For representation of a provenance, at least 25-50 parent trees should contribute to the seed collection, randomly selected at a distance of 100m or more apart to insure out-breeding as far as possible, and to cover the widest range of genotypes.

The deliberate selection of "superior" phenotypes may be desirable, but generally not completely at the expense of smaller slower-growing or lower-yielding individuals. These may well have attributes that only become apparent during the evaluation stage. This is especially important with MPT's where different habits and growth characteristics may be required for particular agroforestry land use systems. In addition, characteristics such as resistance to particular pests and diseases or to various plant stress factors may be required in the gene base later, if not sooner.

In standard forestry tree breeding terminology the superior phenotype is called a "plus tree".

Depending on whether it is to be grown singly or communally "plus" implies a different set of characteristics. Later when its genetic superiority is confirmed by progeny testing it becomes an "elite tree". "Minus trees" are sometimes selected to maintain a broad genetic base, and to provide immediate comparisons in progeny trials.

The retention of parent identity is very important for evaluation and future breeding strategy where deliberate selection has been made.

Whatever the situation in which the parent plants are found, it is important to obtain information on the breeding system as far as possible.

This might be done by:

- A study of the literature for that genus/species.

- A close examination of the structure of the flowering organs during the various stages of anthesis, including an examination of pollen ripening and, if necessary, fertilization. This can be done cytologically or crudely, by bagging individual flowers at different stages of anthesis with and without anther removal, and then looking to see if fruits set.

- An appraisal of phenotype variability in relation to separation distances where ecological factors are evident.

More complicated investigations (e.g. using "marker" genes) are probably for the future. Also, it must be remembered that for so-called "in-breeding" species the degree of actual out-crossing depends not only on the characteristics of the plant but on the environmental opportunities which occur e.g. the presence or absence of correct pollinating insect species and suitable combinations of weather conditions for their activity in relation to anthesis

Selection and handling of materials for seed.

Seeds are obtained only by collecting fruits and it is desirable, obviously, to select the largest and healthiest from a tree. However, in general, although fruit size may be greatly diminished by plant stress (especially fleshy fruits) seed size is often less severely effected. Some preliminary

examination of the fruits, even if this is just to ensure that seeds have properly developed, is often a desirable preliminary to actually collecting from any one tree. The extent of parthenocapy or sterility (as indicated by malformed seeds) may need looking into.

Yields of seeds may differ widely between individuals and it may be difficult to ensure that all individual parents are equally represented in a seed collection. The importance of collecting from an adequate number of individuals and, if possible, of keeping the individual parent seed-lot separate, has been referred to above. Bulking of "seed-lots" can be done later in the seed laboratory if necessary.

Each "seed-lot" should be labelled within and outside the container or bag, and strictest precautions must be taken to prevent mixing seedlots (see Appendix 2.8)

It may be difficult to avoid collecting diseased or infested seed on some occasions. Great care will of course be needed for phytosanitary reasons, especially if the seed is to be moved between countries. If there is evidence of large scale seed damage a special research programme may be needed to study this, but some form of sealed storage will help diminish the spread of pests from one container to another and, if the seeds are air or better sun-dry, it will often help retain viability. Fruits such as capsules or pods will normally be collected when mature and at least sun-dried (if this has not happened on the tree). Dehiscent fruits will need to be collected before they have split unless a sheet is spread. It can be a matter of choice as to whether seeds are extracted soon after collecting (e.g. where this is easily done as in, say, *Acacia* spp) or later and perhaps with the aid of special equipment (e.g. *Prosopis* spp). However, transport and hardling are made easier if fruit coats are removed and, also, there is often less chance of pest infestation, especially if a preliminary sorting of damaged seeds is done at the site-however crudely.

If the fruits or seeds are not thoroughly air-dried then storage during transport is probably best done in cloth bags, as plastic containers of any kind usually build up high humidities and encourage the development of fungi. For seeds with a tendency to germinate almost immediately it may be necessary to chill them and to use insulated containers.

Dried fruits or seeds can be treated with a combined fungicide/insecticide dust if there are signs or possibilities of disease or pest infestation and some time is to elapse before they are transported to base (where a methyl bromide fumigation can, if done correctly, eliminate pests).

Although knowledge is rapidly being collected on the viability of tropical seeds and their storage requirements many species are still imperfectly understood. The IUFRO Working party 2.01-06 is one source of information, particularly through its address list of participating research workers.

Where fleshy fruits are collected the question of seed extraction has to be more carefully considered:

- are the seeds "recalcitrant" (i.e. will they not retain their viability if dried and/or kept at low temperatures?).

- are they more easily and safely transported in whole fruits rather than "pulped" or "shelled", and are there field facilities to do this and, perhaps, to clean the seeds (e.g. water and equipment)? Can the extracted seeds be made more easily handleable by, say, coating with wood ash? How will extraction in the field affect viability (most moist seeds are more susceptible to heat damage than dry ones, and temporary storage in the back of a vehicle in the sun may cause damage).

- are the fruit characteristics an important genetic consideration so that a more careful selection needs to be made on return to base ?

Selection and handling of materials for vegetative propagules

Where seed is scarce, diseased or infested, or where vegetative propagation is specifically needed ramets for grafting or direct rooting may be collected. The timing of collection and transport is much more exacting than that for most seeds, and it is easier to raise plants from seed and to propagate vegetatively from these under controlled, ex-situ conditions. If this is done, however, the genetic constitution of the propagules is in considerable doubt, especially in out-crossing species.

Species which show a great range of vegetative vigour and/or habit (even within the same taxon, e.g. *Prosopis* spp.) will need special attention for the production of vegetative material representing its full genetic range.

Material suitable for vegetative propagation may be taken from various parts of trees, and used for direct rooting, or for grafting on to rootstocks. In the tropics detached scion grafting is often difficult without specialized equipment and skilled attention, with the exception of budding techniques. Material for detached scion grafting and/or soft or semi - hardwood cuttings has to be collected while fully turgid (i.e. early in the morning), kept cool and moist, and taken to a nursery in the shortest possible time (a few hours, preferably). Polythene bags (sealed and containing moist peat) can help retain the material in a fit state as long as they are kept cool and shaded at all times. Insulated containers can help.

Where a plant forms them a more robust kind of vegetative material is a rootstock (or sucker) dug up with soil attached. Watering first is a help in retaining the soil. In some cases, where a return visit is possible, it may be feasible to layer branches (ground or air-layers) and come back to remove them already rooted.

The season at which vegetative material is removed can greatly affect the chances of successful rooting. In general (but species differ) rooting success is greater when appropriate plant materials are taken at a time which relates to an appropriate growth stage. For example.

- Budwood - at the exact stage of bud maturation and neither prematurely nor when the bud has become dormant.

- Soft or semi-hardwood cutting materials during the early or later part of a vegetative growth flush, respectively.

- Hardwood cuttings - after a growth flush when there is plenty of well matured wood.

- Layers - made during the very early part of a growth flush, and collected for transport before the end of the flush.

Two important aspects of collecting vegetative materials require some care and observation:

- If there are any obvious signs of virus infection (crinkly leaves, stunted growth, interveinal chlorosis etc) the plant should be avoided (even parts which do not appear to be affected).

- If there are chimaeras (somatic mutations) these may be visible as a change in morphology in a particular shoot.

In general, very little is recorded about virus infection in MPT's (FGNFT's), probably because they have not, as yet, been to any extent examined by plant virologists. As with fruit/seeds it may pay to treat vegetative materials with a combined fungicide/insecticide (by dipping) in order to avoid bringing infested tissue into the nursery.

As with fruits or seeds clear and adequate labelling (inside and out) of the package of vegetative material is essential (See Appendix 2.8).

Micropropagation

Micropropagation techniques such as tissue and meristem culture have now become common practice producing plant materials free of virus and mycoplasma ("Nuclear stock"), but also for general production.

Relatively simple laboratory facilities are needed.

Species differ considerably in the ease with which plantlets can be produced from appropriate tissues. Usually undifferentiated parenchyma cells from the phloem taken from young stems, or from wound callus tissue. A buffered solution containing both nutrient sugars and plant hormones is required, which may differ with species and with time of development; temperature and light must be carefully controlled.

After separation of the cells they are usually maintained in this solution and kept gently shaken until individual cells, or clusters, have started to differentiate into a root and shoot.

At an appropriate stage of growth the young plantlets are removed from the laboratory and placed in favourable nursery conditions under strict environmental control. There are some practical difficulties at this stage in handling young plantlets and the survival rate can be low if great care is not taken. Subsequent nursery stages can be as normal.

Supporting Facilities

Supporting institutions

To facilitate a major international collaborative programme of research and development for tree genetic resources the single most valuable insitution is the central coordinating agency. Some examples with experience of tropical species are the Commonweath Forestry Institute (CFI), Oxford, UK (tropical pines and central American hardwoods) The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Canberra, Australia (eucalypts and Acacias), INIF, Mexico (Mexican species), and the DANIDA Forest Seed Centre* Humlebaek, Denmark (Asian pines, *Gmelina* and *Tectona*). These institutions have provided one or more of the following services for the international trials they coordinate:- taxonomy, seed, experimental design, data processing, wood quality analysis, chemical analysis, genetic studies, soil analysis, monographs, bibliographies and training courses.

For the new programme with multipurpose trees it is unlikely that any one central coordinator could provide all these facilities and services nor the other services that might be required, e.g. *Rhizobium* and *mycorrhizal* inoculation techniques and materials. Such services must be obtained from specialist organisations.

The institutes mentioned above have all been concerned with forestry research. Other institutes are involved with tropical tree research in a wider sense, i.e. with commodity tree crops, forage and range species and with fruits, nuts and spice trees or bushes.

In addition, many of these institutions have developed techniques and methodologies for studying woody species which are directly relevant to work with MPT's. This also includes others in temperate regions which have past or present links with tropical tree research, ecology or other types of experimental programmes which can be of use.

Help with choice of species

In addition to lists of species/site characters prepared by the CFI and the CSIRO, the National Academy of Sciences has drawn up a list of 20 species for trial in the Sahel zone and a monograph on species for fuelwood. The Food and Agricultural Organization of the United Nations (FAO), advised by its Panel of Experts on Forest Gene Resources, has a list of priority species for fodder, fuel and shelterbelt use. These agencies can all give advice on suitable species for trial on a given site and on seed source supplies.

In addition FAO, with financial assistance from the International Board for Plant Genetic Resources (IBPGR), has initiated a project on some 20 arid zone species involving nine countries where the species are indigenous. Research institutions in these countries are collecting seed and making available to the other eight countries. At present there are no plans to distribute samples to other countries but FAO can supply the contact addresses and, later, results of the species trials (see Appendix 2.9).

Taxonomic research

While CFI and CSIRO conduct taxonomic research on the herbarium material of the species they are concerned with there is no clear leading centre for the taxonomy of the many species likely to be included in the NAS sponsored trials. At an early planning stage arrangements should be made with established herbaria such as the Royal Botanic Gardens, Kew, UK, or the Smithsonia Institution, Washington, USA, to undertake the taxonomic confirmation of all the sample populations included in trials. Where indicated, studies of the morphological variation shown in natural stands and in the field trials should also be carried out at suitable centres.
There are also many national herbaria and Botanic Gardens which have excellent resources and experience for identification and information about the species found in their regions.

Chemical analysis

Chemotaxonomy is now widely accepted as a supporting tool in studies of plant variation and in identifying hybrids or unknown populations. It has been used for terpenes in the CFI International Provenance trials of tropical pines. Biochemical characters may also be useful in studies of juvenile-mature correlation.

The types of chemical compound that are most discriminatory between species and population vary with the family or genus; an indication of these and the research interests of individual workers are given in *Chemical Plant Taxonomy*, a semi-annual mimeographed newsletter distributed by the Academy of Natural Sciences of Philadelphia U.S.A.

For the legumes specifically another newsletter, the *Bean Bag*, is distributed by the USDA Plant Taxonomy Laboratory, Beersville, Maryland USA, and the Smithsonian Institute, Washington, D.C., USA; this circular indicates ongoing research in classical taxonomy, chemotaxonomy, genetic variation and breeding. Isozymes are being used to determine genetic variation including gene frequencies and heterogeneity in many species. Many laboratories around the world could undertake suitable studies with additional resources(e.g. CFI. CSIRO and USFS)

As with taxonomic research chemical analysis may be useful in the evaluation of field trials as well as in the exploration phase.

Assessment of wood properties

In the evaluation of trials of species and provenances for industrial species the most important characters have been growth rate, stem form, branch characters and wood quality. Wood is a highly heterogeneous and anisotropic material but its suitablity for end uses can frequently be predicted from a few structural features, particularly wood density and its variation within trees, fibre dimensions and tissue organisation. Since these are influenced by environmental conditions and by correlations with growth rate and tree form, their values in exotic conditions are not predictable precisely from material in natural stands. Nevertheless an indication of the extent and pattern of variation between populations be obtained from such samples. For multipurpose trees these wood properties may have different priorities.

Increment cores taken at breast height from 5-10 trees per population as usually adequate and many national forestry research institutions could determine average core density by gravimetric methods and fibre length from projected images of macerations. However, for large scale screening, especially at the evaluation phase, automated methods are preferable, particularly X-ray densitometry; lists of laboratories projects and publications are provided in another mimeographed newsletter, the Microdensitometry Bulletin, distributed by Dr. J. Evertsen, Irish Institute of Standards (IIRS), Ballymun Road, Dublin, Ireland.

Automated measurement of fibre dimensions and tissue organisation is less advanced but the CFI, Oxford, is currently developing methods of optical image analysis for this purpose. Calirific values do not vary greatly but routine checks are worthwhile since calorific yield is the product of volume, density and calorific value. A joint CFI/TPI project already exists on this subject, and could be extended to provide a service for others.

Assessment of other products

The products from MPT's will include many others than just wood, or wood derivatives. A number of international and national organisations have facilities and experience in assessing the quality of various tree products.

Seed processing

Many countries have facilities for extraction, drying and storage of indigenous seeds in either the Agriculture or Forestry Departments. For an international trial programme the seed donor countries could be asked to do all the seed processing and distribution; it is more efficient and more secure (with regard to maintenance of seed source identity) to maintain the seed stocks and distribute them to recipient organisations from a central store at which the staff are skilled and facilities are available for research on seed problems if needed.

This central store may or may not be located at the centre that coordinates the whole trial programme. Examples of major seed stations with experience of tropical trees include:- Division of Forest Research, CSIRO, Canberra, Australia; Danish Tree Seed Centre, Humblebaek, Denmark; Forestry Commission Research Station, Alice Holt Lodge, Farnham, UK; Royal Botanic Gardens, Wakehurst Place, Sussex, UK; US Forest Service Tree Seed Laboratory, Macon, Georgia, USA.

Collection and interpretation of climatic data

Many research stations in the tropics have some provision for recording climatic data, if only a rain gauge and a Stevenson screen with a thermohygrograph. Equipment for these minimal records should be provided at the site of each trial. Lists of equipment and suppliers are given in Part 3E. In the exploration phase, however,

it is unlikely that a meteorological station will exist at the site of each seed collection and in this case the data must be obtained from the nearest station with detailed information on the geographic/topographic differences between the two locations.

The types of data and the equipment used for measuring them are outlined in the Annex to Section 3b but further advice may be sought from specialised agencies and institutions such as:- World Meteorological Organisation, Geneva, Switzerland; FAO, Rome, Italy; NERC Institute of Hydrology, Wallingford, UK.

Soil analysis

It is desirable to collect and analyze soil samples both from species collection sites and from field trial sites. Analysis can be for nutrients (available and reserve), chemical properties (reaction, exchangeable cations and capacity, salinity) and soil moisture characteristics; the last requires special sampling of undisturbed soil cores.

Two warnings are necessary, however. First, soil analysis is time-consuming and expensive, and should not be undertaken without reasons, i.e. it is known what use will be made of the results. The so-called 'routine' soil analyses found in many reports serve little purpose.

The second warning is that soil chemical properties exhibit large local variability, with coefficients of variation of the order of 30-70% within an apparently uniform area. Consequently a single sample, as from a soil pit, is of little value; the apparent precision with which chemical analyses of representative profiles are commonly given is misleading. If meaningful values of nutrient levels and other chemical properties are required, composite samples should be taken. (see Appendix 2.6).

Rhizobial and mycorrhizal techniques

The collection and culture of isolates and their distribution and inoculation in field trials require specialised techniques. A number of organisations have such expertise, e.g. CFI and USFS for mycorrhizae and NIFTAL, University of Hawaii, USA, for rhizobia.

In fundamental research on these organisms isotopic tracing is commonly used and advice on this technique can be obtained from the International Atomic Energy Authority, Vienna, Austria.

General

Various specialist organisations can give advice and assistance on the individual topics noted above and some, such as CFI, CSIRO, CTFT, FAO, and ICRAF, can help with a range of subjects offering advice on species, equipment, methods, information, staff and, occasionally, direct finance for research. Another important source of expertise is the International Union of Forestry Research Organisations (IUFRO).

IUFRO is a non-Governmental organisation with 400 member institutions and 8000 individual scientists in 95 countries grouped into six scientific divisions with a hierarchy of 40 subject groups, 150 working parties and 16 inter-divisional project groups. Apart from a small financial contribution by each member institution, IUFRO has no funds, but through the activities of individual scientists supported by the administrative services of their parent institutions, it is highly effective in stimulating cooperative research on given species or problems.

IUFRO is managed by voluntary divisional coordinators, subject group leaders, working party chairmen and their deputies on a 5-year appointment, renewable for a further period of five years. Its latest reorganisation took place on January 1, 1982, and the full list of working parties and officers is included in the IUFRO Annual Report for 1982. The following selected working parties are, however, particularly active and immediately relevant to the exploration, evaluation, conservation and utilisation of the genetic resources of multipurpose trees:-

Division	Subject Group	Working Party	Title and Chairman
S1	07	07	Agroforestry Dr. G. Budowski / B. Lundgren CATIE Turrialba, Costa Rica.
S2	01	06	Seed problems Dr. F.T. Bonner Forest Tree Seed Lab. P.O. Box 906, Starkville Mississippi, USA.
S2	02	08	Tropical Species provenances Mr. G.L. Gibson Commonwealth Forestry Inst. South Parks Road Oxford, England.
S2	02	09	Eucalpt provenances Dr. J.W. Turnbull Division of Forest Research CSIRO P.O. Box 4008 Canberra, Australia.
S2	03	01	Breeding tropical Species Dr. R.D. Barnes, Commonwealth Forestry Inst. South Parks Road, Oxford, England.
S2	03	01	Breeding eucalypts Dr. J. Davidson P.O. Box 419 Armidale NSW 2350, Australia.

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NOTES ON THE IMPLEMENTATION FLOW CHART FOR MPT EXPLORATION

- by P.J. Robinson*

1. Identification of national ecozones i.e. areas with similar land-use systems and similar resource bases. Generally these would be on a larger scale than that used by FAO for agro-ecological zonation.

2. Land use systems may experience physical or socio-economic constraints on productivity. Future problems e.g. fuelwood shortage should also be identified where possible. The role of trees is to provide year-round employment and production, multiple products and improved environments. Species from other ecozones, countries or regions should be considered where they have solved problems.

3. Possible benefits from MPT's should be examined not only for the specific ecozone but for different sites also. Benefits include soil improvement (direct through nitrogen fixation or indirect through reduction in dung burning for example), shelter effects, dry season fodder etc.

4. Match possible benefits from MPT's against the identified land use constraints, ranking them in order of importance for each particular ecozone.

5. Preliminary list usually contains more species than can be worked upon.

6 to 10. Rank all possible species, drawing on published and unpublished information, rejecting or prioritizing until a number that can be handled is arrived at.

11 to 12 For each species, using all sources of information determine distribution, environmental and historical parameters likely to have led to genetic adaptation, including barriers to gene flow and human selection pressures.

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* With acknowledgements to P.A. Huxley, P.J. Wood and J. Burley for useful comments.

13. Decide on sampling strategy, e.g. range-wide if little is known, more intensive where genetic variability is better understood. Reduce programme in extent or intensity if resources are a constraint.

14a. Locate sampling sites and collect:-

- seeds and vegetative propagules
- reference herbarium material
- material for population genetic studies (leaves, flowers, wood, chemicals)
- material for other purposes e.g. medicinal

14b. Collect information on:-

- environmental parameters.
- tree characteristics
- local knowledge on value and management of species
- any other local species of potential (return to stage 6 for any found)

15. Seeds, propagules and information stored and retrievable for evaluation.

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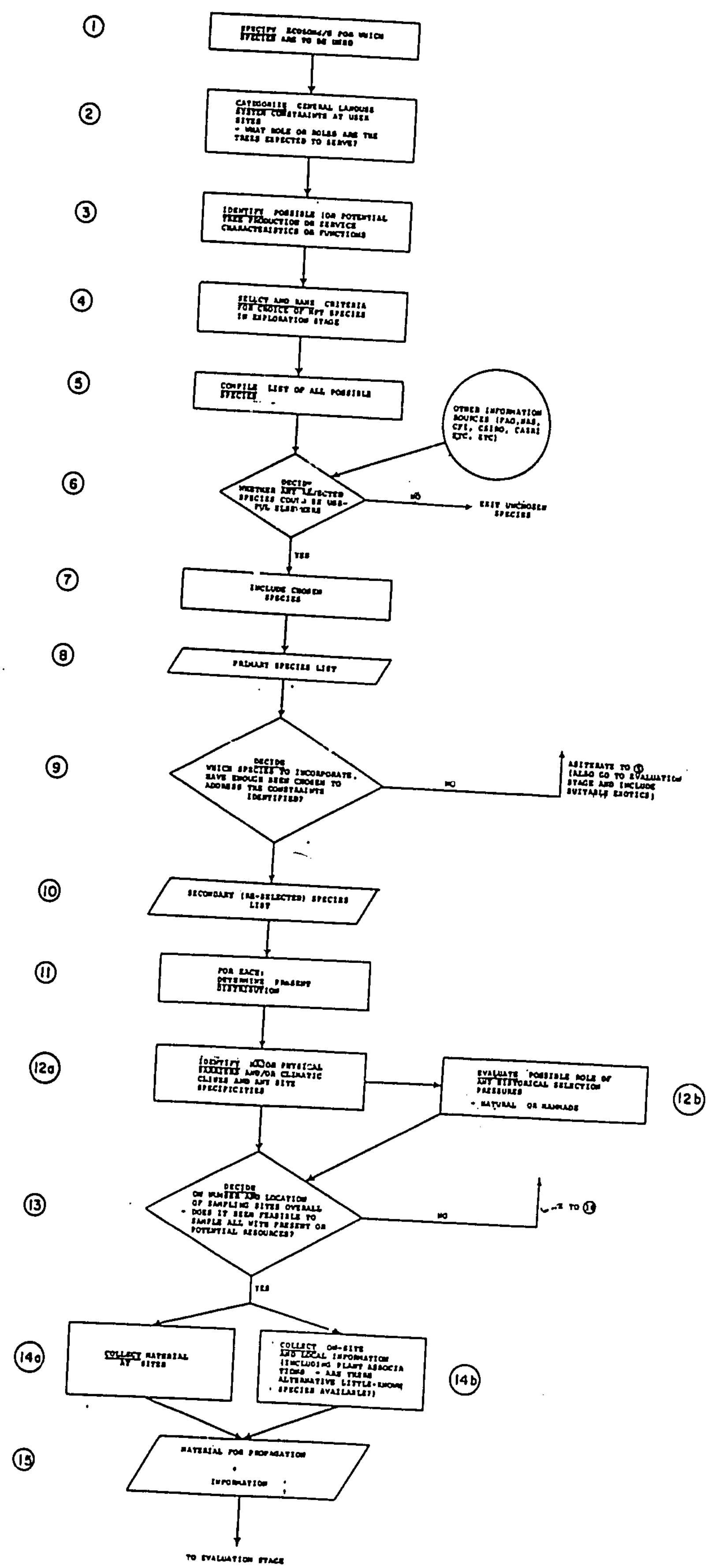
IMPLEMENTATION FLOWCHART OUTLINING A NATIONAL STRATEGY FOR MPT EXPLORATION



SECTION TWO

PART 2A

ANNEX

Appendix 1

Aide Memoire of Information Required to help show a Species' Distribution and Potential Clinal and Non Clinal Variation in Characteristics

Botanical name (and authority):

Common name(s)

Name of the area under your responsibility: Surface area ...Km^2

Latitude limits: Longitude limits:

Species present/absent

If absent was it present in the recent past (e.g. 50 years)?
Yes/No

Comments and/or data on the following, where appropriate

- Climate

A. Information on meteorological station/s

- Coordinates and altitude of meteorological station/s to which data refer;
- Number of years of data recording;
- Comments on likely/possible variation in temperatures and precipitation between climatic station and areas where species present.

B. Information related to species

- Altitude range of species
- Precipitation preferably, mean monthly totals (otherwise yearly mean and number of dry months).
- Temperature
  - monthly means of daily temperatures
  - mean maximum of hottest month (and absolute maximum)
  - number of frost days
  - frost pockets Yes/No

Note: This Aide Memoire may refer to national or more restricted coverage as required.

- <u>Other Site Factors</u>

  - Are there any stands[1] which are unaffected by man or livestock and greater than 20 ha[2] in size? Yes/No.

  - Are any of these stands likely to remain unaffected for some time? Yes/No.

  - Do any stands occur on the following sites and compiy with the conditions above?

  - Frequent fires (and experienced for a long time) Yes/No

- <u>Soil factors</u>

  - Strongly acid soils (pH 5.0) Yes/No

  - Alkaline soils (pH 8.5) Yes/No

  - Waterlogging: - permanent Yes/No
    - seasonal Yes/No

  - Shallow soils (50 cm to rock, laterite, etc.) Yes/No

  - Saline soils (visible salt precipitation) Yes/No

- <u>Phenology</u>

  - Briefly describe the periodicity of vegetative growth.

  - Briefiy describe the flowering/fruiting frequency

  - Briefly describe the periodicity of vegetative growth (seasonal timing, duration, regularity).

  - Briefly describe the flowering/fruiting frequency (seasonal timing, on/off years and periodicity).

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1 Not all species occur in stands (e.g. the majority of Miombo species).

2 Possibility of having more than 25 dominants and codominants separated by more than 100m each, see Section 2.3, for species which do not occur in stands, the minimum area would have to be much larger.

- Other comments
  (Evidence of root phenology; relation of this species' phenophases to that of associated vegetation; relation of species behaviour on this site to that in other altitudinal ranges etc; advice on best seed collecting times).

Appendix 2

Collector's Species and site collection data sheets: exploration phase

NOTES

1. The collector may not be able to fill in all the information; some (e.g. the elaboration of a klimadiagram) may have to be compiled at headquarters after the relevant data searches and calculations are made.

2. Any answer provided which originates from hearsay rather than direct observation by the collector or Forest or Agriculture Department staff should be preceded by an asterisk(*).

3. Not all the headings are relevant for each collection site.

4. As detailed information as possible is desirable for certain subjects (e.g. climate) However, for many sites little information will be available. Further much of the information may be difficult to interpret and only some can be easily and meaningfully characterized or coded for mechanical or computer storage. Other information may be more seasily stored on supplementary paper files referred to in the computer files.

5. Items shown in bold typescript should be answered whenever possible; answers to those in italic typescript may not be appropriate or may not be essential in each case.

FORM II

SITE ENVIRONMENTAL ASSESSMENT

Site collection Number (or code)

A. Climate

1. Climatic records from the most appropriate meteorological station

- Location of Meteorological Station
  - Latitude Longitude
  - Altitude Map reference
  - Aspect
- Brief description of site "morphology"
- Map distance and direction between meteorological station and collecting site:
- Indications of likely differences in climate at sampling site due to major topographical variations
- Number of years of records
- Class/standard of station
- Temperature (T) mean of monthly daily records

  J F M A M J J A S O N D (Mean Annual total)

  - *mean daily maximum of hottest month*
  - *absolute daily maximum recorded*
  - *mean number of frost days and dates of first and last frosts*
  - *maximun number of frost days 1 year in 5*
  - *lowest maximum likely 1 year in 5*
- Precipitation (in mm)

  P (80% *reliability i.e. exceeded 4 years in 5)* See also Appendix .

  J F M A M J J A S O N D (Mean Annual total).

Other details (storm intensity data, prevailing winds etc).

- Evaporation (in mm)

J F M A M J J A S O N D (Annual mean

E (actual)

E_o (potential)

Note In some cases it may be possible to adjust these data for the collection site, on the basis of altitude difference or rainfall gradient; such adjustment should only be made where the differences are substantial and assured.

2. Climatic information from the actual collection site

- Incidence of:
  - normal wind (may also record wind run from met. site), average wind run (Km) and prevailing direction.
  - excessive winds (dates of occurence)
  - sand storms (dates of occurence)
  - frosts (dates of occurence or periods)
  - fire
  - dew
  - others

B. Landforms

- angle of slope (degrees)
- position on slope (crest, upper slope, midslope, lower slope, base)
- aspect (compass bearing)

C. Soils

1. Soil characteristics

Morphological and physical:

- texture: 0-20 cm
  B horizon (c. 50 cm)
- colour 0-20 cm
  B horizon
- effective depth (cm)
- drainage class (excessive, well drained, imperfect, poor, very poor)
- depth to water table: wet season (cm)
- other features dry season (cm)

Chemical

- pH
- salinity (ECe)
- other

2. Soil type

If identifiable, give soil class in one or more of the following systems:

- FAO Soil Map of the World Legend:
- US Soil Taxonomy
- Any other classification, e.g. national:

Soil class:

Classification system:

FORM 11JA

Kuchler's (1949) scheme of vegetation description

Kuchler himself describes his scheme as a physiognomic classification of vegetation. This is not strictly true as in his scheme it is possible to have many different descriptions, all of which will have the same general appearance and thus constitute one physiognomic class. It is more correct to regard the system as a means of vegetation description. The following categories are used:-

CAPITAL LETTERS

Woody vegetation:-

B : evergreen broadleaf

D : deciduous broadleaf

E : evergreen needleleaf (coniferous)

N : deciduous needleleaf (coniferous)

O : without leaves

Herbaceous vegetation:-

G : graminoids

H : forbs

L : lichens and mosses

SMALL LETTERS:-

Group I : Height:-

t : tall, minimum height of trees : 25 m
minimum height of herbaceous

m : medium tall; trees: 10 - 25 m
herbaceous plants: 0.5 - 2 m

l : low; maximum height of trees: 10 m
maximum height of herbaceous plants: 0.5 m

s : shrubs, minimum height: 1 m

z : dwarf shrubs; maximum height: 1 m

Group II : Density:-

c : continuous growth

i : plants usually do not touch

p : woody plants scattered singly or in groves
herbaceous plants in disconnected patches

r : rare, yet conspicuous

b : barren; vegetation largely or entirely absent

Group III : Special features:-

e : epiphytes

j : lianas

k : succulents

q : cushion plants

n : palms

v : bamboos

w : aquatic vegetation

y : tree ferns and tuft plants

Using this system a larch stand with semi-deciduous ericaceous shrubs and a continuous ground cover of sedges resting on Sphagnum moss, is denoted by Nmi. Dzi. Glc. Lc. the use of periods to separate the synusiae is important to ensure clarity. Each segment of the formula should contain one capital letter and one letter each of groups I and II, with the exception of group III features when they occur.

This method is preferable to one involving fixed classes. Allowance is made for all possible combinations without the inevitable confusion that would arise if an attempt was made to pre-define those combinations.

In this Chapter the system is presented in tabulated checklist form to facilitate application in the field. Provision is also made for adding information on the floristic composition of each synusia, which should be regarded as a necessary option if the required expertise is available.

This presentation will accommodate the derivation of classifications using one or more of items 1 to 4 previously described in the list of data categories. Separate notes on items 5 to 7, i.e. dynamics, habitat, and history, can be included if it is possible to make the necessary deductions.

Site collection Number
(or Code)

FORM 111B

Date:

VEGETATION DESCRIPTION
Woody Vegetation

	B evergreen broadleaf	D deciduous broadleaf	E evergreen needleleaf (coniferous)	N deciduous needleleaf (coniferous)	O without leaves
Height:-					
t: tall; minimum ht. 25 m					
m: medium 10-25 m					
l. low max. ht. 10 m					
s: min. ht. 1 m					
z: max. ht. 1 m					
Density:-					
c: continouus growth					
i: plants usually do not touch					
p: scattered singly or in groves					
r: rare, yet conspicuous					
Principal species					

Site Collection Number
(or Code)

FORM 111C

Date:

VEGETATION DESCRIPTION
Herbaceous Vegetation

	G graminoids	H forbs	L lichens and mosses
Height:-			
t: tall; minimum ht. 2 m			
m: medium tall; 0.5 - 2 m			
l: low; max. ht. 0.5 m			
Density:-			
c: continuous growth			
i: plants usually do not touch			
p: disconnected patches			
r: rare, yet conspicuous			
Principal species			

VEGETATION DESCRIPTION
Special Features

	e epiphytes	j lianas	k succulents	g cushion plants	u palms	v bamboos	w aquatic vegetation	y tree-ferns tuft-plants
Density:-								
c: continuous cover								
i: plants usually do not touch								
p: disconnected patches								
r: rare yet conspicuous								
Principal species								

FORM 111D

Site Collection Number (or Code)

Date:

FORM IV

TREE CHARACTERISTICS

A. Stand Structure, Tree Form and Sociability

Variability in character (range) (where relevant) between stands, trees or sociability of concerned tree species with itself or other species.

- Height of dominant tree (DT)
- Ratio Crown diameter to bole diameter (BH) of DT
- Ratio of crown diameter to crown depth of DT
- Canopy density - dense/medium/open
- Leaf size
  - length
  - width
- Thorniness
  - frequency of occurence - prolific/many/scattered/scarce/none
  - size of thorns
  - position on the plant (stems/stipular/other)
- Branchiness/stem and bud characteristics
  - self-pruning stem
  - height at which main stem branches (if applicable)
  - diameter of first branch up to bole
  - Branch morphology/hierarchy sympodial/monopodial orthotropic/plagiotropic
  - Bud morphology and characteristics
- Evidence of root characteristics.
  - depth of rooting
  - root spread
  - Types of surface roots
- Fruiting
  - Position of fruiting points in relation to stem growth (short-shoots, old wood, new season's growth, etc.
  - characteristics of flowers,(shape, size, time of anthesis).
  - evidence of fruit set (infertility and abortion, later fruit drop etc).

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Site collection Number
(or Code)

FORM V

Date:

SPECIES UTILISATION AND FUNCTIONS

Room is left for brief comments/notes where applicable. These could include remarks about the quality characteristics as perceived and experienced by the people living in the broad vicinity of collection sites (e.g. with similar site conditions). Also locally perceived quality of the product and the time (monthly spread) at which best quality is obtained, where this is relevant and obtainable. In addition the range of quality as perceived by rural users in different areas, or by commercial users, can be usefully commented upon.

Quality condes can be named as:

G = Good; F = Fair; P = Poor; O = Nil

Where relevant the appropriate age of the tree at first cropping and the resting period between harvests can be included

Food

Oil/fats
- Leaf
- Fruit
- Wood
- Other

fleshy fruits

nuts

dry seeds

extracted starch
- Fruit
- stem

Spices
- leaf
- fruit
- bark

vegetables
- leaf
- flower

masticatories
- fruits/seeds
- stems
- leaves

sap

other

<u>Fodder</u>

leaves

young stems

pods/seeds

by-products

bee forage

other

<u>Wood</u>

construction poles

fuelwood

charcoal

chips

pulp

saw-timber

vemeer

turnery/carvings

shringles/floor tiles

other

<u>Other uses</u>

oils/fats/waxes/soap — leaf / fruit / wood

essential oils — leaf / fruit / wood

tanning/dues — leaf / fruit / bark

gums

fibre - string/twine bark
wood

medicinal leaf
fruit
bark
flower
root

incense leaf
stem
fruit
flower

religious leaf
stem
fruit
flower

basketry

silk worms

smoking material leaves
wood
bark

toothpicks

animal bedding

other

Agro-ecology (potentially negative features should also be noted)

- likely to have great/small competitive effects on adjacent understorey crops/grasses (specify)
- a soil fertility imprcver
- a useful soil conservation species
- a sand stabilizer
- a useful saline/alkaline soil species
- withstands root interference (e.g. planted on invertisols or shifting soils)
- good in exposed, windy sites
- a potential "nurse" species for interplanted fruit tree crops.

- shade tree for men/stock
- useful for live fencing
- dead fencing (for man, for cattle)
- wind-breaks
- useful for mulch (woody mulch/leafy mulch)
- has land draining characteristics
- a salinity reducer
- an acidity reducer
- has ability to reverse development of indurations
- possesses allelopathic characters

Site Collection number (or code)

FORM VI

Date:

INFORMATION ON MATERIAL COLLECTED

A. Fuit/Seed Collection (and where relevant vegetative material)

- Method of
  - collection?
  - extraction?
  - treatment/processing
- Number of trees?
  - separate?
  - bulked?

  sketch map of tree locations? Yes/No
- Spacing of trees (individual exposure)?
- Maturity of fruits?
- Condition of seed/fruit/cone?
- Number of seeds per fruit (average/range)?
- Material taken for vegetative propagation (specify kind, amount and condition)?
- Possibility of further collections?
- Remarks

B Other Material

- Number of herbarium specimens taken
  - leaves
  - leafy shoots
  - flowers
  - fruits
  - roots

B. Phenology (These notes should include comments on differences between sites, between trees within sites, and within trees if these are obvious).

Of undisturbed trees

- Leaves
  - sap-rising time
  - bud burst/leaf flush (dates* (approximately)
  - duration of leaf flush dates
    mean leaf number
  - leaf fall
  - average age of leaf Years/seasons/months
- Time of suckering
- Flowers
  - flower bud formation dates
  - flowering time (interval within year) dates
  - flowering interval between years years
  - relation to climatic factors (start/middle/end of rains, dry/cool season, others)
- Fruits
  - development/maturation period dates
  - ripe fruits present dates
  - visible signs of maturity (brief description)
  - fruiting interval between years years
  - fruit description

---

* or time in relation to season

- Seed characteristics
  - average size (mm) x y z axes
  - shape
  - seed coat characteristics
- Ecological/physiological
  - light demanding
  - shade semitolerant
  - shade tolerant
  - shade tolerant when young only
  - shade demanding when young only
  - tolerates water-logging/drought/sandblast compacted or loose soil/other (inferential)
  - competitive ability of seedlings (inferential)
  - regenerating abilitv after cutting/browsing etc
  - general health/vigour
- Pattern of regeneration in relation to other vegetation (brief comments).

  Evidence about: -

  - pattern of regeneration in relation to larger individuals of its own species;
  - relative density and condition of ground vegetation under the canopy compared to that under canopies of other species of trees/bushes;
  - ditto compared to that away from all trees/bushes;
  - change in type of vegetation underneath canopy compared to awav from canopy;
  - pattern of soil loss/gain around the trunk of the trees; in comparison to other tree species;
  - wind resistance;
  - Cropping over the past (give time scale)? Yes/No For what product/s (list);
  - size class distribution of the species, if unusual;
  - Abundance in the area (conservation status);
  - Presence of seedlings? Yes/No.

- Seed dispersal observations
  - unaided (mechanism?)
  - wind
  - water
  - fish
  - bird
  - grazier (ingested)
  - coat (mechanism?)
  - human activities (describe)

- Seed germination observations
  - unaided direct germination (epigeal/hypogeal)
  - fire - stinulated germination
  - other (e.g. dung - digestive enzyme stimulated)
  - evidence of favourable micro-sites (describe)

- Roots
  - evidence of fine (surface) root growth activity
  - evidence of nitrogen-fixing nodules

- Management related
- Re-growth characteristics
  - notes on position and delay in bud sprouting after cutting and duration of growth of new branches in relation to seasonal climate
  - from severe bole pruning
  - from coppicing
  - from pollarding
  - from general browsing

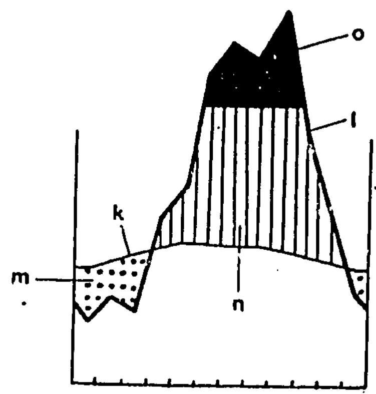
C Other

- Pest and/or disease incidence
- Mammalian/avian habitat evidence (e.g. inside bole, on branches)

- Number of wood samples and location within the tree
- Material taken for Rhizobium examination/ collection?
- Material taken for mycorrhizal examination collection?
- Gum/resin samples taken?
- Photographs (specify, of what, how many and give identifying code for negatives)
- Soil samples taken? (specify how many, from where and how taken)

Appendix 3

INTERPRETATION OF THE KLIMADIAGRAMS



The monthly means of temperature (k-thin line) and of precipitation (l-thick line) are drawn as curves. Both stand in a fixed proportion to each other; ten degrees centigrade corresponds to a precipitation of twenty millimetres. Using this proportion, and working with data from the Mediterranean region, Gaussen /1 established that an arid period prevails as soon as precipitation falls below the temperature curve (m-dotted area), and a humid period as soon as precipitation exceeds temperature (n-hatched area).

Precipitation above 100 mm is printed on the scale 1:10 and marked in black (o).

The full system as proposed by Gaussen uses additional data, mainly annotations on the mean values of annual rainfall and the extremes of temperature. Since this data, and more, has already been tabulated in the site descriptions it has been omitted here to preserve clarity.

A useful aid for making rapid comparisons of the climatic regimes of different regions is the atlas of climodiagrams produce by Walter and Lieth /2.

/1 Gaussen, H.: 8me Congres Internationale Botanique, Paris, 1954, Sections 7 et 3, 125-130.

/2 Walter, H. and Lieth, H. (1960). Klimadiagram - Weltatlas, VEB Gustav Fischer Verlag, Jena. 86 pp.

Appendix 2.5 Measurement of soil moisture content and soil available water capacity

- by A. Young

Measurement of soil moisture content and soil available water capacity.

Soil moisture content is the amount of moisture in the soil at any given time. It can be expressed as percentage by weight (weight of moisture as a percent of weight of soil) or in volumetric terms, usually as equivalent depth (millimetres of water per metre of soil). Conversion from one form to the other requires measurement or assumption of the dry bulk density of soil (typically 1.8).

Available water capacity (AWC) is a measure of the ability of the soil to supply water to plants. It is used in calculations of the growing period, and of drought hazard during a dry season or dry spells. With respect to the growing period, the amount of stored soil water permits calculation of how long plant growth will continue after the point at which rainfall becomes less than potential evapotranspiration. Regrettably, data on soil water characteristics are not usually available from standard soil survey reports.

For an individual soil horizon, AWC is measured in millimetres of water per metre depth of soil (mm m^{-1}). The storage capacity of the soil profile is obtained by multiplying the AWCs of each horizon by their thicknesses and summing; this is done down to a limiting horizon (rock, laterite) or to 2 m, as a standard for comparison between soils. Where one specific plant is being assessed, summation can be to its rooting depth.

AWC is conceptually obtained by subtraction of wilting point (WP) from field capacity (FC), where field capacity is the amount of water the soil will hold against gravity, and wilting point the amount held (in fine pores) at the point where plants wilt. Many plants, however, suffer moisture stress at points above the absolute wilting point.

Measurement of soil moisture content

There are four methods available:

- Direct sampling or gravimetric method. Samples of the soil are taken, weighed, oven dried at 105°C (or sun dried), and weighed again. The moisture content is the difference between the two weights, and is expressed as a percentage by weight of the dry soil

This is by far the best method where it is practicable, because it is cheap and simple, and because it directly gives the information required. The method must in any case be used to calibrate the instruments in all other methods. Disadvantages are the fact that sampling disturbs the soil, preventing continuous monitoring, and the effort of sampling.

- Electrical resistance blocks. Porous blocks made of gypsum, nylon or similar material, in which two electrodes are contained, are buried in the soil. Wires lead from the electrodes to the surface. The resistance between the electrodes is measured, which varies with the moisture content of the blocks, which in turn are in equilibrium with the surrounding soil. Blocks may be buried at several depths. This method permits continuous monitoring at a fixed site. The apparatus must be calibrated for the soil at the site.

- Tensiometers. Porous cups, connected by tubes to vacuum gauges, are buried in the soil. Movement of water from the cups to the soil sets up a negative pressure (suction). the same features apply as for resistance blocks: there can be continuous monitoring at a fixed site, at several depths. The instrument gives a direct reading of moisture tension, but must be calibrated by a soil moisture curve (see below) if moisture content is required. There are also instrumental problems, and the method is not recommended except in irrigation control.

- Neutron probe. A probe emitting fast neutrons is inserted into the soil along access tubes. Fast neutrons are slowed by contact with hydrogen atoms, hence a count of slow neutrons is the vicinity of the source is related to moisture content. Access tubes must be made, there is a need for calibration, and the instrument is expensive.

Further details of methods, and their uses, advantages and problems, are given in the reference cited.

Measurement of soil available water capacity

Available water capacity is obtained by measurement of field capacity and wilting point, and subtraction. Both can be measured directly, and there is much to be said for doing so. However, much the most common practice is to estimate field capacity and wilting point indirectly, by means of soil moisture tension apparatus.

- Direct measurement: field capacity. Thoroughly saturate the undisturbed soil, in the field, digging pits down to the levels required; cover with plastic to prevent evaporation, then allow to drain for 24 hours. Then remove a sample and determine the moisture content by the gravimetric method. Alternatively, an undisturbed block of soil may be removed in a rigid ring (or cocoa tin) placed on a gauze to allow drainage, and the same procedure followed.

- Direct measurement: wilting point. This is slower than measurement of field capacity, and less often done. It has the merit of being based directly on the result of interest, whether plants will die from lack of moisture. Undisturbed (or reconstituted) soil samples are placed in pots and a test plant grown: dwarf sunflower, *Helianthus annus*, is the 'standard', but the plant under investigation can be used if practicable. The soil around the stem is covered with plastic to prevent evaporation. When the plant is established, cease to add water and wait until the plant dies. Determine the remaining moisture content of the soil.

- Soil moisture tension curves. Samples of undisturbed soil are taken in special rings, supplied to fit a soil moisture tension apparatus. By subjecting the samples to increasing tensions (suctions), a curve is obtained relating soil water tension to soil water content. Field capacity is commonly taken as corresponding to one third atmosphere for clays or one tenth atmosphere for sands. Permanent wilting point is similarly taken as the water remaining at 15 atmospheres, although many plants exhibit moisture stress well above this water content.

Approximate estimation of soil moisture

Available water capacity varies approximately with soil texture. Typical values are given in Table A2.5.1.

It is possible to estimate from the feel and appearance of the soil the amount of available moisture. A table relating percent available moisture remaining. A table relating percent available moisture remaining to feel and appearance, for soils of different textures, is given in Doneen (1972), p.30.

Table A2.5.1. Approximate values for soil available water capacity in relation to texture.

Texture	Available water, mm water per m soil
Coarse sand	30 - 60
Loamy sand	60 - 85
Sandy loam	85 - 140
Silt loam	140 - 180
Clay loam and clay	150 - 200

Source: Doneen (1972), p.1[illegible].

References

Doneen, I.D. 1972 Irrigation practice and water management. FAO Irrigation Drainage Paper 1, Rome; pp. 7 - 30.

Kramer, P.J. 1972 Plant and soil water relationships. McGraw Hill, New York; Chapters 2 and 3.

World Meteorological Organization 1971. Guide to meteorological instruments and observing practices. 4th Edition, Section V, pp. 11-22.

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Appendix 2.6 Soil characteristics to measure

- Description of geology etc at collection sites

- Description of soils

- Soil classification systems.

  - by A. Young

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Appendix 6:

Description of geology, landforms and soils at collection sites

Description of geology and landforms

Geology/soil parent material. Information on geology is required principally as a possible indication of soil parent material. At a scale intermediate between the broad zones of climate and the local variation caused by relief, the distribution of many soil types is related to parent material. Parent material-related soil types may in turn be an indicator of nutrient status or micro-nutrient deficiencies. It should be stressed that often, soils are not derived from the rock which lies beneath them, so a check for other indications of the parent material, e.g. stones remaining in the soil, is desirable. Observations may be possible from any or all of a geological map, rock exposures, or the soil profile.

- Geological map. If a geological map is available, abstract from it:
  - name of geological formation (e.g. Garbelowe Series)
  - age (e.g. Jurassic)
  - lithology (-rock type, e.g. sandstone, biotite-gneiss).

  Lithology is the most relevant attribute, name and age being mainly for identification. If superficial (drift) deposits are mapped it is these that should be recorded, not the underlying solid geology.

- Rock exposures. Break off unweathered rock from any nearby exposures with a heavy hammer (protect the eyes). Describe the lithology, particularly the position on a range from felsic to basic. Felsic (siliceous, formerly called 'acidic') rocks are light in colour and contain free quartz. Basic (mafic) rocks are dark, containing black ferromagnesian minerals and with no free quartz.

- Soil profile. If identifiable stones remain in the soil profiel, record lithology similarly.

Landforms. There is a distinction between landforms of the surrounding area (radius 1-10 km) and the relief at the precise collection site (radius 1-10 m). The surrounding area provides a broad context of species provenance; the relief at the collection site indicates position within the catena of landforms, hydrology and soils.

- Surrounding area. Record landform class, plus any distinctive features.

Landform class	Predominant slopes
Very steep (mountanious)	30°
Moderately steep (hilly)	3° - 30°
Undulating	5° - 8°
Gently undulating	2° - 5°
Level or nearby level	2°

- Collection site. Record slope angle, shape of slope, position on slope.

  - Slope angle. In degrees, by clinometer or estimation.
  - Shape or slope. Profile form (i.e. down the slope):
    : convex (becomes steeper downslope), rectilinear,
    : concave (becomes gentler downslopes).
    Plan form (i.e. along the slope):
    : divergent (contours convex, e.g. spurs),
    : straight, convergent (contours concave, e.g. hollows).
  - Position on slope. Crest, upper slope, midslope, lower slope, base.

  Further details on landform description are given in FAO 91977), Young (1976, pp -) and Dent and Young (1981, pp. 39-44).

Description of soils

It is possible to record soils information at very different levels of detail, ranging from brief statements of the nature "reddish brown" sandy loam, iron concretions at 60 cm" to full soil profile descriptions, with or without sampling for analysis. Observations can be made either by the collector, or by securing the assistance of the national soil survey organization. This appendix is written for the collector, and does not attempt to provide a comprehensive guidelines for soil description.

Soil description can include that of individual soil properties (e.g. texture, pH) or identification of the soil class (e.g. acric ferralsol, langama Series). The latter will not usually be possible in the present circumstances. Moreover, a warning is necessary about deriving information from soil maps, where they exist. Owing to the high spatial variability of soils over short distances, soil class can rarely be identified reliably from soil maps without

direct observations; this applies to soil maps at all scales, but particularly those at regional, national or continental levels (scales 1:250 000 or smaller) which should be treated with extreme caution.

Observations of the topsoil (0-20 cm) are quickest to make, but as this frequently differs from the lower horizons, an auger boring or, better, a pit to 150 cm is very desirable. The non-professional observer may wish to restrict observations to the topsoil and one lower horizon, in which case 50 cm is a generally a representative depth.

The following is a list of the main properties it is desirable to observe, together with brief indications of how to recognise descriptors. For further details, refer to "Guidelines for soil profile description" (FAO, 1977) or national handbook. Of the features listed, the most important are texture, drainage class,effective depth and reaction.

Soil surface

- Outcrops and boulders, % of surface
- Stoniness: qualitative, very stony to stoneless.
- Evidence of erosion: e.g. gullies, rills.

Soil profile. Topsoil (0-20 cm) and subsoil (c. 50 cm) (or all horizons):

Except where otherwise specified, for

- Colour: qualitative or, preferable from Munsel color book
- Mottling: depth at which mottling becomes (i) first detectable

• clear and common (of. soil drainage class, below).

- Texture: a high proportion of tropical soils, being low in silt, fall somewhere on a scale sand-sandy loam-sandy clay loam-sandy clay-clay-heavy clay. For how to recognise, see FAO handbooks.
- Stones and gravel: qualitative or as percent.
- Organic matter: peat (partly or fully decomposed), humus.
- Roots: presence and frequency, qualitative.
- Laterite: hard iron concretionary material - record depths and thicknesses of any horizons, describing each as:

  massive: more or less continuous ironstone

cemented nodular: individual concretions, but mostly cemented together.

nodular: individual concretions, non-cemented, occupying more than 40% of soil volume with few/ common laterite concretions: occupying less than 40% volume.

- Other secondary materials: presence of:

  calcium carbonate, $CaCO_3$ (other than parent rock)

  calcium sulphate, gypsum (hydrated $CaSO_4$)

  soluble salts

Soil profile as a whole

- Drainage class:

excessive	no mottles, very sandy
well	no mottles
moderately well	faint mottling in depth
impeded	clear mottling in depth, possibly faint to near surface
poor	clear mottling throughout profile, possibly fully reduced (grey) or waterlogged in depth.
very poor	waterlogged to or above surface all or most of year

- Effective depth: depth at ehich a limiting horizon of rock, weathering rock, massive or nodular laterite encountered, such as impedes development of all or most roots.

- Soil class. If identifiable, any or all of:
  - local name (e.g. Langama Sèries)
  - national classification system
  - international classification system

  See Appendix 2C

Note that the above descriptors will not alone be sufficient for soil class identification. In the field, observation of structure and consistence will additionally be necessary, and frequently analytical data also.

Field tests. There is no better indicator of general soil chemical conditions than reaction (pH), and this record is desirable even if no other analyses are done. Obtain, for topsoil and 50 cm, in one of the following ways:

- field pH test kit, colorimetric
- field pH meter

either in the field, or by taking small samples and conducting tests in groups at field base

Sampling for analysis

Soil samples for general analysis should be about 500 g, e.g. a plastic bag about 20 x 15 cm, three-quarters full. Place the bag with soil inside a second bag, with the label between the two; this both protects against breakage and keeps the label dry. Samples should be labelled by site, profile number, and range of depth, e.g. 40-50 cm. For the surface horizon, the usual method of standardization is to sample evenly from 0 to 20 cm and mix; this eliminates the gradient of organic matter found at this level in undisturbed soils, and allows comparison with the plough/hoe horizon of cultivated soils.

Composite sampling

For reliable mean values of chemical properties and organic matter, single samples are of little value, and a composite sample is recommended, at least for the topsoil. At 10 pseudo-random points around the site, take samples evenly over 0-20 cm depth, using a hoe, spade, bucket auger or best, a specially-constructed corer (a piece of strong piping, approximately 10 cm diameter, 20 cm in length, sharpened at one end, which is hammered into the ground then dug out, to give a core of uniform thickness). But all 10 samples in the same bag. Later crush, throughly mix and subsample, discarding the surplus. There is also high variability in lower horizons, so composite samples are desirable although more time-consuming; a compromise is to auger to 15-55 cm at 4 or 5 locations.

Sampling for soil moisture characteristics. The samples must be undisturbed, not in a bag. Obtain special sampling rings from the laboratory doing the analysis.

Handbooks for soil description

The recommended standard handbook is FAO (1977). Besides the soil soil itself, this also contains methods for site description, including geology, landforms, vegetation and landuse.

Some national soil survey organizations have their own field manuals. The basic methods of description are fairly well standardized, but national manuals give particular attention to soil features common in the country. Some also contain guides to the identification of locally-recognized soil classes.

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Soil classification systems

The primary purpose of soil classification is to permit the transfer of agricultural technology. Crops which respond to management in a particular way (e.g. yield response to P-fertilization) on a particular soil class and climate in one location should respond similarly in another; far as we are from achieving this state of affairs, it remains the aim. A further purpose, relevant in the present context, is to assist in assessment of land suitably for particular crops or trees; given also a similar climate, trees which are observed to grow well (in the wild, or on experimental sites) on a particular soil type should be suited to transfer to wherever that soil type is mapped. This applies particularly to tolerances of soil limitations, e.g. shallowness, acidity, salinity.

A highly confusing situation prevailed up to about 1970, with a large number of different systems in use. This has since been partly rationalized in two ways. First, three international classification systems have gained fairly widespread recognition in the Western world: the FAO classification, the US soil taxonomy, and the French ORSTOM system. Moreover, tables for approximate conversion from one to the other are available. Secondly, it is recognized that some countries will continue to use a national classification system, which takes special account of features of their own soils, alongside international ones.

No hard and fast rules can be laid down, since collectors, or the survey organizations which assist them, will have differing practices. For the present purposes, however, the following guidelines are suggested:

Minimum requirement	The soil class should be identified according to one of the following systems: FAO, US taxonomy, ORSTOM.
Preferred	In addition, approximate equivalents should be given for the two other international systems.
Optional	The soil may also be identified according to the national classification system of the country.

Introduction to some classification systems

The FAO classification. This was initially devised as the legend to the FAO/UNESCO Soil Map of the World, but has since become widely used as a classification system. There are two categories (levels of classification). The higher category is in nown form (e.g. ferralsols, gleysols) and contains 26 classes. The lower is adjectival (e.g. orthic ferralsols, humic gleysols) giving 106 classes, but with many of the adjectives common to several higher classes. The classification is a relatively simple one,

and is partly based on diagnostic horizons similar to those of the US taxonomy.

Source: FAO-UNESCO (1974).

The US soil taxonomy. This is a development from what was for a number of years known as the "7th approximation", a name that is now obsolete. Devised primarily for use within the United States, it has become widely used internationally; mainly as a consequence of a recognized weakness on tropical soils, a number of revision committees have been established. It is extremely complex, with 7 categories, and very numerous classes at the lower levels. At the highest levels there are 10 soil orders (e.g. ultisols), 47 suborders (e.g. ustults) and over 2000 soil families. Precise rules, including methods of analysis, are laid down for all identification. In this original form the system is extremely complex, but simplified guides to identifications at higher levels are available.

Source: Soil Survey Staff (1975). See also International Soil Museum (1980).

The ORSTOM system. This is in widespread use in francophone counties. It inherits many features from earlier more 'natural' classifications, as opposed to the 'artificial' nature of the FAO and US systems. Some of its classes are in common use (in anglicised forms) as widely-recognized natural soil names, (e.g. leached ferrallitic soils, from soils ferallitiques lessives).
Source: Boulaine, J. (1967).

Conversion tables

Conversion from one classification to another is only approximate, since the various systems do not use the same soil characteristics or set boundaries at the same values. Thus for precision, the original soil description must be re-identified in each system. Despite this, it helps readers familiar with only one system to know the approximate equivalent. Some published conversion tables are given in Table .

Table A2.6.1. Conversion tables between soil classification systems

Based on	Equivalents in	Reference
FAO	Eight national systems	FAO-UNESCO 1974, pp.14-20
FAO	ORSTOM, US taxonomy	Aubert and Tavernier (1972)
ORSTOM	US taxonomy	Aubert and Tavernier (1972)
FAO	US taxonomy	ILACO (1981), pp. 138-9

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<u>Selected references: soil and site description, soil classification, tropical soils</u>

Boulaine, J. (ed.) 1967 Classification des sols. Commission de Pedologie et de Cartographie du Sols, Grignon.

Dent, D. and A. Young 1981, Soil survey and land evaluation.

Allen and Unwin, London. (Includes remote sensing, field survey, soil mapping units; note also Appendix, 'How to obtain soil maps')

FAO 1977 Guidelines for soil profile description. 2nd edition.

FAO, Rome. Also in French, Spanish. (The standard handbook for soil description; includes also site description).

FAO-UNESCO 1974. Soil map of the world. Vol. 1. Legend. UNESCO, Paris. (basic statement of the FAO soil calssification).

FAO-UNESCO 1970-80. Soil map of the world 1:5 000 000. Vols 1-10. UNESCO, Paris. (Each volume consists of a text volume and one or more map sheets).

Hodgson, J.M. 1978. Soil sampling and soil description. Oxford Univ. Press.

ILACO (1981) Agricultural compendium. Elsevier, Amsterdam, 739 pp. (See Chapter 2, Soil and land classification, pp. 51-196; inc. Section 2.7, Systems of soil classification, pp. 123-140).

International Soil Museum (1980). Field extract of 'Soil Taxonomy'. International Soil Museum, Wageningen, 95 pp.

Sanchez, P.A. 1976. Tropical soils and their management.

Wiley, New York. (Emphasis on soil chemical properties in relation to agricultural management.)

Soil Survey Staff 1951. Soil survey manual. Agric. Handbook 18, US Dept. Agric., Washington D.C. (The source from which much later material on soil survey methods is derived; obsolescent, revised edition forthcoming).

Soil Survey Staff 1975. Soil taxonomy. A basic system for making and interpreting soil surveys. Agric. Handbook 436, US Dept. Agric. Washington D.C. (Basic system of the US soil classification; weighs 2¼ kg

Young, A. 1976. Tropical soils and soil survey. Cambridge Univ. Press. (Emphasis on field soil properties; includes site description methods, soil classification).

For any country in which work is carried out, enquiry should also be made as to whether a national soil description handbook and/or classification system exists.

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Appendix 2.7 Seed Collection - equipment list.

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Appendix 7:

SEED COLLECTION

Annotated list of equipment which may be needed for collection of seed, site information and herbarium specimens

A. Seed collection

Seed containers (field). Sacks and bags (can be re-used), sealable tins, wooden boxes or wider baskets(for fleshy fruits).

Seed containers (despatch). Cotton bags, canvas sacks despatched with seed).

Tree markers, e.g. plastic tape, paint.

Climbing equipment. Foot spurs or tree bicycles or ladders. Safety belt, safety ropes, safety helmets, tool lines.

Seed cutters, e.g. conehooks, cone rakes, pruning shears, secateurs (hand).

Plastic sheeting (heavy gauge) for protection when storing fruits, extracting seed, etc.

Binoculars for studying tree crowns, fruit development, etc.

Walkie-talkie radios (special permission may be needed)

Insecticidal and fungicidal powders for seed protection (use with care).

Axe, saw, machete, knife.

Rope, string, labels, felt marking pens

B. Site description

Notebook, description forms
Maps (outline copies also for plotting)
Compass
Altimeter
Meteorological equipment (hygrometer, max/min thermometer)
Soil survey equipment (auger, colour charts, pH test kit)
Tree measuring equipment (altimeter, diameter tapes, bark gauge clinometer, etc).
Camera and equipment including a suitable lens selection.
Tape recorder (battery powered) for note taking
spade

C. Specimen collection

Botanical presses (may be made locally).
Drying papers (local newspapers will do)
Plastic bags
Specimen bottles
Preservative fluid
Increment borer (for wood samples).
Carpenter's brace and auger (for resin samples).
Insulated container (e.g. ice box)
Hand lens
Insecticide spray (for herbarium material).

Sterilized specimen/tubes/jars (+ throw-away sterilized spatulas) and tweezers (+ alcohol) for collections of soil or roots for rhizobia.

ALSO Medical supplies, camping equipment, vehicles and equipment as appropriate.

Appendix 8:

LABELLING SEED LOTS AND VEGETATIVE MATERIAL

Most of the principles involved in labelling are self evident. Because mistakes are made and accidents happen, extra safeguards are needed for valuable and sometimes unrepeatable collections of MPT germ plasm.

1. Type of label. The most durable external label is of galvanised steel or aluminum, wired to the package, with the information written in waterproof ink or paint. Heavy duty card, wired or fastened with durable cord, with typed information are almost as good and cheaper. Clearly written information using ball pen will last sometime, but fades in sunlight. Within the package/envelope/drum/bag etc. there should always be included a duplicate label (a single label legible through the polythene of a small package may be adequate).

2. Information needed. The following are in suggested order of priority.

   (a) Collector's or seed store unique identification number

   (b) Species

   (c) Date collected

   (d) Originating Supplier/seed store

   (e) Very brief details of origin plus provenance plus parent tree number - with reference to seed collection data where appropriate

   (f) Mention any fungicide or insecticide treatment.

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Appendix 9:

Extract from FAO/IPBGR's Priority list

tions, and with financial assistance from the International Board for Plant Genetic Resources (IBPGR), FAO's Forestry Department initiated in 1979 a project for the conservation and better utilization of genetic resources of arboreal species for the improvement of rural living. The main emphasis was placed on fuelwood species. After an initial phase, consisting of an on-the-ground survey of needs and possibilities, a second, operational phase was started in January 1981.

The situation for genetic resources of fuelwood species is clearly a serious one. No one disagrees. Yet, it has been difficult to obtain financial support for this project. The projects that receive priority in international development today are those requested by governments of developing countries to meet pressing short-term needs. Ironically, more widespread needs, ones that are serious, long-term and essentially international may not be seen. It is a classic example of the forest not being seen for the trees, and by foresters at that. Furthermore, national projects involving impressive amounts of financial and physical resources tend to crowd out those that are not only long-term and international in scope but which do not involve large amounts of money. This project, for instance, is costing less than $400 000 for two years, of which $250 000 is from IBPGR and the balance from the FAO Regular Programme, mainly the Forestry Department's Seed Funds. Normally, the regular programme budget does not finance projects. The United Nations Development Programme pays for most of FAO's projects. And $450 000 for a two-year project is small indeed.

Since dry regions face more difficult fuelwood problems than either the humid tropical lowlands or the tropical highlands, it was decided that the project should give priority to the 600 million hectares of arid and semi-arid woodlands receiving less than 500 mm of annual precipitation (NAS, 1980) and to the additional areas of seasonally dry tropical regions which suffer six or more rainless months.

The main aims of the FAO/IBPGR project are to act as a catalyst for gathering genetic information on arid

Table 1. 41 tree species of arid and semi-arid environments that are particularly important for fuelwood

Trees	Utilization **
* *Acacia albida*	Fd Fu FF
* *A. aneura*	Fd Fu Sh SS
* *A. saligna* (syn. *A. cyanophylla*)	Fu Sh SS
A. ligulata	Fu Sh SS
* *A. nilotica*	Fd Fu FF
A. peuce	Fu Sh SS
A. salicina	Fu Sh SS
* *A. senegal*	Fu FF
* *A. tortilis*	Fu FF
Anacardium occidentale	Fo FF
Argania sideroxylon	Fd Fu SS
* *Atriplex* spp.	Fd SS
* *Azadirachta indica*	Fu Sh FF
Calligonum spp.	SS
Casuarina decaisneana	Fu Sh SS
Ceratonia siliqua	Fd Fu
Conocarpus lancifolius	Fu Sh SS
Eucalyptus astringens	Fu Sh SS
E. brockwayi	Fu Sh SS
* *E. camaldulensis*	Fu Sh
E. gomphocephala	Fu Sh SS
E. intertexta	Fu Sh SS
E. leucoxylon	Fu Sh
E. loxophleba	Fu Sh SS
* *E. microtheca*	Fu Sh SS
E. occidentalis	Fu Sh SS
E. ochrophloia	Fu Sh SS
E. salmonophloia	Fu Sh SS
E. salubris	Sh SS
E. sargentii	Fu Sh SS
E. sideroxylon	Fu Sh
E. tereticornis	Fu Sh
* *Gleditsia triacanthos*	Fd Fu Sh SS
Haloxylon spp.	Fd Fu SS
Kochia spp.	Fd SS
Morus alba	Fo Fu FF
* *Leucaena leucocephala*	Fd Fu FF SS (for wetter areas)
* *Prosopis spicigera* (syn. *P. cineraria*)	Fd Fu Sh SS
* *Prosopis* spp.	Fd Fu Sh SS
Tamarix aphylla	Fu Sh SS
Zizyphus spp.	Fd Fu SS

* Selected as priority species for the improvement of agricultural environments and rural living.

** Fo = Food; Fd = Fodder; Fu = Fuelwood, Sh = Shelterbelt; SS = Soil stabilization; FF = Farm forestry.

Source: Report of Fourth Session of the FAO Panel of Experts on Forest Gene Resources, [illegible]

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Extract from FAO/IPBGR's Priority list

Table 2. National assignments for provenance collections

Nine countries cooperating in the FAO project on genetic resources of arid and semi-arid tree species

Country	Species	Observations
Australia	*Eucalyptus camaldulensis* Dehnh.	11 new provenances collected for project with special emphasis on arid zones.
	E. microtheca F. Muell.	73 seedlots collected for first-stage evaluation.
	Acacia aneura F. Muell. ex Benth.	5 provenances collected by early 1980.
Chile	*Acacia caven* Mol.	
	Atriplex repanda Phil.	
	Prosopis tamarugo F. Phil.	
	Prosopis spp. ("Algarrobo")	May include several species, *P. atacamensis, P. siliquastrum, P. chilensis, P. burkartii.*
India	*Acacia nilotica* (L.) Willd. ex Del.	ssp. *indica*/var. *vediana*; var. *jaquemontii*; var. *cupressiformis*
	A. senegal (L.) Willd.	"Land Race"
	A. tortilis Hayne	"Land Race"; according to some sources may in fact be *A. raddiana* Savi.
	Prosopis cineraria (L.) Druce (*syn. P. spicigera* L.)	
Israel	*Acacia albida* Del.	
	A. raddiana Savi (*syn. A. tortilis* (Forsk) Hayne ssp. *raddiana* (Savi) Brenan)	
	A. tortilis Hayne (*syn. A. tortilis* (Forsk) Hayne ssp. *tortilis* Hayne) Brenan)	
Mexico	*Atriplex canescens*	
	Prosopis spp. ("Mezquite")	May include several species, *P. juliflora, P. glandulosa, P. alba, P. torreyana.*
Peru	*Capparis angulata*	
	Prosopis spp. ("Algarrobo")	May include several species, *P. chilensis, P. limensis, P. juliflora.*
Senegal	*Acacia albida* Del.	
	A. nilotica (L.) Willd. ex Del.	Incl. var. *adansonii*
	A. raddiana Savi	
	A. senegal (L.) Willd.	
	A. tortilis Hayne	
Sudan	*Acacia nilotica* (L.) Willd. ex Del.	ssp. *nilotica*; ssp. *tomentosa*; ssp. *astringens*
PDR Yemen	*Prosopis cineraria* (L.) Druce	
	Acacia nilotica (L.) Willd. ex Del.	"Land Race"
	A. senegal (L.) Willd.	
	A. tortilis Hayne	
	A. tortilis Hayne	"Land Race"

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Appendix 10

ASPECTS OF EVOLUTION IN HERBACEOUS AND TREE CROPS RELEVANT TO AGROFORESTRY *

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ABSTRACT. Agroforestry involves the cultivation on the same unit of land of herbaceous and tree (or sometimes shrub and tree) species. One component of the system is usually fully domesticated, while the other (often grown for forage, shade, fuelwood or pulpwood) is frequently little changed from the wild state. Guidelines for improvement of the latter component may be sought from the changes which have taken place in the fully domesticated crops (including forest trees). Attributes of successful crops include a ready supply of propagules, easy germination and establishment, reliable yields in as short a period as possible, and easy handling and processing. The different adaptive strategies of herbaceous and woody wild species, particularly as regards the components of their genetic systems, are reflected in the success with which they adapt to, and can be improved under, cultivation. Breeding systems also influence strategies for collecting wild material for future improvement of crop species for agroforestry. Large-scale agroforestry is too new a development for significant studies to have been made on the co-adaptation of the various components, but potential areas for investigation include effects on soil composition, pollination biology, and pests and diseases.

INTRODUCTION

The term agroforestry currently covers a wide range of associations of herbaceous and woody (or even woody and woody) plants grown together under man-managed conditions. Some of these attempt to simulate the natural environment of one component: for example coffee and cacao, both of which occur naturally as understorey trees in tropical rainforest, are often cultivated under shade trees. Other agroforestry systems combine crops from very dissimilar environments. Trials of 'Desiree' potatoes under coconut palms in eastern Peru bring together a North European

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* From "Plant Research and Agroforestry (Ed. P.A. Huxley) pp. 309-321. ICRAF, Nairobi.

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cultivar of a highland South American crop and a palm from the strand zone of the Pacific islands, in an environment where the natural vegetation is lowland rainforest. Sometimes the perennial crop is the economically important one, as in rubber plantations undersown with leguminous fodder or cover crops. In other instances, the herbaceous component is valued more, as in most combinations of annual food crops with tree legumes such as *Leucaena* or *Acacia* for fodder or fuel. The different components may yield simultaneously, as in cacao plantations shaded by coconuts, or successively, as in the taungya system whereby forestry plantations are intercropped with annual or short-duration food crops while the trees are becoming established. Agroforestry may also refer to the system of agriculture practised rather than to the actual crops grown. In this context, it has been used to cover the spectrum from primitive shifting cultivation to mixed cropping in plantation agriculture.

Since such diverse associations of plants, and such different types of systems are included under the one term, it is not easy to formulate valid generalizations about evolutionary aspects of agroforestry systems. However, agroforestry, like both agriculture and forestry, involves a reduction in genetic diversity. Rigorous selection of the parents that contribute progeny to the next generation, establishment of crop populations from small samples of wild plants, and an inevitable element of inbreeding all erode variability and produce a genetic structure in the man-managed populations different from that in conspecific wild populations. These genetic changes are in fact the first stages in domestication, and a further characteristic of many agroforestry systems is that a fully domesticated crop (usually the herbaceous component) is combined with a crop which is only at the stage of incipient domestication (usually the tree component, although many tropical forage and ground cover crops are not fully domesticated either). Agroforestry also, and increasingly, involves cultivation of crops for purposes which were previously met by exploitation of natural vegetation. Various species are under trial as fuel-, timber, pulpwood or cover crops, and these are still only a generation or so removed from the wild.

Some basic concerns of agroforestry are therefore, first, to predict which species will prove amenable to cultivation; second, to identify and incorporate in the cultivated populations the most desirable of the variants present in the wild; third, to improve by breeding and selection the comparatively undomesticated components in the system. Evolutionary changes which have occurred in the fully domesticated crops may offer useful guidelines on changes which should be sought, or induced, in the newer and less domesticated crops. The effects of mixed cropping on reproductive biology and on the build-up of pests and diseases in the crops concerned, together with other aspects of co-adaptation, also deserve consideration.

ATTRIBUTES OF SUCCESSFUL CROP PLANTS

The ideal crop plant is one which establishes readily; produces economic returns as soon as possible; yields reliably despite year-to-year fluctuations in climate; yields at levels that are

both profitable in themselves and competitive with other species; is reasonably uniform both in the field and in terms of its product; is easily handled and/or processed; and can be grown in different regions.

Supply of propagules

The first essential in the establishment of a crop is a readily available supply of high quality propagules. Many herbaceous crops are derived from wild annuals which are colonizing species and produce abundant seed every year. Examples include wheat, barley, sunflower, lentil and many cucurbits. Since many of these crops are also cultivated for their seeds or fruits, seed for propagation is always available.

Perennial species in stable, closed communities are not dependent on regular annual seed crops to maintain population size and may produce heavy seed crops at regular or irregular intervals with little or no seed production in the intervening years (mast fruiting, biennial bearing, monocarpy, and related phenomena). Shortages of seed have periodically limited the cultivation of *Eucalyptus citriodora* (National Academy of Sciences, 1980); and the perennial groundnut (*Arachis glabrata*), under trial as a fodder and cover crop in various parts of the tropics (National Academy of Sciences, 1979), often does not produce seed so it must be propagated vegetatively.

Populations established from seed are usually more variable than populations of vegetatively cloned plants. Outbreeding species are more heterozygous and their populations contain more diverse and different genotypes than inbreeders, but even in inbreeders, seed-established populations are likely to be derived from more than one parent and contain significant heterogeneity. Seed-propagated crops thus have a capacity to respond to natural or human selection which is lacking in vegetatively propagated crops. Progress in breeding sexually sterile crops, such as yams, therefore involves first restoring seed fertility followed by conventional programmes of crossing and selection (Sadik and Okereke, 1975).

Outcrossing plants will not breed true from seed, so superior genotypes are lost by recombination unless they can be multiplied clonally. This is often worthwhile in perennial crops, where heterogeneous stands established from seed may have significantly lower yields than clonal stands in which every individual has the same high-yielding genotype. Yields of rubber in Malaysia approximately doubled when plantations were established from budwood of selected trees rather than from unselected seedlings (Purseglove, 1968). Replication by cloning may also facilitate distinction between genetic and environmental effects in yield trials of woody species (Longman, 1976), and the product is more uniform than when seed propagation is used. This uniformity has proved very advantageous in tea and certain other perennial crops.

An ideal crop plant thus has the capacity for both sexual and asexual reproduction. Improved techniques of tissue culture, manipulation of breeding systems, use of hormones to root cuttings and other technical advances are conferring this facility on species which in the wild never possessed such versatility.

Germination

Difficulty in germinating seed is a barrier to successful cultivation of some species, particularly tropical timber trees. Sometimes this is due to ignorance of germination requirements, for example species of open habitats such as *Eucalyptus microtheca* may require light for germination (National Academy of Sciences, 1980). Wild species often have dormant seeds, which do not germinate until conditions are favourable and then germinate irregularly, which prevents the entire crop of seedlings being destroyed by a single catastrophe. Man, on the other hand, requires crop seeds to germinate rapidly and uniformly, to produce a dense stand which will keep down weeds and in which the plants are all the same age and so can be harvested together. Many crop plants have, therefore, lost the seed dormancy characteristics of their wild progenitors; for example, cereals (Harlan *et al.*, 1973) and grain legumes (Smartt, 1978). Many trees suitable for agroforestry still have dormant seeds, and this dormancy has to be broken by mechanical scarification, chilling or treatment with boiling water or concentrated acid (see National Academy of Sciences, 1980, for examples).

Complete absence of dormany may be disadvantageous if crop seeds sprout before harvest, thereby reducing seed yield and seed quality. Lack of dormancy may also be associated with a short period of seed viability. *Inga* spp. are often used as shade crops for coffee and cacao and are established from seed. However, the seed lacks a testa and it soon loses viability, especially if dried. Cacao seed is notorious for its short viability, which may be lost in the few days necessary for transport, customs clearance and delivery (Goldbach, 1980), seriously hampering dissemination of this crop. Although selection by man may eliminate dormancy in domesticates, it has not so far been possible to select for dormancy in species where seed dormancy is absent.

Establishment

Most crops are sown on cleared ground, so their seedlings compete with one another rather than with previously established vegetation. Large seeds often produce more vigorous seedlings, which can emerge from deeper planting, than smaller seeds (Harlan *et al.*, 1973). Large seeds have been favoured during domestication of many crops grown for their seeds, although the effects on crop establishment have been unconscious by-products of selection for increased yield.

Some crops depend on associations with micro-organisms for successful establishment and early growth. Certain cultivated legumes, for example *Arachis*, *Glycine* and *Vigna*, nodulate reasonably effectively with a wide range of strains of *Rhizobium*. Others, for example *Leucaena*, nodulate with a very restricted range of strains, so that inoculation of the seed may be necessary to ensure effective nodulation, especially when the crop is introduced to new areas (Date and Halliday, 1980). *Alnus acuminata*, a non-leguminous nitrogen fixer grown for fuelwood, timber and soil improvement, requires inoculation of soil with the appropriate *Actinomycetes* species if *Alnus* has not been grown previously (National Academy of Sciences, 1980).

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EVOLUTIONARY ASPECTS

The role of vesicular-arbuscular (VA) mycorrhizas in the mineral nutrition of plants has only recently become clear (Mosse, 1973). According to Janos (1980), pioneer species (which include many recently advocated for cultivation for fuelwood, pulp and paper) are often non-mycorrhizal, their ability to start growth without infection giving them a competitive advantage in their short-lived ecological niche. Species of disturbed or nutrient-poor habitats, such as *Pinus* and various Caesalpinioideae, are often ectomycorrhizal, while lowland tropical trees are mostly obligate mycotrophs. Since the fungi involved in VA associations produce few spores, of short viability, Janos (1980) suggests that ectomycorrhizal species could divert succession by decreasing spore populations of the VA mycorrhizal fungi so much that characteristic forest species might be unable to re-establish. Continued cultivation of non-VA plants might likewise preclude later cultivation of VA species on that same piece of land.

Time to harvest

Selection under domestication has converted some perennial seed and fruit crops to annuals. Returns are produced in the first year, the crop passes the unfavourable season of low temperature or low rainfall as seed, and the carry-over of pests and diseases is reduced. Annual cottons, evolved in response to the shorter growing seasons of high latitudes, have therefore displaced perennial cottons, even in low latitudes. Selection for improved harvest index may also reduce the amount of vegetative material produced, and hence the time to onset of the reproductive phase. New cultivars of temperate fruits such as apple and cherry are being developed which have a dwarf habit, crop heavily at an early age (and thus have a short productive life) and can tolerate planting at high plant populations.

Where vegetative parts are harvested selection under domestication may delay the onset of flowering. Wild beet becomes reproductive in its first season; domesticated beet behaves as a biennial, producing a large harvestable root in the first favourable season and flowering, after vernalisation during winter, in the second. Improved cultivars of cassava branch less freely than primitive types. Since cassava branches when inflorescences are initiated this is, in effect, selection against flowering (Jennings, 1976), although the effects on root yield and quality are not reported.

Amongst woody crops rapid growth rates are desirable in species grown for shade, soil conservation, or coppicing for fuel. A corollary of rapid growth is often lack of strength and/or density in the wood produced, and especially fast growing trees, such as *Musanga* and *Cecropia*, which occupy a weedy niche as wild plants in forest clearings and the like, may be suitable only for chipboard, pulping or fuel. Ashton (1976) therefore suggests that the most attractive candidates for commerical cultivation for timber are neither the pioneers nor the slow growing, light-intolerant climax species but those of intermediate successional stages which will tolerate bright light and which grow relatively rapidly but produce reasonably hard, dense wood.

Ease of handling or processing

Foliage and seeds of many plants are vulnerable to attack by herbivorous predators, particularly insects. Thus, wild plants have evolved various forms of mechanical or chemical protection, but this process is often reversed under domestication when man selects crops for improved palatability to himself or to his domestic animals, or for easier handling. Wild lettuces are prickly, whereas the domesticates have smooth leaves. On the other hand, spininess is retained in safflower grown for seed under traditional cultivation in Turkey and India because the spines deter birds from taking the seeds (Knowles, 1969). *Leucaena* is a valuable forage for cattle in the dry tropics, but the foliage contains mimosine, which makes the hair of horses and pigs fall out and is toxic even to ruminants if fed alone for too long. Low-mimosine strains have, however, now been selected (National Academy of Sciences, 1979). Gossypol-free cotton was developed so that flour from the seeds could be used as a protein supplement for man and other non-ruminant animals, but glandless cottons suffer far more insect damage in the field than normal, glanded types. By selecting for increased palatability in his crops man has, therefore, often inadvertently selected for increased vulnerability to pests and, consequently, a greater need for crop protection activities.

Janzen (1969) distinguishes two strategies which plants can adapt to evade seed predation: production of numerous small seeds, some of which escape predation; or production of a few large seeds in which the metabolic cost of chemical protection is justified because each seed represents a significant amount of the total effort invested in reproduction. Large-seeded species are more likely to have been selected for cultivation by man in the early stages of the development of agriculture, and to have persisted in cultivation thereafter. Many cultivated pulses have large seeds and are notorious for containing toxins and antimetabolites (cyanogenic glycosides, trypsin inhibitors, non-protein amino acids, phytohaemagglutinins, and so on). Most of these are removed by prolonged cooking, but this may become increasingly less desirable as fuelwood becomes limiting in many parts of the tropics. Although these pulses have been domesticated for thousands of years, there is obviously still scope for further improvement in processing, palatability and nutritional qualities.

Some crops have recently been losing ground because they require elaborate processing. *Chenopodium quinoa* contains saponins in its seeds, which have to be leached out by repeated washings. For this and other reasons the crop is being increasingly supplanted by barley in the Andes. The Andean lupin, *Lupinus mutabilis*, needs similar, elaborate processing to remove alkaloids from the seeds, and is giving way to the introduced *Vicia faba*.

Breeding system

The genetic systems of plant species represent a balance between ecological 'flexibility' and 'fitness'. That is, between factors favouring recombination, which generates variability, and factors restricting recombination, which conserves particular

genotypes (Stebbins, 1950; Grant, 1958). In short-lived colonizing species, the brief generation time and large numbers of progeny favour recombination, but these are often offset by self-pollination, which increases homozygosity and restricts opportunities for recombination. Chromosome numbers are often low in herbaceous plants, so that many genes are linked, but chiasma frequencies in inbreeders tend to be high, so that maximal variability is released in the generations immediately following an occasional outcross. Long-lived species in stable communities, on the other hand, produce comparatively few progeny which survive to reproductive maturity, and recombination is further restricted by the long generation time. However, these plants are often outbreeders, thus heterozygous at many genetic loci. Outbreeding woody species generally have higher chromosome numbers but smaller frequencies of chiasmata than inbreeding herbaceous plants, so variability is released in a steady trickle rather than a sudden burst, and by reassortment rather than crossing-over.

Herbaceous crops grown for their seeds or fruits are often habitually self-pollinated and derived from self-pollinated ancestors, for example many cereals and pulses. In others, selection under domestication has favoured a shift from out- to inbreeding. Wild relatives of *Lycopersicon esculentum* have exserted stigmas and are insect-pollinated; domesticated tomatoes have the stigma included within the anther cone and pollen is shed directly on to it (Rick, 1976). Self-pollination is advantageous in crops grown for seed or fruit because reliable yields are obtained even when conditions at flowering are not favourable for animal pollinators, and because spread of the crop is not restricted by absence of pollen vectors in certain regions. The latter advantage is also shared by wind-pollinated plants. Thus self-pollinated groundnut and chili pepper, and wind-pollinated maize, spread rapidly throughout the tropics whereas, among the insect-pollinated crops, Smyrna figs failed in California until the fig wasp was introduced, sunflowers have failed in some parts of Africa because of insufficient bees for pollination, and the New World *Vanilla* has to be hand-pollinated in the Indian Ocean islands which now produce the spice commercially. Self-pollinated crops have further advantages over outbreeders in that they are more likely to breed true from seed, a process which would have facilitated rapid improvement by selection in the early stages of their domestication. In addition, they contain less plant-to-plant variation in the population, a desirable trait under modern mechanized agriculture.

Tree crops, even those grown for seed or fruit, are mostly derived from outbreeding ancestors and have remained outbreeding in cultivation. Mechanisms include genetic self-incompatibility, found for example in apples, cherries, cacao, tea and teak; dichogamy, as in avocado and black pepper; and monoecy or dioecy as in nutmeg, pawpaw, rubber, oil palm and mahogany. Problems of plant-to-plant variation in outbreeding crops may be overcome by clonal reproduction, or by the use of F_1 hybrids produced by crossing artificially inbred (hence largely homozygous) lines so that every plant in the F_1 population has virtually the same heterozygous genotype. Clonal propagation is used for crops such as tea and rubber. F_1 hybrids are used when the crop lacks the

capacity for vegetative propagation, as in maize and coconuts, or where hybrid vigour may be exploited, as in oil palm. However, in many tree species it is impractically time consuming to produce inbred parents in order to obtain a uniform F_1. F_1 hybrid varieties produced by crosses between heterozygous parents may be as heterogeneous as the original population.

Domestication itself may entail a degree of inbreeding, since crop populations are often established from comparatively few selected parents. Species which are naturally self-pollinated even if only facultatively so, will tolerate this increasing homozygosity in successive sexual generations better than obligate outbreeders. The type of breeding system is therefore relevant to success in cultivation even of crops which are not grown for fruit or seed. Furthermore, the type of breeding system markedly affects the strategy to be adopted in sampling from the wild, especially where it is necessary to enhance the diversity present in future populations of crops.

Adaptability and adaptation

Many successful crops are those that are grown on a large enough scale to sustain basic research on agronomy and improvement. Successful crops must therefore be adaptable to changes in management, in its modest sense. Wild species vary very considerably in this trait. Whitmore (1976) contrasts *Casuarina equisetifolia*, a morphologically invariable species confined to a single habitat, with *Campnosperma brevipetiolatum*, which is restricted to dry land in the southern Solomon Islands and to freshwater swamps in New Guinea. Since introductions into cultivation are usually made on the basis of a small quantity of seed from a limited area, the subsequent fate of the crop may be influenced by sampling accidents at the start. Serendipity result- in seed of the widely planted tropical pines *Pinus caribaea* and *P. kesiya* being obtained from populations (in Belize and the Philippines, respectively) which were subsequently shown to be productive in a wide range of environments. Seed of *P. oocarpa*, on the other hand, came from populations poorly adapted to growth in other areas (Burley, 1976). It was just chance that Wickham's collections of rubber seeds, on which the Southeast Asian plantations were founded, were all *Hevea brasiliensis*, the best yielding species in the genus, and that Wickham happened to collect them in the central Amazon, where the trees produce better quality latex than those down river. However, had Wickham collected even further up the Amazon he could have secured seed from trees which combine large yield, good quality and disease resistance, and the Far Eastern rubber industry might not be as vulnerable to the spread of leaf blight as it is today (Imle, 1977).

Factors which affect the distribution and rate of spread of genetic variation, and thus the strategies for collecting seed from the wild to establish or improve species in cultivation, are population size, population density, dispersal of pollen and dispersal of seeds. Colonizing annuals and temperate trees such as conifers commonly occur in large populations and nearly pure stands. Tropical forests, on the other hand, are conventionally thought to contain many species per unit area but few individuals of any one species. However, several tropical tree species do

occur in clumps (Hubbell, 1979). Genetic differentiation is likely to occur more rapidly in small, semi-isolated populations than in large interbreeding populations (Ehrlich and Raven, 1969) but Levin and Kerster (1969) have shown that, in some animal-pollinated plants, genes migrate more slowly in dense populations so that density may, paradoxically, lead to genetic subdivision of a population. This occurs because movement of pollen is usually strictly limited, reaching an extreme in the case of self-pollinated plants. Even anemophilous outbreeders, such as many temperate trees, are likely to be pollinated by their near neighbours to which, in the absence of effective seed dispersal, they may be genetically related. Opinions differ on the relative importance of outbreeding (Bawa, 1974) versus apomixis (Kaur *et al.*, 1978) in tropical forests. Outbreeding species have various flowering strategies (Gentry, 1974). These range from the 'big bang' in which a massive crop of flowers is produced for a few days only, so that most pollen movement is likely to be from flower to flower in the same crown (geitonogamy), to 'steady state' in which a few flowers are produced each day over long periods, so cross-pollination between different individuals is more likely. Superimposed on this are differences in the foraging behaviour of pollinators. Honey bees work systematically on individual plants or patches of flowers before moving on, hence they disperse pollen over limited distances. Euglossine bees, on the other hand, are often trapliners (Janzen, 1971), and follow the same foraging route each day, visiting plants separated by considerable distances so that they can effect cross-pollination between apparently isolated individuals. Data on seed dispersal are even more limited than data on pollen dispersal, but in general seeds do not move as freely as pollen, and restricted seed dispersal may be primarily responsible for the clumped distributions of some tropical forest species (Hubbell, 1979).

Consideration of these factors led Bawa (1976) to suggest that between-population variation in tropical hardwoods may be greater than in temperate trees. So that breeders would be better advised to sample a small number of individuals from a large number of populations rather than a large number of individuals from a small number of populations, as in temperate forestry.

Species thus show inherent differences in adaptation and adaptability based on differences in their reproductive biology. However, occasionally, breeding programmes have conferred on particular cultivars immediate adaptation to a wide range of environments. The 'green revolution' wheats were bred in Mexico by raising two generations a year, one in high latitudes in summer, and one in low latitudes in winter. The resultant cultivars could initiate inflorescences under either lengthening or shortening days and were thus pre-adapted to cultivation in various latitudes and at various seasons of the year.

CO-ADAPTATION IN AGROFORESTRY SYSTEMS

Herbaceous and tree species growing together may interact in various ways. Their root systems may be distributed differently in the soil profile, giving the tree species access to nutrients and water unavailable to the herbaceous crop. The plant nutrients may then be returned to the surface layers in the leaf litter and

become available to the herbaceous crop. *Acacia albida* comes into leaf in the dry season and sheds its leaves at the start of the rainy season. The leaves decay rapidly, releasing nutrients for crops planted under the trees in the wet season, when the *Acacia* does not shade them. Groundnuts and millet have yielded significantly more when grown directly under *A. albida* rather than further away. In the dry season, livestock are pastured and fed in the shade of the trees, and their droppings further improve the soil (National Academy of Sciences, 1979).

Leaf litter of certain other species has deleterious effects. *Tamarix* spp. have been recommended for shelter belts, soil stabilization, shade and fuelwood. Their extensive root systems extract from the soil large quantities of soluble salts, which are accumulated in, and excreted from, the leaves and thus returned to the topsoil. Tamarisks can therefore cause salinization of the topsoil even on non-saline soils. Crop yields may be reduced up to 50 m from a tamarisk shelter belt (National Academy of Sciences, 1980).

Agroforestry may require different habits and canopy structures in the crop compared to those favoured under monoculture. Bunting (1980) gives an instructive example from cowpeas, where selection for short-season, small-statured, non-climbing types proved misdirected in a context where growers wanted cowpeas that could withstand shading in the lower layers of mixed crops and reach the light by climbing up other components of the stand. More work is required on morphological and physiological plant attributes which are desirable for agroforestry, as compared with either agriculture or forestry.

Competition for pollinators may reduce yields where two components of a mixed crop flower simultaneously and are both insect-visited. Dandelions, growing as weeds in grassed orchards notoriously attract pollinating bees away from the fruit trees. Many shade and timber trees are valuable sources of high quality honey, for example *Eucalyptus*, *Acacia*, *Inga* and *Prosopis*, and they could conceivably lessen yields of lower storey crops which require bee pollination.

One often cited advantage of mixed cropping, or agroforestry, over monoculture is that pests and diseases may be less severe: presumably because they cannot build up to such devastating levels as in stands of uniformly susceptible individuals. However, Bunting (1980) has cautioned that cross-infestations may occur in some circumstances. For example, the stem borer of sorghum is the same pest as the bollworm of cotton. Again, bruchid beetles are serious pests of many legume seeds, including pulses such as *Phaseolus* and *Cajanus* as well as trees such as *Acacia* and *Prosopis*. Many tree legumes are prolific producers of seed which is not harvested by man and so falls to the ground as a potential source of infestation for other crops. Bruchids vary in their host specificity, some being confined to a single legume species and others being more catholic, but host ranges are not yet well enough known to permit the dangers of intercropping legumes with legumes to be assessed precisely.

When pests or diseases do become established in mixed crops, control may be more difficult than in monoculture, at least in high-input systems. This is because of such factors as the different sensitivities of plant species to chemical sprays,

the difficulty of getting spray machinery through mixed crops and achieving adequate penetration of the canopy by the spray.

SUMMARY AND CONCLUSIONS

Although man has probably been interplanting herbaceous and tree crops, at least on a garden or orchard scale, since the beginning of agriculture, agroforestry in the modern sense is a comparatively new development. Suggestions about the directions that evolution might take in such systems are necessarily speculative. In the immediate future, the tree or herbaceous forage components of the system may need improvement, since in yield, morphology and adaptation to cultivation they are often still close to the wild populations from which they have been derived only recently. Sometimes improvement may require expanding the genetic base of the populations in cultivation, and studies of the biosystematics of the wild populations may enable new introductions to be made from provenances likely to contain desirable traits. Eventually, however, the species will have to be considered as components of an integrated system, rather than in isolation, and this will require work on morphology, physiology and crop protection, and will include attention to reproductive as well as vegetative features.

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EVOLUTIONARY ASPECTS

DISCUSSION

STEPPLER - Domestication of plants has involved moving them from associations, in their natural forms, to planting them in monoculture. For monocultural systems plant breeding objectives can be clearly established. Do you envisage difficulties in developing breeding objectives for agroforestry, where you will be dealing with the outcome of numerous interactions between plant species?

PICKERSGILL - We will need to wait for information from other disciplines, such as plant morphology and physiology, in order to plan breeding programmes designed to select plants specifically for agroforestry land use systems. For example, cowpea breeders have tended to concentrate on developing determinate cultivars which are suitable for monoculture; whereas in intercropping situations, the semi-climbing ones are preferred.

LEDIG - In systematic forest breeding programmes we select plants from a broad area in order to conserve a wide genetic diversity.

PICKERSGILL - In outbreeding crops, such as many tree species, you get considerable segregation in early generations following subcrossing or inbreeding. And I think this segregation accounts for some of the diversity observed by tree breeders. Also, tree breeding work is comparatively recent and we are now aware of the need to maintain genetic diversity. This was not true of early work on the improvement of herbaceous crops.

LEDIG - You have tended to generalize too much when discussing seed dormancy, and there are a number of exceptions from the broad generalization.

PICKERSGILL - Where seed dormancy is present, and viability is quickly lost, you tend to have potential variation which can form the basis for selection for or against dormancy. Some species do not have seed dormancy at all and breeding for dormancy as far as I knew has not been possible in those species.

STEPPLER - There are cases where seed dormancy has been transferred between species. For example, in wild to cultivated oats.

RACHIE - Relatively undomesticated plants may be subject to many unexpected hazards when brought under more intensive cultivation. By intercropping, however, it may be possible to buffer the pest and disease problems until more information and expertise are available to deal with these environmental and biological hazards.

PICKERSGILL - That is entirely correct. But, the crop protection industry will invest efforts only for crops grown on a large enough scale to afford an economic outlet for their products. This is why it is important that any new crops be adapted to cultivation on a reasonably large scale. Furthermore, diversification of genotypes may provide an additional measure of protection.

AN ENVIRONMENTAL DATA BASE FOR AGROFORESTRY

Anthony Young

Excerpt from

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A B S T R A C T

An environmental data base has the function of relating different kinds of information in agroforestry research to a common basis of environmental information. The paper outlines the principles and structure of the data base, the information contained within it, and its potential uses. Information is included on geology, landforms, climate, hydrology, soils, vegetation, fauna and disease, and land use. There are two levels of detail: Level 1 to provide a broad environmental setting and Level 2 to contain more detailed information. Data is transferred from check lists to computerized storage, and output on the line printer, by means of an interactive computer program AFENV. Potential uses of the data base include, first, the collection, storage and selective retrieval of information on individual aspects of agroforestry: multipurpose trees, agricultural crops, agroforestry systems, and agroforestry experimental work. Secondly, it may be used for synthesis of these different kinds of information, as in land evaluation, diagnostic and design studies, and advisory work.

APPENDIX 1

GUIDE TO THE CHECK LISTS AND LEGEND SHEETS

Input to the environmental data base may be made at two levels of detail: Level 1 for a basic environmental setting.

Level 2 for a more detailed environmental description.

At each of these levels there is a check list, one copy of which is completed for each site entered; and a legend sheet, giving instructions for completing the check lists.

The following are available. Items marked with an asterisk are included in this Appendix:

- * Check list, Level 1
- * Check list, Level 2
- Legend sheet, Level 1
- * Legend sheet, Level 2
- Check list, Level 1, modified version as used in the agroforestry systems inventory
- * Attachment A: the Koppen climatic classification, with identification key
- Attachment B: the FAO soil classification system, with guidelines

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ICRAF ENVIRONMENTAL DATA BASE. LEVEL 1. CHECK LIST

DATA SET

User's initials .... User's ref. .... Title ....

SITE REFERENCE NO. _______

User's ref. _______ Title .... Source ....

Country .... Location ....

Latitude _______ Longitude _______ Rel. _______/ Altitude _______ Rel. _______/

GEOLOGY

ROCK TYPE _______/ ....RELIABILITY _______/

LANDFORMS

LANDFORMS OF AREA _______/ RELIABILITY _______/

Description ....

Slope angle at site: _______ degrees or _______ percent

CLIMATE

GENERALIZED CLIMATIC TYPE _______/ RELIABILITY _______/

KÖPPEN CLIMATIC CLASS _______/ RELIABILITY _______/

Altitude zone _______/ Rainfall regime _______/

Mean annual temp. _______ Mean annual rainfall _______ No. of dry months _______

HYDROLOGY

SURFACE WATERLOGGING _______/ RELIABILITY _______/ Groundwater type _______/

Groundwater depth: Average _______

SOILS

GENERALIZED SOIL TYPE _______/ RELIABILITY _______/

FAO CLASSIFICATION: MAIN GROUP ....RELIABILITY _______/

SOIL UNIT ....

Other soil class ....on ....Classification

Texture _______/ Reaction _______/

Drainage _______/ Other features _______/ ....

VEGETATION

GENERALIZED VEGETATION TYPE: AREA _______/ SITE _______/ RELIABILITY _______/

Physiognomic vegetation type ....

Vegetation association ....

FAUNA AND DISEASE

AFFECTING PLANTS _______/ ....

AFFECTING ANIMALS _______/ ....REL. _______/

LAND USE

MAJOR KIND OF LAND USE _______/ RELIABILITY _______/

Description ....

Agroforestry practices _______/ ....

<u>USER-DEFINED ADDITIONAL DATA</u>

Coded 1 _______/ Coded 2 _______/ Coded 3 _______/

Numeric 1 _______ Numeric 2 _______ Numeric 3 _______

Descriptive 1 ....

Descriptive 2 .... Descriptive 3 ....

<u>GENERAL NOTES ON SITE</u>

....

....

....

....

(October 1983 version)

ICRAF ENVIRONMENTAL DATA BASE. LEVEL 2 CHECK LIST

DATA SET

User's initials .... User's ref. .... Title ....

SITE REFERENCE NO. ______

User's ref. ______ Title .... Source ....

Country .... Location ....

Latitude ______ Longitude ______ Rel. ______/ Altitude ______ Rel. ______/

GEOLOGY

ROCK TYPE ______/ ....RELIABILITY ______/

Grain size ______/ Geological formation: name ....

age .... lithology ....

LANDFORMS

LANDFORMS OF AREA ______/ RELIABILITY ______/

Description ....

Slope angle at site: ______ degrees or ______ percent

Relative relief ______

At site: slope curvature ______/ position on slope ______/

CLIMATE

GENERALIZED CLIMATIC TYPE ______/ RELIABILITY ______/

KOPPEN CLIMATIC CLASS ______/ RELIABILITY ______/

Altitude zone ______/ Rainfall regime ______/

Mean annual temp. ______ Mean annual rainfall ______ No. of dry months ______

Mean monthly rainfall, mm:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
______	______	______	______	______	______	______	______	______	______	______	______

Mean temp., hottest month ______ Mean temp., coldest month ______

Rainfall, driest month ______ Occurrence of frost ______/

Mean annual Eo ______ By which method? ....

Humidity index r/Eo ______ Growing period ______

HYDROLOGY

SURFACE WATERLOGGING ______/ RELIABILITY ______/ Groundwater type ______/

Groundwater depth: average ______ lowest ______ highest ______

Flooding frequency ______/ River regime ______/ Degradation ______/

SOILS

GENERALIZED SOIL TYPE ______/ RELIABILITY ______/

FAO CLASSIFICATION: MAIN GROUP ....RELIABILITY ______/

SOIL UNIT ....

Other soil class ....on..................Classification

Texture ______/ Reaction ______/

Drainage ______/ Other features ______/ ....

Texture class: topsoil .... B horizon ....

pH: topsoil ______ B horizon ______

Drainage class: ______/ Depth to limiting horizon ______

Soil degradation: type ______/ severity ______/

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VEGETATION

GENERALIZED VEGETATION TYPE: AREA ______/ SITE ______/ RELIABILITY ______/

UNESCO CLASSIFICATION: AREA .... RELIABILITY ______/

SITE ....

Physiognomic vegetation type ....

Vegetation association ....

Vegetation degradation: severity ______/

nature, causes ....

FAUNA AND DISEASE

AFFECTING PLANTS ______/ ....

AFFECTING ANIMALS ______/ ....REL. ______/

LAND USE

MAJOR KIND OF LAND USE ______/ RELIABILITY ______/

Description ....

Agroforestry practices ______/ ....

USER-DEFINED ADDITIONAL DATA

Coded 1 ______/ Coded 2 ______/ Coded 3 ______/

Numeric 1 ______ Numeric 2 ______ Numeric 3 ______

Descriptive 1 ....

Descriptive 2 .... Descriptive 3 ....

GENERAL NOTES ON SITE

....

....

....

....

SUPPLEMENTARY DATA

(October 1983 version)

ICRAF ENVIRONMENTAL DATA BASE

LEVEL 2: LEGEND SHEET

This sheet covers the full list of data items used in Level 2. The legend sheet gives only instructions, explanations and codes for completing the check list. For background discussion, including reasons for data selected, see "An environmental data base for agroforestry information" ICRAF Working Paper 5 (1983).

Instructions in italics refer to computer-compatibility; they need not be followed if the data is to be stored and processed manually.

Using one copy of the check list for each site, enter code numbers or fill in values. *Data shown as _______ must be numbers only.* Data shown as .... may be words and/or numbers.

Multiple values. *Up to two values can be accepted for any data item.* Two (un-coded) numerical values are assumed to represent a range. *The computer will expect one value; to instruct that two are to be given, enter 888 (this applies to coded as well as numeric responses). If there are more than two values, the third onwards can be given under 'General Notes' at end.*

No data 'No data' includes 'not relevant, not applicable'. For 'no data' enter:

Coded data:	9
Numerical data:	999
Verbal data:	_ or n.d.

N.B. *Do not simply press the Return key, as this deletes the whole entry.*

Sentences · *In longer verbal data, do not use commas, semi-colons, colons except at ends of lines.*

Reliability codes throughout: The following codes for reliability of information are used

1 Confident
2 Probable
3 Guess
9 No data

DATA SET

This refers to the data set as a whole, e.g. 'Sites of recorded AF Systems', or 'Growth requirements of multipurpose trees'.

User's initials ....

User's ref. .... — User's reference to data set; may be a reference number and/or letters.

Title .... — Title of data set, see examples above.

Description of data set — This is not entered on each check list, but on a separate sheet. For manual reference, it can be of any length. *For computer storage, it is entered only once, with a maximum of 5 lines.*

SITE

REFERENCE NO. _______ — Sequential reference number; for any data set must be successively 1, 2, 3, ... etc.

User's ref. no. _______ — If the site is already known to the user by a different number, it may be entered here; otherwise re-enter sequential number.

Title .... — Short title of site.

Source .... — Source of information, e.g. 'Parkinson (1979).'

Country ....

Location .... — E.g. district, nearby town, experiment station.

Latitude _______ Longitude _______ — *Enter minutes as a pseudo-decimal e.g.* $15^{o}47$ *as 15.47. Enter South latitude and West longitudes as negative numbers.*

Reliability _______/ — Give as 1 if confident to ∓ 1°.

Altitude (m) _______

Reliability _______/ — Give as 1 if confident to ∓ 100 m.

GEOLOGY

1 Crystalline, felsic — Igenous or metamorphic, non-basic, eg. granite, gneiss
2 Crystalline, basic — Ig. or met., basic or ultrabasic, eg. basalt, andesite
3 Sedimentary, siliceous — Sedimentary other than calcareous, eg. sandstone, shale
4 Calcareous — Limestones
5 Superficial deposits — Alluvium, boulder clay, blown sand, etc.
6 Other
9 No data

Reliability _______/ — See above

Rock type .... — Any known name; age can also be given if wishes, eg. Jurassic sandstone

Grain size:

1 Coarse grained
2 Medium grained
3 Fine grained
9 No data

Geological formation:

name ....e.g. Kapata Beds
age ....e.g. Jurassic
Lithology ....e.g. sandstone

LANDFORMS

Landforms of area: give more detailed (two-digit) class if appropriate and data sufficient, otherwise generalized class as for Level 1.

					degrees	percent
1		Steeply sloping	Dominant slopes		>17°	>30
	10	Very steep	"	"	>25°	>45
	11	Steep	"	"	17-25°	30-45
2		Moderately sloping			5-17°	8-30
	12	Moderately steep	"	"	10-17°	18-30
	13	Moderate	"	"	5-10°	8-18
3		Gently sloping	"	"	<5°	<8)
	14	Gentle	"	"	2-5°	3-8) erosional landforms
	15	Very gentle	"	"	<2°	<3)
4		Depositional Landforms (excluding 5)				
	16	Alluvial				
	17	Marine				
5		Swamps				
	18	Freshwater				
	19	Salt water				
9		No data				

Description .... General description of landforms

Slope angle at site _______ degrees or _______ percent

If not a specific small area, angle not relevant, enter 777 degrees
If a small area, but no data on angle, enter 999 degrees

Relative relief (m) _______ local average highest difference, e.g. hill-valley

At site: slope curvature
1 convex)refers to shape in profile,
2 straight)i.e. cross-section
3 concave)
9 no data

position on slope
1 crest
2 upper slope
3 midslope
4 lower slope
5 base
6 other (slopes of complex) shape)
9 no data

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CLIMATE

A. GENERALIZED CLIMATIC TYPE ______/ RELIABILITY ______/

The definitions of the generalized climatic types are in terms of the Köppen climatic classes included in each; where sufficient data are available, it is therefore better to fill in Section B below first. The guidelines are approximate only, for use where more detailed data are not available.

Code and name	Köppen classes included
1 Humid tropics	Af, Am
2 Subhumid tropics	Aw, Aw", Cw, Cw"
3 Semi-arid	BShw, BSk
4 Arid	BWh, BWk
5 Humid subtropics	Cfa
6 Mediterraean	Cs, BShs
7 Temperate maritime	Cfb
8 Cool or cold	D, E
9 No data	

Approximate guidelines and notes

Code and name	Approximate guidelines (lowland tropics): Rainfall (mm)	Dry months	Notes	Typical locations
1 Humid tropics	>1500	<4	Permanently humid or short dry season	Singapore Belem
2 Subhumid tropics	600-1500	4-8	Seasonally humid with with dry season(s)	Lusaka Caracas
3 Semi-arid	250-600	8-10	Short rainy season; 'steppe', 'sahel'; excluding Mediterranean, see 6	Delhi Niamey
4 Arid	<250	11-12	Desert	Khartoum Lima
5 Humid subtropics	High-sun (summer) rainfall		East sides of continents; includes also montane humid	Hongkong New Orleans
6 Mediterranean	Low-sun (winter) rainfall		Excluding arid, see 4 above	Rome San Francisco
7 Temperate maritime				London Wellington
8 Cool or cold			Includes tropical high montane	Moscow Kilimanjaro
9 No data				

B. KÖPPEN CLIMATIC CLASS ______/ RELIABILITY ______/

For definitions and key, see Attachment A.

A: Hot climates

1 Af Humid tropics, permanently humid
2 Am Humid tropics, short dry period ('monsoonal')
3 Aw Subhumid tropics, one wet season
4 Aw'' Subhumid tropics, two wet seasons

B: Dry climates

5 BSh Semi-arid, hot
6 BSk Semi-arid, warm to cold
7 BWh Arid, hot
8 BWk Arid, warm to cold

C: Warm climates

10 Cfa Humid subtropics; also montane humid
11 Cfb Temperate maritime
12 Cw Highland subhumid, one wet season)Including
13 Cw'' Highland subhumid, two wet seasons) Köppen
14 Cs Mediterranean)a, b and c

D, E: Cold climates

15 D Temperate continental; also tropical and subtropical montane zone
16 E Cold tundra; also high montane zone
9 No data

Notes Cfb is used as an abbreviation to cover Cfb and Cfc
Cs excludes summer-rainfall climates which fall into BS or BW.

RELIABILITY ______/

Give as 1 if calculated or if estimated with much confidence; for other estimates, give as 2 or 3.

C. ALTITUDE ZONE

Computer will include this automatically if altitude has been included under site data above.

1 0-500 m
2 500-1000 m
3 1000-1500 m
4 1500-2000 m
5 2000-2500 m
6 Over 2500 m
9 No data

D. RAINFALL REGIME

1 Unimodal, maximum in high sun period (summer)
2 Unimodal, maximum in low sun period (winter)
3 Bimodal (only give as bimodal if clearly so)
4 Uniform (all-year wet with no clear maximum, or all-year dry)
9 No data

E. PRINCIPAL VALUES

Mean annual temperature, °C _______) If no data enter 999
Mean annual rainfall, mm _______)
Mean monthly rainfall, mm: *If no data, enter 999 for January and computer will omit other months*

Number of dry months _______
(tropics< 60 mm, subtropics or other <30 mm) *Computer will enter automatically if monthly values given*

Mean temperature, hottest month (°C) _______) In conjunction with data
Mean temperature, coldest month (°C) _______) given at Level 1, these
Rainfall, driest month (mm) _______) permit calculation of Köppen class

Occurrence of frost:
1 never or rare
2 common
3 every year
9 no data

Mean annual Eo (mm) _______ Open-water evaporation, observed or calculated
By which method? .... 'Pan' = class A evaporation pan
'Penman' = calculated by Penman formula
or name ther formula used

Computer will print rainfall: evaporation ratio, r/Eo

Growing period _______ Days, as calculated by FAO agro-ecological zones method. (World Soil Resources Report 48/3, 1981).

Users may wish to add monthly values of temperature, and further evaporation data at the end of the check list. This information is not computer-stored.

HYDROLOGY

SURFACE WATERLOGGING _______/ RELIABILITY _______/

1 None
2 Seasonal — May include standing water
3 Permanent — " "
9 No data

Groundwater type _______/

1 Fresh
2 Saline
9 No data

Computer will assume fresh unless 2 or 9 is marked, i.e. 'no data' implies there is doubt whether saline.

Groundwater depth, m: average _______ approximate average for year
lowest _______ usually late dry season
highest _______ wet season

Flooding frequency _______/
1 never or rare
2 common
3 frequent
9 no data

River regime: of largest river easily accessible from site (guideline <5 km, but flexible according to circumstances)

1	Perennial	At least some discharge throughout year in every or nearly every year
2	Seasonal	Continuous discharge for some substantial period of every year, dry for part of year
3	Intermittent	Flow only for short periods, after rains
4	None	No easily accessible river
9	No data	

Degradation: Has river flow regime deteriorated adversely through human activities, e.g. lower or shorter base flow, more flash floods?

1	Absent	A positive statement that there has been no substantial flow degradation
2	Present	
3	Severe	
9	No data	

SOILS

A. GENERALIZED SOIL TYPE ______/ RELIABILITY ______/

The definitions of the generalized soil types are in terms of the FAO soil classes included in each (see Attachment B). The guidelines and synonyms are for use where the FAO class is not known.

Code and name	FAO soil classes included	Guidelines & synonyms
1 Latosols	ferralsols, acrisols, luvisols, nitosols	'Red and yellow' tropical soils; includes ferallitic and ferruginous soils (CCTA, French), oxisols and ultisols (US)
2 Vertisols	vertisols	Black cracking clays, 'black cotton soils'
3 Calcimorphic soils	chernozems, phaeozems, kastanozems, rendzinas	Free $CaCO_3$ present; includes brown soils of semi-arid regions (CCTA), 'chestnut soils'
4 Desert soils	xerosols, yermosols	Sand or rock; slight or no horizon development
5 Saline or alkaline soils	solonchak, solonetz	Of desert or coastal origin
6 Gleys, alluvial soils or peat	gleysols, fluvisols planosols, histosols	See note below
7 Shallow or immature soils	lithosols, rankers, regosols, arenosols, andosols	Excluding desert soils, which are placed in class 4
8 Temperate soil types	cambisols, podzols, podzoluvisols, greyzems	Brown earths, 'podzolic soils', podzols
9 No data		

Note. Poorly-drained soils of valley floors and swamps should be classed as 6, Gleys, unless there is positive evidence of being widely-cracking black clays (=2, vertisols).

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FAO CLASSIFICATION: MAIN GROUP ..../ SOIL UNIT ..../ RELIABILITY ______/

Give the class of soil according to the FAO system (FAO/Unesco (1974) Soil Map of the World 1: 5 000 000, Volume 1, Legend). Attachment 2 gives the soil units and their letter codes, together with a summary and analogues in the US soil taxonomy. For further details, refer to the Legend Volume.

As the classification employs letter codes, these same codes are used in the data base, hence the symbol ..../

'Main group' refers to capital-letter (noun) classes, e.g. J Fluvisols. 'Soil unit' refers to two-letter (adjective-noun) classes, e.g. Je Eutric fluvisols. Enter letter code alone or, preferably, code plus name.

Other soil type	Any other known name; two or more names may be included.
On which classification?	Refers to previous question: international classification (e.g. US, French/ORSTOM) or local name.

B. PRINCIPAL SOIL PROPERTIES

Texture, reaction and drainage, predominant for profile.

Texture	1	sandy	sand, loamy sand
	2	loamy	sandy loam, sandy clay loam, medium loam, silty textures
	3	clayey	sandy clay, clay, heavy clay
	9	no data	
Reaction:	1	strongly acid	pH >5.0 (only if clearly so)
	2	acid	pH 5.0-6.5
	3	neutral	pH 6.5-7.5 (or if profile transgresses 7.0)
	4	alkaline	pH >7.5
	9	no data	
Drainage	1	well drained	drainage classes excessive, well-drained
	2	imperfect	" " moderately well, imperfect,
	3	poor	poor, very poor
	9	no data	

Other features:

1	shallow	limiting horizon (rock, laterite, etc.)at <50cm
2	saline	
3	other ....Mark 3 and name feature	
9	none or no data	

The generalized information given at Level 1 is supplemented by the following more precise data if representative profile descriptions are available.

'Topsoil' refers to 0-20 cm depth or the plough/hoe layer.
'B horizon' has its standard pedological meaning, typically c. 50 cm depth.

Texture class: topsoil	) Enter capital-letter abbreviation of
B horizon	) standard international textural classes using 'Z' for silt, viz:

S, LS, SL, L, ZL, SCL, CL, ZCL, SC, C or N.D.

Reference: FAO (1977) Guidelines for soil profile description, 2nd edition.

pH: Topsoil _______ B horizon _______ In water at 1:2.5 if data available

Drainage class _______/ The codes used are the same as the class numbers of the standard international system (FAO, 1977, see above). To avoid confusion in computer storage, 'Class 0: very poorly drained' should not be used, but combined with, and entered as, Class 1.

1 Poorly drained (see note above)
2 Imperfectly drained
3 Moderately well drained
4 Well drained
5 Somewhat excessively drained
6 Excessively drained
9 no data

Depth to limiting horizon (cm)_______ To rock, laterite, or other obstruction to roots. If no limiting horizon recorded to at least 150 cm, enter 150. Note that the usual unit for soil depth, centimetres, is employed.

Users may wish to attach one or more soil profile descriptions to the check list. This information is not computer-stored.

Soil degradation: type _______/ severity _______/

Is it believed that soil properties have deteriorated, and/or are deteriorating? The types of degradation are those given in FAO (1979), A provisional methodology for soil degradation assessment, except that an additional and more generalized descriptor is given, 'fertility decline', to be used where precise causes are not known.

1	Water erosion	Including sheet and/or gully erosion
2	Wind erosion	
3	Salinization or sodication	
4	Chemical degradation	Including acidification, lowering of bases or nutrients, toxicities (except as in 3)
5	Physical degradation	Loss of pore space, compaction, decline in permeability and water storage capacity, etc.
6	Biological degradation	Decline in organic matter, biological activity in soil
7	Fertility decline	Lowering of the capacity of soil to produce crops, through combination of chemical, physical or biological degradation.
9	No data	

Severity:

1	Absent	A positive statement that there has been no substantial soil degradation
2	Present	
3	Severe	
9	No data	

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VEGETATION

GENERALIZED VEGETATION TYPE   AREA .... SITE ....

Code and name	Description and notes
1 Rain forest	Including evergreen, semi-deciduous and montane
2 Tropical seasonal forest	Deciduous, including savanna woodland, crowns>40% cover; S. America cerradão
3 Savanna	Tree/shrub cover <40%, predominantly broad-leaved, plus well-developed grass cover; S. America cerrado
4 Thorn scrub or thorn woodland	Xeromorphic vegetation, predominantly thorny and/or microphyllous
5 Grassland	Of any origin, including climatic, hydromorphic, montane, but excluding sown pastures, see 13
6 Semi-desert vegetation	
7 Desert	
8 Temperate deciduous woodland	
10 Coniferous woodland	Excluding plantations, see 13
11 Montane vegetation	Excluding montane grassland, see 5
12 Swamp	Including mangrove and other coastal swamp
13 Planted vegetation	Including crops, forest plantations, sown pasture (see also land use, below)
9 No data	

Reliability ______/

UNESCO CLASSIFICATION: AREA ..../

SITE ..../   RELIABILITY ______/

Give the type of vegetation according to Unesco (1973) International classification and mapping of vegetation. As the classification employs letter codes, they are used in the data base, hence the symbol ..../ The subdivision should be given, e.g. III.A (not III). For detailed definitions, refer to the source given. Enter code plus name.

I	CLOSED FOREST	IV	DWARF-SCRUB AND RELATED COMMUNITIES
I.A	Mainly evergreen forest	IV.A	Mainly evergreen dwarf-scrub
I.B	Mainly deciduous forest	IV.B	Mainly deciduous dwarf-scrub
I.C	Extremely xeromorphic forest	IV.C	Extremely xeromorphic dwarf-shrubland
II	WOODLANDS	IV.D	Tundra
II.A	Mainly evergreen woodland	IV.E	Mossy bog formations with dwarf-shrub
II.B	Mainly deciduous woodland	V	HERBACEOUS VEGETATION
II.C	Extremely xeromorphic woodland	V.A	Tall graminoid vegetation
III	SCRUB	V.B	Medium tall grassland
IIIA	Mainly evergreen scrub	V.C	Short grassland
IIIB	Mainly deciduous scrub	V.D	Forb vegetation
IIIC	Extremely xeromorphic (sub-desert) shrubland	V.E	Hydromorphic fresh-water vegetation
9.D.	No data	VI	PLANTED VEGETATION

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Physiognomic vegetation type .... Description (maximum one line)
Vegetation association .... Main genera or species, trees and shrubs and/or grasses etc.

Vegetation degradation: severity ______/
nature, causes ....

Is it believed that the vegetation is degraded as compared with its condition in some past period?

Severity: 1 Absent — A positive statement that it is believed there has been no substantial degradation
2 Present
3 no data

FAUNA AND DISEASE

Significant fauna, plant or animal pests or diseases affecting plants (trees and/or crops) or animals (livestock).

Affecting plants ______/ 1 Yes 2 No 9 No data

Details...

E.g.:
- animal pests (e.g. rabbits)
- bird pests (e.g. Quelea)
- locusts; termites
- other insect pests
- soil fauna
- plant diseases

Affecting animals ______/ 1 Yes 2 No 9 No data

Details ....

Pests affecting stored produce, and diseases of humans, are not currently included in the data base.

RELIABILITY ______/ Of information on fauna

LAND USE

Intercropping and other mixed systems, including agroforestry, are indicated by use of more than on code, e.g. coconuts with grazing beneath as 2 8 /, maize and coffee with fuelwood trees as 1 2 11 /. Enter multiple uses in order of importance, e.g. plantation forestry with subsidiary recreation as 11 12 /. *For this item, the computer will accept up to three codes; enter 888 to request more than one, then if there are only two, enter zero for the third.*

Code and name	Notes
1 Annual crops	Including cassava, hill rice, vegetables if on a field scale; excluding swamp rice, vegetables if on a small plot/ garden basis
2 Tree and shrub crops	Including fruit trees; excluding crops listed under 3
3 Field perennial crops	Sugar cane, sisal, pineapple, bananas
4 Swamp rice	If irrigated, code also as 6
5 Gardens	Intensive cultivation on small plots
6 Irrigated agriculture	Including rice if water brought to fields but not if retention of rainfall only; including irrigated grazing
7 Livestock production, natural pastures	Including nomadic grazing, ranching
8 Livestock production, improved pastures	Sown or substantially improved pastures
10 Forestry, natural forests	For timber and/or other products
11 Forest plantations	
12 Recreation and tourism	
13 Wildlife conservation	With specific intention of this purpose
14 Water catchments	With specific intention of this purpose
15 Engineering uses	Any form of construction
16 Unused	No specific intention of use
17 Other uses	
9 No data	

Description ....

Agroforestry practices ______/

1 Absent
2 Present (on site)
9 No data

Description ....

There is at present no standard or widely-accepted classification of agroforestry systems in use, within ICRAF or elsewhere. However, individual users may have their own classification systems which they wish to include in the data base. Coded agroforestry classes may then be entered in user-defined additional data, see below.

USER-DEFINED ADDITIONAL DATA

There may be items of environmental data specific to a particular data set which the user wishes to insert. Provision is made for inclusion of up to 3 coded items, 3 numeric items, and 3 descriptive (verbal) items. For the coded items, the user must define the classes. Code no. 9 should always be allotted to 'no data/not relevant'.

GENERAL NOTES ON SITE

A short description of the main, or distinctive, features of the environment at the site. *Maximum of 4 lines; commas, colons and semi-colons may only be used at the ends of lines.*

ATTACHMENT A. THE KÖPPEN CLIMATIC CLASSIFICATION

The following simplified version of the Köppen classification is constructed with special reference to the tropics and subtropics, and to aspects relevant to agro-forestry. Köppen's definitions and values have not been modified. For descriptive names, see the Legend Sheet. *A computer subroutine is available to carry out classification.*

1. THE CLASSIFICATION

Code	Koppen class	Mean annual temp. °C =t	Mean annual rainfall mm =r	Temp. of coldest month °C	Temp. of hottest month °C	Rainfall driest month mm	Period of dry season
1	Af		Wetter than for B climates	>18		>60	
2	Am			>18		$>100-\frac{r}{25}$	
3	Aw			>18		drier than for Am	Low sun
4	Aw"			>18			Two
5	BSh	> 18	r/t formulae see below				
6	BSk	< 18					
7	BWh	> 18					
8	BWk	< 18					
9	Cfa		Wetter than for B climates	<18 >-3	>22	>30	
10	Cfb			<18 >-3	10-22	>30	
11	Cw			<18 >-3	>10	<30	Low-sun
12	Cw"			<18 >-3	>10	<30	Two
13	Cs			<18 >-3	>10	<30	High-sun
14	D			< -3	>10		
15	E				<10		

Formulae for B climates:

Season of rainfall	BS	BW	Notes
Summer/high sun*	r < 20t+280	r<10t+140	Applies to most tropical and sub-tropical areas
Uniform	r < 20t+140	r<10t+70	
Winter/low sun	r < 20t	r<10t	Applies to 'Mediterranean type' climates

*Also equatorial climates with bimodal rainfall

Notes (i) B climates take precedence. In particular, 'Mediterranean type' climates in which rainfall is below the limits specified are placed in BS or BW, not Cs.
(ii) In this simplified form of the classification, Cfb includes Köppen Cfc. Cw, Cw" and Cs include the Köppen temperature subdivisions a, b and c. The cold climates, D and E, are not here subdivided.

2. SOME SHORT CUTS FOR TROPICAL LATITUDES

The following guidelines are for use where data needed for Köppen rules are insufficient; they apply to the tropics only.

(i) Approximate mean annual rainfall known, but not temperature. Is it a B (dry) climate?

Rainfall >900 mm:	Not a B climate
Rainfall >750 mm:	Unlikely to be a B climate, unless annual temperature is unusually high (>23.5°C)

(ii) Approximate altitude known, but not temperature. Is it an A or a C climate?

Altitude >1200m Very probably a C climate

Note, however, that C climates can occur as low as 500 m close to the equator, and down to sea level close to $23\frac{1}{2}^{o}$ latitudes N and S.

3. IDENTIFICATION KEY TO KÖPPEN CLIMATES

[illegible] for a computer subroutine to carry out this identification.

r = mean annual rainfall, mm t = mean annual temperature, °C

1. Is r less than:

20t+280	if rainfall is	high sun or bimodal?)	
20t+140	"	uniformly distributed)	YES 2 / NO 5
20t	"	in winter/low sun?)	

(See also short cut (i) above.)

2. Is r less than:

10t+140	if rainfall is	high sun or bimodal?)	YES 3
10t+ 70	"	uniformly distributed)	NO 4
10t	"	in winter/low sun?)	

3. Is t >18°? — YES BWh / NO BWk

4. Is t >18°? — YES BSh / NO BSk

5. Is temperature of coldest month >18°? — YES 6 / NO 9

(See also short cut (ii) above.)

6. Is rainfall of driest month >60 mm? — YES Af / NO 7

7. Is rainfall of driest month $>100 - \frac{r}{25}$? — YES Am / NO 8

8. Are there two distinct dry seasons? — YES Aw" / NO Aw

9. Is temperature coldest month $> -3^{o}$?
YES 10
NO 14

10. Is rainfall of driest month $>$ 30 mm?
YES 11
NO 12

11. Is temperature of hottest month $> 22^{o}$?
YES Cfa
NO Cfb

12. Are there two distinct dry seasons?
YES Cw''
NO 13

13. Is dry season in winter/low sun period?
YES Cw
NO Cs

14. Is temperature of hottest month $> 10^{o}$?
YES D
NO E

APPENDIX 2

EXAMPLES OF OUTPUT FROM THE DATA BASE

The examples given refer to the Malaysian site in the Collaborative and Special Projects Programme, a forest reserve in Selangor State, Malaysia.

The data was input at Level 2. Output, for the same site, is given at the following levels of detail:

- Summary level
- Level 1
- Level 2

For clarity of reproduction, the original computer output has been re-typed.

ICRAF ENVIRONMENTAL DATA BASE, SUMMARY LEVEL

SITE 1 RANTAU PANJANG SELATAN FOREST RESERVE

		RELIABILITY
SOURCE	VARIOUS	
LOCATION	PENINSULAR MALAYSIA 100 KM NW OF KUALA LUMPUR LATITUDE: 3.25 N LONGITUDE: 101.32 E ALTITUDE ZONE: 0 - 500 M	1
GEOLOGY	SEDIMENTARY, SILICEOUS	2
LANDFORMS	MODERATELY SLOPING	1
CLIMATE	HUMID TROPICS	1
KOPPEN:	AF HUMID TROPICS, PERMANENTLY HUMID	
HYDROLOGY	WATERLOGGING: NONE	2
SOILS	LATOSOLS	1
	FAO CLASSIFICATION: MAIN GROUP: F FERRASOLS AND N NITOSOLS SOIL UNIT: NO DATA OR SERDANG-MUNCHONG ASSOCIATION ON MALAYSIAN CLASSIFICATION	2
VEGETATION	AREA: RAIN FOREST SITE: RAIN FOREST	
LAND USE	FORESTRY, NATURAL FORESTS	
	SECONDARY FOREST (MALAY BELUKAR)	1
	AGROFORESTRY PRACTICES: NONE AT PRESENT	

ICRAF ENVIRONMENTAL DATA BASE, LEVEL 1

SITE 1 RANTAU PANJANG SELATAN FOREST RESERVE

		RELIABILITY
SOURCE	VARIOUS	
LOCATION	PENINSULAR MALAYSIA 100 KM NW OF KUALA LUMPUR LATITUDE: 3.25 N LONGITUDE: 101.32 E ALTITUDE: 100 M	1 1
GEOLOGY	SEDIMENTARY, SILICEOUS SANDSTONES QUARTZITES ETC	2
LANDFORMS	MODERATELY SLOPING UNDULATING AND ROLLING TERRAIN WITH NARROW FLAT VALLEY FLOORS SLOPE ANGLE 6 - 12 DEGREES (10 - 21 PERCENT)	1
CLIMATE KOPPEN:	HUMID TROPICS AF HUMID TROPICS, PERMANENTLY HUMID ALT.ZONE: 0 - 500 M RAINFALL REGIME: BIMODAL ANNUAL TEMPERATURE 26.1 C ANNUAL RAINFALL 2437 MM WITH 0 DRY MONTHS	1 1
HYDROLOGY	WATERLOGGING: NONE GROUNDWATER: FRESH GROUNDWATER DEPTH, MEAN: NO DATA	2
SOILS	LATOSOLS OR SERDANG-MUNCHONG ASSOCIATION ON MALAYSIAN CLASSIFICATION TEXTURE: SANDY TO CLAYEY REACTION: ACID DRAINAGE: WELL DRAINED	1
VEGETATION	NATURAL SITE: RAIN FOREST AREA: RAIN FOREST SECONDARY LOWLAND EVERGREEN RAIN FOREST DIPTEROCARP FORMATION	 1
FAUNA,DISEASE	AFF. PLANTS: WILD BOAR SQUIRRELS AFF. ANIMALS:	 3
LAND USE	FORESTRY, NATURAL FORESTS SECONDARY FOREST (MALAY BELUKAR) AGROFORESTRY CLASS: NONE AT PRESENT	1

GENERAL NOTES ON SITE

TYPICAL PERMANENTLY HUMID LOWLAND RAIN FOREST ENVIRONMENT WITH STRONGLY LEACHED SOILS. RAPID PLANT GROWTH. DESCRIPTION REFERS TO INTERFLUVES. ALSO PRESENT ARE FLAT ALLUVIAL VALLEY FLOORS WITH POOR DRAINAGE (MALAY LOPAK).

ICRAF ENVIRONMENTAL DATA BASE, LEVEL 2

SITE 1 RANTAU PANJANG SELATAN FOREST RESERVE

		RELIABILITY
SOURCE	VARIOUS	
LOCATION	PENINSULAR MALAYSIA 100 KM NW OF KUALA LUMPUR LATITUDE: 3.25 N LONGITUDE: 101.32 E ALTITUDE: 50 - 250 M	1 2
GEOLOGY	SEDIMENTARY, SILICEOUS SANDSTONES QUARTZITES ETC COARSE GRAINED AND FINE GRAINED GEOLOGICAL FORMATION: NO DATA TRIASSIC SANDSTONES QUARTZITES ETC	
LANDFORMS	MODERATELY SLOPING UNDULATING AND ROLLING TERRAIN WITH NARROW FLAT VALLEY FLOORS SLOPE ANGLE 0 - 20 DEGREES (0 - 36 PERCENT) RELATIVE RELIEF 50 M SLOPE CURVATURE: NO DATA POSITION : NO DATA	1
CLIMATE KOPPEN:	HUMID TROPICS AF HUMID TROPICS, PERMANENTLY HUMID ALT.ZONE: 0 - 500 M RAINFALL REGIME: BIMODAL ANNUAL TEMPERATURE 26.1 C ANNUAL RAINFALL 2437 MM WITH 0 DRY MONTHS MEAN MONTHLY RAINFALL, MM:	1 1

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
179	132	202	303	207	149	134	165	173	268	277	248

HOTTEST MONTH: 26.6 C
COLDEST MONTH: 24.8 C
DRIEST MONTH : 132 MM
FROST NEVER OR RARE
ANNUAL EO : 2000 MM BY APPROX. ESTIMATE
HUMIDITY INDEX R/EO: 1.22
GROWING PERIOD: 365 DAYS

		RELIABILITY
HYDROLOGY	WATERLOGGING: NONE GROUNDWATER : FRESH GROUNDWATER DEPTH, MEAN : NO DATA LOWEST : NO DATA HIGHEST: NO DATA	1

LEVEL 2 (CONTINUED)

	RIVER REGIME: PERENNIAL DEGRADATION : ABSENT	
SOILS	LATOSOLS	1
	FAO CLASSIFICATION: MAIN GROUP: ACRISOLS SOIL UNIT : NO DATA OR SERDANG-BUNGOR ASSOCIATION ON MALAYSIAN CLASSIFICATION TEXTURE: SANDY REACTION:ACID DRAINAGE:WELL DRAINED TEXTURE CLASS, TOPSOIL : NO DATA B HORIZON : NO DATA DRAINAGE CLASS: WELL DRAINED NO DATA ON DEPTH TO LIMITING HORIZON DEGRADATION: NO DATA	1
VEGETATION	NATURAL	
	SITE: RAIN FOREST AREA: RAIN FOREST	1
	UNESCO CLASSIFICATION: SITE: 1.A MAINLY EVERGREEN FOREST AREA: AS SITE SECONDARY LOWLAND EVERGREEN RAIN FOREST DIPTEROCARP FORMATION DEGRADATION ABSENT	1
FAUNA, DISEASE	AFF. PLANTS: WILD BOAR SQUIRRELS AFF. ANIMALS:	3
LAND USE	FORESTRY, NATURAL FORESTS SECONDARY FOREST (MALAY BELUKAR) AGROFORESTRY CLASS: NONE AT PRESENT	1

GENERAL NOTES ON SITE

TYPICAL PERMANENTLY HUMID LOWLAND RAIN FOREST ENVIRONMENT WITH STRONGLY LEACHED SOILS. RAPID PLANT GROWTH. DESCRIPTION REFERS TO INTERFLUVES. ALSO PRESENT ARE FLAT ALLUVIAL VALLEY FLOORS WITH POOR DRAINAGE (MALAY LOPAK).

SECTION TWO

PART 2B

MPT data storage and retrieval and lists of species

PART 2B

CONTENTS

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Data Storage and retrieval at the CFI
- by J. Burley

There are several advantages in having a central organisation responsible for the storage and retrieval of data from international species and provenance trials. (See Part 1A and Andrew and Burley 1973; Burley et al, 1974). Information may be needed, for example, about the performance or properties of certain populations under specific environmental conditions at the trial site when combined with varying management inputs, or about the source of a particular provenance. This a quick, efficient, secure and accurate system of storage and retrieval must be developed which can have any set of data or information cross-referenced against any other.

As it may be desirable to be able to include any number of multipurpose tree species in the cross-referencing (for instance to find a suitable combination of species, to satisfy a particular mix of product and function demands on a site with a specific combination of environmental variables) the amount of information to be stored and retrieved is likely to be very large indeed and, therefore, requires the use a computer. For the storage and retrieval of information collected during the exploration phase a system has been developed, at the Commonwealth Forestry Institute (Burley, *et al* 1973). It is flexible in order to allow for data to be missing; for data of varuing types to be included - for example, quantitative, qualitative (categorical) and subjective comments; and, since it is open ended, addition of files to contain data which unexpectedly become important, or the deletion of obsolete files causes no problem. The system comprises several computer fiels each containing different sets of data, each cross-referenced to all others and together these form the data banks.

The major problems associated with any large data processing system are those of space and accessibility. Information has therefore to be coded, and the sequence in which data items are stored must be consitent (although variable length formats may be used, each item being delimited by an appropriate code). Nevertheless it does require the information to be easily classified and coded. The kind of information which Appendix 2.2 (in Part 2A) seeks to obtain obviously varies in terms of suitability for categorization and cod··ıg. The subdivision of the information on the actual first and

second priorities is done to help focus on the key information to collect in the field, both because of the meaningfulness and relative ease of interpretation as such information and because of the greater ease in coding some of it. Information which is difficult to code can remain on a paper file and a reference to the existence of such information can be included as part of the sequence of coded subject items (e.g. see Appendix 1).

Information is retrieved by using a label specific for each attribute which is on computer file. The meaning of each label, its range of values and units where applicable is compiled in a "thesaurus" a form of which can be held in the retrieval system. The output summarises the questions asked and presented the information in a tabulated form.

REFERENCES

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THE COMPUTERISED SEED STORE RECORD SYSTEM of the CSIRO TREE SEED CENTRE, AUSTRALIA

by

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INTRODUCTION

In the past two decades extensive seed collection of Australian trees has been undertaken by a national seed collection and distribution centre, now part of the Division of Forest Research, CSIRO, Canberra. The Seed Centre maintains stocks of about 3500 seedlots of 700 species including 436 Eucalyptus spp., 150 Acacia spp. and 29 Casuarina spp. Most species are represented by several provenances and for those species with an extensive natural distribution there may be numerous provenances, e.g. there are over 200 seedlots of E.camaldulensis in the store.

Eucalypts have been used throughout the world for many years to provide timber, pulpwood, posts and poles, essential oils and other products. Now fuelwood plantations and agroforestry projects are being initiated on a greater scale than previously and are using a wider range of species and genera. In the genera Eucalyptus, Acacia and Casuarina the total number of Australian species exceeds 1000 and the potential demands on the Seed Centre to provide seeds for research purposes and to establish founder stock are very great. For these purposes meticulous records and comprehensive documentation of each seedlot despatched are essential.

In 1971 the Seed Centre handled 262 orders for 2155 seedlots from 73 countries. The statistics for 1981 show 384 orders for 3723 seedlots from 87 countries. As the demand for seed increased it became necessary to consider employing additional staff or instituting a more efficient system for maintaining records of stock and processing orders, for example using a computer. Computerised systems to record and retrieve data on seed sources and inventory have been used to a modest extent in other tree seed stores e.g. Pickett (1974) describes such an operation in Canada at the Petawawa Forest Experiment Station seed bank; to assist in the selection of species (Webb et al. 1980); and to control accessions and information in plant gene banks (IBPGR 1976).

In January 1981 a computer-based system was introduced to aid retrieval of seedlot information , to maintain and control filing of records and to provide documentation of seed origin and other details for all seedlots distributed by the Seed Centre. The following account, by drawing attention to the desirable features of such a system, as well as the availability of this particular system, may assist other seed centres to similarly improve operations.

THE SYSTEM

2.14

The CSIRO computerised seed store system consists of two distinct parts: a databank containing all relevant information and a collection of programs which allow users to manipulate and present this information.

The seed database described in this paper has been implemented on a Digital PDP11/34 computer using the RSX-11M operating system with RMS Input/Output support software subsystem.

DATABANK

The databank consists of five files stored on magnetic disk. In order to minimise retrieval time in interrogation of the databank, an indexed sequential filing organisation is used. Generally, indexed sequential file records are stored in such a manner that they can be accessed in ascending order by the value of selected record fields, called key fields. The key fields are designated at the time of creation of files and their selection reflects users' demands for retrieval of information. For example, in the case of many species the seed store has collections (seedlots) from different localities (provenances). In order to extract information about all seedlots of the same species an indexed sequential search using species name as a key can be conducted. A search of this nature is possible because the species name field, present on every record, has been declared as a key at the time of seedlot file creation (see 'Seedlot' file description). Such a search will directly access only records in the database that have the matching key in the appropriate field. This type of search/ retrieval procedure,which is extremely fast since it reduces disk input/output to an absolute minimum , is essential for efficient operation.

File description

1) The 'Seedlot' file contains information about seedlots in the store and is the major part of the databank. Each seedlot is represented by one unique record in the file. Records consist of the following fields:
   - Seedlot number, a sequential number from 1 to n unique to each seedlot.
   - Species name, represented by a three character code unique to each species, eg. Eucalyptus regnans is coded REG.
   - Genus, eg. Eucalyptus is coded EUC.
   - The name of the seed collection site ('Location').
   - Latitude, longitude and altitude of the collection site.
   - Number of parent trees sampled to make up the seedlot.
   - Year of collection.
   - Year of the last viability test.
   - Total weight of seed available.
   - Location of the seed stock in the seed store.
   - Price category.

   Species name, latitude, longitude and altitude have been designated as key fields for use in indexed sequential searches, reflecting the demand for searches on these particular

attributes.

2) The 'Species name' file contains botanical names of all species in the store. It is a support file for the 'Seedlot' file and the 'Transaction' file which is described below. Records have only two fields, the unique three character species code and the corresponding species name. The full species name can be obtained by a single access of this file with species code as key. This file was created to minimise the amount of repetitive information in the database.

3) The 'Transaction' file contains details of seed transactions. Each transaction creates one record, where the following information is recorded:
- Seedlot number (*).
- Species code (*).
- Date of transaction.
- Country of destination indicated by a three-character code unique to each country. eg. Denmark is coded 067.
- First line of the consignee's address.
- Weight of seed processed.
(* These fields are as previously described for the 'Seedlot' file).
To cater for information retrieval from this file the following fields for seedlot number, species code, transaction date and country code were designated as keys.

4) The 'Country names' file contains names of all countries and is a support file for the 'Transaction' file. Each record has two fields; a unique country code and the corresponding full country name, which can be obtained by a single access of the file with country code as a key.

5) The 'Meteorological data' file contains a selection of climatic data from meteorological stations throughout Australia. Information about the climate near the collection site can be accessed through latitude and longitude.

PROGRAMS

The programs enable the tasks and functions in the seed store to be carried out each working day. The system of programs is designed for easy use by operators with little experience or background in computing. This has been achieved by constructing fully interactive programs which communicate with the operator in a non-ambiguous manner. The user simply logs onto the computer and initiates the seed store system by activating the supervising program with a single instruction. All further communication between the computer and the operator is expressed in English. Each program has internal error-checking procedures which monitor all operator entries. On the detection of an error an appropriate message is displayed to the operator and recovery procedure is initiated.

The prime feature of the system design is the emphasis on structured programing so that programs are easy to maintain and if

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necessary to expand. All programs are written in Digital Fortran IV with emphasis on Standard Fortran.

The six major programs in the seed store system are logically connected and bound together by a supervising program written in 'Job control ' language. The supervisor permits the user to branch interactively to individual programs represented in the interactive comments by their seed store functions(Fig.1).

Insert Figure 1, hereabouts
A typical search for seedlots from the database

Program description

1) The program 'Update' enables the user to update seedlot records by adding new seedlots, deleting expended seedlots and changing any information about existing seedlots in the 'Seedlot' file. It allows the operator to interactively access any seedlot record in the database and any field within that record. Because this program can alter the state of the database, its use is restricted by a password to authorised personnel.

2) The program 'Inquiry' enables the user to search the database for all seedlots which satisfy specified criteria. The criteria can be expressed in terms of species code, a range of latitudes, a range of longitudes and a range of altitudes. Criteria can be selected in any order and any combination. They enable the user to ask the program to find all records (seedlots) of a particular species collected between a specified range of latitudes and longitudes, and within certain altitudinal limits. The speed of retrieval depends on the number of records checked and whether they comply with all specified criteria. The outcome of the search can be presented to the user in two forms: an information summary on the visual display terminal or full information on the central printer. A sample search is illustrated in Fig.1.

3) The program 'Selseed' enables the user to remove the required amount of seed from a selected seedlot record for a specific customer and produces on the central printer a standard consignment note for despatch with the seed to the customer(Fig.2). The amount of seed outstanding is automatically updated and details of the transactions are recorded in the 'Transaction' file. If the amount of seed requested exceeds the amount available an error message is displayed and the transaction is deleted. The program also warns the user if the amount of seed is reduced below a selected limit. The use of this program is restricted by a password.

Insert Fig.2 hereabout - Consignment note

4) The program 'Account' enables users to obtain information about registered transactions of seed. Retrieval criteria are presented in terms of : species code, a range of dates, country code and seedlot number(Fig. 3). The user can select criteria in any combination with the exception of species name and seedlot

number (the species name is uniquely specified by the seedlot number). User can ask the program to locate information about all transactions of a particular species, to a particular country, within a particular range of dates. The total amount of seed processed in the located transactions is also displayed with detailed information about individual transactions.

Insert Fig.3 hereabouts the database.

5) The program 'Accupd' enables the user to examine and delete faulty transactions from the 'Transaction' file. New transactions can be entered only via the 'Selseed' program. This program, to which access is restricted by password, is seldom used.

6) The program 'Metdata' for meteorological data inquiry locates all meteorological stations within user specified pairs of latitudes and longitudes. A printout of available climatic information can be mailed together with the consignment note and seed if required (Fig.4)

Insert Fig.4 - hereabouts

Fig.5 Programs and data files interactions - insert hereabouts

DISCUSSION and CONCLUSIONS

Prior to the introduction of the computer-based system seedlots suitable for a consignee were chosen by professional staff who scanned written records on stock cards. When appropriate seedlots were selected, a typist transcribed data on origin and viability from the corresponding cards to a consignment note. After the seed consignment was withdrawn from the store a record of the consignee and date of despatch was made on the stock cards by the staff for accounting purposes. Many of these tasks were both laborious and error prone.

The computerised system has increased the efficiency of operations in the Seed Centre and has enabled an improved service to the recipients of seed. Examples of increased efficiency are:

(1) Seed sources can be selected promptly at any time and according to nominated criteria. Several users can interrogate the database simultaneously.
(2) Information on each seedlot to be despatched can be transferred quickly and accurately to a consignment note obviating the need for a typist.
(3) Each transaction is automatically recorded in a readily retrievable form. The amount of seed remaining is also automatically updated. Hence the need for manual filing procedures has been eliminated.
(4) A range of statistical information on the transactions of the seedstore is readily available. For example, in 1981 it could easily be determined that the species most frequently despatched was E.camaldulensis with 484 seed samples weighing 49.386 kg.

Data for other rankings were available e.g., E.citriodora was ranked ninth in demand with 82 samples weighing 8 484 kg . This information can be further dissected to provide a listing of provenances of each species which were most frequently requested or recommended. This type of statistical information can be used for predictions of the rate of usage of species and provenances in the store and thus provides a basis for the long term planning of seed collection activities to replenish seed stocks.

(5) An up-to-date hard copy inventory can be produced at any time so facilitating stock control or auditing.

(6) The computerized seed store system is safe. It is protected against corruption by users by passwords and error checking procedures. It is also protected against damage resulting from hardware failures by frequent 'back-ups'. Currently there are five almost identical copies of the entire system, stored on magnetic disks, located in different parts of the complex.

The service to the seed users has improved as they can now be provided readily with a listing of provenances held in stock for a particular species; the data accompanying the seed consignment is accurate and not subject to typing errors; and additional data such as appropriate meteorological information can be given.

A disadvantage of the computer system is the high initial cost of the hardware and the need for programming skills in setting up the operation. However in the CSIRO Seed Centre the high cost of the hardware is offset to a large extent by sharing the computer with other users and by the savings in labour costs.

The system is very flexible and, although improvements are possible, the current programs meet the majority of needs of the CSIRO Seed Centre. The system and programs could be applicable with minor amendments to other tree seed centres. The senior author is willing to provide more detailed information on request.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of P.N.Martensz and other colleagues at the CSIRO Division of Forest Research in the preparation of this paper.

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Pickett, T.L. (1974). Seed source search and white spruce seed inventory. Information Report, Petawawa Forest Experiment Station, Canada. No.PX-X-50.

Webb, D.B., Wood, P.J., and Smith, J. (1980). A guide to species selection for tropical and subtropical plantations. Tropical Forestry Paper 15. Commonwealth Forestry Institute, Oxford.

[illegible] 1. A typical search for seedlots from the database.
[illegible] this example a search is made of the database to give all seedlots of E.foecunda according to [illegible]ified criteria.

```
HELLO JOHND/CFTXJD
```

Log on procedure.

```
        RSX-11M BL26 MULTI-USER SYSTEM

[illegible] AFTERNOON
[illegible]-81 16:20 LOGGED ON TERMINAL TT17:

[illegible] to RSX-11M V3.2 timesharing

[illegible]
```

Activates the supervisor program.

```
:    AVAILABLE OPTIONS ARE:
:        LIST - LISTS DATABANK ENTRIES
:        UPDATE - UPDATES DATABANK(ADD,DELETE,CHANGE)
:        SELSEED - PRINTS FORMS FOR CONSIGNEES
:        INQUIRY - INFORMATION RETRIEVAL SYSTEM--SEEDLOTS
:        ACCOUNT - INFORMATION RETRIEVAL SYSTEM--TRANSACTIONS
:        BACKUP - DATABASE BACKUP
:        METDATA - METEOROLOGICAL DATA INQUIRY
:        STOP - STOPS RUN
: [illegible] OPTION [S]: INQUIRY
```

User specifies the option required.

```
[illegible] ON LINE INQUIRY SYSTEM
[illegible] CRITERIA ARE:
[illegible]  SPECIES CODE OF THREE CHARS
[illegible]  LATITUDE (1 to 45 DEGREES)
[illegible]  LONGITUDE (112 to 154 DEGREES)
[illegible]  ALTITUDE (0 to 2200 METRES)
[illegible] TO STOP CRITERIA
[illegible] PRIMARY CRITERION:CODE
[illegible] LETTER SPECIES CODE:FOC
[illegible] SECONDARY CRITERION(RETURN STOPS):LAT
[illegible] LOWER AND UPPER LIMITS:30 35
[illegible] SECONDARY CRITERION(RETURN STOPS):LON
[illegible] LOWER AND UPPER LIMITS:115 125
[illegible] SECONDARY CRITERION(RETURN STOPS):ALT
[illegible] LOWER AND UPPER LIMITS:20 300
[illegible] SECONDARY CRITERION(RETURN STOPS):
    2 RECORDS FOUND
[illegible] T=TERMINAL,B=BOTH:T
```

FORM INQUIRY:
User inputs retrieval criteria - Seedlots of Eucalyptus foecunda
between 30-35 degrees latitude
and 115-125 degrees longitude
within 20-300 metres altitude
return button depressed

Seedlots found

[illegible]

SEEDLOT	GEN	SPEC	LOCATION	LAT	LON	ALT	WEIGHT	PARENT	VIAB
9907	EUC	FOC	70.8KM N KONDININ WA	3158	11830	280	94	1	4000
9908	EUC	FOC	N BUNGALLA WA	3137	11735	200	180	1	1030

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[illegible] UNI OF STELLENBOSCH

ATTN:DR.D.G.M. DONALD

DEPT. OF FOREST SCIENCE

STELLENBOSCH-S.AFRICA

CSIRO, DIVISION OF FOREST RESEARCH

CONSIGNMENT NOTE AND SEED CERTIFICATE

POST OFFICE BOX 4008

CANBERRA, A.C.T. AUSTRALIA

FILE NUMBER: DA1/239

SEEDLOT NO	SPECIES	NO. OF PARENT TREES	QUANTITY NG	QUANTITY G	ORIGIN LOCALITY		LAT DEG	LAT MIN	LON DEG	LON MIN	ALTITUDE M	VIABLE SEEDS/10G
12349	EUC CAMALDULENSIS	3	0	10	LENNARD RIVER	WA	17	23	124	45	60	10800
12346	EUC CAMALDULENSIS	20	0	10	GIBB R KIMBERLEY AREA	WA	16	8	126	30	430	13400
12964	EUC CAMALDULENSIS	25	0	10	EMU CREEK PETFORD	QLD	17	20	144	58	460	9910
10507	EUC CAMALDULENSIS	1	0	10	123KM N TENNANT CREEK	NT	18	38	133	56	360	3885
6940	EUC CAMALDULENSIS	5	0	10	64KM E OF HUGHENDEN	QLD	20	49	144	48	450	4400
12418	EUC TERETICORNIS	20	0	10	SIRINUMU SOGERI PLAT	PNG	9	30	147	26	580	5150
8202	EUC TERETICORNIS	UNKNOWN	0	10	29KM W COOKTOWN	QLD	15	40	145	15	120	22750
10961	EUC TERETICORNIS	UNKNOWN	0	10	4KM S OF HELENVALE	QLD	15	45	145	15	120	5600
8215	EUC TERETICORNIS	1	0	10	REEDY ST GEORGE CK	QLD	16	20	144	50	75	7500
11956	EUC PELLITA	12	0	10	5KM S HELENVALE	QLD	15	45	145	15	150	3760
12421	EUC ALBA	1	0	5	MANNING CREEK	WA	16	41	125	55	460	450
10412	EUC EXSERTA	UNKNOWN	0	20	48KM E SURAT	QLD	27	10	149	2	250	500
12542	EUC CREBRA	3	0	20	33KM SW MT GARNET	QLD	17	53	144	55	650	800
12967	EUC TESSELLARIS	10	0	10	NW OF MAREEBA	QLD	16	58	145	15	450	1090
12379	EUC CITRIODORA	42	0	10	HERBERTON-IRVINEBANK	QLD	17	53	145	35	960	1190

[illegible] CLIMATIC DATA SEE SUMMARY OF METEOROLOGICAL DATA IN AUSTRALIA LEAFLET 114, FORESTRY AND TIMBER BUREAU, DEPT OF NAT. DEV.

N.S.W: NEW SOUTH WALES; QLD: QUEENSLAND; SA:SOUTH AUSTRALIA; TAS.: TASMANIA; VIC.: VICTORIA; WA:WESTERN AUSTRALIA;
NT: NORTHERN TERRITORY; ACT: AUSTRALIAN CAPITAL TERRITORY; PNG: PAPUA-NEW GUINEA.

THIS IS TO CERTIFY THAT THE CONTENT OF THIS PACKET WAS FUMIGATED WITH CARBON DISULPHIDE (CS2) DATE: 18-JAN-82

* REQUIRES COLD MOIST STRATIFICATION

** REQUIRES BOILING WATER TREATMENT

....

CERTIFYING OFFICER

Figure 3. A typical search for transactions from the database.
This example shows a search to determine number of seedlots of E.tereticornis despatched over a specified period.

```
* ENTER OPTION: [S]: ACCOUNT

[illegible] TRANSACTION INQUIRY SYSTEM
[illegible] CRITERIA ARE:
[illegible] - DATE OF TRANSACTION
[illegible]   COUNTRY (FILE NUMBER)
[illegible] - SPECIES CODE
[illegible] TO STOP CRITERIA

[illegible] PRIMARY CRITERION(RETURN STOPS):DATE
[illegible] FROM YR MO DA:81 12 1
[illegible] TO   YR MO DA:81 12 2
[illegible] SECONDARY CRITERION(RETURN STOPS):CODE
[illegible] 3 CHARS SPECIES CODE:TRT
[illegible] SECONDARY CRITERION(RETURN STOPS):
[illegible] ORDS FOUND
[illegible] T=TERMINAL,B=BOTH:T
[illegible]
```

User specifies the option required

FORM INQUIRY:

User inputs retrieval criteria
Search for all transactions from 1/12/81
to 2/12/81

of Eucalyptus tereticornis
return button depressed

[illegible]	SPEC	YR	MO	DA	FILE NO	CONSIGNEE	WEIGHT
[illegible]	TRT	81	12	1	DA1/004	MR. A. IRVING	50
[illegible]	TRT	81	12	1	DA1/004	MR. A. IRVING	50
[illegible]	TRT	81	12	1	DA1/004	MR. A. IRVING	50
[illegible]	TRT	81	12	1	DA1/004	MR. A. IRVING	50
[illegible]	TRT	81	12	1	DA1/004	MR. A. IRVING	50

[illegible] WEIGHT= 250

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Figure 4. Meteorological data report.

STATION 031011 CAIRNS AERO QUEENSLAND REF 33P

LATITUDE 16 DEG 53 MIN S LONGITUDE 145 DEG 45 MIN E ELEVATION 3 M

LOW TEMPERATURES AVERAGE NUMBER OF FROSTS/YR 0 AVERAGE LENGTH OF FROST-FREE PERIOD 365 DAYS RECORD LOW TEMPERATURE 6 DEG C

		PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
DAILY TEMPERATURE	MEAN MIN DEG C	1942-1972	24	24	23	22	20	18	17	18	19	21	22	23	21
DAILY TEMPERATURE	MEAN MAX DEG C	1942-1972	32	31	30	29	27	26	25	27	28	29	31	31	29
RAINFALL	MEAN MM	76 YEARS	421	422	460	264	110	72	39	42	43	50	98	203	2224
RAINDAYS	MEAN NUMBER	76 YEARS	17	18	19	16	13	11	9	8	8	7	9	11	146

RAINFALL MM/YR RECORD LOW 927 TEN PERCENTILE 1339 FIFTY PERCENTILE 2089 NINETY PERCENTILE 3069 RECORD HIGH 4434 DATA FOR 91 YR

STATION 015540 ALICE SPRINGS NORTHERN TERRITORY REF 104L

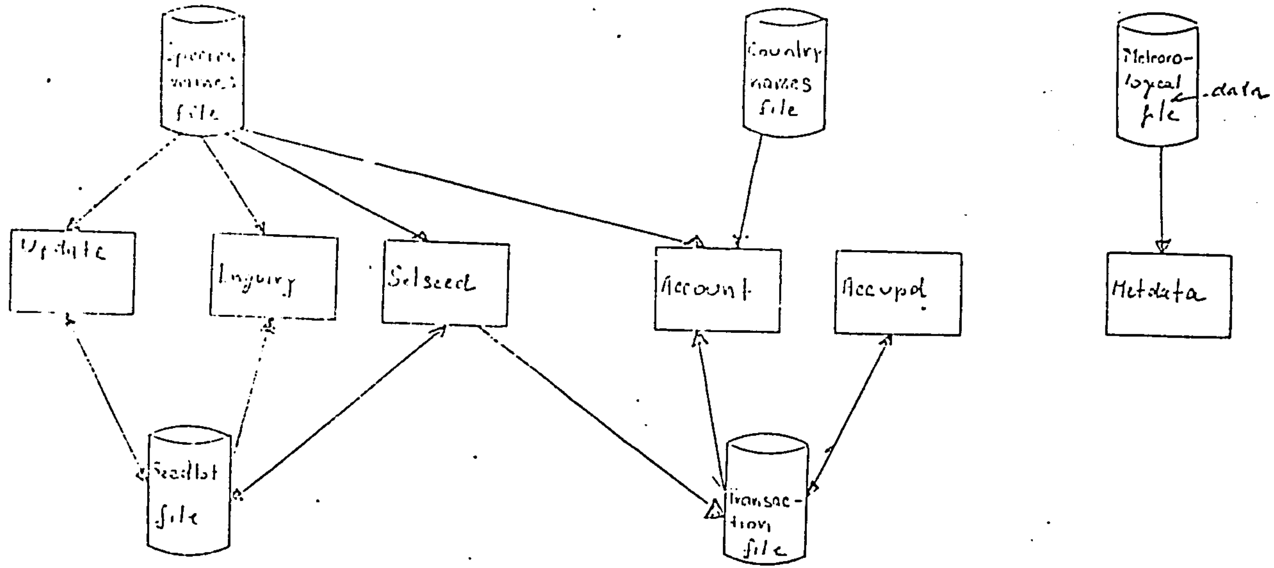
LATITUDE 23 DEG 36 MIN S LONGITUDE 133 DEG 36 MIN E ELEVATION 547 M

LOW TEMPERATURES AVERAGE NUMBER OF FROSTS/YR 12 AVERAGE LENGTH OF FROST-FREE PERIOD 263 DAYS RECORD LOW TEMPERATURE -7 DEG C

		PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
DAILY TEMPERATURE	MEAN MIN DEG C	1940-1972	22	21	18	14	9	6	5	7	10	15	18	20	14
DAILY TEMPERATURE	MEAN MAX DEG C	1940-1972	37	36	33	29	23	20	19	22	26	31	34	35	29
RAINFALL	MEAN MM	90 YEARS	39	42	28	17	16	15	10	9	8	20	24	36	264
RAINDAYS	MEAN NUMBER	90 YEARS	4	4	3	2	3	2	2	2	1	4	4	4	35

RAINFALL MM/YR RECORD LOW 60 TEN PERCENTILE 137 FIFTY PERCENTILE 256 NINETY PERCENTILE 431 RECORD HIGH 726 DATA FOR 92 YR

Figure 5. Information flow between data files and individual programs.



Micro-computers: The ICRAF experience

- by L. Fidaali

Introduction

ICRAF deals with collecting, evaluating and disseminating information about agroforestry. There are many different sources and kinds of information and data, a range of degrees of complexity relating to the evaluation processes and differing needs for the nature and style of output required by users. In 1982, some 4 years after its initiation, ICRAF staff realized that the manual assemblage and sorting of the growing collection of information in the form of journal articles, books, pamphlets, correspondence etc. etc. would no longer be effective and that some form of computerization was essential. This step was taken only after the general structure and content of the information bases within different forms of activity in ICRAF had become established. A premature step into the computer age can lead to both confusion and frustration!

At this early stage it seemed fairly obvious what computer was needed for:

- Storage and retrieval of scientific information contained in documents - mainly those in ICRAF's library.
- Office activities (such as accounting and word processing)

In fact the "prompt" for taking the actual leap into the computer age (for ICRAF) came through the initiation of a joint project with the Australian National University, funded by the IDRC, to further develop an interactive computer software package designed to assist in the economic approach of perennial crops being grown in long-term landuse systems, so as to make it useful for agroforestry combinations (see the 'Mulbud' Programme in Part 6A). This programme was designed for micro-computers and, despite earlier considerations of IDRC's information storage and retrieval programme (based on a mini-computer) the actual need for a low-prized "micro" helped make the decision easier.

In fact, the availability of a micro-computer unleashed a whole new demand for its services

that had, up to then, hardly been envisaged. Numerous activities dealing with information storage and retrieval, the processing of data and the development of simple predictive "tools"(= models) are now being dealt with far less effort and time than before and, in some cases, would probably not have been attempted had the relatively small investment required for micro-computer purchase not been undertaken.

Micro-computers versus larger machines

Thus the computer trend at ICRAF is definitely towards small stand-alone machines rather than a single large system. Micros offer the following advantages to ICRAF:

- Price This is especially significant when working on projects in developing countries. ICRAF can help develop systems and make recommendations on purchases of computers which are reasonably priced.

- Reliability The breakdown of one machine does not mean holding up of all computer applications, one simply switches over to another machine of the same (or a compatible) kind.

- Portability ICRAF certainly takes advantage of the tranportable nature of the micros they have. Not only can they be moved around from office to office but one ICRAF scientist has travelled to Malaysia with a computer in hand. On the less extreme end, members of staff regularly take the computers home in the evenings or over the week-ends.

- Easy Access On larger machines one often has to wait a long time between submitting a job and receiving the results. The interactive nature of micros alleviates this delay.

- Software availability The populatiry of micros has led to ever increasing software productions in practically all areas of application. At ICRAF where there is a wide variety of uses, the "micro" has proved to be a most flexible machine.

No doubt there are certain trade-offs when chosing a "micro" as against a "mini" e.g. speed of execution and greater accuracy in arithmetical manipulations, but these have not been major setbacks at ICRAF so far. Table 1 indicates the levels of investment in equipment and skills that are needed to undertake computerization with micros.

TABLE 1: GUIDE TO MICRO COMPUTER PURCHASES FOR ICRAF TYPE SITUATIONS

Tasks	Recommended machine	Additional peripherals	Software and personnel required
Small database storage and management. No programming experience required	Price range up to $2,000 Any bit CP/M machine with dual disk drives (portable machines have been found to be useful under some circumstances).	Dot matrix printer $800	Often included with machine purchased e.g. Osborne Wordprocessing, Database management, BASIC or PASCAL, spreadsheet package No specialized staff necessary
Somewhat larger databases Word processing and Mailing lists	As above	Letter quality printer $1,500	As above with secretary trained on word processing
As above but with graphs and small programming jobs.	As above	Printer with graphics capability $1,000 Graphics adapter hardware	Graphics software $300 - $600 Operator with programming skill required.
More complex databases. Word processing High resolution graphics	Price upto $10,000 16 bit micro e.g. IBM PC WANG PC NCR Decision Mate V System would include at 1 floppy disk drive, a monitor 1 keyboard and dot matrix printer	Hard disk drive $3,000-5,000 Graphic card $600 Letter quality printer with graphics capacity $1,000-2,000	Wordprocessing Data base management Spreadsheet Statistics Graphics Language interpreter or compiler Full time programmer/operator recommended.

LEITNAMEN	SYNONYMA	
	Butyrospermum paradoxum subsp. parkii (G. Don) Hepper	= B. parkii
BUTYROSPERMUM PARKII (G. DON) KOTSCHY		
CADABA FARINOSA FORSK.		
CADABA GLANDULOSA FORSK.		
	Cadaba mombassana Gilg et Benedict	= C. farinosa
	Caillea dichrostachys Guill. et Perrott.	= Dichrostachys cinerea
CALOTROPIS PROCERA (AIT.) AIT. F.		
	Capparis aphylla Heyne ex Roth	= C. decidua
CAPPARIS CORYMBOSA LAM.		
CAPPARIS DECIDUA (FORSK.) EDGEW.		
	Capparis fischeri Pax.	= C. corymbosa
	Capparis persicifolia A. Rich.	= C. tomentosa
	Capparis puberula DC.	= C. tomentosa
CAPPARIS TOMENTOSA LAM.		
	Cassia florida Vahl	= C. siamea
	Cassia kotschyana Oliv.	= C. sieberiana
CASSIA OCCIDENTALIS L.		
CASSIA SIAMEA LAM.		
CASSIA SIEBERIANA DC.		
CASUARINA EQUISETIFOLIA J.R. ET G. FORST.		
	Celastrus coriaceus Guill. et Perrott.	= Maytenus senegalensis
	Celastrus senegalensis Lam.	= Maytenus senegalensis
CELTIS INTEGRIFOLIA LAM.		
	Combretum abbreviatum Engl. et Diels	= C. paniculatum
COMBRETUM ACULEATUM VENT.		
	Combretum altum Perr.	= C. micranthum
	Combretum elliotii Engl. et Diels	= C. nigricans
	Combretum floribundum Engl. et Diels	= C. micranthum
COMBRETUM GLUTINOSUM PERROTT. EX DC.		
	Combretum leconanthum Engl. et Diels	= C. nigricans
	Combretum leonense Engl. et Diels	= C. glutinosum
COMBRETUM MICRANTHUM G. DON		
COMBRETUM NIGRICANS LEPR. EX GUILL. ET PERROTT.		
COMBRETUM PANICULATUM VENT.		
	Combretum passargei Engl. et Diels	= C. glutinosum
	Combretum pincianum Hook	= C. paniculatum
	Combretum raimbaultii Heck	= C. micranthum
	Combretum ramosissimum Engl. et Diels	= C. paniculatum
COMMIPHORA AFRICANA (A. RICH.) ENGL.		
	Commiphora calcicola Engl.	= C. africana
	Commiphora pilosa Engl.	= C. africana
	Conocarpus leiocarpus DC.	= Anogeissus leiocarpus
CRATEVA ADANSONII DC.		
	Crateva religiosa Forst.	= C. adansonii
DALBERGIA MELANOXYLON GUILL. ET PERROTT.		
	Dichrostachys arborea N.E. Br.	= D. cinerea
DICHROSTACHYS CINEREA (L.) WIGHT ET ARN.		
	Dichrostachys glomerata (Forsk.) Hutch. et Dalz.	= D. cinerea
	Dichrostachys nutans (Pers.) Benth.	= D. cinerea
	Dichrostachys platycarpa Welw. ex Oliv.	= D. cinerea
DIOSPYROS MESPILIFORMIS HOCHST. EX A. DC.		
	Diospyros senegalensis Perrott. ex A.DC.	= D. mespiliformis
	Elayuna biloba Raf.	= Piliostigma reticulatum
ENTADA AFRICANA GUILL. ET PERROTT.		
	Entada sudanica Schweinf.	= E. africana
	Entada ubanguiensis De Wild.	= E. africana
	Entadopsis sudanica (Schweinf.) Gilbert et Boutique	= E. africana

LEITNAMEN	SYNONYMA	
ERYTHRINA SENEGALENSIS DC.	-	
EUCALYPTUS CAMALDULENSIS DEHNHARDT		
	Eucalyptus rostrata Schlecht.	= E. camaldulensis
EUPHORBIA BALSAMIFERA AIT.		
	Euphorbia rogeri N.E.Br.	= E. balsamifera
	Euphorbia sepium N.E.Br.	= E. balsamifera
	Faidherbia albida Del.	= Acacia albida
FERETIA APODANTHERA DEL.		
	Feretia canthioides Hiern	= F. apodanthera
	Ficus bibracteata Warb.	= F. platyphylla
	Ficus bongouensis Warb.	= F. iteophylla
FICUS CAPENSIS THUNB.		
	Ficus dekdekena (Miq.) A. Rich.	= F. iteophylla
FICUS GNAPHALOCARPA (MIQ.) STEUD. EX A. RICH.		
FICUS INGENS (MIQ.) MIQ.		
FICUS ITEOPHYLLA MIQ.		
	Ficus lutea Vahl	= F. ingens
	Ficus kawuri Hutch.	= F. ingens
FICUS PLATYPHYLLA DEL.		
	Ficus pseudovogelii A. Chev.	= F. vogelii
	Ficus sassandrensis A. Chev.	= F. iteophylla
	Ficus senegalensis Miq.	= F. vogelii
	Ficus sprogueana Mildbr. et Burret	= F. iteophylla
	Ficus sycomorus L.	= F. gnaphalocarpa
FICUS THONNINGII BLUME		
	Ficus umbrosa Warb.	= F. platyphylla
	Ficus trachyphylla Fenzl	= F. gnaphalocarpa
FICUS VOGELII (MIQ.) MIQ.		
	Fluggea microcarpa Bl.	= Securinega virosa
	Fluggea virosa (Roxb. ex Willd.) Baill.	= Securinega virosa
GARDENIA AQUALLA (SCHWEINF.) STAPF ET HUTCH.		
GARDENIA ERUBESCENS STAPF ET HUTCH.		
	Gardenia jovis-tonantis Hiern	= G. ternifolia
	Gardenia medicinalis Vahl ex Schum.	= G. ternifolia
GARDENIA SOKOTENSIS HUTCH.		
GARDENIA TERNIFOLIA K. SCHUM. ET THONN.		
	Gardenia thunbergia Hiern	= G. ternifolia
	Gardenia triacantha var. parvilimbis F.N. Williams	= G. erubescens
	Grewia betulifolia Juss.	= G. tenax
GREWIA BICOLOR JUSS.		
	Grewia corylifolia Guill. et Perrott.	= G. villosa
GREWIA FLAVESCENS JUSS.		
	Grewia grisea N.E.Br.	= G. bicolor
	Grewia guazumifolia A. Chev.	= G. flavescens
	Grewia kwebensis N.E.Br.	= G. bicolor
	Grewia miniata Mast. ex Hiern	= G. bicolor
GREWIA MOLLIS JUSS.		
	Grewia mossambicensis Burret	= G. bicolor
	Grewia pilosa Lam.	= G. flavescens
	Grewia populifolia Vahl	= G. tenax
	Grewia salvifolia Heyne ex Roth	= G. bicolor
GREWIA TENAX (FORSK.) FIORI		
	Grewia venusta Fres.	= G. mollis
GREWIA VILLOSA WILLD.		
GUIERA SENEGALENSIS J.F. GMEL.		
	Gymnosporia dinteri Loes.	= Maytenus senegalensis
	Gymnosporia senegalensis (Lam.) Loes.	= Maytenus senegalensis
	Heudelotia africana A. Rich.	= Commiphora africana
HYPHAENE THEBAICA (L.) MART.		
KHAYA SENEGALENSIS (DESR.) A. JUSS.		

ICRAF's present computer activity

At present ICRAF is equipped with 4 micro computers and 2 printers. The two major usages are Data Storage and Wordprocessing. Other activities include statistical analysis, linear programming, agroforestry analysis (MULBUD) and various smaller programmes that are written in-house.

- Data Storage The table shows the large number of data-bases currently on the micros. There are also a number of mailing data bases being updated. The big advantage of computerized databases is the possibility of quick retrieval of any record based on some *ad hoc* inquiry. Already we have such queries coming in from other countries. Another major advantage is that summerised reports of the data can be outputted, in any form desired.

- Word Processing A number of scientists are now encouraging the use of micros for word processing when writing their reports. The secretaries welcome this trend as it means the regular cut-and-paste jobs can be done at the touch of simple key strokes rather than by retyping many pages.

- Agro-economic analysis (MULBUD) The final version of MULBUD is now fuctioning well and proving to be a very useful tool.

- Statistical analysis ICRAF has recently purchased a statistical package, which is still being tested by various scientists. This package works on data stored in the scientific databases and helps form the basis of a well integrated software environment.

- In-house utilities There are times when ICRAF's needs are so specialized that programmes have to be custom built. For example, in devising predictivite new or modifying existing agroforestry systems in ICRAF's 'COSPRO' Programme. ICRAF is slowly building up a library of such aids which will be made available to other interested parties.

Table 2 lists ICRAF's current activities with databases and 'utility' programmes etc. with micros.

T A B L E 2

DATABASES AT ICRAF

A. Scientific Databases	No of Records
1. Plant species with antipest properties	500
2. Woody species with agroforestry potential	50
3. Woody species used in agroforestry systems/practices in developing countries	200
4. Woody perennials with fodder value	600
5. Climatic database - daily rainfall temperature, wind and humidity data from Kathama field station Machakos	*
6. Stick fuelwood inventory database, Kathama	1,000
B. Library/Bibliographic Databases	
1. Books in ICRAF library	1,350
2. Experimental library database	50
3. Description - list of words in agroforestry used in indexing	1,009
4. Corespondence register	*
5. Bibliography of agroforestry systems/practices	*
6. Annotated bibliography of economic analysis in agroforestry systems	75

C. Mailing list

1. Addresses of Training Institutions
2. Addresses of Research Series: Educational Institutions in Forestry, Agriculture etc worldwide.
3. Addresses to which ICRAF sends regular newsletters and other publications.

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* Constantly up-dated.

Looking ahead

One thing that is evident from the present activities is that more and more of ICRAF staff are becoming aware of the potential of micro-computers. It is obvious that more machines will be required. ICRAF intends to take full advantage of the phenomenal technical advances that are taking place in the micro-computer industry.

However, purchases will be made only after very careful considerations of the available alternatives. When buying micro-computers, compatibility is a very important issue to bear in mind. This means that it should be possible to transfer data and programs between two machines, otherwise sharing data becomes very difficult and awkward.

Apart from the computers themselves, ICRAF intends to equip itself better with computer peripherals e.g. hard disk drives, graph plotters and high resolution graphics terminals.

PART 2B

ANNEX

Contents of the INTFORPROV Computer files for description of seed sources and collections for provenance of *Pinus oocarpa* (from Greaves 1979).

The following information is stored in the four INTFORPROV computer files:-

Source file

1. provenance seed collection code number
2. collector's number
3. seed store number
4. country
5. site
6. latitude
7. longitude
8. altitude
9. mean annual rainfall
10. dry season severity code
11. number of trees in the collection
12. number of herbarium specimens
13. number of resin samples
14. number of increment cores

*15. indicates if additional meteorological data are available
*16. indicates if additional site data are available
*17. indicates if additional comments on the collection area available

Distribution file

1. provenance trial code number
2. the provenances included in the trial

Site file

1. provenance trial code number
2. country
3. site
4. latitude
5. longitude
6. altitude
7. mean annual rainfall
8. dry season severity code
9. total number of treatments in the trial
10. the number of treatments planted with seed not distributed by CFI

*11. indicates if additional meteorological data are available
*12. indicates if additional site data are available
*13. indicates if additional comments on the trial are available
*14. indicates if there are any publications which refer to the results obtained from the trial

Growth file

1. provenance trial code number
2. provenance seed collection code

*3. indicates if additional comments are available

4. growth traits and survival data in both the nursery and field, and the ages at which the measurements were made

* Information relating to these items is stored on supplementary paper files.

Lists of Multipurposes Tree Species Compiled
From Various Sources - by J. Burley

From Appendix 8 in "Global needs and problems of collection, storage and distribution of multipurpose tree germplasm" by J. Burley in Proceedings of a Multipurpose Tree Germplasm Planning Workshop, June, 1983. Washington D.C. (in the press).

ESPECIE	FAMILIA	Aptitud para las principales zonas de vida (1)								Calidad de la madera (2)				
		bh-T	bs-T	bms-T	bmh-P	bh-P	bs-P	bh-MB	bmh-MB	Lc	As	Po	Ch	Pu
Acacia auriculiformis	Leguminosae	x	x		x					+	o			+
Albizia falcata	Leguminosae	x			x						o		+	+
Albizia lebbek	Leguminosae	x	x	x	x	x	x			+	+			
Alnus acuminata	Betulaceae				x			x	x	+	+		+	+
Azadirachta indica	Meliaceae		x	x						+	+	+		
Calliandra calothyrsus	Leguminosae	^	x		x	x				+	+			
Casuarina equisetifolia	Casuarinaceae	x	x	x	x	x	x			++	+	+		+
Cordia alliodora	Boraginaceae	x			x	x				+	++		+	
Enterolobium cyclocarpum	Leguminosae	x	x		x	x				o	+		+	
Eucalyptus camaldulensis	Myrtaceae		x	x		x	x			++	o	+		o
Eucalyptus citriodora	Myrtaceae		x			x				++	+	+		o
Eucalyptus grandis	Myrtaceae				x	x		x	x	++	o	+	o	+
Eucalyptus robusta	Myrtaceae		x			x				?+	+	+		o
Eucalyptus saligna	Myrtaceae				x	x		x	x	+	+	+	o	+
Eucalyptus tereticornis	Myrtaceae		x	x		x	x			+	+	o		o
Gliricidia sepium	Leguminosae	x	x	x	x	x	x			++	+	+		
Gmelina arborea	Verbenaceae	x	x		x	x				o	+		+	+
Grevillea robusta	Proteaceae				x	x	x	x		+	+		+	
Guazuma ulmifolia	Sterculiaceae	x	x	x	x	x				++	+			
Inga vera	Leguminosae	x	x		x	x				+	o			
Leucaena leucocephala	Leguminosae	x	x	x	x					++	o	+		+
Pinus caribaea var hondurensis	Pinaceae	x	x		x	x				o	+	+		+
Pinus maximinoi	Pinaceae				x	x		x		o	+			?+
Pinus oocarpa	Pinaceae		x		x	x	x	x		+	+	+		+
Sesbania grandiflora	Leguminosae	x	x		x					o				+
Swietenia macrophylla	Meliaceae	x	x		x	x					++		+	
Tabebuia pentaphylla	Bignoniaceae	x	x		x	x				+	+		+	
Tectona grandis	Verbenaceae	x	x		x	x				+	++	+	+	
Terminalia ivorensis	Combretaceae	x			x						+		+	o
Terminalia superba	Combretaceae	x			x						+		+	o

(1) Véanse las observaciones sobre el # 20 del formato, página

(2) Lc = Leña y/o carbón
As = Aserrío
Po = Postes
Ch = Chapas, láminas
Pu = Pulpa para papel

++ = muy buena
\+ = buena
o = regular, con limitaciones

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Species tested in Costa Rica

(Source: Camacho, 1981)

NOMBRE COMUN	NOMBRE TECNICO	FAMILIA BOTANICA
Albizia	Albizzia falcataria (L.) Fosberg.	Mimosaceae
Jaul	Alnus acuminata (HBK) O. Ktze.	Betulaceae
Espavel	Anacardium excelsum (Bert y Balb) Skeels	Anacardiaceae
Ron-Ron	Astronium graveolens Jacquin	Anacardiaceae
Pochote	Bombacopsis quinatum (Jacq) Dugand	Bombacaceae
Jiñocuabe	Bursera simaruba (L.) Sarg.	Anacardiaceae
María	Calophyllum brasiliense Camb.	Guttiferae
Cedro Macho	Carapa guianensis Aubl	Meliaceae
Casuarina	Casuarina equisetifolia L.	Casuarinaceae
Cedro amargo	Cedrela mexicana Roem	Meliaceae
Cedro dulce	Cedrela tonduzii C.DC.	Meliaceae
Ceiba	Ceiba pentandra (L.) Goerth	Bombacaceae
Laurel	Cordia alliodora (Ruíz y Pavón) Cham	Boraginaceae
Laurel venezolano	Cordia apurensis	Boraginaceae
Ciprés	Cupressus lusitanica Mill	Cupressaceae
Ciprés macrocarpa	Cupressus macrocarpa (Gord) Hartw.	Cupressaceae
Primavera	Cybistax donnell-smithii (Rose) Sqibert	Bignoniaceae
Cocobola	Dalbergia retusa Hensl.	Caésalpiniaceae
Malinche	Delonix regia (Bojer) Raf.	Caesalpiniaceae
Papayillo	Didymopanax morototoni (Aubl) Dec y Planch	Araliaceae
Guachipelín	Diphysa robinioides Benth	Papilionaceae
Chilemuelo	Drymis granadensis L.	Winteraceae
[illegible]acaste	[illegible] (Jack)Gri[illegible]	Mimosaceae
[illegible]	[illegible]	[illegible]aceae
[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Maiden	[illegible]

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NOMBRE COMUN	NOMBRE TECNICO	FAMILIA BCTANICA
Eucalypto	Eucalyptus maculata Hook	Myrtaceae
Eucalypto	Eucalyptus saligna Smith	Myrtaceae
Manzana Rosa	Eugenia jambos Linn.	Rosaceae
Madero Negro	Gliricidia sepium (Jack) Stend	Papilionaceae
Melina	Gmelina arborea Roxb	Verbenaceae
Grevilia	Grevillea robusta A. Cunn.	Proteaceae
Guácimo	Guazuma ulmifolia Lum.	Sterculiaceae
Guapinol	Hymenaea courbaril L.	Caesalpiniaceae
Jacaranda	Jacaranda copaia (Aubl) D. Don	Bignoniaceae
Jacaranda	Jacaranda mimosifolia D. Don.	Bignoniaceae
Nogal	Juglans olanchanum Standl. y Will.	Juglandaceae
Ipil-Ipil	Leucaena leucocephala (Lam.) de Wit.	Mimosaceae
Manú	Minquartia guianensis Aubl	Olacaceae
Tobús	Montanoa dumicola Klatt	Compositae
Bálsamo	Myroxylon balsamum (L.) Harms	Papilionaceae
Gavilán	Pentaclethra macroloba (Wild) Ktze.	Mimosaceae
Pino	Pinus caribaea var. caribaea Barr y Golf.	Pinaceae
Pino engelmannii	Pinus engelmannii Carr.	Pinaceae
Pino oocarpa	Pinus oocarpa Schiede.	Pinaceae
Pino patula	Pinus patula Schl. y Cham.	Pinaceae
Cashá	Pithecolobium pseudo-tamarindus (Britt) Standl.	Mimosaceae
Cenízaro	Pithecolobium saman (Jack) Benth	Mimosaceae
Cristóbal	Platimyscium pleiostachyum Donn Sm.	Papili naceae
Cristóbal	Platimyscium pinnatum (Jack) Dugand	Papilionaceae
Cipresillo	Podocarpus oleifolius Don.	Podocarpaceae
Quibra	Pseudolmedia spurea (SW.) Grisebach.	Moraceae
Encino Blanco	Quercus seemannii sin. corrugata Hooker	Fagaceae
Gallinazo	Schizolobium parahybum (Vell) Blake	Caesalpiniaceae
Panamá	Sterculia apetala (Jack) Karst.	Sterculiaceae
Vainillo	Stryphnodendron excelsum Harms.	Mimosaceae

NOMBRE COMUN	NOMBRE TECNICO	FAMILIA BOTANICA
Come Negro	*Swartzia panamensis* Benth	Caesalpiniaceae
Caoba	*Swietenia humilis* Zucc.	Meliaceae
Caoba	*Swietenia macrophylla* G. King	Meliaceae
Corteza Amarilla	*Tabebuia chrysantha* (Jacq) Nichol.	Bignoniaceae
Roble Negro	*Tabebuia palmeri* Rose.	Bignoniaceae
Roble Sabana	*Tabebuia rosea* (vertol) DC.	Bignoniaceae
Teca	*Tectona grandis* Linn.	Verbenaceae
Amarillón	*Terminalia amazonia* (Gmel.) Exell.	Combretaceae
	Terminalia ivorensis A. Chev.	Combretaceae
Surá	*Terminalia lucida* Hoffm.	Combretaceae
Cedro Australiano	*Toona ciliata* M. Roem	Meliaceae
Capulín Rojo	*Trichosperma mexicanum* (DC.) Baill	Tiliaceae

List of Recommended Species of Trees and Shrubs
for Nepal Community Forestry Development Project

Source: FAO/IBRD (1978)

Glossary of abbreviations on the use of tree species.

Capital letters = main use

Small letters = potential use

E	e	edible
F	f	firewood
G	g	gum/resin/tanning/lac/silk
H	h	hedges
I	i	small timber, implements
L	l	lopping for animal fodder (or breeding)
M	m	medicinal/religious material
O	o	oil seed
R	r	fibre/ropes
S	s	soil improvement/erosion control
T	t	timber

Distribution of species

X	mainly occurring in the ecological range
x	eventually occurring in the ecological range
(N)	new species to be introduced into Nepal

Latin Name	1 - Tree 2 - Small tree 3 - Shrub	Nepali Name (English name)	Upper Tropical	Sub-tropical	Temperate	Sub-alpine	Dry sites	Rich sites	Utilization (see legend)
			Ecology						
bies spp.	1	Bunga salla			x	X	X	X	fT
cer spp.	1, 2	Phangaru		x	x	X		X	LFt
esculus indica	1	Lampatte phangaru			X				LF
Albizzia mollis	1	Siris	x	X					Lft
Alnus nepalensis	1	Utis		X	X			X	LFts
Artocarpus lakoocha	1	Padahar	X	x				x	ELIf
Arundinaria spp.	(3)	Nigalo (mountain bamboo).			X	x			LIS
Bassia butyracea	1	Chiuri	X	x				x	EfION
Bassia latifolia	2	Mahuwa						x	EfOIM
Bauhinia purpurea	2	Tanki	X	x			X		LiFgS
Bauhinia variegata	2	Koiralo	X	x			X		ELFigS
Betula utilis	2	Bhuja patra				X	X		LFImrSt
Brassaiopsis alpina					x	X			Lf
Brassaiopsis nainla		Chuletro		X	x				Lf
Buchanania latifolia	2		X				X		EgS
Buddleia spp.		Dhurse		x	X				L
Butea frondosa	2	Palash	X					X	LfIRMGS
Corylus colurna	2	(hazelnut)				X		X	EftI
Corylus avellana (N)	3	(hazelnut)			x	X		X	EfltI
Castanea sativa (N)	1	(chestnut)		x	X				EFlT
Castanopsis histrix	1	Patle katus		X	X		X	x	elFTs
Castanopsis indica	1	Dalne katus		X			X	x	ElFTs
Castanopsis tribuloides	1	Musuri katus		X	x		X	x	elFTs
Cedrela toona	1		X	x				X	FT
Cedrus deodara	1	Debdar			X		X	x	lfT
Choerospondias axillaris	1	Lapsi	X	X	x		x	X	Etf
Cupressus torulosa	1	Dhupi		x	X	x	X		FlT
Dendrocalamus hamiltonii	(2)	Bans (bamboo)	X	X					elfIMS
Elaeocarpus spp.	1		X	x					M
Erythrina arborescens	2	Phaledo	x	X			x	X	LFS
Eugenia jambolana	2		X	x				X	EF
Euphorbia spp.	3	Sihundi, sija	X	X	x		X	x	Hs
Euria cerasifolia		Pate		X					L
Ficus elavata		Borulo godilo	x	X				X	L
Ficus glaberrima		Pakhuri	X	x				X	L
Ficus nemoralis	1	Dudhilo	x	X	x			X	L
Ficus roxburghii		Nemarro	x	X	x			X	LE
Ficus semicordata		Khannim	x	X				X	LE
Fraxinus spp.	1	Lankuri		X	X			X	LTF

Latin Name	1 - Tree 2 - Small tree 3 - Shrub	Nepali Name (English name)	Upper-tropical	Sub-tropical	Temperate	Sub-alpine	Dry sites	Rich sites	Utilization (see legend)
			Ecology						
Grewia spp.	1, 3		x	X			X	X	EFLRIS
Hippophae salicifolia	3	Armalito		x	X		X		EES
Ilex spp.	2	Bhokre		x	X		x	X	L
Juglans regia	1	Okhar		x	X	x		X	ETFM
Juniperus spp.	1, 3				x	X	X	·	tFS
Larix spp.	1					X	X	x	Tfs
Litsea citrata	2	Sil timur		X	x		X	x	elFM
Litsea polyantha	2	Kutmiro	X	x			x	X	LFt
Machilus odorotissima	1	Bhate kaulo	x	X					LF
Melia azedarach							x	X	Ft
Michelia champaca	1	Champ, Tsampo	X	X				X	LTMo
Michelia dottsopa	1	Sated champ		X	x			X	LTF
Moringa pterygosperma (N)	2		X	x			x	X	ELOs
Morus alba	1	Oeshi kimbu	x	X					ELfG
Morus nigra	1	Kimbu	X	x					ELfG
Mucuna macrocarpa	1	Baldyangro	X	x					L
Olea cuspidata	2, 3			x	X		X		LI(o)
Picea spp.	1				x	X	x	X	Tf
Pistacia integerrima	3					X	X		(?)Ifs
Pieris ovalifolia	2		x	X			X		fS
Pinus excelsa	1	Tingre sallo			X	X	x	X	fTg
Pinus roxburghii	1	Aule sallo	x	X			X	x	fTg
Pinus gerardiana	2	(Chilgoza)			X	X	X		EFS
Populus ciliata	1	Bhote pipal				X	x	X	tFS
Populus euphratica (N)	1, 2		x	x	x	X	X	x	tIFS
Premna barbata	2	Ginderi (?)		X			X		Lf
Princepia utilis	3	Dhatela		x	X		X		OSh
Prunus cerasoides	1	Painyu		X	x			X	LFt
Prunus padus	2	Dur kaphal			X	x			Lf
Pyracantha crenulata	3	Ghangaru		x	X		X		E
Pyrus pashya	1	Mayel, Naspati		x	X			X	Eft
Quercus incana	1, 2	Banj		X	x		X	x	LtF
Quercus lamellosa	1, 2	Falant		X	x		X	x	LtF
Quercus lanata	1, 2	Banj		X	x		X	x	LtF
Quercus semecarpifolia	1, [illegible]	Khasru			X	x	X	x	LtF
Rhododendron spp.	2, 3				x	X			F
Rhus javanica	2, 3	Bhakimlo		X	x				Lf
Rhus succedana	2, 3	Bhalayo		x	X		X	x	LfG
Salamalia malabarica	1	Simal	X	x				X	TFM
Salix spp.	1, 3	Bains		x	X	X	x	X	Lif

Latin Name	1 - Tree 2 - Small tree 3 - Shrub	Nepali Name (English name)	Upper-Tropical	Sub-tropical	Temperate	Sub-alpine	Dry sites	Rich sites	Utilization (see legend)
			Ecology						
Saurauja nepalensis	1	Gogan		X					L
Schima wallichii	1	Chilaune		X				X	LItF
Schleicheria trijuga	1		X				x	X	EoGIFts
Shorea robusta	1	Sal	X				x	X	TlFm
Sorbus spp.	1, 2	Maile			x	X			LtF
Symplocos crataegoides	1	Lodh		x	X				LF
Tsuga dumosa	1				X	x	X	X	Tif
Viburnum coriaceum	3	Pitho char		x	X				L
Vitex negundo	2, 3				X				IIh
Woodfordia floribunda	2, 3					X	X		fS
Xylosma controversum	2	Maidallo		X					L
Ziziphus jujuba	2	Bayer, Jujube	x	X			X		ELHtFSmg

Species or genera recommended by Koivisto (1979) for Asia Pacific region

A. Basically wood production species (known in the region)

Conifers	Pinus caribaea P kesiya P. merkusii P. oocarpa	Wetter, hotter tropics
	P. nigra var. maritima P. eldarica P. griffithii P. roxburghii	drier, West Africa
	P. densiflora P. koraiensis	Cooler, East Asia
	P. elliottii P. patula P. radiata	Cooler, higher altitudes
	Agathis dammara A. macrophylla A. obtusa A. robusta	
	Araucaria cunninghamii A. hunsteinii	
	Cunninghamia lanceolata	
Hardwoods	Albizia falcataria Gmelina arborea Eucalyptus camaldulensis E. deglupta E. grandis E. saligna E. tereticornis	
	Swietenia macrophylla	
	Tectona grandis	

B. Multipurpose forestry species (known in the region)

Acacia auriculiformis
A. catechu
A. confusa
A. dealbata
A. decurrens
A. mearnsii
A. melanoxylon

Dalbergia sissoo
Leucaena leucocephala
Terminalia spp.

C. Potential species (not widely tested in the region)

Aleurites spp.
Artocarpus utilis
Ceratonia siliqua
Durio zibethinus
Dyera costulata
Inocarpus edulis
Mangifera minor
Morus spp.
Parkia spp.
Pentadesma spp.
Pithecolobium spp.
Prosopis spp.
Tamarindus indica

D. Agricultural plantation tree species with secondary forestry uses

Cocos nucifera
Hevea brasiliensis

E. Bamboos

Bambusa arundinacea
Dendrocalamus strictus
Melocanna spp.
Oxytenanthera spp.
Phyllostachys edulis

Species for African savannas

(Source: Laurie, 1974)

Climatic type 1. Desert - omitted from consideration

2. Subdesert

Acacia albida
A. nilotica
A. senegal
Azadirachta indica
Conocarpus lancifolius
Dalbergia sissoo
Eucalyptus camaldulensis
E. microtheca
E. tereticornis
Prosopis chilensis

3. Dry tropical

Anacardium occidentale
Azadirachta indica
Callitris spp.
Cassia siamea
Dalbergia sissoo
Eucalyptus camaldulensis
E. citriodora
E. microtheca
E. tereticornis

4. Semihumid tropical

Acrocarpus fraxinifolius
Araucaria cunninghamii
Callitris calcarata
C. glauca
C. intratropica
C. robusta
Cassia siamea
Eucalyptus camaldulensis
E. citriodora
E. cloeziana
E. grandis
E. pilularis
E. propinqua
E. saligna
E. tereticornis
Pinus caribaea
P. kesiya
P. merkusii
P. oocarpa

5. Humid tropical and equatorial

Acrocarpus fraxinifolius
Araucaria cunninghamii
Chlorophora excelsa
C. regia
Eucalyptus citriodora
E. cloeziana
E. deglupta
E. grandis
E. propinqua
Gmelina arborea
Pinus caribaea
Pinus kesiya
Tectona grandis

(b) <u>Hardwood species for lowland tropics recommended by Fenton et al. (1977)</u>

Annotated bibliographies have been prepared for the following tropical hardwood species:-

1. *Acacia auriculiformis*
2. *Albizia falcataria*
3. *Anthocephalus chinensis*
4. *Campnosperma brevipetiolata*
5. *Cedrela odorata*
6. *Cordia alliodora*
7. *Eucalyptus alba*
8. *Eucalyptus deglupta*
9. *Eucalyptus torelliana*
10. *Eucalyptus urophylla* - not formally named
11. *Grevillea robusta*
12. *Melaleuca leucodendron*
13. *Maesopsis eminii*
14. *Octomeles sumatrana*
15. *Terminalia brassii*
16. *Terminalia calamansanai*
17. *Terminalia catappa*
18. *Terminalia ivorensis*
19. *Terminalia superba*
20. *Toona ciliata*
21. *Tetrameles nudiflora*
22. *Eucalyptus tereticornis*
23. *Eucalyptus robusta*

Plants for arid and semi-arid lands

(Source Adams et al., 1978)

2.1 THE SELECTION OF PLANTS FOR CENTRAL SAUDI ARABIA

The purpose of the following lists of plants is to define a range of species, based on one phytogeographical region. A list of possible plant introductions is also given that might be considered provided soil conditions, climate and water availability are not limiting. Whenever a final plant list is compiled, it is essential that all the environmental factors and the restrictions they might impose are analysed beforehand.

Phytogeographical zone: Saharo–Sindian

INDIGENOUS TREES

Acacia albida
A. arabica
A. gerradii
A. giraffae
A. gummifera
A. mellifera
A. nilotica
A. raddiana
A. senegal
A. seyal
A. tortilis
Albizzia julibrissim
A. lebbek
Eugenia jambolana
Eleagnus angustifolia
Ficus bengalensis
F. benjamina
F. retusa nitida
F. religiosa
Maerua crassifolia
Melia azedarach
Moringa aptera
Phoenix dactylifera
Pistacia atlantica
Prosopis cinerea
P. juliflora
P. spicigera
P. stephaniana
Salvadora oleoides
S. persica
Schinus terebinthifolius
Tamarix aphylla
T. articulata
T. gallica
T. ramosissima
T. passerinoides
T. stricta
Terminalia catappa
T. bellerica
Thespesia populnea
Vitex agnus-castus
Zizyphus jujuba
Z. lotus
Z. mauretania
Z. spina-christi

TREE INTRODUCTIONS

Acacia cyanophylla
A. farnesiana
Albizzia chinensis
Anona cherimifolia
Brachychiton acerifolia
B. gregorii
Callistemon citrinus
C. lanceolatus
Casuarina cristata
C. cunninghamiana
C. equisetifolia
C. glauca
C. lehmanii
C. stricta
C. torrulosa
Cupressus arizonica
Delonix regia
Duranta plumieri
Eucalyptus astringens
E. brockwayi
E. camaldulensis
E. campaspe
E. cladocalyx
E. coolabah
E. forrestiana
E. gomphocephala
E. intertexta
E. kruseana
E. landsdowneana
E. largiflorens
E. longicornis
E. microtheca
E. patellaris
E. pimpiniana
E. robusta
E. redunca
E. salubris
E. sargentii
E. spathulata
E. stricklandii
E. transcontinentalis
E. woodwardii
Ficus carica
F. sycomorus
Grevillea robusta
Hypheane thebaica
Jacaranda mimosiaefolia
Melaleuca pauperifolia
Parkinsonia aculeata
Prosopis chilensis
P. tamarugo
Schinus molle
Washingtonia filifera

INDIGENOUS SHRUBS AND GROUND COVER PLANTS

Achillea fragrantissima
A. santolina
Anabasis articulata
A. setifera
Artemisia herba-alba
A. monosperma
Atriplex halimus
Balanites aegyptiaca
Caesalpinia gilliesii
C. pulcherrima
Calligonum arborescens
C. comosum
Calotropis procera
Capparis decidua
C. spinosa
Carex physodes
Cassia lanceolata
C. obovata
Clerodendrum inerme
Coronilla juncea
Cyperus conglomeratus
C. laevigatus
Dodonea viscosa
Ephedra alata
E. distachya
Euphorbia ceratoides
E. guyonianum
E. mauritanica
E. nereifolia
Genista saharae
Haloxylon aphyllum
H. articulatum
H. persicum
H. salicornicum
Heliotropium dasycarpum
Ipomoea pes-capre
Iris sisyrinchium
Lagerstroemia indica
Launea spinosa
Leptadenia pyrotechnica
Limoniastrum guyonianum
L. monopetalum
Lycium arabicum
L. persicum
Monsonia nivea
Nerium oleander
Phlomis brachyodon
Plumeria acutifolia
P. rubra
Punica granatum
Retama raetam
Rhanterium epapposum

Rhus oxyacantha
Salsola tetrandra
Salvia aegyptiaca
S. lanigera
Sesbania aegyptiaca
Siedlitzia rosmarinus
Tecoma stans
Tecomaria capensis
Thevetia nereifolia
Zilla macroptera
Z. spinosa
Zygophyllum coccineum
Z. dumosum

SHRUB AND GROUND COVER PLANT INTRODUCTIONS

Allamanda cathartica
Aloe spp.
Arundo donax
Atriplex nummularia
Bougainvillea spectabilis
Carpobrotus acinaciformis
C. edulis
Hibiscus rosa-sinensis
H. syriacus
Iris spp.
Jasminum arabicum
Lantana camara
Lavandula spica
L. stoechas
Lippia citriodora
Myoporum spp.
Myrtus communis
Pistacia lentiscus
P. vera
Plumbago capensis
Polygonum capitatum
Rosa spp.
Santolina chamaecyparissus
Yucca gloriosa

2.2 THE SELECTION OF SUCCULENT PLANTS FOR CENTRAL SAUDI ARABIA

Reference: Herman Jacobsen: *Handbook of Succulent Plants*, Blandford Press, London 1960

Saharo–Sindian zone

Aeonium leucoblepharum
Aloe eru
A. inermis
A. pendens
A. rubroviolacea
A. sabacea
A. tomentosa
A. vacillans
Caralluma adensis
C. anemoniflora
C. arabica
C. chrysostephana
C. cicatricosa
C. commutata
C. flava
C. luntii
C. penicilliata
C. quadrangula
C. subulata
Ceropegia rupicola
Echidnopsis bentii
E. planiflora
E. scutellata
Euphorbia ammak
E. cactus
E. fruticosa
E. inarticulata
E. parciramulosa
Euphorbia tenuirama
E. tenuirama
Huernia macrocarpa var. *arabica*
Kalanchoe teretifolia
Opophytum forskhali
Rosularia hausskriechtil
R. lineata
R. parviflora
R. pertica
R. sempervivum
Sedum acre spp. *neglectum*
S. album
S. alpestre
S. bornmulleri
S. littoreum
S. lydium
S. microcarpum
S. obtusifolium
S. palaestinum
S. pilosum
S. sanguineum
S. tenuifolium
Sempervivum iranicum
Senecio anteuphorium var. *odorus*
S. pendulus
Suaeda fruticosa
Umbilicus intermedius
U. rupestris

Sudano–Deccanian Zone

Aloe perryi
A. tomentosa
A. vacillans
Caralluma adensis
C. anemoniflora
C. arabica
C. cicatricosa
C. penicilliata
C. quadrangula
C. socotrana
C. subulata
Cotyledon barleyi
Edithcolea sordida
Euphorbia arbuscula
E. fruticosa
E. inarticulata
E. parciramulosa
E. schimperi
E. spiralis
Kalanchoe abrupta
K. citrina
K. laciniata
K. robusta
K. rotundiflora
K. scapigera
Senecio anteuphorbium
S. pendulus

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2.3 SELECTION OF PLANTS ACCORDING TO SALINITY TOLERANCE

Reference: R. Firmin *Afforestation*, Report to the Government of Kuwait, FAO, Rome 1971

Electrical conductivity in micromhos	Plant species
50,000+	*Avicennia marina, Nitraria retusa, Prosopis juliflora* (Kuwait strain), *Suaeda vermiculata, Zygophyllum coccineum*
40,000	*Casuarina glauca, Conocarpus lanciformis, Phoenix dactylifera, Tamarix maris-mortui, T. pasterinoides*
35,000	*Atriplex nummularia, A. vesicaria, Juncus actutus, Prosopis stephaniana, P. tamarugo, Tamarix arvensis, T. deserti, T. dioica, T. florida, T. mannifera, T. meyeri, T. orientalis, T. pentandra*
30,000	*Acacia ligulata, Casuarina equisetifolia, Kochia indica, Phragmites communis, Prosopis juliflora, Tamarix aphylla, Zizyphus vulgaris*
25,000	*Acacia sowdenii, Tamarix nilotica,*
18,000	*Acacia pendula, A. salicina, Casuarina glauca, Eucalyptus camaldulensis, E. sargentii, E. spathulata, Nerium oleander, Parkinsonia aculeata*
16,000	*Acacia farnesiana, A. salicina, Callistemon lanceolatus, Casuarina cristata, C. stricta, Eucalyptus calcicultrix, E. camaldulensis var. obtusa, E. coolabah, E. microtheca, Prosopis chilensis, P. juliflora var. velutina*
14,000	*Acacia arabica, Albizzia chinensis, Casuarina lehmanii, Clerodendrum inerme, Eucalyptus pimpiniana, Haloxylon salicornicum, Sesbania grandiflora*
12,000	*Acacia stenophylla, Nassia latifolia, Callitris glauca, Dodonea viscosa, Eucalyptus kruseana, Melaleuca pauperifolia, Melia azederach, Punica granatum, Thevetia nereifolia*
10,000	*Albizzia lebbek, Butea monosperma, Eucalyptus annulata, E. brachycorys, E. cornuta, E. melliodora, E. occidentalis, E. stricklandi, Ficus carica, F. religiosa, Hakea laurina, Lagenaria pattersoni, Ricinus communis var. persicus, Salvadora oleoides, Thespesia populnea, Vitex agnus-castus*
8,500	*Caesalpinia gilliesii, Calligonum comosum, Casuarina cunninghamiana, Dalbergia sissoo, Dodnonea attenuata, Eucalyptus cladocalyx, E. forestiana, E. grossa, E. lansdowneana, E. largiflorens, E. Le Soueffi, E. robusta, E. salubris, E. spathulata, Inga dulcis, Terminalia arjuna*
8,000	*Brachychiton gregorii, Eucalyptus brockwayi, E. dundasi, E. intertexta, E. woodwardii, Ficus bengalensis, Myrtus communis, Prosopis spicigera, Schinus molle, Terminalia catappa*
6,000	*Acacia deani, A. saligna, Agonis flexuosa, Balanites aegyptiaca, Cupressus arizonica, Euclayptus oleosa, E. torquata, Grevillea robusta, Olea europea, Pritchardii filifera, Tamarindus indica, Tecoma stans*
5,000	*Cordia myxa, Cupressus sempervirens var. stricta, Elaeagnus angustifolia, Eucalyptus astringens, E. campaspe, E. longicornis, E. redunca, E. transcontinentalis, Lantana aculeata, Populus euphratica, Terminalia belerica.*
4,500	*Bombax malabaricum, Eucalyptus citriodora, Populus bolleana*
3,000	*Acacia tortilis, Albizzia julibrissim, Ficus sycomorus, Robinia pseudoacacia, Salix alba*
2,500	*Acacia cyanophylla, A. cyclopis, A. mellifera, A. raddiana, A. forestiana, A. gerradii*
2,000	*Eucalyptus tereticornis, Hypheane thebaica, Poinciana (Delonix) regia, Duranta plumieri, Populus oblega*
1,000	*Azalea* spp., *Bougainvillea* spp., *Populus euramerica, P. thevestina*

2.5 RELATIVE TOLERANCE OF PLANTS TO BORON

Reference: *Saline and Alkali Soils*, U.S. Salinity Lab., 1969

Tolerant	Semi-tolerant	Sensitive
Atnel (*Tamarix Aphylla*)	Sunflower (Native)	Pecan
Asparagus	Potato	Black walnut
Palm (*Phoenix canariensis*)	Acala cotton	Persian (English) walnut
Date palm (*P. dactylifera*)	Pima cotton	Jerusalem artichoke
Sugar beet	Tomato	Navy bean
Mangel	Sweetpea	American elm
Garden beet	Radish	Plum
Alfalfa	Field pea	Pear
Gladiolus	Ragged Robin rose	Apple
Broadbean	Olive	Grape (Sultanina and Malaga)
Onion	Barley	Kadota fig
Turnip	Wheat	Persimmon
Cabbage	Corn	Cherry
Lettuce	Milo	Peach
Carrot	Oat	Apricot
	Zinnia	Thornless blackberry
	Pumpkin	Orange
	Bell pepper	Avacoado
	Sweet potato	Grapefruit
	Lima bean	Lemon

(In each group the plants first named are considered as being more tolerant and the last named more sensitive.)

Natural distribution of species included in FAO/IBPGR trials in arid/semi-arid lands

(Source: FAO/IBPGR, 1980)

Species	Distribution
Acacia albida Del.	Senegal, Gambia, Portuguese Guinea, Sierra Leone, Liberia, Ivory Coast, Ghana, Togo, Dahomey, Nigeria and Cameroon, extending north throughout the drier parts of North Africa into Egypt, Israel, Lebanon and Cyprus, and from East Africa (Tanzania, Kenya, Uganda), to Zambia, Transvaal and Natal.
Acacia nilotica (L.)Willd.ex Del.	(including 3 varieties) extends from tropical and sub-tropical West Africa (Senegal, Gambia, Ivory Coast, Ghana, Togo, Dahomey, Nigeria, Cameroon) East Africa (Tanzania, Kenya, Uganda), and North Africa (the Sahel, Egypt) through eastern Sudan and Arabia as far eastwards as India.
Acacia senegal (L.) Willd.	(including 2 varieties), characteristic of the drier parts of Somalia, Ethiopia, the Sudan and Chad through to Mauritania, extending west to Senegal, Gambia, Ivory Coast, Ghana, Togo, Dahomey, Nigeria and Cameroon, east to Tanzania, Kenya and Uganda.
Prosopis cineraria (L.) Druce (syn. *P. spicigera* L.)	India, Pakistan, Iran, Arabian peninsula.
Prosopis alba Gris.	(including one variety), extends from the plains of subtropical Argentina to Uruguay, Paraguay, southern Bolivia and Peru.
Prosopis chilensis (Molina) Stuntz	(including 2 varieties), from Peru and Bolivia to Central Chile and north-western Argentina.
Prosopis juliflora (Swartz) DC	(including 2 varieties), from the coastal regions of Venezuela, Colombia and Panama, through Central America to Mexico, as well as in the Antillean Islands (perhaps introduced).
Prosopis nigra (Gris.) Hieronymus	(including 2 varieties), occurs in southern Bolivia, the Gran Chaco of Argentina, Paraguay and western Uruguay.
Prosopis tamarugo F. Philippi	arid mesetas in the northern provinces of Chile
Eucalyptus camaldulensis Dehnh.	a large part of inland Australia, with great climatic and genetic variation.
Eucalyptus microtheca F.Muell.	a large part of central and northern Australia with a separated occurrence on the west coast.
Acacia aneura F. Muell.	inland arid Australia.
Azadirachta indica Juss.	Burma, India (Siwalik Hills; Karnatic region; parts of the Deccan, south of the river Godavari).

NOTE:- A limited number of additional species within the same distribution areas as the above could be considered for the presently proposed phase of the Project, e.g. *Acacia tortilis*.

ALPHABETISCHE LISTE DER BOTANISCHEN NAMEN UND SYNONYMA

LEITNAMEN	SYNONYMA	
	Acacia adansonii Guill. et Perrott.	= A. nilotica var. adansonii
	Acacia adstringens (Schum. et Thonn.) Berhaut	= A. nilotica var. adansonii
ACACIA ALBIDA DEL.		
	Acacia arabica (Lam.)Willd.	= A. nilotica var. tomentosa
	Acacia arabica Willd.	= A. nilotica var. adansonii
	Acacia arabica var. adansoniana Dubard	= A. nilotica var. adansonii
	Acacia arabica var. adstringens (Schum. et Thonn.) Bak	= A. nilotica var. adansonii
	Acacia arabica (Lam.) Willd. var. nilotica (L.) Benth.	= A. nilotica var. nilotica
	Acacia arabica Willd. var. tomentosa (Benth.)	= A. nilotica var. tomentosa
ACACIA ATAXACANTHA DC.		
	Acacia buchanani Harms	= A. macrothyrsa
	Acacia caffra Willd. var. campylacantha Aubrev.	= A. polyacantha var. campylacantha
	Acacia campylacantha Hochst. ex A.Rich.	= A. polyacantha var. campylacantha
	Acacia catechu Willd. var. campylacantha (Hochst. ex A.Rich.) Roberty	= A. polyacantha var. campylacantha
	Acacia catechu Oliv.	= A. polyacantha var. campylacantha
	Acacia dalzielliii Craib	= A. macrothyrsa
ACACIA DUDGEONI CRAIB EX HOLL.		
ACACIA EHRENBERGIANA HAYNE		
	Acacia fasciculata Guill. et Perrott.	= A. raddiana
	Acacia flava (Forsk.) Schweinf.	= A. ehrenbergiana
	Acacia glauca Moench	= Leucaena leucocephala
ACACIA GOURMAENSIS A.CHEV.		
	Acacia gyrocarpa Hochst.	= A. albida
	Acacia hockii De Wild.	= A. seyal
ACACIA LAETA R. BR. EX BENTH.		
	Acacia lebbeck (L.) Willd.	= Albizia lebbeck
	Acacia leucocephala	= A. albida
ACACIA MACROSTACHYA REICHENB. EX BENTH.		
ACACIA MACROTHYRSA HARMS		
ACACIA MELLIFERA (VAHL) BENTH.		
	Acacia nefasia Schweinf.	= A. sieberiana
	Acacia nilotica var. adansoniana (Dubard) A.F. Hill	= A. nilotica var. adansonii
ACACIA NILOTICA VAR. ADANSONII (GUILL. ET PERROTT.) O. KTZE.		
	Acacia nilotica var. adstringens (Schum. et. Thonn.) Chiov.	= A. nilotica var. adansonii
ACACIA NILOTICA (L.) WILLD. EX DEL. VAR. NILOTICA		
ACACIA NILOTICA VAR. TOMENTOSA (BENTH.) A.F. HILL		
ACACIA PENNATA (L.) WILLD.		
ACACIA POLYACANTHA WILLD. VAR. CAMPYLACANTHA (HOCHST. EX A.RICH.) BRENAN		
	Acacia pseudopinnata Stapf	= A. macrothyrsa
ACACIA RADDIANA SAVI		
	Acacia rupestris Stokes	= A. senegal
	Acacia saccharata Benth.	= A. albida
	Acacia samoryana A. Chev.	= A. dudgeoni
	Acacia scorpioides (L.) W.F.Wight var. nilotica (L.) A. Chev.	= A. nilotica var. nilotica
	Acacia scorpioides (L.) W.F.Wight var. pubescens A.Chev.	= A. nilotica var. tomentosa
ACACIA SENEGAL (L.) WILLD.		
	Acacia senegal (L.) Willd. ssp. mellifera (Vahl) Roberty	= A. mellifera
ACACIA SEYAL DEL.		
ACACIA SIEBERIANA DC.		
	Acacia singuinea Guill. et Perrott.	= A. sieberiana
	Acacia stenocarpa Hochst. ex A. Rich.	= A. seyal
	Acacia suma Benth.	= A. polyacantha var. campylacantha
	Acacia tortilis (Forsk.) Hayne ssp. raddiana (Savi) Brenan	= A. raddiana

LEITNAMEN	SYNONYMA	
	Acacia tortilis Hayne	= A. raddiana
	Acacia tortilis Hayne var. pubescens A. Chev.	= A. raddiana
	Acacia trentinieni A. Chev.	= A. laeta
	Acacia trispinosa Stokes	= A. senegal
	Acacia verek Guill. et Perrott.	= A. senegal
	Acacia verugera Schweinf.	= A. sieberiana
ADANSONIA DIGITATA L.		
	Adansonia sphaerocarpa A. Chev.	= A. digitata
	Adenium arabicum Balf. f.	= A. obesum
	Adenium castaneum Stapf	= A. obesum
	Adenium honghel A. DC.	= A. obesum
ADENIUM OBESUM (FORSK.) ROEM. ET SCHULT.		
	Agialida barteri Van Tiegh.	= Balanites aegyptiaca
	Agialida senegalensis Van Tiegh.	= Balanites aegyptiaca
	Agialida tombouctensis Van Tiegh.	= Balanites aegyptiaca
ALBIZIA CHEVALIERI HARMS		
ALBIZIA LEBBECK (L.) BENTH.		
ANACARDIUM OCCIDENTALE L.		
	Annona chrysophylla Boj.	= A. senegalensis
ANNONA SENEGALENSIS PERS.		
	Annona senegalensis var. chrysophylla (Boj.) R. Sillans	= A. senegalensis
	Annona senegalensis var. latifolia Oliv.	= A. senegalensis
ANOGEISSUS LEIOCARPUS (DC.) GUILL. ET PERROTT.		
	Anogeissus leiocarpus var. schimperi (Hochst. ex Hutch. et Dal.) Aubrév.	= A. leiocarpus
	Anogeissus schimperi Hochst. ex Hutch. et Dalz.	= A. leiocarpus
	Antelaea azadirachta (L.) Adelbert	= Azadirachta indica
AZADIRACHTA INDICA A. JUSS.		
BALANITES AEGYPTIACA (L.) DEL.		
	Balanites ziziphoides Mildbr. et Schlechter	= B. aegyptiaca
	Balsamodendron africanum Arn.	= Commiphora africana
	Bassia parkii G. Don.	= Butyrospermum parkii
	Bauhinia abyssinica Rich.	= Piliostigma thonningii
	Bauhinia adansoniana Guill. et Perrott.	= B. rufescens
	Bauhinia benzoin Kotschy	= Piliostigma reticulatum
	Bauhinia glabra A. Chev.	= Piliostigma reticulatum
	Bauhinia glauca A. Chev.	= Piliostigma reticulatum
	Bauhinia pyrrhocarpa Hochst.	= Piliostigma thonningii
	Bauhinia reticulata DC.	= Piliostigma reticulatum
BAUHINIA RUFESCENS LAM.		
	Bauhinia thonningii Schum.	= Piliostigma thonningii
	Bombax andrieui Pellegr. et Vuillet	= B. costatum
	Bombax buonopozense P. Beauv.	= B. costatum
BOMBAX COSTATUM PELLEGR. ET VUILLET		
	Bombax houardii Pellegr. et Vuillet	= B. costatum
	Bombax vuilletii Pellegr.	= B. costatum
BORASSUS AETHIOPUM MART.		
	Borassus flabellifer L. var. aethiopum Warb.	= B. aethiopum
BOSCIA ANGUSTIFOLIA A. RICH.		
	Boscia octandra Hochst. ex Radlk.	= B. senegalensis
	Boscia patens Sprague et M.L. Green	= B. angustifolia
	Boscia powellii Sprague et M.L. Green	= B. salicifolia
BOSCIA SALICIFOLIA OLIV.		
BOSCIA SENEGALENSIS (PERS.) LAM. EX POIR.		
	Boscia tenuifolia A. Chev.	= B. angustifolia
	Brehmia spinosa (Lam.) Harv. ex DC.	= Strychnos spinosa
	Brehmia spinosa ssp. lokua (A.Rich.) E.A. Bruce	= Strychnos spinosa

LEITNAMEN	SYNONYMA	
LANNEA ACIDA A. RICH.		
	Lannea djalonica A. Chev.	= L. microcarpa
LANNEA MICROCARPA ENGL. ET K. KRAUSE		
LEPTADENIA PYROTECHNICA (FORSK.) DECNE.		
	Leptadenia spartium Wight	= L. pyrotechnica
	Leucaena glauca (Moench) Benth.	= L. leucocephala
LEUCAENA LEUCOCEPHALA (LAM.) DE WIT.		
	Leucaena salvadorensis Standley	= L. leucocephala
MAERUA ANGOLENSIS DC.		
MAERUA CRASSIFOLIA FORSK.		
	Maerua rigida R.Br.	= M. crassifolia
	Maerua senegalensis R.Br.	= M. crassifolia
MANGIFERA INDICA L.		
MAYTENUS SENEGALENSIS (LAM.) EXELL		
	Melia azadirachta L.	= Azadirachta indica
	Melia indica Brandis	= Azadirachta indica
	Mimosa adstringens	= Acacia nilotica var. andansonii
	Mimosa arabica Lam.	= Acacia nilotica
	Mimosa asperata L.	= M. pigra
	Mimosa biglobosa Jacq.	= Parkia biglobosa
	Mimosa cinerea L.	= Dichrostachys cinerea
	Mimosa glauca L.	= Leucaena leucocephala
	Mimosa glomerata Forsk.	= Dichrostachys cinerea
	Mimosa juliflora Swartz.	= Prosopis juliflora
	Mimosa lebbeck L.	= Albizia lebbeck
	Mimosa leucocephala Lam.	= Leucaena leucocephala
	Mimosa mellifera Vahl	= Acacia mellifera
	Mimosa nilotica L.	= Acacia nilotica
	Mimosa nutans Pers.	= Dichrostachys cinerea
	Mimosa pennata L.	= Acacia pennata
MIMOSA PIGRA L.		
	Mimosa scorpioides L.	= Acacia nilotica
	Mimosa senegal L.	= Acacia senegal
	Mitragyna africana (Willd.) Korth	= M. inermis
MITRAGYNA INERMIS (WILLD.) O. KTZE.		
MORINGA OLEIFERA LAM.		
	Moringa pterygosperma Gaertn.	= M. oleifera
	Nauclea africana Willd.	= Mitragyna inermis
	Nerium obesum Forsk.	= Adenium obesum
	Odina acida (A.Rich.) Oliv.	= Lannea acida
PARKIA BIGLOBOSA (JACQ.) BENTH.		
PARKINSONIA ACULEATA L.		
PHOENIX DACTYLIFERA L.		
	Phyllanthus virosus Roxb. ex Willd.	= Securinega virosa
PILIOSTIGMA RETICULATUM (DC.) HOCHST.		
PILIOSTIGMA THONNINGII (SCHUM.) MILNE-REDH.		
	Piliostigma rufescens (Lam.) Benth.	= Bauhinia rufescens
	Podoria senegalensis (Pers.) Lam. ex Poir	= Boscia senegalensis
	Poupartia birrea (A.Rich.) Aubr.	= Sclerocarya birrea
PROSOPIS AFRICANA (GUILL., PERROTT. ET RICH.) TAUB.		
	Prosopis chilensis	siehe Prosopis juliflora
	Prosopis dubia Guill. et Perrott.	= Acacia sieberiana
	Prosopis glandulosa U.A.	siehe Prosopis juliflora
PROSOPIS JULIFLORA (SW.) DC.		
	Prosopis lanceolata Benth.	= P. africana
	Prosopis oblonga Benth.	= P. africana
	Prosopis velutina	siehe P. juliflora
	Pterocarpus abbyssinicus Hochst.	= P. lucens
	Pterocarpus angolensis DC.	= P. erinaceus
	Pterocarpus echinatus DC.	= P. erinaceus

LEITNAMEN	SYNONYMA	
PTEROCARPUS ERINACEUS POIR.		
PTEROCARPUS LUCENS LEPR. EX GUILL. ET PERROTT.		
	Pterocarpus lucens var. simplicifolius (Bak.) A. Chev.	= P. lucens
	Pterocarpus simplicifolius Bak.	= P. lucens
SALVADORA PERSICA L.		
SCLEROCARYA BIRREA (A.RICH.) HOCHST.		
SECURIDACA LONGEPEDUNCULATA FRESEN		
	Securidaca pallida Klotzsch	= S. longepedunculata
	Securidaca spinosa Sim.	= S. longepedunculata
SECURINEGA VIROSA (ROXB. EX WILLD.) BAILL.		
	Securinega microcarpa (Blume) Pax et Hoffm.	= S. virosa
	Sodada decidua Forsk.	= Capparis decidua
	Spondias birrea A. Rich.	= Sclerocarya birrea
	Sterculia cinerea A. Rich.	= S. setigera
STERCULIA SETIGERA DEL.		
	Sterculia tomentosa Guill. et Perrott.	= S. setigera
	Stereospermum dentatum A. Rich.	= S. kunthianum
STEREOSPERMUM KUNTHIANUM CHAM.		
	Strychnos buettneri Gilg.	= S. spinosa
	Strychnos djalonis A. Chev.	= S. spinosa
	Strychnos courtti Chev.	= S. spinosa
	Strychnos emarginata Bak.	= S. spinosa
	Strychnos dulcis Chev.	= S. spinosa
	Strychnos gracillima Gilg.	= S. spinosa
	Strychnos luxa Solered.	= S. spinosa
	Strychnos lokua A. Rich.	= S. spinosa
STRYCHNOS SPINOSA LAM.		
	Strychnos spinosa var. pubescens Bak.	= S. spinosa
	Strychnos volkensi Gilg.	= S. spinosa
	Swietenia senegalensis Desr.	= Khaya senegalensis
	Sycomorus gnaphalocarpa Miq.	= Ficus gnaphalocarpa
TAMARINDUS INDICA L.		
TAMARIX SENEGALENSIS DC.		
	Terminalia adamauensis Engl.	
TERMINALIA AVICENNIOIDES GUILL. ET PERROTT.		
	Terminalia chevalieri Diels	= T. macroptera
	Terminalia dawei Rolfe	= T. macroptera
	Terminalia dictyoneura Diels	= T. avicennioides
	Terminalia elliotii Engl. et Diels	= T. macroptera
	Terminalia lecardii Engl. et Diels	= T. avicennioides
TERMINALIA MACROPTERA GUILL. ET PERROTT.		
	Terminalia suberosa Chev.	= T. macroptera
	Uncaria inermis Willd.	= Mitragyna inermis
	Urostigma dekdekena Miq.	= Ficus iteophylla
	Urostigma ingens Miq.	= Ficus ingens
	Urostigma vogelii Miq.	= Ficus vogelii
	Vinticena flavescens (Juss.) Burret	= Grewia flavescens
	Vitellaria paradoxa Gaertn.	= Butyrospermum parkii
	Vitex chariensis Chev.	= V. doniana
	Vitex cienkowski Kotschy et Peyr.	= V. doniana
	Vitex cuneata Schum. et Thonn.	= V. doniana
VITEX DIVERSIFOLIA BAK.		
VITEX DONIANA SWEET		
	Vitex paludosa Vatke	= V. doniana
	Vitex simplycifolia Oliv.	= V. diversifolia
	Vitex umbrosa G. Don ex Sabine	= V. doniana
XIMENIA AMERICANA L.		
	Ximenia aegyptiaca L.	= Balanites aegyptiaca
	Ziziphus amphibia A. Chev.	= Z. spina-christi
	Ziziphus jujuba (L.) Lam.	= Z. mauritiana
ZIZIPHUS MAURITIANA LAM.		
	Ziziphus mitis A.Rich.	= Z. mucronata
ZIZIPHUS MUCRONATA WILLD.		
	Ziziphus orthacantha DC.	= Z. mauritiana
ZIZIPHUS SPINA-CHRISTI (L.) DESF.		

Species under trial for plantations in dry tropical Africa

Source: Delwaulle (1979)

(* = not promising)

Eucalyptus alba (and hybrids)
E. camaldulensis (and hybrids)
E. citriodora
E. crebra
E. microtheca
E. paniculata
E. saligna
E. sideroxylon
E. tereticornis
E. tesselaris
E. torreliana

Euphorbia balsamifera
E. kamerunica
E. tirucalli

Faidherbia albida

Ficus spp.

* Funtumia elastica

* Gleditsia triacanthos

Gmelina arborea

Grevillea pyramidalis
* G. refracta

Guaiacum officinale

Guiera senegalensis

Gyrostemon spp.

* Hakea spp.

Holarrhena spp.

* Hura crepitans

* Hyphaene thebaica

Isoberlinia doka

Jacaranda acutifolia

Jatropha curcas

Khaya senegalensis

* Lamarkea acheifolia

Lawsonia inermis

Leucaena leucocephala

Lonchocarpus sericeus

Markhamia tomentosa

Melaleuca spp.

Melia azedarach
* M. dubia

* Milletia laurentii

Mimosa pigra

Mitragyna inermis

Moringa oleifera

Nauclea diderichii

Nerium oleander

* *Opuntia ficus indica*

* *Parinari macrophylla*

Parkia africana
P. filicoides

Parkinsonia aculeata

* *Peltophorum ferrugineum*

* *Petalostylis labicheoides*

Piliostigma monandra
* *P. reticulatum*

Pinus caribaea
* *P. halepensis*
* *P. pinaster*
* *P. pinea*

Pithecellobium dulce

* *Populus* spp.

Prosopis africana
P. chilensis
P. cineraria
P. tamarugo

* *Pterocarpus erinaceus*

Ptilotus exaltatus

Ricinodendron heudelotii

Robinia pseudoacacia

Salvadora persica

Samanea saman

Schinus molle
* S. terebinthifolius

Sclerocarya birrea

* *Simmondsia chinensis*

Spondias monbin

Sterculia tomentosa
* *S. urens*

Stylobasium spatulatum

Sweetia panamensis

Tamarindus indica

Tamarix spp.

Tecoma stans

Tectona grandis

Terminalia arjuna
* *T. carpentariae*
* *T. catappa*
T. ivorensis
T. mantaly
T. superba

Thevetia peruviana

* *Thuja orientalis*

* *Vitex doniana*

* *Ximenia americana*

* *Ziziphus mauritiana*
* *Z. mucronata*

Species recommended for arid zones by Goor and Barney(1976)

Abies cilicica

Acacia cyanophylla

Acacia tortilis
Acer negundo
Ailanthus altissima
Alnus orientalis
Araucaria excelsa
Aspidosperma quebracho-blanco
Azadirachta indica
Bulnesia retamo
Calligonum comosum

Casuarina equisetifolia
Casuarina glauca
Cedrus libani
Celtis australis
Ceratonia siliqua

Crataegus azarolus
Cupressus sempervirens
Dalbergia sissoo

Elaeagnus angustifolia

Eucalyptus camaldulensis

Ficus sycomorus
Fraxinus syriaca
Gleditsia triacanthos
Grevillea robusta
- *Haloxylon ammodendron*
Juglans regia

Juniperus excelsa
Melia azedarach

Morus alba
Parkinsonia aculeata
Pinus brutia
Pinus canariensis
Pinus halepensis
Pinus nigra

Pinus pinaster
Pinus pinea

Pistacia atlantica
Platanus orientalis

× *Populus euramericana*
Prosopis juliflora
Prosopis spicigera

Quercus suber
Rhus coriaria

Robinia pseudoacacia
Salix spp.
Schinopsis lorentzii

Schinus molle

Tamarix articulata
Taxodium distichum
Tetraclinis articulata
Ulmus pumila
Zizyphus spina-christi

Tropical tree legumes of special significance as fuelwood

From Brewbaker *et al.* (1981)

Genus	Species adapted to:	
	Humid tropics	Arid tropics
Acacia	auriculiformis, mearnsii*	brachystegia, cambagei, cyclops, nilotica, saligna, senegal, seyal, tortilis
Albizia	--	lebbek
Calliandra	calothyrsus	--
Cassia	--	siamea
Derris	indica	--
Gliricidia	sepium	--
Inga	vera*	--
Leucaena	leucocephala	--
Mimosa	scabrella	--
Pithecellobium	--	dulce
Prosopis	--	alba, chilensis, cineraria, juliflora**, pallida, tamarugo
Sesbania	grandiflora	--

* Highland-adapted species

** Mesquite is widely considered an undesirable thorny pest

(a) Firewood species described in NAS (1980)

(b) Master list of firewood species prior to selection of 60 species for NAS (1980)

The following species received the highest rating in replies to the inquiry sent to several hundred plant scientists and foresters before the panel met to write this report. Species chosen by the panel for inclusion in the report are marked with an asterisk.

Humid Tropics

Acacia auriculiformis*
A. aulacocarpa
A. crassicarpa
A. flava
A. koa
A. leucophloea
A. polyacantha
A. siamensis
A. tomentosa
Acrocarpus fraxinifolius
Adansonia digitata
Adina cordifolia
Afzelia africana
A. xylocarpa
Aglaia spp.
Albizia falcata
A. lebbek*
A. moluccana
A. odoratissima
A. procera
Aleurites moluccana
Alnus jorullensis*
Alstonia spp.
Anacardium occidentale
Anogeissus latifolia*
A. leiocarpus*
Anthocephalus cadamba
Antidesma ghaesembilla
Artocarpus spp.
Aspidosperma spp.
Astronium urundeuva
Aucoumea spp.
Avicennia spp.*
Azadirachta indica*
Bambusa spp.
Baphia kirkii
Bauhinia malabarica
B. tomentosa
Bischoffia javanica
Bocageopsis multiflora
Bombax spp.
Bruguiera spp.*
Caesalpinia sappan
Cajanus cajan*
Calliandra calothyrsus*
C. surinamensis
Callicarpa arborea
Caloncoba gilgiana
Cananga odorata
Capparis spp.
Carapa guineensis
Cariniana pyriformis
Casearia spp.
Cassia macrantha
C. siamea*
C. spectabilis*
Casuarina cunninghamiana*
C. equisetifolia*
C. lepidophloia*
C. nobile
Cecropia spp.
Cedrela spp.
Ceiba pentandra
Celtis spp.
Ceriops spp.
Chilopsis linearis
Chlorophora tinctoria
C. excelsa
Chloroxylon swietenia
Citrus spp.
Coccoloba sp.
Cocos nucifera
Coffea spp.
Combretum spp.
Conocarpus erectus
Cordia spp.
C. alliodora
Cratoxylon spp.
Crescentia cujete
Croton spp.
Cupressus lusitanica
Cynometra cauliflora
Daniella oliveri
Dendrocalamus strictus
Derris microphylla
Detarium senegalense
Dialium guineensis
D. ovoideum
Dichrostachys glomerata
Dillenia spp.
Diospyros spp.
Diphysa robinioides
Dinizia excelsa
Duabanga grandiflora
D. moluccana
Elateriospermum spp.
Enterolobium cyclocarpum
Erythrina spp.
Erythrophleum spp.
Eschweilera mexiana
Eucalpytus alba
E. botryoides
E. brassiana
E. camaldulensis*
E. citriodora*
E. cloeziana
E. deglupta
E. grandis*
E. microtheca*
E. moluccana
E. pellita
E. resinifera
E. robusta
E. saligna*
E. tereticornis*
E. torelliana
E. urophylla
Eugenia jambos
Ficus benghalensis
Garuga pinnata
Gliricidia maculata*
G. sepium*
Gmelina arborea*
Grevillea robusta*
Grewia spp.
Guatteria ferruginea
Guazuma ulmifolia*
Hcematoxylon campechianum
Hevea brasiliensis
Holoptelea integrifolia
Hymenocardia acida
Inga spp.
I. alba
I. edulis*
I. laurina
I. vera*
Inocarpus edulis
Intsia bijuga
Iryanthera hostmani
Khaya senegalensis
Kydia calycina
Laguncularia spp.

Lantana spp.
Leucaena leucocephala•
Libidibia corymbosa
Licania spp.
Lindackeria maynensis
Lumnitzera racemosa
Macaranga spp.
Machaerium nictitans
Madhuca latifolia
Malmea spp.
Mammea americana
Mangifera indica
Mangroves•
Melaleuca leucadendron
Melastoma spp.
Melia azedarach
M. composita
Michelia champaca
Moringa oleifera
Morus mesozygia
Muntingia calabura •
Murraya paniculata
Musanga cecropioides
Myristica spp.
Nauclea diderrichii
Nectandra spp.
Ocotea spp.
Octomeles sumatrana
Olea africana
Ouratea calophylla
Parinari excelsa
Parkia spp.
Parkinsonia aculeata•
Peltophorum pterocarpum
Pentaclethra macrophylla
Pentadesma butyracea
Persea spp.
Phyllanthus discoideus
Pinus caribaea
P. insularis
P. kesiya
P. merkusii
Piptadenia spp.
Pithecellobium dulce•
P. jiringa
P. lobatum
Platonia insignis
Pongamia glabra•
Populus euphratica
Pourouma spp.
Pseudosamanea guachapele
Psidium guajava
P. cattleianum
Pterocarpus erinaceus
P. indicus
Pterygota alata
Quercus spp.
Q. oocarpa
Q. penduncularis
Q. sapotaefolia·
Rhamnus spp.
Rhizophora apiculata
R. candelaria
R. mangle•
R. mucronata•
Salix humboldtiana
Salvadora persica
Samanea saman
Schleichera oleosa
Schizolobium parahyba
Securinega virosa
Serialbizzia splendens
Sesbania aegyptica
S. grandiflora•
Sterculia urens
Swartzia sp.
S. fistuloides
S. madagascariensis
Sweetia brachystachya
Swietenia macrophylla
S. mahogani
Symphonia globulifera
Syzygium cummii•
S. guineense
Tamarindus indica
Tamarix passerinoides
Tectona grandis
Terminalia spp.•
T. paniculata
T. tomentosa
Tetragastris altissima
Tetrameles nudiflora
Thespesia populnea
Trema guineensis•
T. micrantha•
T. orientalis•
other *Trema* spp.•
Trichilia hirta
Triplaris guayaquilensis
Triplochiton scleroxylon
Tristania obovata
Vitex spp.
Ximenia americana·
Xylia kerrii
Xylocarpus spp.
Zanthoxylum spp.
Z. xanthoxyloides
Zizyphus spp.
Z. thyrsiflora

Tropical Highlands

Acacia acuminata
A. baileyana
A. cavenia
A. dealbata•
A. decurrens•
A. elata
A. macracantha
A. mearnsii•
A. melanoxylon
A. pycnantha
A. visco
Acer negundo
A. obtusifolium
A. pseudoplatanus
Ailanthus glandulosa
Alnus formosana
A. glutinosa•
A. jorullensis•
A. nepalensis•
A. nitida
A. orientalis
A. rubra•
Altingia excelsa
Amorpha fruticosa
Aristotelia chilensis
Araucaria spp.
Aspidosperma quebracho-blanco
Baeckea frutescens
Bambusa sp.
Bauhinia retusa
Brachychiton populneum
Buddleia spp.
Callitris macleayana
Calycophyllum multiflorum
Carya spp.
Castanopsis spp.
C. acuminatissima
Casuarina cunninghamiana•
C. equisetifolia•
C. junghuhniana•
C. luehmannii•
Ceanothus spp.
Cedrela spp.
Cercocarpus
Cestrum spp.
Cinnamomum camphora
Citrus spp.
Coffea arabica
Commiphora spp.
Croton glabellus
Cupressus benthamii
C. cashmeriana
C. forbesii
C. goveniana
C. lusitanica
C. macnabiana
C. macrocarpa
C. sempervirens
C. torulosa
Dendrocalamus strictus
Didymopanax morototoni
Drimys winteri
Elaeagnus angustifolia
Escallonia spp.
Eucalyptus albens
E. bicostata•
E. blakelyi
E. botryoides
E. calophylla
E. camaldulensis•
E. citriodora•
E. cladocalyx
E. cloeziana
E. deanei
E. delegatensis
E. diversicolor
E. globulus•
E. gomphocephala•
E. grandis•
E. gummifera
E. largiflorens
E. leucoxylon
E. macarthuri•
E. maculata
E. maidenii•
E. melanoxylon
E. melliodora
E. microcorys
E. neglecta
E. nova-anglica
E. odorata
E. ovata
E. paniculata
E. resinifera
E. robusta
E. saligna•

321.

E. tereticornis
E. trabutii
*E. viminalis**
E. wandoo
Eugenia sp.
Ficus palmata
F. salicifolia
Fraxinus sp.
Gleditsia triacanthos
*Grevillea robusta**
Grewia spp.
Leptospermum spp.
Lespedeza bicolor
L. cyrtobotrya
L. maximowiczii
Ligustrum lucidum
Liquidambar formosana
L. styraciflua
Liriodendron tulipifera
Lithocarpus spp.
Maclura pomifera
Maytenus boaria
Melaleuca leucadendron
M. pubescens = M. preissiana
Melia azedarach
Nyssa aquatica
Olea africana
O. chrysophylla
O. cuspidata
O. europaea
Peumus boldus
Pinus canariensis
P. caribaea
P. elliottii
P. excelsa
P. kesiya
P. merkusii
P. nigra
P. oocarpa
P. pinea
P. pseudostrobus
P. radiata
P. rigida
Platanus occidentalis
P. orientalis
Podocarpus oleifolius
Polylepis spp.
P. tomentella
Populus balsamifera
P. betulifolia x *P. trichocarpa*
P. deltoides
P. grandidentata
P. nigra
P. tremuloides
Quercus sp.
Q. dilatata
Q. incana
Q. virginiana
Robinia pseudoacacia
Salix babylonica
S. caprea
S. humboldtiana
Schinopsis spp.
Schinus molle
Sophora japonica
Styrax sp.
Tecoma spp.
T. stans
Teusmanniodendron ahernianum
Tetraclinis articulata
*Trema orientalis**
Tipuana tipu
Trevoa trinervis
Ulmus pumila
U. wallichiana
Vernonia baccharoides
Wendlandia spp.

Arid and Semiarid Regions

Acacia spp.
A. acuminata
A. albida
A. aneura
*A. arabica**
*A. auriculiformis**
A. baileyana
*A. brachystachya**
A. caffra
*A. cambagei**
A. catechu
A. cibaria
A. concinna
*A. cyanophylla**
*A. cyclops**
A. dealbata
*A. decurrens**
A. drepanolobium
A. elata
A. excelsa
A. farnesiana
A. giraffae
A. greggii
A. harpophylla
A. heteracantha
A. heterophylla
A. hockii
*A. holosericea**
A. homalophylla
A. karroo
A. kempeana
A. lasiopetala
A. leenthamii
A. leucophloea
A. litakunensis
A. longifolia
A. macracantha
A. melanoxylon
A. modesta
*A. mollissima**
*A. nilotica**
A. nilotica subsp. *adansonii*
A. nilotica var. *tomentosa*
A. oswaldii
A. pallacantha
A. pendula
A. peuce
A. planifrons
A. polyacanthe subsp. *campylacantha*
A. pycnantha
*A. raddiana**
A. senegalensis
*A. seyal**
A. siamensis
A. tomentosa
*A. tortilis**
A. victoriae
*Albizia lebbek**
*Anogeissus leiocarpus**
*A. pendula**
Argania sideroxylon
Artemisia herba-alba
A. monosperma
A. scoparia
Aspidosperma quebracho-blanco
Atriplex bracteosa
A. canescens
A. leucoclada
*Azadirachta indica**
Balanites aegyptiaca
Bauhinia reticulata
B. thonningii
Bombacopsis quinata
Brasilettia mollis
Bunchosia armeniaca
Burkea africana
Caesalpinia paraguariensis
*Cajanus cajan**
Calliandra spp.
Calligonum comosum
Callistemon sp.
Carapa guineensis
Cassia garrettiana
*C. siamea**
C. sturtii
*Casuarina cristata**
*C. decaisneana**
*C. equisetifolia**
*C. glauca**
*C. stricta**
Cedrela odorata
Celtis integrifolia
C. spinosa
Ceratonia siliqua
Chloroxylon swietenia
*Colophospermum mopane**
Combretum ghasalense
C. glutinosum
Commiphora spp.
C. africana
Cordeauxia edulis
Cupressus arizonica
Cybistax donnell-smithii
Dalbergia sissoo
Diospyros spp.
Dodonaea viscosa
Erythrina senegalensis
Erythrophleum africanum
Eucalyptus alba
E. astringens
E. bicolor
E. blakelyi
E. brockwayi
E. calycogona
*E. camaldulensis**
E. cambageana
*E. citriodora**
E. crebra
E. flocktoniae
E. gardneri
E. glaucina
*E. gomphocephala**
E. gracilis
E. intertexta
E. melliodora
*E. microtheca**
*E. occidentalis**

E. oleosa
E. pilularis
E. platypus
E. populnea
E. pyriformis subsp. youngiana
E. robusta
E. rudis
E. salmonophloia
E. salubris
E. stricklandii
E. tereticornis*
E. tetrodonta
E. torquata
E. viminalis*
Ficus spp.
Geoffraea decorticans
Gleditsia triacanthos
Gmelina arborea*
Grevillea pterosperma
Hakea leucoptera
Haloxylon spp.
H. aphyllum*
H. persicum*
Heterotheca abaxillaris
Hyphaene thebaica
Inga feyillei
Isoberlinia dalzielii
I. doka
Jacaranda acutifolia
Juglans neotropica
Krugeodendron ferreum
Lannea coromandelica
L. schimperi
Leucodendron argenteum
Lophira lanceolata
Lucuma paradoxa
Lysiloma sabicu
Maerua cressefolia
Melaleuca leucadendron
Melia azedarach
Mitragyna africana
Monotes kerstingii
Morus nigra
Olea europaea
Olneya tesota
Parkia clappertoniana
Parkinsonia aculeata*
Pinus brutia*
P. canariensis
P. edulis
P. eldarica*
P. halepensis*
P. pinea
Pistacia lentiscus
P. palaestina
P. terebinthus
Pithecellobium dulce*
Popelhax macrantha
Prosopis africana
P. alba*
P. blanca
P. caldenia*
P. chilensis*
P. cineraria*
P. farcta*
P. ferox
P. glandulosa
P. inermis
P. juliflora*
P. nigra
P. pallida*
P. palmeri
P. pubescens
P. spicigera
P. stephaniana
P. tamarugo*
P. torquata
Prunus andersoni
Pterocarpus erinaceus
P. lucens
Quercus spp.
Q. coccifera
Q. farnetta
Q. pubescens
Retama raetam
Rhanterium epapposum
Salvadora persica
Schinus molle
Sclerocarya birrea
Sterculia setigera = S. tomentosa
Tamarix spp.*
T. aphylla*
T. articulata*
T. gallica
T. meyeri
T. passerinoides
T. stricta
Terminalia glaucescens*
T. tomentosa
Zizyphus abyssinica
Z. jujuba*
Z. mauritiana*
Z. nummularia*
Z. spina-christi*
Z. vulgaris

Some Australian species, other than eucalypts, with potential for fuelwood (and multiple-use) in humid tropics, tropical highlands and the sub-tropical arid/semi-arid regions.

Source: Boland and Turnbull (1981)

1. Humid tropics
   - *Acacia aulacocarpa*+
   - *A. auriculiformis*+
   - *A. bakeri*
   - *A. cincinnata*
   - *A. crassicarpa*
   - *A. hylonoma*
   - *A. mangium*+
   - *Acmena smithii*
   - *Agathis robusta*
   - *Ailanthus* spp.
   - *Albizia* spp.+
   - *Alphitonia petriei*+
   - *A. whitei*
   - *Alstonia muellerana*
   - *Argyrodendron* spp.
   - *Banksia dentata*+
   - *B. integrifolia*+
   - *Capparis* sp.
   - *Cardwellia sublimis*
   - *Casuarina equisetifolia*+
   - *Cassia* spp.+
   - *Commersonia bartramia*
   - *Celtis* sp.
   - *Croton* spp.
   - *Diospyros* spp.
   - *Elaeocarpus grandis*
   - *Euroschinus falcata*
   - *Macaranga tanarius*+
   - *M. subdentata*
   - *Pithecellobium* spp.+
   - *Pleiogynium timorense*
   - *Terminalia sericocarpa*
   - *Tieghemopanax murrayi*
   - *T. elegans*
   - *Trema orientalis*+
   - *Vitex* spp.

2. Tropical highlands
   - *Acacia dealbata*
   - *A. decurrens*
   - *A. mearnsii*
   - *Agathis* spp.
   - *Aleurites moluccana*
   - *Alphitonia excelsa*+
   - *A. petriei*
   - *Alstonia scholaris*+
   - *Araucaria bidwillii**
   - *Backhousia anisata*
   - *Callicoma serratifolia*
   - *Callistemon salignus*
   - *Callitris macleayana*
   - *Casuarina cunninghamiana*+
   - *C. glauca*
   - *C. torulosa*
   - *Choricarpa subargentea*
   - *Diploglottis australis**
   - *Flindersia bourjotiana*
   - *Grevillea robusta*
   - *G. hilliana*+
   - *G. pinnatifida*+
   - *Macadamia* spp.*
   - *Mallotus paniculatus*
   - *M. philippensis*
   - *M. ricinoides*
   - *Melaleuca leucadendron*
   - *Oreocallis wickhamii*+
   - *Orites excelsa*+
   - *Syncarpia glomulifera*
   - *Trema orientalis*
   - *Tristania conferta*
   - *T. laurina*
   - *T. neriifolia*
   - *Xanthostemon* spp.

3. Arid/semi-arid sub-tropical regions
   - *Acacia aneura***
   - *A. brachystachya*
   - *A. cambagei*
   - *A. cyclops*
   - *A. estrophiolata***+
   - *A. fasciculifera*
   - *A. holosericea*
   - *A. plectocarpa*
   - *A. polystachya*+
   - *A. shirleyi*
   - *A. tumida*
   - *Alphitonia excelsa*+
   - *A. philippense*
   - *Alstonia actinophylla*
   - *A. constricta*
   - *Atalaya hemiglauca*
   - *Brachychiton populneus***
   - *B. gregorii***
   - *Callitris* spp.
   - *Casuarina cristata*
   - *C. luehmannii*
   - *Codonocarpus* spp.
   - *Dodonaea viscosa*
   - *Erythrina vespertilio*
   - *Erythrophleum chlorostachys*
   - *Flindersia maculosa*
   - *Grevillea parallela*+
   - *Grevillea striata***+
   - *G. pteridifolia*
   - *Hakea leucoptera*
   - *H. suberea***+
   - *Lysiphyllum cunninghamii*
   - *Melaleuca viridiflora*
   - *Melia azedarach*
   - *Parinari nonda**
   - *Syzygium suborbiculare**
   - *Terminalia platyphylla*
   - *T. volucris*
   - *Tristania suaveolens*
   - *T. grandiflora*

* fruit, ** fodder, + high priority species for seed collection and testing overseas.

Species for tropical plantations (included in Webb et al. (1979) and to be included in second edition, mid-1983)

Acacia albida
Acacia auriculiformis
Acacia cyanophylla
Acacia cyclops
Acacia decurrens
Acacia farnesiana
Acacia mangium
Acacia mearnsii
Acacia melanoxylon
Acacia nilotica
Acacia pendula
Acacia salicina
Acacia senegal
Acacia tortilis
Acrocarpus fraxinifolius
Agathis dammara
Albizia falcataria
Albizia lebbek
Alnus acuminata
Alnus nepalensis
Alnus rubra
Anacardium occidentale
Anthocephalus chinensis
Araucaria angustifolia
Araucaria cunninghamii
Araucaria hunsteinii
Aucoumea klaineana
Azadirachta indica
Bombacopsis quinata
Brachychiton populneum
Butyrospermum paradoxum
Calliandra calothyrsus
Callitris glauca
Callitris columellaris
Campnosperma brevipetiolata
Cariniaria pyriformis
Cassia siamea
Casuarina decaisneana
Casuarina equisetifolia
Casuarina glauca
Casuarina junghuhniana
Cedrela odorata
Ceratonia siliqua
Chlorophora excelsa
Cleistopholis glauca
Colophospermum mopane
Conocarpus lancifolius
Cordia alliodora
Cryptomeria japonica
Cunninghamia lanceolata
Cupressus arizonica
Cupressus lusitanica (including C. benthamii)
Cupressus macrocarpa
Cupressus torulosa
Dalbergia sissoo
Delonix regia

Elaeagnus augustifolia
Eucalyptus botryoides
Eucalyptus brockwayi
Eucalyptus camaldulensis (Northern Provenances)
Eucalyptus camaldulensis (Southern Provenances)
Eucalyptus citriodora
Eucalyptus cladocalyx
Eucalyptus cloeziana
Eucalyptus crebra (Inland Provenances)
Eucalyptus dalrympleana
Eucalyptus deglupta
Eucalyptus delegatensis
Eucalyptus fastigata
Eucalyptus globulus
Eucalyptus globulus subsp. maidenii
Eucalyptus gomphocephala
Eucalyptus grandis
Eucalyptus intertexta
Eucalyptus largiflorens
Eucalyptus maculata
Eucalyptus melliodora
Eucalyptus microcorys
Eucalyptus microtheca
Eucalyptus ritens
Eucalyptus obliqua
Eucalyptus occidentalis
Eucalyptus paniculata
Eucalyptus pellita
Eucalyptus propinqua
Eucalyptus regnans
Eucalyptus resinifera
Eucalyptus robusta
Eucalyptus st. johnii
Eucalyptus saligna
Eucalyptus salmonophloia
Eucalyptus sargentii
Eucalyptus sideroxylon (Inland Victoria Provenances)
Eucalyptus tereticornis (Queensland and New Guinea Provenances)
Eucalyptus torelliana
Eucalyptus urophylla
Eucalyptus viminalis
Euphorbia tirucalli
Ficus benghalensis
Gleditsia triacanthos
Gliricidia sepium
Gmelina arborea
Grevillea robusta
Haloxylon aphyllum
Jacaranda copaia — Hieronyma chocoensis
Jacaranda mimosifolia
Khaya senegalensis
Leucaena leucocephala (Hawaiian type)
Leucaena leucocephala (Salvador type)
Liquidambar styraciflua
Maesopsis eminii
Melaleuca leucadendron
Musanga cecropioides
Nauclea diderrichii

Ochroma pyramidale
Octomeles sumatrana
Parkia biglobosa
Parkinsonia aculeata
Paulownia tomentosa
Peltophorum pterocarpum
Pericopsis elata
Pinus ayacahuite
Pinus brutia
Pinus canariensis
Pinus caribaea var. bahamensis
Pinus caribaea var. caribaea
Pinus caribaea var. hondurensis
Pinus chiapensis
Pinus elliottii var. elliottii
Pinus greggii
Pinus halepensis
Pinus kesiya
Pinus merkusiana (Continental Provenances)
Pinus merkusii (Island Provenances)
Pinus michoacana
Pinus montezumae
Pinus occidentalis
Pinus oocarpa
Pinus palustris
Pinus patula subsp. patula
Pinus patula var. tecumumanii
Pinus pinaster (Portuguese Provenances)
Pinus pinea
Pinus ponderosa var. arizonica
Pinus pseudostrobus
Pinus radiata
Pinus roxburghii
Pinus taeda
Populus deltoides var. deltoides
Prosopis chilensis
Prosopis cineraria
Prosopis juliflora
Prosopis tamarugo
Robinia pseudoacacia
Roseodendron donnell-smithii
Salix babylonica var. sacramenta
Samanea saman
Schinus molle
Schizolobium parahybum
Sesbania grandiflora
Simmondsia chinensis
Swietenia macrophylla
Tabebuia rosea
Tamarix aphylla
Taxodium distichum
Tectona grandis
Terminalia brassii
Terminalia calamansanai
Terminalia ivorensis
Terminalia superba
Toona ciliata var. australis
Triplochiton scleroxylon
Zizyphus spina-christi

Trees and bamboos for integrated landuse systems in Malawi

(Source: Personal communication, I.D. Edwards, Forestry Research Institute of Malawi)

Acacia
A. albida
A. polycantha
Acrocarpus fraxinifolius
Adina microcephala
Afzelia quanzensis
Albizia
A. amara
A. glaberrima
A. gummifera
A. lebbekk
A. versicolor
Amblygonocarpus andongonsis
Azadirachta indica
Bambusa vulgaris
Bauhinia petersiana
Bauhinia thonnigii
Borassus aethiopum
Brachystegia
B. floribunda
Burkea africana
Caesalpinia decapetala
Cassia siamea
Cassia spectabilis
Cinchona sp.
Colophospermum mopane
Combretum
C. imberbe
C. ternifolium
Cordyla africana
Cupressus lusitanica
Dalbergia sissoo
Diplorhynchus condylocarpon
Entada abyssinica
Erythrina abyssinica
Eucalyptus spp.
Euphorbia turicalli
Gliricidia sepium
Gmelina arborea
Grevillea robusta
Hardwickia binata
Hyphaene Spp.
Idermitis
Julbernardia paniculata
Kigelia africana
Kirkia acuminata
Leucaena leucocephala
Lonchocarpus cappassa
Maesopsis eminii
Markhamia obtusifolia
Melia azedarach
Monotes africanus
Morus spp.
Oxythenanthera abyssinica
Parinari curatifolia
Parkia filicoidea
Pericopsis angolensis
Pinus spp.
Pseudolachnostylis mapronueifolia
Pterocarpus angolensis
Pterocarpus rotundifolius
Sclerocarya caffra
Solanum aculeastrum
Strychnos innocua
Strychnos spinosa
Terminalia sericea
Toona ciliata
Uapaca kirkiana
Ziziphus mauritiana

East Pokot agricultural project: tree planting summary 1978-1982

(Personal communication, E. Barrow)[1]

Species	Comments	Species	Comments[2]
°Acacia albida*		Zizyphus mauritiana*	1,3,6
°Acacia tortilis*	2,3,4	Zizyphus mucronata	
°Acacia senegal*	2,3,6	Ceiba pentandra	
Acacia cyanophylla	1,3,4	°Balanites aegyptiaca*	2,3,4,5
Acacia halosericea**	1,3,4	°Balanaites orbicularis	
Acacia aneura	2,3,4	Leucaena leucocephala K8*	1,4,5
Acacia salicana	2,3,4	°Adansonia digitata	1,3,4
°Acacia eliator*	2,3,5	Ceratonia siliqua	2,3
Acacia victoria		Bauhinea purpurea	
°Acacia mellifera*	2,3,6	°Tamarindus indica*	2,3,4
Eucalyptus camaldulensis	1,3,5	Erythrina rotunda	
Eucaluptus citriodora		°Salvadora perssa	
Eucalyptus microtheca	1,5	Atriplex nummularia	1,3,4
Eucalyptus wandoo		Atriplex halimus	
Eucalyptus astringens		Simmondsia chinesis	
Eucalyptus torquata		Casuarina equisetifolia	1,5
Eucalyptus fernestina		Schinus molle	
Eucalayptus torquata		Stylosanthes scabra	
woodwardii		Conocarpus lancifolius	
Prosopis cineraria		Moringa stenopecla	
Prosopis juliflora		°Delonix elata*	
(Baobab Farm, Mombasa)	1,3,4,5	°Diospyros scabra	
Prosopis juliflora		Bombax spp	
(Israel,Ben Gurion)	1,3,4,5	Guava	
Prosopis chilensis*	1,3,4,5	Cashew	
Prosopis pallida	1,3,4,5	Mango, Orange, Pawpaw	
Cassia sturtii*	2,3,4		
Cassia siamea*	1,3,7		
Cassia spectabilis			
Parkinsonia aculeta	1,3,7		
Azadirachta indica			

° = indigenous * = lots of seed available ** = some seed available.

[1] E. Barrow, East Pokot Agricultural Project, Kositei, Nginyang, P.O. Marigat, Nakum, Kenya.

[2] No comment = not worth commenting on!

Comments Code

1.....Fast growing
2.....Slow growing
3.....Drought resistant
4.....Fodder
5.....Timber and fuel
6.....Live fencing
7.....Shade

List of Indigenous Species for Kenya

(Source: Owino, 1983)

LEGUMINOSAE

Acacia albida
Acacia abyssinica
Acacia adenocalyx
Acacia brevispica
Acacia clavigera
Acacia etbaica
Acacia lahai
Acacia mellifera
Acacia nilotica
Acacia polyacantha
Acacia recifiens
Acacia senegal
Acacia seyal
Acacia tortilis
Acacia xanthophloea
Albizia anthelmintica
Albizia coriaria
Albizia grandibracteata
Albizia gummifera
Albizia zygia
Enteda abyssinica
Mimosa pigra
Newtonia buchanani
Newtonia paucijuga
Parkia filicoidea
Adenocarpus mannii
Cordyla africana
Craibia brownii
Dalbergia melanoxylon
Dalbergia microcarpa
Erythrina abyssinica
Erythrina burtii
Erythrina excelsa
Indigofera arrecta
Lonchocarpus bussei
Milletia dura
Milletia usambarensis
Mundulea sericea
Ormocorpum kirkii
Sesbania sesban
Tephrosia elata
Tamarindus indica
Trachylobium verrucosum
Julbernardia magnistipulata
Erythrophleum guineense
Cynometra webberi
Delonix elata
Cassia petersiana
Brachystegia spiciformis
Bauhinia tomentosa
Afzelia quanzensis
Acacia gerrardii
Acacia kirkii
Crotelaria laburnifolia
Piliostigma thonningii

MULTI-PURPOSE SPECIES

Adansonia digitata
Anacardium occidentale
Balanites aegyptiaca
Borassus aethiopium
Casuarina equisetifolia
Chlorophora excelsa
Chrysophyllum albidum
Commiphora africana
Commiphora trothae
Cordia abyssinica
Cordia milleni
Euphorbia tirucelli
Ficus sycomorus
Markhamia hildebrandtii
Markhamia platycalyx
Markhamia zanzibarica
Morinfa oleifera
Terminalia catappa
Trema guineensis

Seed available from National Academy of Sciences for Sahel trials

	Species	Common Name	Supplier	Number	Origin	Comments
Field Crops						
*1.	Amaranthus cruentus	Grain Amaranth	Rodale Research Center	R104	Mexico	Mexican grain-type amaranth. High-protein grain, protein-rich leaves; fast growing; daylength neutral.
*2.	Amaranthus hypochondriacus	Grain Amaranth	Rodale Research Center	R103	Mexico	Mercado grain-type amaranth. High-protein grain, protein-rich leaves; fast growing.
3.	Phaseolus acutifolius	Tepary Bean	Meals for Millions		Sells, Arizona	Drought-tolerant crop.
4.	Psophocarpus tetragonolobus	Winged Bean	University of Florida	Tpt-1		Edible seeds, pods, leaves, and roots; edible seed oil; livestock feed; relatively high water requirements.
5.	Tylosema esculentum	Morama Bean	Southwest Texas State University		Kalahari desert	Edible tuber and seeds, oil, browse; drought tolerant.
6.	Zea mays		University of Florida		Southern Arizona	Currently out of stock.
Trees and Shrubs						
7.	Acacia albida	Apple-ring Acacia	ISRA/CNRF, Senegal	82/598	Nayobe region, Senegal	Comes into leaf at the end of the rainy season and remains green during the dry season. Soil conservation, livestock feed, tannin, easily carved wood.

* New Accessions

8.	A. aneura	Mulga	CSIRO, Australia	12791	New South Wales, Australia	Currently out of stock.
*9.	A. berlandieri	Huajillo	Texas Department of Health		McMullen County, Texas	Browse, honey production, fuel.
10.	A. cambagei	Gidgee	CSIRO, Australia	13485	Queensland, Australia	Currently out of stock
11.	A. farnesiana	Sweet Acacia	CSIRO, Australia	11147	New South Wales, Australia	Wood for fuel and posts, tannin, gum for making mucilage, fodder, living fences.
12.	A. ligulata	Umbrella Bush	CSIRO, Australia	13425	Northern Territory, Australia	Currently out of stock.
13.	A. linarioides		CSIRO, Australia	11506	Western Australia	Soil conservation.
14.	A. nilotica var. adansonii	Egyptian Thorn	ISRA/CNRF, Senegal	81/443	Bomdia area, Senegal	Fuel, construction, fodder, tannin, gum.
15.	A. nilotica var. tomentosa		ISRA/CNRF, Senegal	82/597	Mayobe region, Senegal	Fuel, living fences and windbreaks, fodder tannin, gum.
16.	A. raddiana	Umbrella Thorn	ISRA/CNRF, Senegal	82/599	Mayobe region, Senegal	Fuel, construction, fodder, sand control.
17.	A. salicina	Cooba	CSIRO, Australia	13379	Western Australia	Fuel, soil conservation.
18.	A. senegal	Gum Arabic	ISRA/CNRF, Senegal	82/593	Northern Ferlo, Senegal	Fuel, construction, gum arabic, fodder, soil conservation, edible seeds.
19.	A. tumida		CSIRO, Australia	11496	Western Australia	Currently out of stock.
20.	A. victoriae	Prickly Wattle	CSIRO, Australia	13271	Queensland, Australia	Currently out of stock.
21.	Adansonia digitata	Baobab	ISRA/CNRF, Senegal	82/603	Bandia, Senegal	Food, bark used to make mats and paper.
22.	Anogeissus leiocarpus		ISRA/CNRF, Senegal	82/571	Boulel, Senegal	Fence posts, construction and wood-working, ashes, yield potash.

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23.	*Argania spinosa*	Argan Tree	Forest Service, Morocco	77307	Tamanar, Morocco	Oil, construction, charcoal, fruit and foliage eaten by cattle and goats.
24.	*Atriplex canescens*	Four-Wing Saltbush	Texas Tech University		Western, Texas	Browse, ground cover.
25.	*A. nummularia*	Old-man Saltbush	Western Australia Dept. of Agriculture	Acc WA-/1981	Western Australia	Browse, ground cover.
26.	*Balanites aegyptiaca*	Desert Date	ISRA/CNRF, Senegal	82/602	Louga region, Senegal	Construction, edible fruit, browse; emulsion from the fruit is lethal to the snails which are intermediary hosts of schistosomiasis and to the water flea that carries the Guinea-worm disease, is used to poison fish.
27.	*Centrosema* sp.	Centro	CSIRO, Australia	65967	Progreso, Equador	Currently out of stock.
28.	*C. brasilianum*		CSIRO, Australia	55696	Petrolina, Brazil	Browse shrub.
29.	*C. pascuorum*		CSIRO, Australia	55697	Petrolina, Brazil	Browse shrub.
30.	*Conocarpus lancifolius*	Damas	Baobab Farm, Kenya		Mombasa, Kenya	Construction, charcoal, fodder.
31.	*Cordeauxia edulis*	Ye-eb	Baobab Farm, Kenya		Mombasa, Kenya	Currently out of stock.
32.	*Desmanthus virgatus*		CSIRO, Australia	65947	Salinas, Equador	Currently out of stock.
33.	*Eucalyptus brockwayi*	Dundas Mahogany	CSIRO, Australia	12266	Western Australia	Sawlogs, posts, firewood.
34.	*E. camaldulensis*	River Red Gum	CSIRO, Australia	12184	Northern Territory, Australia	Coppices well; posts, poles, piles, fuel, honey production.
35.	*E. camaldulensis*	River Red Gum	CSIRO, Australia	12346	Western Australia	Same as above.
36.	*E. camaldulensis*	River Red Gum	CSIRO, Australia	13476	Queensland, Australia	Same as above.

37.	E. intertexta	Inland Red Box	CSIRO, Australia	11736	New South Wales, Australia	Fuel, shelterbelts.
38.	E. melanophloia	Silver-Leaved Ironbark	CSIRO, Australia	13158	Queensland, Australia	Fuel, honey production.
39.	E. microtheca	Flooded Box	CSIRO, Australia	12846	Queensland, Australia	Fuel, poles and posts, conservation.
40.	E. microtheca	Flooded Box	CSIRO, Australia	13360	Western Australia	Same as above.
41.	E. occidentalis	Flat-Topped Yate	CSIRO, Australia	9806	Western Australia	Fuelwood, timber, shade.
42.	E. oleosa var. oleosa	Narrow-Leaved Giant Mallee	CSIRO, Australia	12310	South Australia	Construction, fuel, essential oil, honey.
43.	E. terminalis		CSIRO, Australia	11966	Queensland, Australia	Fuelwood, honey.
44.	E. tessellaris	Carbeen	CSIRO, Australia	12967	Queensland, Australia	Fuelwood, honey production.
45.	E. torquata	Coral-Flowered Gum	CSIRO, Australia	10106	Western Australia	Ornamental plantings, honey production.
*46.	Geoffroea decorticans		SACOR, CHILE	BE-7463	Chilean coastal desert	Multiple use.
47.	Leucaena leucocephala	Leucaena	University of Hawaii	K6		Currently out of stock.
48.	L. leucocephala	Leucaena	University of Hawaii	K8	Zacatecas, Mexico	Fuelwood, forage, construction, soil improvement.
49.	L. leucocephala	Leucaena	University of Hawaii	K30	Merida, Mexico	Fuelwood, forage, soil conservation.
50.	L. leucocephala	Leucaena	University of Hawaii	K67	Santa Cruz Porillo, Salvador	Same as above.
51.	L. leucocephala	Leucaena	University of Hawaii	K500	Australia	"Cunningham" forage cultivar.
52.	Macroptilium atropurpureum	Siratro	CSIRO, Australia	85002	Cabo San Lucas, Mexico	Currently out of stock.
53.	M. atropurpureum	Siratro	CSIRO, Australia	Siratro		Browse shrub.

54.	M. martii		CSIRO, Australia	49780	Bahia, Brazil	Browse shrub.
55.	M. martii		CSIRO, Australia	55783	Petrolina, Brazil	Currently out of stock.
56.	Mitragyna inermis		ISRA/CNRF, Senegal	82/604	Bandia, Senegal	Firewood, medicine, fish baskets.
57.	Parkinsonia aculeata	Horse-Bean Tree	ISRA/CNRF, Senegal	80/258	Bandia, Senegal	Fuel, erosion control, fodder.
58.	Phaseolus filiformis		CSIRO, Australia	85005	La Paz, Mexico	Currently out of stock.
59.	Prosopis sp.		University of California, Riverside	PC 004		Currently out of stock.
60.	Prosopis sp.		University of California, Riverside	PC 005		Currently out of stock.
61.	P. africana		ISRA/CNRF, Senegal	106	Keur-Mactar, Senegal	Charcoal, tannin, construction
62.	P. alba	Algarrobo Blanco	Texas A&I University	0166	Argentina (?)	Fuel, timber, fodder, food, amenity planting.
63.	P. alba	Algarrobo Blanco	Texas A&I University	0388	Argentina (?)	Same as above.
64.	P. alba	Algarrobo Blanco	University of California, Riverside	JO 053	Argentina	Currently out of stock.
65.	P. glandulosa	Honey Mesquite	University of Arizona	A	Yuma, Arizona	Currently out of stock.
66.	P. glandulosa	Honey Mesquite	University of Arizona	B	Yuma, Arizona	Currently out of stock.
67.	P. glandulosa var. glandulosa	Honey Mesquite	University of California	PC 032	Santa Ana, Mexico	Currently out of stock.
*68.	P. glandulosa var. glandulosa	Honey Mesquite	Texas Department of Health		Southern Texas	Browse, food for human consumption, fuel, posts, honey production.
69.	P. juliflora	Mesquite	ISRA/CNRF, Senegal	79/194		Fuelwood, construction, fodder, food for human consumption, gum, honey.

Uses, local names, and location of some species in Malaysia

Species	Present/suggested uses	Local name	Location
Bambusa arundinacea	—	—	Penang, Singapore Botanic Gardens
B. blumeana	—	Buloh duri	Penang, Selangor (Kepong), Pahang (Pekan)
B. burmanica	—	Buloh aloh bukit	Kedah, Alor Star, Singapore
B. glaucescens	Picket fences, garden stakes, trellises, baskets, ornamental and hedge plants [a]	Buloh pagar	Originally from Japan and China
B. heterostachya	—	Buloh tilan/minyak/pering/pengat	Perak, N. Sembilan, Melaka, Johore, Singapore
B. klossii	—	—	Kedah, Perak (1000 m)
B. magica	—	Buloh perindu	Pahang, Cameron Highland, Selangor, Ulu Semangkok
B. montana	—	—	Penang Hill, Kedah
B. pauciflora	—	Buloh padi	Pahang, Fraser Hill
B. ridleyi	—	Buloh akar	Pahang, Singapore
B. spinosa	Building purposes, baskets, mats, hats [a]	—	—
B. ventricosa	—	—	Originally from China
B. vulgaris	Furniture, paper, pulp, shoots, landscaping [a,b]	Buloh minyak aao/aro/beting/pan	All over Malaysia
B. wrayi	—	Buloh sumpitan	Perak-Gunong Inas (1500-2000 m)
Dendrocalamus asper	Laminated trays, plywood, veneer, bridges, fences, water vessels, racks, tables, chairs, cages, fish traps, shoots [a,b]	Buloh beting	Cultivated for shoots all over; Peninsular Malaysia
D. dumosus	—	—	Kedah (Baling Hill), Langkawi
D. elegans	—	—	Kedah, Pulau Langkawi, Penang
D. giganteus	—	Buloh betong	Originally from Burma
D. hirtellus	—	Buloh kapur	Johore, Perak (Taiping), Kedah, Kelantan
D. pendulus	Basket making	—	Perak, Selangor, N. Sembilan
D. sinuatus	—	Buloh akar	Perak, N. Sembilan, Trengganu, Pahang
D. strictus	—	—	Originally from India
Dinochloa scandens	Rope making [b]	Buloh akar	Perak
Gigantochloa sp.	Structures [b]	—	—
G. apus	—	—	Selangor (Serdang), Singapore Botanic Gardens
G. hasskarliana	—	—	Penang, Singapore
G. latifolia	—	Buloh pahit	Kedah, Perak, Pahang
G. levis	—	Buloh bisa	Selangor, Melaka, Johore, Singapore
G. ligulata	—	Buloh tikus/bilalai	Perlis, Kedah, Perak, Pahang, Selangor, Kelantan
G. maxima	—	—	Selangor (Serdang)
var. *viridis*	—	—	Johore; Kota Tinggi
var. *minor*	—	—	FRI, Kepong
var. *ridlei*	—	—	Province Wellesley, Singapore Botanic Gardens
G. scortechinii		Buloh semantan, telur/rayah/Pa-aao/gala/seremai	Kedah, Penang, Perak, Selangor, N. Sembilan, Kelantan, Pahang
G. wrayi	—	Buloh beti	Kedah, Pahang, Province Wellesley, Perak, Selangor
Schizostachyum aciculare	Handicrafts	Buloh padi/akar	Johore, Selangor, N. Sembilan, Melaka
S. brachycladum	—	Buloh nipis/lemang/padi/urat/rusa/pelang	Kedah, Penang, Perak, Pahang, Johore
S. gracile	—	Buloh rapen/akar	Johore: Selat Teberau, Kota Tinggi, Segamat, Sg. Sedili; Melaka: Bukit Tungal, Air Panas Selangor: Sungai Labu; Pahang: Kuala Bera, Pekan
S. grande	Rims for large baskets [b]	Buloh semeling/semenyeh	Kedah: Grik; Perak: Cameron Highland; Pahang: Kuala Lipis, Kelantan, Selangor
S. insulare	—	—	Pulau Langkawi, Kedah, Penang, Johore
S. jaculans	Wind instruments, handicrafts [a]	Buloh sumpitan/temiang/kerap/tikus	Pahang, Selangor, Melaka, Johore, Singapore, Perak
S. longispiculatum	—	—	In all states except Perlis, Kedah, P. Pinang, Trengganu, Province Wellesley
S. terminale	—	—	Kedah: Inchong Estate, Sg. Kenan
S. zollingeri	Handicrafts, baskets, traps, hats, woven wares, rafts, floors, walls, partitions, cooking vessels [a]	Buloh telor/pelang nipis/dinding/kasap/lemang/aur	Perak, Selangor, N. Sembilan, Pahang, Johore

[a] Kiang Tao and Lin Wei-Chin (196).
[b] Holttum, R.E. (166).

Species and uses of bamboos in Asia
(Source: Lessard and Chouinard, 1980)

Species of bamboos and their uses in Indonesia. Table 8n.2

Species	Building material	Smokehouses for tobacco	Baskets	Furniture	Handicraft	Fishing tool	Firewood	Water pipe	Traditional customs	Edible shoot	Musical instrument	Paper industry	Medicine	Ornamental plant
…rundinaria japonica	•						•			•				•
…mbusa arundinacea	•		•				•			•		•		
atra	•		•				•						•	•
blumeana						•	•			•				
glaucescens	•				•		•							•
polymorpha							•			•				
vulgaris	•			•	•		•			•			•	•
…ndrocalamus asper	•		•	•	•	•	•	•		•	•			
…inochloa scandens					•		•							
…gantochloa opus	•	•	•	•	•	•	•	•	•		•			
atter	•		•	•	•	•	•	•		•	•			
aff. atter	•		•	•	•		•	•		•	•			
verticillata	•		•	•	•		•	•		•	•			
…stus elegantissimus	•	•												
…yllostachys aurea					•									
nigra														•
…hizostachyum blumei	•	•			•	•	•			•	•			•
brachycladum	•	•	•	•	•	•	•			•	•			
caudatum	•								•					
lima	•				•	•	•			•	•			
zollingeri	•		•	•	•	•	•	•		•				
…yrsostachys siamensis							•							

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Table 8n.3

. Consumption (%) of bamboos in the Asia-Pacific Region by end-use and a breakdown of the uses by species (country codes in the breakdown are India, In: Bangladesh, Ba; Burma, Bu; Philippines, Ph; Indonesia, Ind; Thailand, Th; Japan, Ja; Taiwan, Tai; Korea, Ko).

Country	Construction		Rural uses	Packaging	Pulp manufacture	Other uses
	Housing	Others				
Bangladesh	50	10	20	5	10	5
Burma	33	32	32	5	-	1
India	16	16	30	7	17	14
Japan	24	7	18	7	4	41
Philippines	80	-	15	2	-	3
Thailand	33	20	6	-	8	33

Walling of native huts
Bambusa tulda (Bu, Bu, Ind)
B. polymorpha (Bu)
B. blumeana (Ph)
B. atra (Ind)
Dendrocalamus asper (Ind)
Gigantochloa nigrociliata (Ind)
Melocanna baccifera (Ba)
Neohouzeoua dulloa (Bu, Ba)
Sinobambusa elegans (In)
Schizostachyum lumampao (Ph)
Thyrsostachys siamensis (Ph)
T. oliveri (Th)

Lance staves
Bambusa blumeana (Ph)
Dendrocalamus strictus (In, Bu)
Ochlandra travancorica (In)
O. scriptorica (In)
Schizostachyum lima (Ind)
Thyrsostachys siamensis (Th)
T. oliveri (Th)

Thatching and roofing
Bambusa arundinacea (In, Ba, Bu, Ind)
B. tulda (In, Ba, Bu)
B. vulgaris (Ind)
B. blumeana (Ph)
B. polymorpha (In, Bu, Ba)
Dendrocalamus strictus (In, Ind)
D. longispathus (Ba, Bu)
D. membranaceus
D. brandisi
D. hamiltonii
Gigantochloa atter (Ind)
Chimonobambusa falcata (In)
Melocanna baccifera (Ba, Bu)
Neohouzeoua dulloa (Ba, Bu)
Oxytenanthera monodelpha (In)
Schizostachyum brachycladum (Ind)

Tea estates
Pseudostachyum polymorphum (In)

Constructions
Bambusa polymorpha (In, Ba, Bu, Ind, Th)
B. balcoa (In)
B. tulda (In, Ba, Bu, Ind)
B. arundinacea (In, Ba, Ind, Th)
B. nutans (In, Bu, Th)
B. khasiana (In)
B. vulgaris (In, Ba, Ph, Ind)
B. burmanica (Ba)
B. pallida (Bu)
B. blumeana (Ph, In)
B. atra (Ind)
Cephalostachyum pergracile (In, Ba, Bu)
Dendrocalamus membranaceus (In, Ba, Bu)
D. hamiltonii (In, Ba, Th, Bu)
D. giganteus (In, Ba, Ind, Bu)
D. longispathus (In, Ba, Th)
D. strictus (In, Bu)
D. calostachyus (Bu)
D. merrillianus (Ph)
D. asper (Ind)
Gigantochloa nigrociliata (In, Ind)
G. verticillata (Bu, Ind)
G. levis (Ph)
Melocanna baccifera (In, Ba, Bu)
Neohouzeoua dulloa (In, Bu)
Oxytenanthera nigrociliata (Ba, Bu)
Schizostachyum lumampao (Ph)
S. brachycladum (Ind)
S. lima (Ind)
Teinostachyum beddomei (In)
Thyrsostachys oliveri
Phyllostachys sp. (Ja, Tai, Ko)

Walking sticks
Arundinaria armata (In)
Dendrocalamus strictus (In, Bu)
Oxytenanthera nigrociliata (Ba, Bu)
Phyllostachys manni

(continued)

Table 8n.3 continued

Basket making
Arundinaria intermedia (In)
Bambusa nutans (In, Bu)
B. pallida (In, Th)
B. khasiana (In)
B. arundinacea (In, Bu, Ind, Th)
B. tulda (Ba, Bu, Ind, Th)
B. vulgaris (Ba, Bu, Ph, Ind)
B. villulosa (Bu)
B. flexuosa (Th)
B. polymorpha (Ba, Ind, Th)
B. blumeana (Ph, Ind)
Chimonobambusa falcata (In)
Cephalostachyum pergracile (Ba, Bu)
Dendrocalamus hamiltonii (In, Bu)
D. longispathus (In, Ba, Bu, Th)
D. strictus (In, Bu)
D. giganteus (In, Ba, Ind)
D. merrillianus (Ph)
D. asper (Ind, Th)
Dinochloa compactiflorus (Bu)
Gigantochloa nigrociliata (In, Bu)
G. macrostachya (Bu)
Indocalamus wightiana (In)
Melocanna baccifera (Ba, Bu)
Neohouzeoua helferi (In)
N. dulloa (Bu)
Oxytenanthera ritcheyi (In)
O. nigrociliata (Ba, Bu)
O. monostigma (Bu)
Pseudostachyum polymorphum (Bu)
Schizostachyum diffusum (Ph)
S. lumampao (Ph)
Thamnocalamus spathiflora (In)
Teinostachyum helferi (Bu)
T. griffithii (Bu)
Phyllostachys sp. (Ja, Ko, Tai)

Loading vessels
Neohouzeoua dulloa (In)
Teinostachyum dulloa

Bows and arrows
Bambusa flexuosa (Th)
B. arundinacea (In)
Cephalostachyum capitatum (In)
C. pergracile
Dendrocalamus strictus (In)
Schizostachyum rogersii (Bu)
S. lima (Ind)

Cooking utensils
Bambusa arundinacea (Ind, Ba, Bu, Th)
B. blumeana (Ph)
Cephalpstachyum pergracile (In, Ba, Bu, Th)
Gigantochloa atter (Ind)
Neohouzeoua dulloa
Schizostachyum zollingeri.

Mats
Arundinaria intermedia (In)
Bambusa nutans (In, Bu)
B. teres (In, Bu)
B. tulda (In, Ba, Bu, Ind, Th)
B. pallida (In, Ba, Th)
B. arundinacea (In, Ba, Bu, Ind, Th)
B. blumeana (Ph, In)
Cephalostachyum pergracile (In, Ba, Bu)
Dendrocalamus strictus (In)
D. hamiltonii (In, Ba, Bu, Th)
D. merrillianus (Ph)
D. membranaceus (Th)
D. brandisi (Th)
Dinochloa distans (Bu)
Gigantochloa levis (Ph)
G. atter (Ind)
G. macrostachya (Bu)
G. apus (Ind)
Indocalamus wightiana (In)
Melocanna baccifera (Ba)
Pseudostachyum polymorphum (Bu)
Schizostachyum lumampao (Ph)
Teinostachyum dulloa (In, Bu)
Thyrsostachys siamensis (Th)

Water and milk vessels (*Chunga*); water buckets; cups; containers
Bambusa pallida (In, Ba)
B. tulda (Ba, Bu)
B. blumeana (Ph)
Dendrocalamus sikkimensis (In)
D. giganteus (In, Ba, Bu, Ind, Th)
D. hookeri (In, Bu)
D. brandisi (Bu)
D. asper (Ind)
D. hamiltonii (Th)
Gigantochloa levis (Ph)
G. asper (Ph)
Melocanna baccifera (Ba, Bu)

Hedges
Bambusa nana (In, Ba, Bu, Th)
B. vulgaris (Ba, Ind)
B. balcoa (Ba, Ind)
B. arundinacea (Bu)
Cephalostachyum pergracile (Bu)
Cephalostachyum burmanicum (Bu)
Dendrocalamus giganteus (In, Ba, Bu, Ind, Th)
Gigantochloa atter (Ind)
G. nigrociliata (Ind)
Oxytenanthera nigrociliata (Ba)
Thyrsostachys siamensis

Fuel
All bamboos and rhizomes of bamboos (In, Ba, Bu, Ind)

(continued)

Table 8n.3 continued

Seed food
Bambusa arundinacea (In, Ba, Bu)
Cephalostachyum pergracile (In, Ba, Bu)
Dendrocalamus strictus (In)
Dinochloa compactiflora (Bu)
Melocanna baccifera (Ba, Bu)
Thyrsostachys oliveri (Ba, Bu)

Furniture
Bambusa tulda (Ba, Bu)
B. glaucescens (Ind)
B. vulgaris (Ind)
B. arundinacea (Th)
Dendrocalamus strictus (In, Ba, Bu)
D. membranaceus (Th)
D. brandisi (Th)
D. latiflorus
D. longispathus (Th)
D. asper (Th)
Gigantochloa atter (Ind)
G. apus (Ind)
Melocanna baccifera (Ba, Bu)
Schizostachyum diffusum (Ph)
Thyrosostachys siamensis (Ind, Th)
All thick-walled species (Ph, Ind)
Phyllostachys sp. (Ja, Ko, Tai)

Agricultural implements
Bambusa vulgaris (Ba, Bu, Ind, Ph)
B. balcoa (Ba, Bu, Ind)
B. blumeana (Ph, Th)
B. flexuosa (Th)
Dendrocalamus strictus (In, Bu, Th)
D. merrillianus (Ph)
D. asper (Th)
Ochlandra travancorica (In)
Thyrsostachys siamensis (Th)
T. oliveri (Th)
All thinner varieties (In, Ba, Bu)

Fodder
Arundinaria racemosa (In)
Chimonobambusa densifolia (In)
Cephalostachyum pergracile (In)
Dendrocalamus strictus (In)
D. sikkimensis (In)
Leaves of all bamboos (Ba, Bu, Ind)

Floats for timber; rafts
Bambusa arundinacea (In, Bu, Th)
B. blumeana (Ph, Ind)
Dendrocalamus hamiltonii (In, Bu)
D. longispathus (Ba)
D. distans
D. asper (Ind)
D. membranaceus (Th)
Ochlandra scriptoria (In)
Melocanna baccifera (Ba, Bu)
M. compactiflorus (Th)
Neohouzeaua dullooa (Ba)

Tool handles
Bambusa blumeana (Ph, Th)
B. flexuosa (Th)
B. polymorpha (Ba, Bu, Ind)
Dendrocalamus asper
D. strictus (In, Th)
D. merrillianus (Ph)
Ochlandra travancorica (In)
Teinostachyum griffithii (Ba, Bu)
Thyrsostachys siamensis (Th)
Solid varieties (Ind)

Fencing
Indocalamus wightianus (In, Ba, Bu, Ind, Ph, Th)
All bamboos (In, Ph, Ba, Bu, Ind, Th, Ja, Ko, Tai)

Hookah pipes
Chimonobambusa falcata (In)
Phyllostachys sedan (Bu)
Thamnocalamus spathiflora (In)
T. aristatus
Teinostachyum griffithii

Fishing rods
Arundinaria amabilis (In)
Bambusa glaucescens (Ind)
B. atra (Ind)
Chimonobambusa falcata (In)
C. khasiana (In)
C. intermedia (In)
Dendrocalamus strictus (In)
Schizostachyum zollingeri (Ind)
S. blumei (Ind)
S. lima (Ph)
Thyrsostachys siamensis (Th, Ind)
T. oliveri (Th)
Phyllostachys nigra (Ja)

Shoots for food
Bambusa tulda (In, Ba, Bu, Ph, Ind)
B. arundinacea (In, Ba, Bu, Ind)
B. nana (Bu)
B. vulgaris (Bu, Ph, Ind)
B. blumeana (Ph)
B. glaucescens (Ind)
Dendrocalamus hamiltonii (Ba, Bu)
D. latiflorus (Tai)
D. giganteus (In, Ind)
D. longispathus (Ba)
D. flagellifer (Bu)
D. merrillianus (Ph)
D. asper (Ind, Th)
Dinochloa scandens (Ind)
Gigantochloa nigrociliata (Ind)
G. hasskarliana (Ind)
G. verticillata (Bu, Ind)
G. levis (Ph)

(continued)

Table 8a.3 continued

G. atter (Ind)
G. albociliata (Th)
Phyllostachys edulis (Ta, Ja, Ko)
Schizostachyum brachycladum (Ind)
S. blumei (Ind)
S. zollingeri (Ind)
Sinobambusa elegans (In)
Thyrsostachys siamensis (Th)
All large bamboos — shoots (Th)
General utility
Bambusa arundinacea (In, Ba, Bu)
B. tulda (Bu)
B. pallida (Bu)
B. blumeana (Ph)
B. vulgaris (Ph)
Cephalostachyum pergracile
C. burmanicum
Dendrocalamus strictus (In, Bu)
D. hookeri (In, Bu)
D. hamiltonii (Ba)
D. calostachyus (Bu)
D. merrillianus (Ph)
Dinochloa sp. (Ph)
Gigantochloa levis (Ph)
G. asper (Ph)
Neohouzeaua dullooa
All strong bamboos (Ind, Th, Ja, Ko, Tai)
Punting poles
Oxytenanthera stocksii (In)
Solid varieties (Ba, Bu)
Phyllostachys nigra (Ja)
Sericultural industry — trays for silkworms
Bambusa arundinacea (In)
Dendrocalamus strictus (In)
Thyrsostachys siamensis (Th)
All bamboos (Ba, Ind)
Chicks for doors and windows
Bambusa arundinacea (In, Bu, Ind, Th)
B. polymorpha (Ba, Bu)
B. blumeana (Ph, Ind)
B. vulgaris (Ind)
Dendrocalamus strictus (In)
D. longispathus (Th)
D. membranaceus (Th)
Melocanna bambusoides
Neohouzeaua dullooa (Ba, P...
Schizostachyum lumampao (Th)
S. zollingeri (Ind)
Thyrsostachys siamensis (Th)
T. oliveri (Th)
All bamboos (Ta, Ko, Tai)
Pipes
Bambusa arundinacea (Bu)
Neohouzeaua dullooa (Bu)
Teinostachyum griffithii (In, Ba)

Haystack stabilizers
Bambusa vulgaris (Ba, Bu)
B. tulda (Ba, Bu)
B. blumeana (Ph)
Dendrocalamus strictus (In)
All bamboos can be used (Ind)
Horticultural pursuits
Bambusa arundinacea (In, Bu)
B. polymorpha (Ba)
B. blumeana (Ph)
Dendrocalamus strictus (In)
Melocanna baccifera (Ba, Bu)
All bamboos (Ind, Th)
Other strong species (Ph)
Cremation; coffins
Bambusa arundinacea (In)
Dendrocalamus strictus (In)
All bamboos
Cradles
Bambusa arundinacea (In)
Dendrocalamus strictus (In)
Scaffolding
Bambusa arundinacea (In)
Dendrocalamus strictus (In)
Cart yokes
All large-sized, hard and solid bamboos (In)
Ladders
Bambusa arundinacea (In)
Dendrocalamus strictus (In)
Musical instruments (flutes; marimba; horns; clarinets; flageolets; saxophones; piccolos; drums; etc.)
Arundinaria sp.
Arundinaria mitskayamensis (Ph)
Dendrocalamus strictus (In, Th)
D. longispathus (Th)
Gigantochloa atter (Ind)
Schizostachyum lima (Ind)
S. blumei (Ind)
All small-sized bamboos (Ph)
Containers for cleaning grains
All bamboos (In)
Protection during grain pounding
Bambusa arundinacea
All large-sized bamboos (In)
Cart sheds; roofs
Bambusa blumeana (Ph)
Dendrocalamus merrillianus (Ph)
All bamboos (In)
Stakes for foresters
Thyrsostachys siamensis (Th)
T. oliveri (Th)
All bamboos (In)

(continued)

Table 8a.3 continued

Country ties
Bambusa arundinacea (In)
Pan trays
Neohouzeaua dalloa (In)
Teinostachyum dalloa (Bu)
Seed drills
Dendrocalamus strictus
Containers to administer medicine to animals
Bambusa arundinacea (In)
Fishing implements; floats; pens; traps
Bambusa polymorpha (Ba, Bu, Ind)
B. atra (Ind)
B. vulgaris (Ba, Bu)
B. blumeana (Ph)
Gigantochloa levis (Ph)
Melocanna baccifera (Ba, Bu)
Neohouzeaua dalloa (Ba, Bu)
Schizostachyum blumeana (Ind)
S. lumampao (Ph)
Boat roofs
Bambusa arundinacea (In)
B. tulda (Ba, Bu)
B. blumeana (Ph)
Melocanna baccifera (Ba, Bu)
Ornaments
Bambusa vulgaris (Ind, Ba, Bu, In, Ph)
B. nana (Ph)
B. vulgaris var. *striata* (Ph)
B. glaucescens (Ph)
B. polymorpha (Ind)
B. atra (Ind)
Cephalostachyum pergracile (In)
Dendrocalamus giganteus
Phyllostachys aurea (Ind)
Schizostachyum brachycladum (Ind)
S. zollingeri (Ind)
Thyrsostachys siamensis
Culm sheaths (irrigation)
Bambusa blumeana (Ph)
Climbing species of bamboos (Ph)
Dendrocalamus longispathus (Bu)
Gigantochloa macrostachya (Bu)
G. levis (Ph)
Cordage
Bambusa vulgaris (Ph)
B. atra (Ind)
Dendrocalamus strictus (Bu)
D. merrillianus (Ph)
Dinochloa scandens (Ind)
Pseudostachyum polymorphum (Bu)
Inner layer of culm sheath as cheroot wrapper
Dendrocalamus hamiltonii (Bu)
Plaited shoes
Dinochloa compactiflora (Bu)

Umbrella handles
Melocanna baccifera (Ba, Be)
Oxytenanthera stocksii (Ind)
Teinostachyum griffithii (Ba, Bu)
Thyrsostachys siamensis (Bu)
Shuttles
Bambusa blumeana (Ph)
Piculan
Bambusa glaucescens (Ind)
Tobacco drying
Dinochloa scandens (Ind)
Nastus elegantissimus (Ind)
Phyllostachys edulis (Jap)

Boat masts
Bambusa blumeana (Ph)
Dendrocalamus brandisii
Gigantochloa levis (Ph)
Joints for cooking glutinous rice
Cephalostachyum pergracile (Bu)
C. burmanicum (Bu)
Bridges
Bambusa blumeana (Ph)
B. vulgaris (Ph)
B. arundinacea (Ph)
Boat plying rods
Bambusa polymorpha (Ba, Bu, Ind)
B. glaucescens (Ind)
Melocanna baccifera (Ba, Bu)
Rickshaw hoods
Bambusa vulgaris (Ba)
Pea sticks
Thamnocalamus spathiflora (In)
Barbecue skewers
Bambusa blumeana
Trellises
Bambusa arundinacea (In)
B. blumeana (In)
All large-sized bamboos
Flues
Bambusa blumeana (Ph)
B. glaucescens (Ph)
Schizostachyum lumampao (Ph)
Hats
Bambusa blumeana (Ph)
B. vulgaris (Ph)
Barrels for toy cannons
Bambusa blumeana (Ph)
Gigantochloa levis (Ph)
Sledges (transport)
Bambusa blumeana (Ph)
Dendrocalamus merrillianus (Ph)
Handicrafts
Bambusa blumeana (Ph, Ind)
B. vulgaris
Dendrocalamus asper (Ind)
Dinochloa scandens (Ind)
Gigantochloa verticillata
G. atter
G. apus
Nastus elegantissimus
Schizostachyum lima (Ph)
S. brachycladum
S. blumei (Ind)
All bamboos (Th)
Sprayers
Bambusa blumeana (Ph)
Polo mallets
Bambusa blumeana (Ph)

Eyeliner
Dinochloa scandens (Ind)
Jaundice treatment
Bambusa vulgaris (Ind)
Ladders
Bambusa arundinacea (Ind)
Dendrocalamus strictus (Ind)
Afforestation of riverbanks and soil conservation areas; shelter belts; windbreaks
All bamboos

Afforestation of river banks and soil conservation areas, shelter belts and wind belts : all bamboos.

Agricultural implements : *Bambusa balcooa, Bambusa vulgaris, Dendrocalamus strictus' Ochlandra travancorica*, all thinner varieties.

Bamboo hats : *Bambusa blumeana, Bambusa vulgaris.*

Basket making : *Arundinaria intermedia, Bambusa arundinacea, Bambusa nutans, Bambusa pallida, Bambusa khasiana, Bambusa tulda, Bambusa vulgaris, Bambusa polymorpha, Chimonobambusa falcata, Dendrocalamus giganteus, Dendrocalamus longispathus, Dendrocalamus hamiltonii, Dendrocalamus strictus, Gigantochloa nigrociliata, Indocalamus wightiana, Neahauzeaua helferi, Oxytenanthera ritchevi, Thamnocalamus spathiflora.*

Boat plying rod : *Bambusa glaucesceus* and *Bambusa polymorpha.*

Bows and arrows : *Bambusa arundinacea, Cephalostachyum capitatum, Cephalostachyum pergracile, Dendrocalamus strictus.*

Bridges : *Bambusa arundinacea, Bambusa vulgaris.*

Cart containers and roof : All bamboos.

Cart yokes : All large sized hard and solid bamboos.

Chicks for doors and windows : *Bambusa arundinacea, Dendrocalamus strictus.*

Combs : *Oxytenanthera bourdillonii.*

Containers for cleaning grains : All bamboos.

Containers to curry maps : *Oxytenanthera bourdillonii.*

Constructions : *Bambusa polymorpha, Bambusa balcooa, Bambusa tulda, Bambusa arundinacea Bambusa nutans, Bambusa khasiana, Bambusa vulgaris, Bambusa blumeana, Cephalostachyum capitatum, Cephalostachyum pergracile, Dendrocolamus membranaceus, Dendrocalamus hamiltonii, Dendrocalamus giganteus, Dendrocalamus longispathus, Dendrocalamus strictus, Gigantochloa nigrociliata, Melocanna baccifera, Neohauzeaua dullooa, Oxytenanthera stocksii, Teinostachyum beddomei, Thyrosostachys oliverii.*

Containers to administer medicine to Bulls and animals : *Bambusa arundinacea.*

Country tiles : *Bambusa arundinacea.*

Cooking utensils : *Bambusa arundinacea, Cephalostachyum pergracile.*

Cradles : *Bambusa arundinacea, Dendrocalamus strictus.*

Cremation & Coffins : *Bambusa arundinacea, Dendrocalamus strictus* and all bamboos.

Fencing : *Indocalamus wightianus, Oxytenanthera monodelpha, Oxytenanthera ritchevi* and all bamboos.

Fishing rods : *Arundinaria amabilis, Chimonobambusa falcata, Chimonobambusa khasiana, Chimonobambusa intermedia, Dendrocalamus strictus.*

Floating timber and rafting : *Bambusa arundinacea, Dendrocalamus hamiltonii, Ochlandra scriptoria.*

Flooring : *Bambusa polymorpha.*

Fodder : *Arundinaria racemosa, Chimonobambusa densifolia, Cephalostachyum capitatum, Cephalostachyum pergracile, Dendrocalamus sikkimensis, Dendrocalamus strictus, Ochlandra travancorica, Bambusa arundinacea* and leaves of all bamboos.

For Jaundice : *Bambusa vulgaris.*

Fuel : All bamboos and rhizomes of bamboos.

Furniture : *Bambusa arundinacea, Bambusa glaucesceus, Bambusa tulda, Bambusa vulgaris*, all thick walled species.

General utility : *Bambusa arundinacea, Bambusa tulda, Cephalostachyum burmanicum, Cephalostachyum pergracile, Dendrocalamus hamiltonii, Dendrocalamus hookeri, Dendrocalamus strictus*, all bamboos which are strong

Handicrafts : *Bambusa blumeana, Bambusa vulgaris.*

Hedges : *Bambusa nana, Dendrocalamus giganteus.*

Hookah pipes : *Chimonobambusa falcata, Thamnocalamus aristatus, Teinostachyum griffithii, Thamnocalamus spathiflora.*

Horticultural pursuits : *Bambusa arundinacea, Dendrocalamus strictus*, all bamboos and other strong species.

Uses of bamboos in India   Source : Varmah and Pant (1981)

Lance staves : *Dendrocalamus strictus, Ochlandra scriptorica, Ochlandra trav....orica.*

Lattle shots : *Dendrocalamus strictus, Ochlandra* species.

Loading vessels : *Neohauzeaua dullooa.*

Mats : *Arundinacia intermedia, Arundinacia racemosa, Bambusa arundinacea, Bambusa blumeana, Bambusa nutans, Bambusa pallida, Bambusa teres, Bambusa tulda, Cephalostachyum pergracile, Dendrocalamus hamiltonii, Dendrocalamus strictus, Indocalamus wightiana, Neohauzeaua dullooa, Ochlandra scriptorica, Ochlandra travancorica, Oxytenanthera nigrociliata, Teinostachyum dullooa.*

Match boxes and splints : *Ochlandra travancorica.*

Musical instruments : (Flutes, mariba, horns, clarionets, flagerlets, saxophones, piccolcs, drums, etc.) : *Arundinaria* spp., *Dendrocalamus strictus*, all small sized bamboos.

Ornamental purposes : *Bambusa vulgaris, Cephalostchyum pergracile, Dendrocalamus giganteus, Phyllostachys aurea, Oxytenanthera monadelpha, Thyrsostachys siamensis.*

Pandals for shade : All bamboos.

Pan trays : *Neohauzeaua dullooa.*

Paper and Pulp :—An idea about the changes in the utilisation pattern of bamboo in the production of paper and paper board can be had from Table I.

Table I

Production of Paper and Paper Board and Consumption of the Raw Material for the Industry

Year	...al Production of Paper & Board in '000 tons	Name of the Raw material and its percentage (by weight) use in the manufacture						
		Grass	Rags	Waste Paper	Agricultural waste	Bamboo	Hard wood	Imported wood
1936	40	29.31	7.27	5.01	0	49.08	0	9.33
1952	130	12.86	6.30	6.30	0	73.59	0	0.95
1958	203	8.23	4.11	4.11	3.29	74.13	1.15	4.98
1970	758	9.75	4.87	7.31	2.43	56.09	19.51	0.04
1975	959	9.83	4.09	6.55	2.45	47.54	29.54	0.00
1980 (estimated)	2001	6.42	3.66	6.42	2.75	29.35	51.37	0.03

Source : Pant, M.M., 1977 : 'Socio-Economic Returns of Applied Research in the Cellulose and Paper Branch of Forest Research Institute'.

The country's paper industry mainly depends upon *Dendrocalamus strictus* and *Bambusa arundinacea.* The mills in the north mainly use the former species while those in the east and the south use both. *Bambusa nutans, Bambusa tulda, Dendrocalamus hamiltonii* and *Melocanna baccifera* are some of the other bamboo species with limited uses. Presently, nearly 3 million tons of bamboos are used annually by the paper industry with possibilities of a substantial rise in the intake if economically available.

Other suitable species are :—*Neohauzeaua dullooa, Ochlandra brandisii, Ochlandra reheedii, Ochlandra scriptoria, Ochlandra setigera, Ochlandra wightii, Oxytenanthera nigrociliata, Bambusa arundinacea, Bambusa nutans, Bombusa polymorpha, Bambusa tulda, Dendrocalamus asper, Dendrocalamus brandisii, Dendrocalamus hamiltonii, Dendrocalamus longispathus, Dendrocalamus membranceus, Thyrsostachys oliveri, Thyrsostachys siamensis.*

Pea sticks : *Thamnocalamus spathiflora.*

Pipes : *Bambusa arundinacea, Dendrocalamus hamiltonii* and *Teinostachyum griffithii.*

Polo mallets : *Bambusa blumeana* (Basal portion of culm).

Protection while pounding grain : *Bambusa arundinacea* and all big sized bamboos.

Punting poles : *Oxytenanthera stocksii, Oxytenanthera ritcheri*, solid varieties.

Rickshaw hoods : *Bambusa vulgaris, Dendrocalamus* species.

Roofing of boats : *Bambusa arundinacea, Bambusa tulda.*

Scaffolding : *Bambusa arundinacea, Bambusa ... teres, Dendrocalamus strictus.*

Seed food : *Bambusa arundinacea, Cephalostachyum pergracile* and *Dendrocalamus strictus.*

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Seed drills : *Dendrocalamus strictus.*

Sericultural Industry : Trays for rearing silk worms : *Bambusa arundinacea, Dendrocalamus strictus, Thyrsostachys siamensis.*

Shoots as vegetables and food : *Bambusa arundinacea, Bambusa nana, Bambusa tulda, Bambusa vulgaris, Dendrocalamus giganteus, Dendrocalamus hamiltonii, Dendrocalamus longispathus, Sinobambusa elegans* and all large bamboo shoots.

Stablishing haystocks : *Bambusa blumeana, Bambusa tulda, Bambusa vulgaris, Dendrocalamus strictus* (All bamboos can be used).

Stakes in Forestry practices : All bamboos.

Tea estates : *Pseudostachyum polymorphum.*

Thatching and roofing : *Bambusa arundinacea, Bambusa polymorpha, Bambusa tulda, Bambusa vulgeris, Chimnobambusa falcata, Dendrocalamus brandisii, Dendrocalamus hamiltonii, Dendrocalamus longispathus, Dendrocalamus membranaceus, Gigantochloa attur. Oxytenanthera monodelpha, Dendrocalamus strictus.*

Tool handles : *Dendrocalamus merrillianus, Dendrocalamus strictus, Ochlandra travancorica* and all solid varieties.

Trellis work : *Bambusa arundinacea, Bambusa blumeana* and all big sized bamboos.

Umbrella handles : *Melocanna baccifera, Neohauzeauo dullooa, Oxytenanthera ritchevi, Oxytenanthera stacksii, Teinostachyum griffithii.*

Working sticks : *Arundinaria armata, Dendrocalamus strictus, Ochlandra travancorica, Oxytenanthera nigrociliata, Oxytenanthera ritchevi, Phyllostachys manni.*

Walling of native huts : *Arundinaria racemosa, Bambusa atra, Bambusa polymorpha, Bambusa tulda, Gigantochloa nigrociliata, Neohauzeaua dullooa, Oxytenanthera nigrociliata, Sinobombusa elegans.*

Vater and milk vessels (Thunga), water buckets, cups and containers : *Bambusa pollida, Bambusa tulda, Dendrocalamus asper, Dendrocalamus giganteus, Dendrocalamus hamiltonii, Dendrocalamus hookeri, Dendrocalamus sikkimmensis, Gigantachloa aspera, Gigantochloa levis. Melocanna baccifera.*

Ecological requirements of some artificially established browse species in North Africa

(Source: Le Houérou, 1980)

Species	Rainfall in mm	Mean minimum t° of January in °C	Soils
Acacia cyanophylla	> 250	> 3	Deep sandy
" ligulata	> 150	> 3	"
" salicina	> 150	> 3	"
" victoriae	> 150	> 3	Silty to sandy
Artemisia herba alba	> 150	>-2	Silty, Shallow
Atriplex canescens	> 200	>-5	Sandy to Silty
" glauca	> 150	> 1	Silty to clayey, saline EC < 30 mmhos
" halimus	> 150	> 1	" " " "
" nummularia	> 200	> 1	Silty to clayey EC < 20 mmhos
Brachychyton populneum	> 300	> 3	Various
Broussonetia papyrifera	> 400	>-1	Various
Calligonum comosum	> 80	>-1	Drifting sand
Cassia sturtii	> 150	> 3	Silty-Sandy
Celtis australis	> 700	> 1	Various
Ceratonia siliqua	> 300	> 3	Silty-sandy Rocky
Chenopodium auricomum	> 200	> 3	Various
Coronilla glauca	> 300	> 2	Silty, Shallow
Eleagnus angustifolia	> 300	>-2	Various
Fraxinus oxyphylla	> 500	> 1	Various
Gleiditshia triacanthos	> 400	>-5	Various
Haloxylon aphyllum	> 80	>-10	Silty-clayey
" persicum	> 80	>-10	Sandy
Medicago arborea	> 300	> 2	Silty, Shallow
Morus alba	> 350	>-5	Various
Olea europaea	> 200	> 2	Deep sandy
Opuntia ficus indica inermis	> 200	> 2	Deep sandy
" fusicaulis	> 200	> 1	" "
" inermis	> 200	> 1	" "
[illegible]iploca laevigata	> [illegible]	> 3	Shallow

Prosopis juliflora	>200	2	Sandy
Vitis berlandieri	>200	-5	Various
" riparia	>200	-5	"
" rupestris	>400	-5	"
" vinifera	>200	-5	"

From the above table it is obvious that with the available plant material, of some 35 species, one can meet most of the ecological conditions prevailing in northern Africa, except in the desert where rainfall does not reach the 100 mark.

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MASTERLIST OF WOODY SPECIES UNDER CONSIDERATION AS NITROGEN-FIXING TREES

(J. Halliday and P.L. Nakao, eds., Prepared for Bellagio Workshop; Document #1)

1. The NFT Masterlist includes:

   -- 997 species

   -- all woody species of the legume family even though confirmation that they individually nodulate and fix nitrogen may be lacking

   -- all species of all other genera in which a species has been confirmed to nodulate or fix nitrogen.

2. The masterlist is abstracted from a larger data base maintained by the University of Hawaii NiFTAL Project. The complete data base includes a general characterization of each species, and specifies its microsymbiotic affinities, both rhizobial and mycorrhizal. The complete data base also cites the scientific literature that substantiates that a listed species does or does not fix nitrogen.

3. The Masterlist is actually the first section of a more complete publication available directly from NiFTAL (P.O. Box O, Paia, Hawaii 96779, USA):

Halliday, J., and P.L. Nakao. 1982. The symbiotic affinities of woody species under consideration as nitrogen-fixing trees. University of Hawaii NiFTAL Project. 85 pages.

Acacia abyssinica
Acacia acinacea
Acacia acuminata
Acacia adenocalyx
Acacia adunca
Acacia alata
Acacia albida
Acacia anceps
Acacia aneura
Acacia arabica (nilotica)
Acacia arenaria
Acacia armata
Acacia aroma
Acacia aspera
Acacia ataxacantha
Acacia aulacocarpa
Acacia auriculiformis
Acacia baileyana
Acacia berlandieri
Acacia berteriana
Acacia bidentata
Acacia biflora
Acacia blakelyi
Acacia bonariensis
Acacia borleae
Acacia brachybotrya
Acacia brachystachya
Acacia burkei
Acacia buxifolia
Acacia byoneana
Acacia caffra
Acacia calamifolia
Acacia calcina
Acacia cambagei
Acacia cana
Acacia cardiophylla
Acacia catechu
Acacia cavan
Acacia cavenia
Acacia celastrifolia
Acacia chariessa
Acacia cognata
Acacia colletoides
Acacia complanata
Acacia confusa
Acacia constricta
Acacia crassicarpa
Acacia cultriformis
Acacia cunninghamii
Acacia cupressiformis

Acacia cyanophylla (saligna)
Acacia cyclops
Acacia davyi
Acacia dealbata
Acacia deamii
Acacia deanei
Acacia decora
Acacia decurrens
Acacia diptera
Acacia doratoxylon
Acacia drummondii
Acacia ehrenbergiana
Acacia elata
Acacia eremophila
Acacia ericifolia
Acacia erinacea
Acacia erubescens
Acacia estrophiolata
Acacia excelsa
Acacia extensa
Acacia exuvialis
Acacia farnesiana
Acacia filifolia
Acacia fimbriata
Acacia fistula
Acacia flava
Acacia fleckii
Acacia flexuosa
Acacia floribunda
Acacia galpinii
Acacia genistoides
Acacia georginae
Acacia giraffae
Acacia gladiiformis
Acacia glaucescens
Acacia glaucescens
Acacia glaucoptera
Acacia glomerosa
Acacia goetzii
Acacia grandicornuta
Acacia granitica
Acacia greggii
Acacia hakeoides
Acacia harpophylla
Acacia harveyi
Acacia hastulata
Acacia hebeclada
Acacia hereroensis
Acacia heteracantha
Acacia heterophylla

Acacia holosericea
Acacia homalophylla
Acacia horrida
Acacia horridula
Acacia huegelii
Acacia instia
Acacia jonesii
Acacia juniperina
Acacia karoo
Acacia kauaiensis
Acacia kempeana
Acacia kirkii
Acacia koa
Acacia koaia
Acacia kraussiana
Acacia latifolia
Acacia leptoneura
Acacia leucophloea
Acacia linearis
Acacia lineata
Acacia lingulata
Acacia loderi
Acacia longifolia
Acacia luederitzii
Acacia lunata
Acacia macrantha
Acacia macrathyrsa
Acacia mangium
Acacia mearnsii
Acacia melanoxylon
Acacia mellei
Acacia mellifera
Acacia microbotrya
Acacia mollissima
Acacia mollissima
Acacia mooreana
Acacia myrtifolia
Acacia nebrownii
Acacia neriifolia
Acacia nervosa
Acacia nigrescens
Acacia nigricans
Acacia nilotica
Acacia nubica
Acacia obliqua
Acacia obscura
Acacia orfota
Acacia oswaldii
Acacia parramattensis
Acacia pence

Acacia pennata
Acacia pentadenia
Acacia pentagona
Acacia perairta
Acacia podalyriaefolia
Acacia polyacantha
Acacia pravissima
Acacia prominens
Acacia pubescens
Acacia pulchella
Acacia pumila
Acacia pycnantha
Acacia raddiana
Acacia reficiens
Acacia rehmanniana
Acacia restiacea
Acacia rhetinodes
Acacia richii
Acacia rigens
Acacia robusta
Acacia rostellifera
Acacia rubida
Acacia salicina
Acacia saligna
Acacia schweinfurthii
Acacia scorpoides
Acacia senegal
Acacia seyal
Acacia siamensis
Acacia sieberana
Acacia silvicola
Acacia spadicigera
Acacia spathulata
Acacia spinescens
Acacia spirocarpa
Acacia squamata
Acacia stenophylla
Acacia stenoptera
Acacia strigosa
Acacia stulmanii
Acacia suavolens
Acacia subcaerulea
Acacia suffructescens
Acacia sulcata
Acacia swazica
Acacia tamminensis
Acacia tennispina
Acacia tetragonocarpa
Acacia tomentosa
Acacia tortilis
Acacia triptera
Acacia tucumanensis
Acacia unicifera
Acacia urophylla
Acacia verek
Acacia verticillata
Acacia victoriae
Acacia visco
Acacia visite
Acacia volubilis
Acacia welwitscii
Acacia xanthophloea
Acrocarpus fraxinifolius
Adenanthera bicolor
Adenanthera intermedia
Adenanthera pavonina
Afzelia africana
Afzelia quanzensis
Airyantha borneensis
Airyantha schweinfurthii
Albizia acle
Albizia adianthifolia
Albizia amara
Albizia anthelmintica
Albizia antunesiana
Albizia bravifolia
Albizia carbonaria
Albizia chinensis
Albizia distachya
Albizia emalensis
Albizia falcataria
Albizia forbesii
Albizia glaberrima
Albizia gummifera
Albizia harveyi
Albizia julibrissin
Albizia katangensis
Albizia lebbek
Albizia lebbekoides
Albizia lophantha
Albizia moluccana
Albizia odoratissima
Albizia petersiana
Albizia procera
Albizia retusa
Albizia saponaria
Albizia schimperana
Albizia stipulata
Albizia tanganyicensis
Albizia versicolor
Albizia zimmermannii
Aldina insignis
Alexa imperatricis
Alnus acuminata
Alnus cordata
Alnus crispa
Alnus firma
Alnus formosana
Alnus fructicosa
Alnus glutinosa
Alnus hirsuta
Alnus incana
Alnus jorullensis
Alnus maritima
Alnus mollis
Alnus multinervous
Alnus nepalensis
Alnus nitida
Alnus orientalis
Alnus rubra
Alnus serrulata
Alnus sieboldiana
Alnus sinuata
Alnus tenuifolia
Alnus tinctoria
Alnus undulata
Alnus viridis
Amblygonocarpus andongensis
Amburana acreana
Amburana cearensis
Amherstia nobilis
Amphimas ferrugineus
Anadenanthera colubrina
Anadenanthera peregrina
Androcalymma glabiforum
Angylocalyx oligophyllus
Angylocalyx zenkeri
Antheroporum pierrei
Anthonotha macrophylla
Apaloxylon madagascariensis
Aphonocalyx cynometroides
Apoplanesia paniculata
Aprevalia floribunda
Apuleia praecox
Arthrocarpum gracile
Arthrosamanea pistaciaefolia
Ateleia pterocarpa
Baikiaea insignis
Baikiaea plurijuga
Baphiopsis parviflora

Barklya syringifolia
Batesia floribunda
Bathiaea rubiflora
Baudouinia sollyiformis
Bauhinia acuminata
Bauhinia benthamiana
Bauhinia bidentata
Bauhinia binata
Bauhinia blakeana
Bauhinia candicans
Bauhinia carronni
Bauhinia corymbosa
Bauhinia cumingiana
Bauhinia diphylla
Bauhinia excisa
Bauhinia galpinii
Bauhinia kirkii
Bauhinia kochiana
Bauhinia kunthiana
Bauhinia macrantha
Bauhinia malabarica
Bauhinia megalandra
Bauhinia monandra
Bauhinia pauletia
Bauhinia petersiana
Bauhinia purpurea
Bauhinia racemosa
Bauhinia reticulata
Bauhinia tomentosa
Behaimia cubensis
Belairia spinosa
Bergeronia sericea
Berlinia acuminata
Berlinia confusa
Berlinia grandiflora
Bolusanthus speciosus
Bowdichia virgilioides
Brachystegia allenii
Brachystegia appendiculata
Brachystegia boehmii
Brachystegia glaberrima
Brachystegia glaucescens
Brachystegia kennedyi
Brachystegia laurentii
Brachystegia leonensis
Brachystegia manga
Brachystegia microphylla
Brachystegia nigerica
Brachystegia spiciformis
Brachystegia utilis
Brachystegia wangermeeana
Brandzeia filicifolia
Brenierea insignis
Brongniartia minutifolia
Brongniartia podalyroides
Brownea ariza
Brownea capitella
Brownea coccinea
Brownea crawfordii
Brownea grandiceps
Brownea latifolia
Browneopsis ucayalina
Brya ebonus
Burkea africana
Bussea occidentalis
Butea eggelingii
Butea massaiensis
Butea monosperma
Cadia purpurea
Caesalpinia echinata
Caesalpinia peltophoroides
Caesalpinia pulcherrima
Cajanus cajan
Calliandra affinis
Calliandra calothyrsus
Calliandra eriophylla
Calliandra foliosa
Calliandra grandiflora
Calliandra guildingii
Calliandra haematocephala
Calliandra haematoma
Calliandra humilis
Calliandra inaequilatera
Calliandra parvifolia
Calliandra selloi
Calliandra surinamensis
Calliandra tweedii
Calpocalyx brevibracteatus
Campsiandra angustifolia
Campsiandra comosa
Campsiandra laurifolia
Caragana arborescens
Caragana aurantiaca
Caragana frutescens
Caragana pekinensis
Cascaronia astragalina
Cassia fistula
Cassia grandis
Cassia javanica
Cassia leiandra
Cassia nodosa
Cassia siamea
Castanospermum australe
Casuarina cristata (C. lepidophloia)
Casuarina cunninghamiana
Casuarina equistifolia
Casuarina fraseriana
Casuarina glauca
Casuarina grandis
Casuarina huegeliana
Casuarina junghuhniana (C. montana)
Casuarina littoris
Casuarina muelleriana
Casuarina muricata
Casuarina nodiflora
Casuarina obesa
Casuarina ologodon
Casuarina pusilla
Casuarina quadrivalis
Casuarina stricta
Casuarina sumatrana
Casuarina tenuissima
Casuarina torulosa
Cathormion leptophyllum
Cathormion moniliforme
Cedrelinga catenaeformis
Cenostigma macrophyllum
Centrolobium robustum
Ceonothus americanus
Ceonothus azureus
Ceonothus cordulatus
Ceonothus crassifolius
Ceonothus cuneatus
Ceonothus delilanus
Ceonothus divaricatus
Ceonothus diversifolius
Ceonothus fendleri
Ceonothus foliosus
Ceonothus fresnensis
Ceonothus glabra
Ceonothus gloriosa
Ceonothus greggii
Ceonothus griseus
Ceonothus impressus
Ceonothus incana
Ceonothus integerrimus
Ceonothus intermedius
Ceonothus jepsonii
Ceonothus leucodermis
Ceonothus microphyllus

Ceanothus oliganthus
Ceanothus ovatus
Ceanothus parvifolius
Ceanothus prostratus
Ceanothus rigidus
Ceanothus sanguineus
Ceanothus sorediatans
Ceanothus thyrsiflorus
Ceanothus velutinus
Ceratonia siliqua
Cercidium floridum
Cercidium praecox
Cercidium torreyanum
Cercis siliquastrum
Cercocarpus betuloides
Chadsia sanguinea
Chordospartium stevensonii
Cladrastis platycarpa
Cladrastis sinensis
Clathrotropis brachypetala
Clathrotropis macrocarpus
Clathrotropis nitida
Colophospermum mopane
Colvillea racemosa
Comptonia peregrina (M. asplenifolia)
Cordeauxia edulis
Cordyla africana
Coriaria angustissima
Coriaria arborea
Coriaria intermedia
Coriaria japonica
Coriaria kingiana
Coriaria lurida
Coriaria myrtifolia
Coriaria plumosa
Coriaria pottsiana
Coriaria pteridoides
Coriaria sarmentosa
Coriaria thymifolia
Craibia baptisarum
Craibia brevicaudata
Craibia grandiflora
Crudia gabonensis
Crudia parivoa
Cyclobium brasiliense
Cyclolobium vecchii
Cylicodiscus gabunensis
Cymbosepalum baroni
Cynometra alexandri
Cynometra ananta
Cynometra bauhiniaefolia
Cynometra cauliflora
Cynometra hankei
Cynometra leonensis
Cynometra ramiflora
Cynometra retusa
Dalbergia baroni
Dalbergia cearensis
Dalbergia cochinchinensis
Dalbergia cubilquitensis
Dalbergia greveana
Dalbergia latifolia
Dalbergia melanoxylon
Dalbergia nigra
Dalbergia retusa
Dalbergia sissoo
Dalbergia spruciana
Dalbergia stevensonii
Dalbergiella nyasae
Dalea spinosa
Daniellia ogea
Daniellia olivera
Daniellia thurifera
Dansera procera
Delaportea armata
Delonix baccal
Delonix elata
Delonix regia
Denistophytum madagascariense
Derris indica
Detarium senegalense
Dewevrea bilabiata
Dialium engleranum
Dialium pachyphyllum
Dialium zenkeri
Dichrostachys cinerea
Dichrostachys glomerata (D.cinera)
Dichrostachys spicata
Dicorynia guianensis
Dicraeopetalum stipulare
Dicymbe altsoni
Dicymbe corymbosa
Didelotia africana
Dimorphandra davisii
Dinizia excelsa
Diphysa floribunda
Diphysa robinoides
Diplotropis purpurea
Dipteryx odorata
Dipteryx trifoliata
Diptychandra epunctata
Discaria toumatou
Distemonanthus benthamianus
Dryas drummondii
Dryas integrifolia
Dryas octopetalia
Duparquetia orchidacea
Dussia discolor
Dussia martinicensis
Elaeagnus angustifolia
Elaeagnus argentea
Elaeagnus commutata
Elaeagnus edulis
Elaeagnus longipes
Elaeagnus macrophylla
Elaeagnus multiflora
Elaeagnus pungens
Elaeagnus rhamnoides
Elaeagnus umbellata
Elignocarpus cynometroides
Elizabetha durissima
Elizabetha princeps
Endertia spectabilis
Englerodendron usambarense
Entada abyssinica
Entada phaseoloides
Entada sudanica (E. africanum)
Enterolobium cyclocarpum
Enterolobium schomburgkii
Enterolobium timbouva
Eperua falcata
Eperua jenmani
Eperua purpurea
Erythrina abyssinica
Erythrina berteroana
Erythrina caffra
Erythrina crista-galli
Erythrina fusca
Erythrina glauca
Erythrina indica
Erythrina lithosperma
Erythrina monosperma
Erythrina orientalis
Erythrina poeppigiana
Erythrina suberosa
Erythrophleum africanum
Erythrophleum ivorense
Erythrophleum suaveolens
Etaballia dubia
Eurypetalum batesii

Eurypetalum tessmannii
Exostyles venusta
Eysenhardtia amorphoides
Eysenhardtia peninsularis
Eysenhardtia texana
Ferreirea spectabilis
Fillaeopsis discophora
Fissicalyx fendleri
Fordia cauliflora
Gagnebina tamariscina
Genista sp.
Geoffroea decorticans
Geoffroea spinosa
Gilbertiodendron deconstrans
Gilletiodendron klainei
Gleditsia amorphoides
Gleditsia caspica
Gleditsia japonica
Gleditsia sinensis
Gleditsia triacanthos
Gliricidia ehrenbergii
Gliricidia lavoii
Gliricidia sepium
Goldmania foetida
Gossweilerodendron balsamiferum
Gourliea decorticans
Guibourtia coleosperma
Guibourtia conjugata
Guibourtia demeusei
Guibourtia schliebenii
Gymnocladus dioica
Haematoxylon brasiletto
Haematoxylon campechianum
Haplormosia monophylla
Hardwickia binata
Hardwickia pinnata
Harpalyce cubensis
Hebestigma cubense
Hesperolaburnum platycarpum
Hesperothamnus littoralis
Heterostemon mimosoides
Hippophae rhamnoides
Holocalyx balansae
Humboldtia laurifolia
Hylodendron gabunense
Hymenaea confertiflora
Hymenaea courbaril
Hymenolobium excelsum
Hymenolobium nitidum
Hymenostegia floribunda
Indopiptadenia oudhensis
Inga altissima
Inga edulis
Inga feuilei
Inga laurina
Inga oerstediana
Inga paterna
Inga vera
Inocarpus edulis
Intsia acuminata
Intsia bakeri
Intsia bijuga
Intsia palembanica
Intsia plurijuga
Intsia retusa
Isoberlinia scheffleri
Isoberlinia angolensis
Isoberlinia dalzielii
Isoberlinia doka
Isoberlinia tomentosa
Isomacrolobium leptorrhachis
Jacqueshuberia quinquangulata
Julbernardia globiflora
Julbernardia hochreutineri
Julbernardia magnistipulata
Julbernardia paniculata
Julbernardia seretii
Julbernardia unijugata
Kalappia celebica
Kingiodendron alternifolium
Kingiodendron pinnatum
Koompassia excelsa
Koompassia malaccensis
Laburnum alpinum
Laburnum anagyroides
Laburnum pratense
Lebruniodendron lepthanthum
Lecointea amazonica
Lennea robinioides
Leonardoxa africana
Leucaena collinsii
Leucaena diversifolia
Leucaena esculenta
Leucaena lanceolota
Leucaena leucocephala
Leucaena macrophylla
Leucaena pulverulenta
Leucaena retusa
Leucaena shannoni
Leucaena trichodes
Leucostegane latistipulata
Librevillea klainei
Loesenera kalantha
Lonchocarpus capassa
Lonchocarpus latifolius
Lonchocarpus punctatus
Lonchocarpus utilis
Lonchocarpus violaceus
Lysidice rhodostegia
Lysiloma auritum
Lysiloma bahamensis
Lysiloma divaricata
Lysiloma latisiliqua
Lysiloma thornberi
Maackia amurensis
Maackia chinensis
Maackia floribunda
Machaerium robiniifolium
Machaerium schomburgkii
Macroberlinia bracteosa
Macrozamia communis
Macrozamia riedlei
Maniltoa grandiflora
Maniltoa schefiera
Marmaroxylon racemosum
Martiodendron excelsum
Melanoxylon brauna
Michelsonia microphylla
Microberlinia brazzavillensis
Milbraediodendron excelsum
Millettia dubia
Millettia grandis
Millettia laurentii
Millettia rubiginosa
Millettia stuhlmannii
Millettia thonningii
Millettia usaramensis
Mimosa bracaatinga
Mimosa scabrella
Mimosa tenuiflora
Mimozyganthus carinatus
Moldenhauera floribunda
Monopetalanthus pteridophyllus
Monopteryx angustifolia
Monoschisma leptostachyum
Mora excelsa
Mora gonggrijpii
Muellera frutescens
Mundulea sericea
Myrica adenophora

Myrica asplenifolia
Myrica carolinensis
Myrica cerifera
Myrica gale
Myrica javanica
Myrica pensylvanica
Myrica pilulifera
Myrica pubescens
Myrica rubra
Myrica sapida
Myrica serrata
Myrocarpus fastigiatus
Myrocarpus frondosus
Myrospermum frutescens
Myroxylon balsamum
Myroxylon pereirae
Myroxylon peruiferum
Neochevalierodendron stephanii
Neodunnia atrocyanea
Neoharmsia madagascariensis
Newtonia buchananii
Newtonia hildebrandtii
Notodon gracilis
Notospartium glabrescens
Oddoniodendron micranthum
Oleiocarpon panamense
Olneya tesota
Ormosia coccinea
Ormosia hosei
Ormosia monosperma
Ostryoderris gabonica
Ostryoderris stuhlmannii
Ougeinia oojeinensis
Oxystigma mannii
Oxystigma msoo
Pachyelasma tessmannii
Pahudia galedupa
Pahudia rhomboidea
Paloue guianensis
Paloveopsis emarginata
Panurea longifolia
Paramachaerium schomburgkii
Paramacrolobium coeruleum
Parapiptadenia rigida
Parasponia andersonii
Parasponia parviflora
Parasponia rugosa
Parkia africana
Parkia biglandulosa
Parkia biglobosa
Parkia clappertoniana
Parkia filicoidea
Parkia javanica
Parkia roxburghii
Parkia speciosa
Parkia timoriana
Parkinsonia aculeata
Parkinsonia africana
Pellegriniodendron diphyllum
Peltogyne catingue
Peltogyne densiflora
Peltogyne excelsa
Peltophorum adnatum
Peltophorum dasyrrhachis
Peltophorum pterocarpum
Peltophorum vogelianum
Pentaclethra eetveldeana
Pentaclethra macroloba
Pentaclethra macrophylla
Pericopsis angolensis
Pericopsis elata
Pericopsis mooniana
Petaladenium urceoliferum
Phyllocarpus riedelii
Phyllocarpus septentrionalis
Phylloxylon xiphoclada
Phylloxylon xylophylloides
Pictetia aculeata
Piliostigma malabaricum
Piliostigma reticulatum
Piliostigma thonningii
Piptadenia excelsa
Piptadenia macrocarpa
Piptadenia paraguayensis
Piptadeniastrum africanum
Piscidia piscipula
Pithecellobium adinocephalum
Pithecellobium arboreum
Pithecellobium carabcboense
Pithecellobium cauliflorum
Pithecellobium collinum
Pithecellobium dulce
Pithecellobium flexicaule
Pithecellobium jiringa
Pithecellobium lobatum
Plagiosiphon discifer
Plathymenia reticulata
Platycelyphium cyananthum
Platycyamus regnellii
Platycyamus ulei
Platymiscium dimorphandrum
Platymiscium pinnatum
Platymiscium trinitatis
Platymiscium ulei
Platypodium elegans
Platysepalum vanhouttei
Platysepalum violaceum
Platysepalum violouttei
Podopetalum ormondii
Poecilanthe effusa
Poeppigia procera
Pogocybe entadoides
Polystemonanthus dinklagei
Pongamia pinnata
Prioria copaifera
Prosopis africana
Prosopis alba
Prosopis articulata
Prosopis chilensis
Prosopis cineraria
Prosopis dulcis
Prosopis glandulosa
Prosopis juliflora
Prosopis kuntzeie
Prosopis nigra
Prosopis pallida
Prosopis ruscifolia
Prosopis tamarugo
Prosopis velutina
Pseudosamanea guachapele
Psorodendron spinosum
Pterocarpus angolensis
Pterocarpus blancoi
Pterocarpus echinatus
Pterocarpus indicus
Pterocarpus marsupium
Pterocarpus officinalis
Pterocarpus podocarpus
Pterocarpus rotundifolius
Pterocarpus santalinoides
Pterocarpus sericeus
Pterocarpus soyauxii
Pterocarpus stevensonii
Pterocarpus vidalianus
Pterodon emarginatus
Pterogyne nitens
Pynaertiodendron congolanum
Ramorinoa girolae
Recordoxylon amazonicum
Robinia hispida

Robinia neomexicana
Robinia pseudoacacia
Robinia viscosa
Sabinea florida
Sakoanala madagascariensis
Samanea pedicellaris
Samanea polycephala
Samanea saman
Samanea saminiqua
Sophora tomentosa
Sopropis palmeri
Spirotropis longifolia
Stachyothyrsus staudtii
Stahlia maritima
Steinbachiella leptoclada
Stemonocoleus micranthus
Storkiella vitiensis
Strombocarpa strombulifera
Xanthocercis zambesiaca
Xeroderris stuhlmannii
Xylia evansii
Xylia ghesquierei
Xylia xylocarpa
Yucaratonia brenningii
Zenia insignis
Zenkerella citrina
Zenkerella citrina

70.	*P. velutina*	Velvet Mesquite	University of Arizona	162	Tucson, Arizona	Currently out of stock.
71.	*P. velutina*	Velvet Mesquite	University of Arizona	163	Tucson, Arizona	Currently out of stock.
72.	*P. velutina*	Velvet Mesquite	University of Arizona	164	Tucson, Arizona	Currently out of stock.
73.	*P. velutina*	Velvet Mesquite	University of Arizona	165	Tucson, Arizona	Currently out of stock.
74.	*P. velutina*	Velvet Mesquite	University of Arizona	171	West of Tucson, Arizona	Currently out of stock.
75.	*P. velutina*	Velvet Mesquite	University of Arizona	172	Tucson, Arizona	Currently out of stock.
76.	*P. velutina*	Velvet Mesquite	Texas A&I University	0457	Kingsville, Texas	Currently out of stock.
77.	*P. velutina*	Velvet Mesquite	University of California Riverside	PC 035	Arizona	Currently out of stock.
78.	*Simmondsia chinensis*	Jojoba	University of Arizona		Southern Arizona	Liquid wax; browse; salt tolerant, drought tolerant.
79.	*Stylosanthes hamata*		CSIRO, Australia	Verano	Coastal South America	Browse shrub.
80.	*S. scabra*		CSIRO, Australia	Q10042	Bahia, Brazil	Browse shrub.
81.	*S. scabra*		CSIRO, Australia	Fitzroy		Browse shrub.
82.	*S. scabra*		CSIRO, Australia	Seca		Browse shrub.
83.	*S. sympodialis*		CSIRO, Australia	67703	Coastal Equador	Browse shrub.
84.	*Tarchonanthus camphoratus*	Camphor Bush	Bolus Herbarium		Bloemfontein, South Africa	Fuelwood, fodder, windbreaks, termite-resistant wood, medicinal uses.

NFTA 82-04A

ECONOMICALLY IMPORTANT NITROGEN FIXING TREE SPECIES

(J. L. Brewbaker and Brian T. Styles. eds.
Prepared for Bellagio Workshop; Document #2A)

Format:

SPECIES (FAMILY)
1. ORIGIN; HEIGHT, SHAPE
2. USES AND CHARACTERISTICS
3. ADAPTATION (INCL.MIN. RAINFALL)
4. COMMENTS, CHROMOSOME NO.

ACACIA ALBIDA DEL. (MIMOSOIDEAE; LEGUMINOSAE)
1. Africa and Israel, to 20 m; leafless in rainy season
2. Forage (pods, foliage), shade
3. Dry tropics, Sahel (to 300 mm min)
4. Slow growth 2n=26

ACACIA AURICULIFORMIS A. CUNN. EX BENTH. (MIMOSOIDEAE; LEGUMINOSAE)
1. Australia, New Guinea; to 30m, spreading
2. Fuelwood, pulpwood; .68 sp.gr.; 15 m3/ha/yr
3. Wide adapt.. acid soils; humid tropics (750 mm. min)
4. Not too tolerant of drought? fire? winds? 2n=26

ACACIA CONFUSA MERR. (MIMOSOIDEAE; LEGUMINOSAE)
1. Philippines, Taiwan; to 14 m, spreading
2. Firewood (high sp. gr.), ornamental
3. Wet subtropics (to 750 mm min), acid soils
4. Slow growth 2n=26

ACACIA FARNESIANA (L.) WILLD. (MIMOSOIDEAE; LEGUMINOSAE)
1. Tropical America; to 10 m, often shrubby
2. Fuelwood; forage, tanning; perfume from flowers; ornamental; black dye used to make ink
3. Dry tropics; wide variety of soils
4. Very thorny; can be weedy 2n=52

ACACIA MANGIUM WILLD. (MIMOSOIDEAE; LEGUMINOSAE)
1. Australia and Papua New Guinea, Indonesia; to 30 m, erect, stately
2. Timber (.65 sp gr), Firewood?, to 30 m3/ha/yr
3. Moist tropics (to 1000 mm min), acid soils?
4. Insects on leaves, genetic variability

ACACIA MEARNSII WILLD. (MIMOSOIDEAE; LEGUMINOSAE)
1. Australia; to 25 m, spreading
2. Fuelwood, charcoal, tannins; dense wood (.75 sp.gr.), to 25 m3/ha/yr
3. Moist sub-tropics, mid elevations; to 800 mm min?
4. Can become weedy 2n=26

ACACIA NILOTICA (L.) WILLD. EX DEL. (MIMOSOIDEAE: LEGUMINOSAE)
1. Africa and India; to 20 m, usually less
2. Firewood, charcoal, fodder (pods, leaves), tannin and gum
3. Dry tropics (but thrives under irrigation)
4. Extremely thorny, variable 2n=52,104

ACACIA SALIGNA (LABILL.) H. WENDL. (MIMOSOIDEAE: LEGUMINOSAE)
1. W. Australia; shrub or small tree to 7 m
2. Fodder; fuel; sand-dune fixation; tannin; recolonization of mining areas; erosion control ornamental
3. Humid to subhumid tropics; 300-1000 mm. rainfall; adapted to both sandy and swampy sites
4. Rapid growth outside native areas; tolerant to drought, salt, winds, and fire; may become weedy

ACACIA SENEGAL (L.) WILLD. (MIMOSOIDEAE: LEGUMINOSAE)
1. Africa Pakistan, India; to 13 m, often shrubby
2. Firewood, charcoal; to 5 m3/ha/yr, gum arabic, feed (pods, foliage)
3. Dry tropics (to 200 mm min), poor soil, hot
4. Extremely thorny, becomes weedy 2n=26

ACACIA TORTILIS (FORSK.) HAYNE (MIMOSOIDEAE: LEGUMINOSAE)
1. Africa, Sahel, Israel, Arabia; to 15 m, often shrubby;
2. Firewood, dense; fodder (pods, leaves)
3. Dry tropics (to 100 mm min), heat tolerant, alkaline soils
4. Thorny, lateral roots

ALBIZIA FALCATARIA (L.) FOSBERG (MIMOSOIDEAE; LEGUMINOSAE)
1. Indonesia, New Guinea; to 45 m
2. Pulpwood, soft, .33 sp. gr., moldings, boxes, soil improvement
3. Moist tropics (to 1000 mm min), midlands
4. Soft wood, poor fuel

ALBIZIA LEBBEK (L.) BENTH. (MIMOSOIDEAE; LEGUMINOSAE)
1. Tropical Asia and Africa; to 30 m
2. Fuelwood (high value, 5200 kcal/kg), foliage for feed, yields to 5 m3/ha/yr, furniture
3. Wide adaptability, dry and moist tropics (to 600 mm min)
4. Slow growth 2n=26

ALNUS ACUMINATA O. KUNTZE (BETULACEAE)
1. C. America; to 25 m or more
2. Firewood, sp. gr. .5; timber, to 15 m3/ha/yr; shoes
3. Cool tropic highlands to 3000 m, moist (1250 mm min)
4. Not heat or drought tolerant

ALNUS GLUTINOSA (L.) GAERTN. (BETULACEAE)
1. Europe to W. Asia; Asia Minor to N. Africa; to 40 m
2. Energy production (fuel); soil stabilization, e.g. river banks, roadsides, mine wastes; shoes; sp.gr. .52
3. Widely adapted, temperate or subtropical, to 500m
4. Not drought tolerant 2n=28

ALNUS NEPALENSIS D. DON (BETULACEAE)
1. Himalayas: to 30 m
2. Firewood but sp.gr. .35; utility timber and forage
3. Cool tropic highlands to 3000m, mesic (800 mm min?)
4. Some insects, soft wood 2n=28

/ CALLIANDRA CALOTHYRSUS MEISSN. (MIMOSOIDEAE; LEGUMINOSAE)
1. C. and S. America; to 10 m, shrubby
2. Firewood; forage (high tannin) and green manure; sp. gr. .65
3. Moist tropics (min. 1000mm), cooler (above 500m?); to 40 m3/ha/yr with annual harvest
4. Shrubby (=C. confusa Sprague & Riley) 2n=22

CASUARINA CUNNINGHAMIANA MIQ. (CASUARINACEAE)
1. Australia, to 35 m
2. Firewood, sp. gr. .7; shade tree; river bank stabilization
3. Cool tropics to warm temperate; 500 mm min.
4. Can be weedy (Florida) 2n=18

CASUARINA EQUISETIFOLIA L. (CASUARINACEAE)
1. Australia and Pacific Isl. to India; to 35 m
2. Firewood, charcoal: sp. gr. 1.0, "best in world"; windbreak; timber for postwood
3. Warm tropics, coastal areas; typhoon tolerant, very saline tolerant; very saline tolerant
4. Coppices poorly?

CASUARINA GLAUCA SIEB. EX SPRENG. (CASUARINACEAE)
1. Australia (N.S.Wales to Qld.); to 20 m
2. Firewood, charcoal, fencing, piles for seawater, windbreaks in coastal areas; sp.gr. .98
3. Warm temperate to subtropics. coastal areas; salt-tolerant; heavy clay soils
4. Produces root suckers and can be weedy (e.g. Florida)

CASUARINA JUNGHUNIANA MIQ. (CASUARINACEAE)
1. Indonesia: to 30 m
2. Firewood, charcoal, poles, piling; wood splits easily
3. Tropical lowlands and midlands, forming dense forests; wide pH tolerance, moderate drought tolerance
4. Little studied: male clone (or hybrid) widely used in Thailand

DALBERGIA SISSOO ROXB. (PAPILIONOIDEAE; LEGUMINOSAE)
1. Indian subcontinent: to 30 m
2. Lumber, fuelwood, sp gr. .68
3. Warm tropics, mesic or arid (to 500 mm min); yields fast for a Dalbergia, slow by other standards
4. Slow growth 2n=20

N.B. / Cajanus cajan

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ERYTHRINA BERTEROANA URBAN (PAPILIONOIDEAE; LEGUMINOSAE)
1. Tropical America: to 10 m; small crown
2. Live fence posts; soft wood which accepts wires and nails well; forage; windbreaks; easily cloned
3. Lowland and submontane moist tropics to 2000 m; usually in wetter areas but needs good drainage
4. Fast growth; resistant to wind 2n=42

ERYTHRINA FUSCA LOUR. (PAPILIONOIDEAE; LEGUMINOSAE)
1. C. & S. America, to 30 m; broad crown
2. Shade for coffee and cacao; live fenceposts; soft wood
3. Lowland moist tropics to 1500 m; often in swamps or on poorly drained clayey soils
4. Fast growth; effective green manure; easily cloned 2n=42

ERYTHRINA POEPPIGIANA (WALPERS) O.F. COOK (PAPILIONOIDEAE; LEGUMINOSAE)
1. S. America to Panama; to 40m
2. Shade for coffee, ornamental; soft wood; paper pulp; forage, mulch
3. Dry to mesic tropics, to highlands
4. Fast growth; coppices and clones easily 2N=42

GLIRICIDIA SEPIUM (JACQ.) WALP. (PAPILIONOIDEAE; LEGUMINOSAE)
1. S. and C. America; small tree to 10 m
2. Firewood, timber, sp. gr. .75, fodder, shade, ornamental; easily propagated by cuttings, living fence, to 8 m3/ha/yr
3. Dry to humid tropics (1000 mm min), also saline areas
4. Toxic bark/seeds/roots; aphids on foliage 2n=20

INGA VERA (L.) BRITTON (PAPILIONOIDEAE; LEGUMINOSAE)
1. Caribbean, C. America; to 20 m
2. Shade for coffee, fuelwood (sp. gr. .75), timber, shade, honey relatively fast growth
3. Humid tropics (1000 mm min?), lowlands
4. Little studied

INTSIA BIJUGA (COLEBR.) O. KUNTZE (CAESALPINIOIDEAE; LEGUMINOSAE)
1. Southeast Asia, E. Africa, India; to 40 m, buttressed
2. Handsome timber, decking, truck bodies ("ipil" in Philippines), highly resistant to rot; slow growth
3. Moist tropics, prob. 2000 mm min;
4. Genetic variability 2n=24

LEUCAENA DIVERSIFOLIA (SCHLECHT) BENTH. (MIMOSOIDEAE; LEGUMINOSAE)
1. C. America, to 18 m (with shrubby variants)
2. Fuelwood (est. .5 sp. gr.), shade, forage
3. Dry to mesic tropics, prob. 500 mm min, to midlands (1500 m)
4. Little studied, great genetic diversity 2n=52

LEUCAENA LEUCOCEPHALA (LAM.) DE WIT (MIMOSOIDEAE: LEGUMINOSAE)
1. C. America and Mexico, to 10 m (with shrubby variants)
2. Fuelwood, nurse tree, forage, small timber and pulpwood; sp. gr. .55, some food use (pods, seeds, leaves), energy plantations, yields to 50 m^3/ha/yr
3. Dry to mesic tropics, 500 mm min, lowland
4. Widely studied 2n=104

MIMOSA SCABRELLA BENTH. (MIMOSOIDEAE; LEGUMINOSAE)
1. S.E. Brazil & Argentina; to 12 m, thornless
2. Fuelwood, pulpwood, ornamental; shade for coffee; rapid growth?
3. Mid-elevation cool tropics and subtropics (flourishes at 2400 m, Guatemala)
4. Little studied

PARKIA JAVANICA (LAM.) MERRILL (MIMOSOIDEAE: LEGUMINOSAE)
1. Indo-Malaysia, Philippines: now widely pantropical; to 40 m, umbrella crown
2. Timber, ornamental, seeds used in local medicine
3. Humid tropics to 1000 mm; 500-700 m elevation
4. Pest-tolerant: protected in Indonesia (also known as P. roxburghii G. Don.)

PARKIA SPECIOSA HASSK. (MIMOSOIDEAE: LEGUMINOSAE)
1. Thailand, Malaysia; to 15 m, thin crown
2. Food (seeds from large pods)
3. Humid tropics, to 1500 m elevation
4. Seeds often insect infested; slow growth; apparently hybridizes with P. javanica; recalcitrant seed

PARKINSONIA ACULEATA L. (CAESALPINIOIDEAE: LEGUMINOSAE)
1. Americas; to 20 m, spreading
2. Fuelwood; fodder; ornamental; fences; local medicine
3. Widely adapted, to moist tropical and dry areas, also sandy and saline soils
4. Very thorny; weedy in Argentina 2n=28

PITHECELLOBIUM DULCE (ROXB.) BENTH. (MIMOSOIDEAE; LEGUMINOSAE)
1. C. to S. America, to 20 m, irregular and untidy spreading tree
2. Fuelwood (to 5500 kcal/kg), smoky; forage, construction postwood, shade (thorny hedges), food (pods), some tannin and oil (seeds)
3. Very wide adaptability, from dry to humid tropics and to cooler elevations (Sn. Florida)
4. Thorny (segregating), poor form 2n=26

PONGAMIA PINNATA (L.) PIERRE (PAPILIONOIDEAE: LEGUMINOSAE)
1. Indian subcontinent, Malaysia, China, Tropical Asia; to 8 m
2. Firewood, fodder (leaves), oil (seeds), pest control (leaves), shade tree, medicine
3. Mesic tropics (min. 600mm), saline tolerant; to full height in 5 yrs.
4. Aggressive spreading roots; also known as Derris indica (Lam.) Bennet

PROSOPIS ALBA/CHILENSIS "Complex"
(Includes P. alba Griseb. and P. chilensis (Mol.) Stuntz; also P. flexuosa and P. nigra)
1. Argentina, Paraguay, Chile, S. Peru; to 15 m
2. Firewood, occasional use as timber; fodder (pods); to 12 m3/ha/yr
3. Cool dry subtropics (200 mm min); to 3000 m in Peru
4. Thorny (segregating) 2n=28

PROSOPIS CINERARIA (L.) DRUCE (MIMOSACEAE; LEGUMINOSAE)
1. India, to 9 m, thorny, spreading
2. Firewood, excellent charcoal; fodder, some timber; green manure, yields to 3 m3/ha/yr (under drought stress)
3. Dry hot tropics, to 100 mm min?
4. Thorny (segregating), weedy

PROSOPIS PALLIDA/JULIFLORA "Complex"
(Includes P. pallida (Humb & Bon ex Willd) and P. juliflora (Swartz) DC)
1. C. and No. S. America; to 15 m, aggressive
2. Firewood (.8 sp. gr.), exc. charcoal; fodder (pods), honey, wood, to 5 m3/ha/yr
3. Dry hot tropics, to 200 mm min; deep roots, some var. frost-tolerant
4. Thorny (segregating), often weedy (P. glandulosa and P. velutina are the mesquites of So. USA and elsewhere in tropics, often labelled juliflora in error) 2n=26,52,56

PROSOPIS TAMARUGO F. PHIL. (MIMOSOIDEAE; LEGUMINOSAE)
1. Chile, to 15 m,
2. Firewood, forage (pods, leaves), some use use (high sp. gr.)
3. Dry hot saline tropics, to 10 mm (uses fog drip?); remarkable saline tolerance
4. Slow growth, thorny but segregating?

PTEROCARPUS INDICUS WILLD. (MIMOSACEAE; LEGUMINOSAE)
1. S. E. Asia, Indo-China, Pacific IslandS; to 40 m, broad crown, lofty
2. Choice timber (narra), ornamental, furniture, flooring
3. Moist tropics; relatively fast growth
4. Needs deep soil; some diseases 2n=22

ROBINIA PSEUDOACACIA L. (PAPILIONOIDEAE; LEGUMINOSAE)
1. N.E. America, to 25 m
2. Fuelwood (dense), erosion control, nurse tree, posts, to 20m3/ha/yr; forage
3. Temperate
4. Restricted to highland tropics (little tested) and temperate regions 2n=20,22,24

SAMANEA SAMAN (JACQ.) MERRILL (MIMOSOIDEAE; LEGUMINOSAE)
1. C. & So. America, Mexico; to 40 m, wide spreading
2. Shade, timber and craftwood, food (pod), sp. gr. .52, ornamental
3. Mesic to wet tropics (to 600 mm min)
4. Not good fuelwood, rapid growth 2n=26

SESBANIA GRANDIFLORA (L.) POIR. (PAPILIONOIDEAE; LEGUMINOSAE)
1. India to SE Asia; to 10m, slender
2. Pulpwood, forage (leaves, pods), food (flower, leaves, young pods), ornamental; sp. gr. .42; to 22 m3/ha/yr, large nodules
3. Moist tropics (1000mm min), onto poor soils
4. (Genetic variability, soft wood, borer susceptibility 2n=14,24

NFTA 82-04B

ECONOMICALLY IMPORTANT NITROGEN FIXING TREE SPECIES "B" LIST

(James L. Brewbaker and Brian T. Styles, Eds.
Prepared for Bellagio NFT Workshop, Sept. 1982)

The following species were considered important economically, but of less importance than the annotated "A" list.

The first list includes species known to fix nitrogen, while the second list are not known to fix nitrogen, which may account for their absence from the "A" list.

Acacia aneura
Acacia aulacocarpa
Acacia caven
Acacia holosericea
Acacia karroo
Acacia koa
Acacia melanoxylon
Acacia peuce
Acacia pennata
Acacia salicina
Acacia seyal
Acrocarpus fraxinifolius
Adenanthera pavonina
Albizia procera
Alnus rubra
Casuarina cristata
Casuarina grandis
Casuarina obesa
Casuarina oligodon
Casuarina sumatrana
Dalbergia latifolia
Enterolobium cyclocarpum
Erythrina indica
Erythrina orientalis
Haematoxylon brasiletto
Inga edulis
Inga paterna
Lysiloma bahamensis
Mimosa tenuiflora
Pericopsis elata
Prosopis glandulosa (a complex, including P. glandulosa, P. torreyana and P. velutina)
Prosopis pubescens
Schizolobium parahyba

N-fixation unknown or uncertain:
Caesalpinia coriaria
Cassia fistula
Cassia grandis
Cassia javanica
Cassia siamea
Cedrelinga catenaeformis
Ceratonia siliqua
Cercidium floridium
Copaifera langsdorfii
Diphysa robinioides
Geoffroea decorticans
Koompassia excelsa
Peltophorum pterocarpum
Pithecellobium jiringa
Sindora javanica
Tamarindus indica

Fodder trees for Nepal hills

Source: Kessler (1981)

Albizzia mollis

Artocarpus lakoocha

Bassia butyracaea

Bauhinia longifolia
B. variegata

Brassiopsis hainla

Castanopsis hystrix
C. indica
C. tribuloides

Erythrina arborescens

Ficus lacor
F. nemoralis
F. glaberrina
F. roxburghii
F. semecordata

Litsea citrate
L. polyantha

Morus alba

Prunus cerrasoides

Quercus incana
Q. lamellosa

Salix spp.

Sarauria nepaulensis

Schima wallichi

Savanna trees of nutritional importance in Nigeria

Source: Okafor (1980)

No.	Species	Family	3	4	5	6	7	8	9	10
1	*Lannea microcarpa*	Anacardiacea			X					
2	*Pseudospondias microcarpa*	"			X					
3	*Sclerocarya birrea*	"			X					X
4	*Spondias mombin*	"			X					
5	*Annona senegalensis*	Annonaceae			X		X			
6	*Hexalobus monopetalus*	"			X					
7	*Balanites aegyptiaca*	Balanitaceae			X				X	X
8	*Kigelia africana*	Bignoniaceae					X			
9	*Adansonia digitata*	Bombacaceae	X	X	X	X		X		X
10	*Bombax costatum*	"			X		X			
11	*Ceiba pentandra*	"	X	X	X	X				
12	*Canarium schweinfurthii*	Burseraceae			X					
13	*Afzelia africana*	Caesalpinaceae				X				
14	*Brachystegia eurycoma*	"				X				
15	*Daniellia oliveri*	"	X							
16	*Detarium microcarpum*	"			X	X				
17	*Dialium guineense*	"			X					X
18	*Tamarindus indica*	"			X					X
19	*Crateva adansonii*	Capparidaceae	X		X					
20	*Parinari curatellifolia*	Chrysobalanaceae			X					
21	*Diospyros elliotii*	Ebenaceae			X					
22	*Diospyros mespiliformis*	"			X					
23	*Antidesma venosum*	Euphobiaceae			X					
24	*Irvingia smithii*	Irvingiaceae				X				
25	*Strychnos innocua*	Loganiaceae			X					
26	*Strychnos spinosa*	"			X					
27	*Parkia clappertoniana*	Mimosaceae			X	X				X
28	*Prosopis africana*	"				X				
29	*Ficus capensis*	Moraceae	X		X					
30	*Ficus polita*	"			X					
31	*Moringa oleifera*	Moringaceae	X				X			
32	*Syzygium guineense* var. *macrocarpum*	Myrtaceae			X					
33	*Borassus aethiopum*	Palmae			X	X		X	X	X
34	*Elaeis guineensis*	"			X	X			X	X
35.	*Phoenix reclinata*	Palmae			X					X
36.	*Raphia sudanica*	"			X					X
37.	*Pterocarpus santalinoides*	Papilonaceae	X							
38.	*Ziziphus mauritiana*	Phamnaceae			X					
39.	*Ziziphus spina-christi* var. *spina-christi*	"			X					
40.	*Gardenia erubescens*	Rubiaceae			X					
41	*Nauclea latifolia*	"			X					
42	*Aphania senegalensis*	Sapindaceae			X					
43.	*Blighia sapida*	"			X					
44.	*Zanha golungensis*	"			X					
45.	*Butyrospermum paradoxum* subsp. *parkii*	Sapotaceae			X				X	
46	*Pachystella brevipes*	"			X					
47.	*Sterculia tragacantha*	Sterculiaceae	X		X					
48.	*Grewia bicolor*	Tiliaceae			X					
49	*Grewia mollis*	"		X	X		X			
50	*Celtis integrifolia*	Ulmaceae	X		X					
51.	*Vitex doniana*	Verbenaceae	X		X					

*Parts Edible

3: Leaves, 4: Bark, 5: Fruit, 6: Seeds, 7: Flowers, 8: Roots, 9: Oil, 10: Local beverage

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LIST OF USEFUL JOURNALS - compiled by P.J. Robinson

Abstracts on Tropical Agriculture

Advances in Agronomy

African Journal of Agricultural Sciences

African Journal of Ecology

Agricultural Meteorological

Agricultura Tropica et Subtropica

Agrindex

Agritrop

Agro-ecosystems

Agroforestry

Agroforestry Review

Agroforestry Systems

Agronomic

L'Agronomié Tropicale

Agronomy Abstracts

Agronomy Journal

American Horticultural Society Procs.

American Journal of Botany

Annali dell'Instituto Sperimentale per la Frulticoltura

Annals of Arid Zone

Annals of Botany

Annual Review - Rubber Research Institute of Sri Lanka

Annual Scientific Report, Tea Research Association, India.

Agricultural Abstracts

Applied Botany Abstracts

Apricot, Pear and Peach Growers Association
Journal

Arboricultural Journal

Arboriculture Fruitière

Arid lands abstracts

Arid lands Newsletter

Australian Forest grower

Australian Forestry

Australian J. of Agricultural Research

Australian Journal of Botany

Australian Journal of Experimental Agriculture
and Animal Husbandry

The Bean Bag

Beitrage fur Tropischen und subtropische
Landwirtschaft und Tropenveterinarmedizin

Biology Nitrogen Fixation Bulletin

Biomass

Boiset Forêts des Tropiques

Bostid Library News

Bulletin d' Information. Institut National de
Recherche Forestiere - Tunis

Bulletin of the International Group for the
Study of mimosoideae.

Bulletin de Recherches Agronomiques de
Germbloux

Cactus and Succulent

Café, Cacao, Thé

Caliers d' Agriculture Pratique des Pays
Chaux

Canadian Journal of Forest Research

Castanea

Central Institute of Medicinal and Aromatic
Plants - Newsletter - CIMAT -

Ceylon Coconut Planters Review

Ceylon Coconut Quarterly

Citrus and Subtropical Fruit Grower

Cocoa Growers Bulletin

Coco y Palma

Commonwealth Forestry Review

Desert Plants

East African Agricultural and Forestry Journal

Ecological Abstracts

Economic Botany

Egyptian Journal of Horticulture

Experimental Agriculture

Experimental Horticulture

Field Crops Abstracts

Forage Research

Forest Ecology and Management

Forest Science

Forestry Abstracts

Fruits d' Ôntre Mer

Ghana J. of Agricultural Science

Haryara Journal of Horticultural Science

Herbage Abstracts

Horticulture Abstracts

Horticultural Research

ICRAF Newsletter

Indian Cashew Journal

Indian Cocoa, Arecanut and Spices Journal

Indian Coconut Journal

Indian Farming

The Indian Forester

Indian Journal of Agricultural Science

Indian Journal of Forestry

Indian Journal of Horticulture

Indian Journal of Soil Conservation

Information Bulletin, Citrus and Subtropical Fruit Research Institute

International Livestock Centre for Afica Newsletter

International Tree Crops Journal

Israel Journal of Botany

Japanese Journal of Tropical Agriculture

Journal of Agricultural Society of Trinidad and Tobago

Journal of Agriculture Tasmania

Journal d' Agriculture Tropicale et de Botanique Appliqué

Journal of the American Society for Horticultural Science

Journal of Applied Ecology

Journal of the Bombay Natural History Society

Journal of Horticultural Science

Journal of Hydrology

Journal of the New Zealand Tree Crops Association

Journal of Nigerian Institute for oil Palm Research

Journal of Plant Nutrition

Journal of Plantation Crops

Journal of Range Management

Journal Research Ludhiana

Journal of Rubber Research Institute of Sri Lanka

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Journal of Soil and Water Conservation in India

Kenya Coffee

Kew Bulletin

La Yaaran

Leucaena Research Reports

Medicinal and Aromatic Plants Abstracts

Mysore J. Agricultural Sciences

N.Z.J. Agricultural Research

N.Z. J. Forestry

Notes from the Royal Botanic Garden Edinburgh

Oleagineux

Orissa J. Horticulture

Pakistan Journal of Forestry

Papua New Guinea Agricultrual Journal

Philippines Journal of Coconut Studies

Plant and Soil

Plants Médicinales et Phytotherapie

Plant Research and Development

Proceedings of the Australian Society of Animal Production

Queensland Agricultural Journal

Queensland Journal of Agricultural and Animal Science

Reme d' Elevage Medicine Veterinaire des Pays Tropicaux

Scientia Horticulturae

Scientific Activities, Applied Research Institute, Ben Gurian University of the Neger

Seed Science and Technology

Sierra Leone Agricultural Journal

Soil Conservation Series of New South Wales Journal

Soils and Fertilizers Abstracts

South African Forestry Journal

Sri Lanka Forester

Tea

Tea Quarterly

Tropical Abstracts

Tropical Agriculture

Tropical Animal Health and Production

Tropical Grasslands

Unasylva

Weed Abstracts

Western Australia Dept. Agricultural Journal

Tropical Oil Seeds Abstracts

Turrialba

Zimbabwe Journal of Agricultural Research

Zimbabwe Agricultural Journal

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SECTION TWO

PART 2C

Guidelines for collecting the root nodules of leguminous trees

PART 2C

CONTENTS

GUIDELINES FOR COLLECTING THE ROOT NODULES OF LEGUMINOUS TREES - by Jake Halliday

Introduction

Many traits contribute to the success of a tree species. Some leguminous tree species have the comparative advantage that in infertile soils they can be self-sufficient for their nitrogen supply. This is by virtue of their symbiotic association with root nodule bacteria (rhizobia) that can fix nitrogen.

Exceptional performance of a leguminous tree in a particular niche may well be a manifestation of an especially effective match between the tree host and the specific strain of *Rhizobium* occupying its nodules. Thus a plant explorer who collects seed alone should not expect to see the full potential of the tree accession in subsequent evaluations unless some attempt is made to reconstitute an equally effective symbiosis.

Commonly, an introduced crop or forage legume fails to encounter effective native strains, and/or nodulate effectively with available inoculants, in a new environment. Such nodulation problems will certainly turn up when some tree species are used in new sites. Knowledge about the need to inoculate trees is improving but is not keeping pace with the expanding array of species being collected and evaluated around the world. Experience shows that nodulation failures can be avoided if strains of *Rhizobium* which are genetically and geographically affiliated with their hosts can be made available for use as inoculants. Thus nodule *(Rhizobium)* collection should be undertaken as a routine procedure by plant explorers when they are collecting seeds.

These guidelines are for plant collectors with no background in microbiology and who do not have back-stopping in legume bacteriology from their home institute/organization. The following instructions describe how a sample should be taken in the field shipped to a receiving laboratory offering *Rhizobium* isolation, evaluation, and preservation services. The instructions should be followed closely to favor successful isolation of the rhizobial strains and also to comply with quarantine protocols applying to the receiving laboratory.

Because of the risks of loss or damage during shipment of samples, plant collectors are encouraged to seek microbiological support from an existing laboratory (e.g. Plant Pathology) at their home institute. For those who are new to handling rhizobia, a separate publication available from the author, details the field and laboratory methods for isolation of *Rhizobium* from nodules, for characterizing the strains in pure culture, for conserving strains in a *Rhizobium* collection, and for testing their nitrogen fixation effectiveness.

Preparation for a collection trip

Ideally a trip to collect root nodules of leguminous trees should take place in the season of vegetative plant growth and adequate soil moisture. This is when legume roots have active nodules and is also the time when the soil is easiest to dig for nodules. But this may not always be possible, since plant exploration is usually conducted in the dry season to facilitate seed collection. Unfortunately, at this time most legumes carry only a reduced nodule complement (if any) and the soil may be dry and baked hard.

It may be necessary to undertake a separate expendition specifically to collect nodules for a tree accession of special interest if the nodule and seed-collecting season do not coincide. Therefore, it is imperative that collection site documentation be sufficiently explicit to permit the exact location and, ideally, the same plant to be re-visited in a different season.

Material and Equipment

The materials required during a nodule collection trip depend on its duration. On trips that are completed in one day, the following are needed: spade; knife; permanent marker; field book; and a selection of polyethylene bags. For trips of up to two weeks, collection vessels (Figure 1) are needed in addition to all the items already listed. For longer trips it is best to forward samples at intervals to the receiving laboratory and this requires packaging materials and sterlizing solution (alcohol or bleach).

Collection

When collecting from roadsides and other disturbed sites, be aware that the soil conditions, plant performance and nodulation may not be typical of the

region. Having located a leguminous tree that is of sufficient interest to prompt you to collect seed, take the following approach:

- If you are dealing with a tall, mature tree, are there any superficial roots (in the leaf litter?) that have nodules? Make sure of course that the roots belong to the tree of interest.

- Are there any seedlings of the tree that can be dug up easily and do they have root nodules?

- If the answers to the above are "no" then it is best to retrieve a sample of a few grams of soil from which it may be possible for the receiving laboratory to isolate rhizobia by an indirect procedure later.

- Has the species ever been reported to nodulate? A masterlist is available from the author. If "no" and you have observed nodules then it becomes very important to confirm that the tree is really the species you think it is, and that nodules occur on the roots of that tree. The receiving laboratory should be advised of the "new nodulation report" so that special care care can be taken to isolate and authenticate the *Rhizobium*.

When it is possible to deliver the sample to the receiving laboratory on the same day, it is simplest to excavate some nodulated root together with the adhering soil and pack it firmly into a polyethlene bag for transport to the laboratory. The receiving laboratory will then isolate from the fresh nodules, or store a sample of the nodules for subsequent isolation.

For trips of more than one day, collected nodules must be prevented from decomposing and protected from invasion by soil microorganisms which interfere with subsequent isolation procedures. Segments of the nodulated root (again, be sure it belongs to the proper tree!) may be collected in the field, stored temporarily in a plastic bag with moist soil, and transferred later to nodule collection vessels. Alternatively they may be retrieved in the field and transferred directly to the collection vessels.

Do not expect to locate nodules on the main rootstock of tree species. Nodules of most legumes have a finite life span, and a maturing root that

may have borne nodules when younger, no longer has the anatomy that would permit reinfection and nodulation. Nodules on tree species can sometimes be located by following a lateral root out to the zone of new growth. This zone may be a long way from the trunk of the tree. Do not expect to find nodules on a sampling plant that has been pulled out of the ground by force. In most species, the connection between the nodule and root is extremely tenuous. Careful excavation (archeologist style) gives best results.

Sample only fresh, firm nodules and avoid taking samples of those which are damaged or decaying, since routine isolation procedures are unsuccessful with such material. If the root to be sampled is abundantly nodulated, section some of the nodules to check for white (= ineffective), pink (= effective), or green (= no longer fixing). Sectioned nodules are of no value for subsequent isolation, and can be discarded. If the root to be sampled bears only a few healthy nodules, it is more important to collect these than to section them to describe their pigmentation.

The inner pigmentation is sometimes visible through the semi-opaque nodule periderm making it easy to pick active nodules for sampling. Try to collect at least 20 nodules per tree. There are two reasons for this. First, it increases the chances of obtaining a viable isolate for a particular species. Second, sometimes only a small proportion of nodules from a single tree contain rhizobial strains that are highly effective at nitrogen fixation. This is not surprising, given the range of effectiveness of strains in the soil population of *Rhizobium* that may infect a native leguminous tree.

Snip the root about 0.5 cm on either side of the nodule so that small root tails are still attached (as in Figure 1). This aids manipulation of the nodules later and also prevents the direct ingression of contaminants which can occur at a cut or damaged nodule surface. Use scissors or a sharp knife to cut the root. Even very fine tree roots can be amazingly resistant to attempts to break them away with fingers. Such efforts usually result in compression damage to the nodules which makes it impossible to isolate rhizobia later. Shake or rub away any adhering soil from the nodules. Blot dry any excess moisture, particularly if you had washed the roots to locate nodules. All of the nodules from a single tree go into the same vessel. Under no circumstances should nodule samples from different plants be combined. The cap on the vessel should be tightly

sealed. Label the vessel with a specimen number that relates it to the documentation of its tree accession and site or origin.

Collecting trips of more than 14 days in duration can pose special problems. No definitive data are available on the loss of viability by rhizobia in desiccated nodules during storage. This specification of 14 days as a safe limit is somewhat arbitrary and probably conservative. A collector who will be away from home base for two weeks or longer should either dispatch samples to a collaborating laboratory periodically over the trip or make isolation enroute. The former is the only practical option unless the collector is prepared to learn some field isolation procedures.

Sample vessels that are to be mailed to a receiving laboratory should be surface sterilized by wiping the outside with alcohol or bleach. This is to reduce the risk that the vessels have pathogenic organisms adhering to them. The receiving laboratory takes responsibility for quarantine and destruction of pathogens inside the vessel adhering to the nodule samples.

Documentation

Most of the information required for nodule collection is the same as would be noted in any case by a plant explorer collecting seeds. The data sought by the NifTAL receiving laboratory for documenting a *Rhizobium* strain is indicated in Figure 2. Figure 3 gives an example for a completed entry. The plant collector contributes the items marked * and the receiving laboratory progessively completes the record. Collection site data should be forwarded with the nodule samples.

Receiving laboratories

There are several soil microbiology laboratories that have *Rhizobium* culture collections including strains for nitrogen fixing trees. These laboratories may be willing to handle limited numbers of isolations as a service to plant explorers if they have a shared interest in the tree germplasm being collected and its rhizobial partner.

Within the framework of the network of Microbiological Research Centres (MIRCENs) sponsored by

by Unesco, several laboratories specialize in Rhizobium germplasm preservation. Among the MIRCENs, the University of Hawaii NifTAL Project has a special interest in *Rhizobium* strains for leguminous trees. NifTAL is willing to receive nodules from plant collectors for isolation evaluation and preservation. Strains and related data are continuously available to the original collector for his/her own purposes.

When intending to utilize the services of a receiving laboratory, it is essential to communicate with the collaborating laboratory at the planning stage of the collection trip. Provide information on the approximate number of samples to expect and of any special emphasis with respect to species or soil type from which material will be collected. Comply fully with instructions from the receiving laboratory on mailing instructions. In the case of NifTAL, mailing instructions and quarantine labels are sent to collectors. Only materials entering Hawaii by approved quarantine channels will be released to NifTAL for handling.

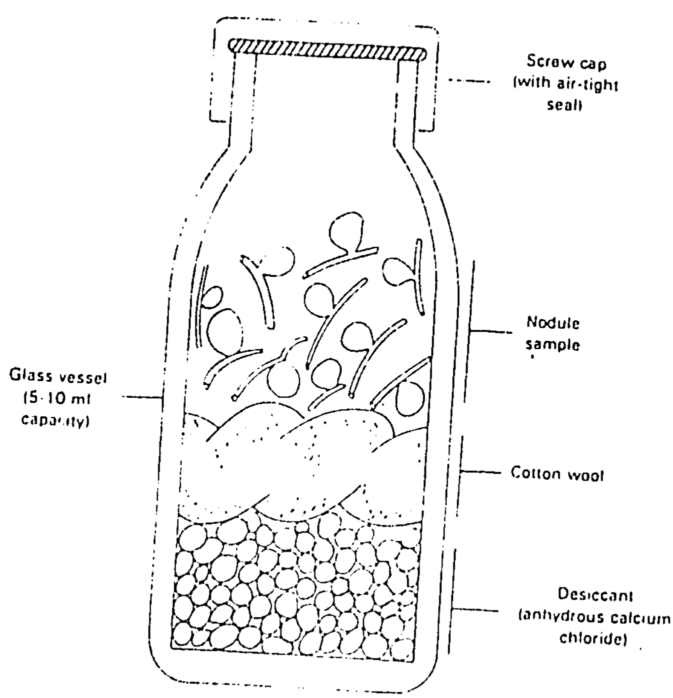

Figure 1 Vessel for storing nodules

Figure 2. Descriptors required by NifTAL for strains of *Rhizobium*.
Items to be provided by the collector are marked "*"

RHIZOBIUM GERMPLASM RESOURCE - University of Hawaii NifTAL Project and MIRCEN — Rhizobium strain TAL ____

Rhizobium strain TAL ____

Receipt by NifTAL ______

Form received: ______

Parent host : * ______

Common names : * ______

Courtesy of : * ____(collector's institute)____

Collected : * ____(location where collected)____

Subfamily : * ______

Uses : * ______

From : *(collector's name)_

(* ____(site data)____)

Fast/slow grower : ______

Acid/alkali producer : ______

Culture form : ______

Last purity check : ______

Host for authentication : ______

Other host tests : ______

Effectiveness : ______

Comments : ______

This strain also known as : ______ Collected in : ______

Availability of antisera : ______ Availability of antibiotic resistant mutants : ______

Enquiries : University of Hawaii, NifTAL Project and Mircen, P.O. Box O, Paia, Hawaii 96779, U.S.A.

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Figure 3. Example of a completed *Rhizobium* germplasm record.

RHIZOBIUM GERMPLASM RESOURCE - University of Hawaii NifTAL Project and MIRCEN — Rhizobium strain TAL 1000

Rhizobium strain TAL 1000

Receipt by NifTAL 9/78
Form received: slant

Parent host : Arachis hypogaea
Common names : peanut
Courtesy of : NifTAL Project, Maui, Hawaii
Collected : 1978 at Hamakuapoko, NifTAL field site

Subfamily : Papilionoideae
Uses : grain legume
From : Dr. P. Singleton
(Typic Haplustoll, pH 6.9

Fast/slow grower : slow
Acid/alkali producer : alkali
Culture form : lyophilized
Last purity check : none

Host for authentication : — Effectiveness :

Arachis hypogaea........................ fully effective

Other host tests :

Macroptilium atropurpureum.............. fully effective
Vigna unguiculata....................... fully effective
Lablab purpureus........................ fully effective
Vigna acontifolia....................... fully effective

Comments : Sensitive to 4 degree C storage in peat inoculants. Very effective on Burpee, Spanish, and Florunner cultivars of peanut.
This strain also known as : NifTAL original — Collected in : Hawaii, USA

Availability of antisera : yes — Availability of antibiotic resistant mutants : special order only

Enquiries : University of Hawaii, NifTAL Project and Mircen, P.O. Box O, Paia, Hawaii 96779, U.S.A.

Table 1. Laboratories with *Rhizobium* collections that include strains for nitrogen fixing trees

AUSTRALIA

CSIRO Cunningham Laboratories, Mill Rd., Saint Lucia, Brisbane, Queensland, Australia 4067. (R.A. Date)

BRAZIL

EMBRAPA, 23460 Seropedica, Km 47, Rio de Janiero 20000, Brazil (J. Döbereiner)

MIRCEN, UFRGS, Caixa Postal 776, 90.000 Porto Alegre, Rio Grande do Sul, Brazil. (J.R. Jardim Freire).

COLOMBIA

CIAT, Laboratorio de Microbiologia de Suelos, A.A. 6713, Cali, Colombia. (R. Bradley)

KENYA

MIRCEN, University of Nairobi, Dept. of Soil Sciences, P.O. Box 30197, Nairobi, Kenya. (S.O. Keya).

SENEGAL

ORSTOM, Boite Postal 1386, Dakar, Senegal. (Y.R. Dommergues)

THAILAND

MIRCEN, TISTR, 196 Phahonyothin Rd. Bangken, Bangkok 9, Thailand. (A. Poonsook)

UNITED KINGDON

Soil Microbiology Department, Rothamsted Experiment Station, Harpenden, Herts, AL5 2JQ England. (J.E. Beringer)

USA

NifTAL Project and MIRCEN, P.O. Box "O", Paia Hawaii 96779. USA (J. Halliday and P. Somasegaran)

Nitragin Co., 3101 W. Custer Ave., Milwaukee, Wisconsin 53209 USA (R.S. Smith)

USDA, Cell Culture and Nitrogen Fixation Lab., Beltsville, Maryland 20705, (D.F. Weber and H.H. Keyser)

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GUIDELINES FOR COLLECTING THE ROOT NODULES OF LEGUMINOUS TREES.

Jake Halliday

University of Hawaii NifTAL Project, P.O. Box O, Paia, Hawaii 96779, U.S.A.

Introduction

Many traits contribute to the success of a tree species. Some leguminous tree species have the comparative advantage that in infertile soils they can be self-sufficient for their nitrogen supply. This is by virtue of their symbiotic association with root nodule bacteria (rhizobia) that can fix nitrogen.

Exceptional performance of a leguminous tree in a particular niche may well be a manifestation of an especially effective match between the tree host and the specific strain of *Rhizobium* occupying its nodules. Thus a plant explorer who collects seed alone should not expect to see the full potential of the tree accession in subsequent evaluations unless some attempt is made to reconstitute an equally effective symbiosis.

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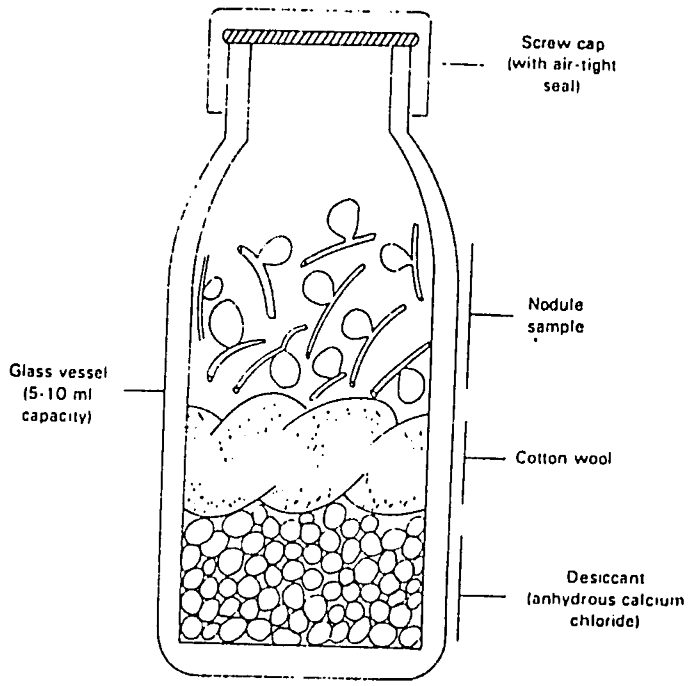

Figure 1 Vessel for storing nodules.

Figure 2. Descriptors required by NifTAL for strains of Rhizobium.
Items to be provided by the collector are marked "*"

RHIZOBIUM GERMPLASM RESOURCE - University of Hawaii NifTAL Project and MIRCEN Rhizobium strain TAL ___

Rhizobium strain TAL ____

Receipt by NifTAL ______
Form received: ______

Parent host : * ______ ______
Common names : * ______
Courtesy of : * ______(collector's institute)______
Collected : * ______(location where collected)______

Subfamily : * ______
Uses : * ______
From : *(collector's name)_
(* ______(site data)______)

Fast/slow grower : ______
Acid/alkali producer : ______
Culture form : ______
Last purity check : ______

Host for authentication : ______ ______

Other host tests : ______ ______

Effectiveness : ______

Comments : ______

This strain also known as : ______ Collected in : ______

Availability of antisera : ______ Availability of antibiotic resistant mutants : ______

Enquiries : University of Hawaii, NifTAL Project and Mircen, P.O. Box O, Paia, Hawaii 96779, U.S.A.

Figure 3. Example of a completed *Rhizobium* germplasm record.

RHIZOBIUM GERMPLASM RESOURCE - University of Hawaii NifTAL Project and MIRCEN — Rhizobium strain TAL 1000

Rhizobium strain TAL 1000	Parent host : Arachis hypogaea		Subfamily : Papilionoideae
	Common names : peanut		Uses : grain legume
Receipt by NifTAL 9/78	Courtesy of : NifTAL Project, Maui, Hawaii		From : Dr. P. Singleton
Form received: slant	Collected : 1978 at Hamakuapoko, NifTAL field site		(Typic Haplustoll, pH 6.9)

Fast/slow grower : slow	Host for authentication :	Effectiveness :
	Arachis hypogaea........................	fully effective
Acid/alkali producer : alkali	Other host tests :	
	Macroptilium atropurpureum..............	fully effective
Culture form : lyophilized	Vigna unguiculata.......................	fully effective
	Lablab purpureus........................	fully effective
Last purity check : none	Vigna acontifolia.......................	fully effective

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Comments : Sensitive to 4 degree C storage in peat inoculants. Very effective on Burpee, Spanish, and Florunner cultivars of peanut.
This strain also known as : NifTAL original — Collected in : Hawaii, USA

Availability of antisera : yes — Availability of antibiotic resistant mutants : special order only

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Enquiries : University of Hawaii, NifTAL Project and Mircen, P.O. Box O, Paia, Hawaii 96779, U.S.A.

Table 1. Laboratories with *Rhizobium* collections that include strains for nitrogen fixing trees.

AUSTRALIA

CSIRO Cunningham Laboratories, Mill Rd., Saint Lucia, Brisbane, Queensland, Australia 4067. (R.A. Date)

BRAZIL

EMBRAPA, 23460 Seropedica, Km 47, Rio de Janiero 20000, Brazil. (J. Döbereiner)

MIRCEN, UFRGS, Caixa Postal 776, 90.000 Porto Alegre, Rio Grande do Sul, Brazil. (J. R. Jardim Freire)

COLOMBIA

CIAT, Laborotorio de Microbiologia de Suelos, A.A. 6713, Cali, Colombia. (R. Bradley)

KENYA

MIRCEN, University of Nairobi, Dept. of Soil Sciences, P.O. Box 30197, Nairobi, Kenya. (S. O. Keya)

SENEGAL

ORSTOM, Boite Postal 1386, Dakar, Senegal. (Y.R. Dommergues)

THAILAND

MIRCEN, TISTR, 196 Phahonyothin Rd., Bangken, Bangkok 9, Thailand. (A. Poonsook)

UNITED KINGDOM

Soil Microbiology Department, Rothamsted Experiment Station, Harpenden, Herts., AL5 2JQ. England. (J.E. Beringer)

USA

NifTAL Project and MIRCEN, P.O. Box "O", Paia, Hawaii 96779. U.S.A. (J. Halliday and P. Somasegaran)

Nitragin Co., 3101 W. Custer Ave., Milwaukee, Wisconsin 53209 U.S.A. (R.S. Smith)

USDA, Cell Culture and Nitrogen Fixation Lab., Beltsville, Maryland 20705. (D.F. Weber and H.H. Keyser)

SECTION THREE

EVALUATION AND ASSESSMENT

PART 3A

CONTENTS

THE EVALUATION STAGE - by J. Burley

The exploration phase is concerned with sampling the geographic range of a species and examining phenotypic variation throughout the range. The objectives of the first phases of the evaluation stage are as follows.

- To estimate the extent and pattern of the genetic components of the phenotypic variation and covariation by comparative studies of a range of population samples grown on the exotic sites.
- To determine the extent and source of Population x Site interactions (synonymous with Genotype x Environment interactions (GxE), where environment effects include managerial treatments).
- If GxE effects are large, to determine the optimal species and seed sources for each site.
- To explain the variation in terms of climatic and edaphic factors at the planting sites and in the natural origins.

Later stages are likely to include increasing numbers of management variables and field measurements in order to decide about the most effective ways in which to manipulate the trees so as to achieve particular objectives with regard to a species' output or service role. This may, eventually, include the addition of field instrumentation, laboratory tests, and so on, but many of the initial investigations are best achieved through basic field management treatments.

Ultimately the evaluation stage must include specific species/provenance trials and management investigations with other potential plant associates designed to give information, and solve problems, concerning the management of the various plant species in actual agroforestry land use systems.

Planning and Control of Research* - by J. Burley

Research activities

In all species and provenance research, whether for dense plantations or agroforestry systems, planning is required at several levels. These range from an overall plan by the central coordinator of an international collaborative programme through national plans for the overall control of the investigation in relation to objectives and policies, to detailed methods and procedures for each specific experiment.

The overall plan should proceed from the definition of objectives and the broad statement of policies that will be pursued to achieve them to deal with the following:-

- The selection, grouping, phasing and designing of research projects leading to the preparation of appropriate programmes of work,
- The operational requirements for research units to put these into effect.

More detailed plans for specific experiments in projects, and for services such as experimental design, computing and analysis should be in the form of appendices to the project plan. This will increase the usefulness of the plan as an operational document and will facilitate the addition of new research and the updating or amendment of existing projects and services.

Research programmes and projects

Research programmes will differ considerably depending on the requirements of particular countries but it would be of considerable advantage, in organising or benefitting from co-operation between countries, if research programmes are compiled from considerations of an agreed standard list of the main activities in this sphere of research. It would be a further advantage if, for individual projects, the detailed procedures could also be agreed and standardized in so far as this is possible.

Outline of research activities (suggested standard list)

The main activities in species and provenance research are as follows.

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* See also Part 3C

- Assessments in the mature stage, including the following:-
    - survival
    - form and yield of individual trees and plots
    - wood quality, the factors that influence it, and their implications for utilization
    - growth form, fodder yield and characters
    - chemical observation of wood and other products
    - managerial properties (e.g. coppicing or pollarding ability)
    - effects on site
    - effects on agricultural crops.

- A review of literature, correspondence and personal knowledge of distribution and variation of species likely to be of value. Discussions with international, regional and national organisations concerned with these species.

- A choice of species and of provenances to test
  - selection of parent stands in natural forest where possible based primarily on their seed production, yield production and genetic quality and position in natural area
  - selection and management of seed stands in plantations where possible
  - procurement, treatment and storage of seed.

- Design, layout and analysis of species and provenance experiments
  - assessment and selection of sites
  - selection of systems of silviculture and standard management
  - planning and design of experiments and their interpretation
  - analysis and interpretation of actual experimental data
  - reports and dissemination of results

- Techniques and assessments in the nursery stage, including early test methods
  - nursery conditions and cultural treatments
  - design and conduct of nursery experiments
  - nursery assessments
  - early test methods including biochemical and anatomical studies, juvenile-mature correlations.

- Techniques and assessments in the juvenile to mature stages
  - definition of types of trials and their objectives
  - design and conduct of mature stage experiments

Research Management and Monitoring- Some Comments - by J. Burley

Research management and monitoring comprises the following.

- A detailed appreciation of the experimental objectives
- The use of "control plans" to carry out the experimental prescriptions
- Field management and assessment at the prescribed times
- Continuous monitoring of the health and condition of the experiment
- A capacity to "look ahead" and be prepared for unplanned events.

Objectives

Each trial should, from the planning stage, have clearly defined overall objectives for example:

"To compare the survival, growth rate and leaf production of three provenances of *Acacia tortilis* at two sites in northern Kenya"

Further amplification should also be given describing what is expected from the results especially the possibility of obtaining data on a wider variety of outputs (other products e.g. fuelwood, and/or a "service" e.g. data on microsite enrichment).

Planning and control

The experimental or "control plan" sets out the work to be done. It should be kept as simple as possible, but should contain all the essential information to enable another research worker to carry out the work. The basics are as follows.

- The objectives of the experiment translated into a step-by-step review of how the observations and measurement data to be obtained will achieve these. This may also include some outlines of the magnitude of likely errors or bias in order that the more sensitive procedures can be watched and the irrelevant ones ignored.

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- The actual detailed programme of work, phased with dates (or growth stages) for completion, and careful descriptions of how observations and measurements are to be made and recorded and how the experimental diary is to be kept.

Field management

In common with any kind of field experiment the allocation of tasks and responsibilities must be very clearly defined. Observations and data collection, which are likely to be more complex for multipurpose trees than in traditional forestry practice, must be carefully supervised and checked whether "on" or "off" station. Because the size of a research programme depends on the resources available, which are always limited, it must be kept practical from a management point of view. The need for testing a number of sites, for instance, will be balanced against logistical considerations such as maintenance. Also from the practical point of view of management *simple* statistical designs and field layouts are desirable whenever possible.

Continuous monitoring

Regular data collection needs to be supplemented by management observations by *all* field staff. They should be told what to look for in terms of general plant development, health (plant wilting or the onset of pests and diseases), accidents, unusual weather effects, etc. Such observations, both in the nursery and field stages, can give valuable guidance for future research work and early warnings can sometimes save whole experiments.

Wider issues

Any species field trial or experiment is likely to form a part of a wider national program of evaluation work on that species and on multipurpose trees (FGNFT's) in general. This wider programme will take into account the broader national objectives of agroforestry research and development and so will include the following.

- Overall objectives of the national research programme for multipurpose trees (FGNFT's) i.e. with regard to a renewable energy programme, the development of animal resources, food production or the rehabilitation of degraded lands.

- A time scale for this research and development programme (in relation to government targets for national development).

- A set of priorities for the outcome of research with MPT's (FGNFT's). That is priority regions , land use types (intercropping combinations), cash or subsistance systems etc.

- Any general limitations regarding management and labour organisation which might influence the experimental approach, assessment procedures, etc.

- Requirements for staff, materials and finance for higher priority national assignments, and so on.

Clearly any *specific* research programme has to be planned against a background of national objectives and resource allocations. It should also take into account the two-way possibilities of exchanging both information and experience on an *international* level in view of the enormous worldwide interest which MPT's (FGNFT's) have now aroused (see Appendix 1, for some international and national organisations concerned with research in this field).

The Need for Phased Trials* - by J. Burley

General considerations

More often than not adequate information is lacking either on the requirements of the species, or on the characteristics of the site, or both. In such cases embarking on agro-forestry or afforestation schemes without a carefully planned and executed experimental programme has often led to costly failures.

The choice of species to use for agroforestry involves the extrapolation of information from elsewhere. Climatic and ecological matching of a new site and the original habitat of a species is rarely enough since it cannot reveal the adaptability of the species to new conditions or its ability to grow satisfactorily in a range of sites. When information is lacking, the best way to acquire it is through trials of a number of species in *small* plots on *representative* locations within the area of the proposed afforestation project. Provided the locations are carefully selected to sample the range of planting sites and are properly looked after, extrapolation of perfomance from small plots to the whole area should involve far less risk than imprecise comparison, based on inadequate data, between widely separated regions of the world.

The advisability of species trials is now generally accepted, but the need for their careful planning and for high standards of maintenance and assessment has often been less appreciated. Species trials themselves can be wasteful and misleading if badly planned or executed and proliferation of plots, if they are ill-sited, ill-tended and ill-protected, is no substitute for a small, wisely planned programme which is tailored to the staff and financial resources available. The objective is to derive the greatest possible information from a given cost or, the other way to obtain the desired information at the lowest possible cost.

For species with naturally wide geographical or ecological ranges, provenance testing is essential. It is easy to be misled in the comparison of species for agroforestry, or for some form of afforestation (including fuelwood lots), if the total range of intra-specific variation is not known.

Identification and comparison of sites must be done on an ecological not a national basis. Results from species trials in other countries in the same climatic zone and on similar soils may

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* see also Section One

be of closer application than those from trials on completely different sites within the same country. In order to make results in one country readily interpretable in another, the value of standardizing methodology, design, methods of assessment and recording, etc, cannot be over-emphasised. The remaining parts of this Manual are intended to facilitate this standardization.

If detailed information is available on all factors significant to the success of a species in plantation and on the status of these factors at the site to be planted, it may be possible to start agroforestry or afforestation without preliminary species or provenance trials. More commonly, however, information has to be acquired gradually. Ideally, when starting from scratch, species and provenance trials should be phased according to the successions:-

Few data on species or on sites. → Increasing data on species/site characteristics

Many species and provenances tested by small plots for short periods. → Fewer species and provenances tested by increasing plot size for longer periods.

Type and duration of trials

In classical species and provenance research for industrial afforestation, distinct phases are commonly encountered and these may be required either singly (sequentially), or in combination (telescoped) or at the same time (parallel) depending on the state of knowledge of the species and afforestation sites.

The ultimate phase is, of course, the complete agroforestry or afforestation project where the source populations are reduced to one or two provenances of one or a few species and where the annual planting area is, in forestry, reckoned in hundreds of thousands of hectares. It must be recognized that there is no standard procedure or time schedule for passage through successive stages of testing; nor is there always a need to use every stage.

A comprehensive phasing in forestry research would include the following.

The species elimination phase (step 10 in the flow diagram)* is the mass screening of a large number of possible species in small plots for a short

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* See below

period (1/10-1/5 rotation) to determine survival and promise of reasonable growth. The *species testing phase* (step 11) is assigned for the critical testing or comparison of a reduced number of promising species in larger plots for longer periods (¼-½ rotation). The *species proving phase* (step 12) is designed to confirm, under normal conditions, the superiority of a few probable species. Three similar stages apply to provenance testing for species with a wide natural distribution, a *range-wide provenance sampling phase*, a *restricted provenance sampling phase* and a *provenance proving phase*. Since these are generally applied to species that are promising or probable their plot size and duration can be larger than the comparable phases of species testing.

In dealing with MPT's (FGNFT's) for land use of one kind or another the experience gained from forestry research is clearly a place from which to start We do, however, have a range of different end-uses to which the species will be put, and a much wider range of species, of vastly different habit and growth forms, from which to chose. The experience of tree crop specialists (for example, dealing with fruits, nuts and beverage crops) and of range ecologists is also relevant, and particularly so where it comes to the later stages of evaluation that involve management treatments and testing for agroforestry systems.

Although the research phases mentioned above apply, in principle, also to multipurpose trees in agroforestry situations, four levels of experimentation are considered in this manual which are covered by the individual steps in the accompanying flow diagram (see the end of the Section).

- Introductory "Elimination" field trials (step 10) maintained for 1 or 2 years, to determine the capability of each population to withstand the initial transplanting shock and to become established under local conditions of site and management. Again these apply to as many natural origins and land races of each species as it is possible to obtain. In view of each species urgency for placing MPT/FGNFT species in trials in as many sites as possible, and the low probability of obtaining range wide provenance collections for many of the species, the sequence of species and provenance trials outlined above are not mandatory.

- Vigor/phenology field trials (Step 11) of the most promising (8-10) sources observed in the elimination field trials, and perhaps in large replicated plots, under the expected "best" management treatments, assessed for all production characters over several rotations.

- Performance/management trials (Steps 12a & b) where optimum management techniques are worked out with regard to individual species, potential sites and end-uses. These will also include nursery experiments (which may also include some comparisons in the field with directly sown material); these apply to all seed sources collected.

- Intercropping trials with mixed tree/crop components:- First to determine the optimum mixture of trees and agricultural crop species (Step 16), second to obtain initial information on their possible "design" factors for various types of agroforestry systems (intercrop screening trials); and third, to include or proceed to full management trials (Step 18) with mixed tree/crop components to evaluate the best ways of handling the species mixtures in actual agroforestry systems.

Taxonomy* - by J. Burley

As shown in the Section on "Exploration" considerable material sampling and taxonomic expertise may be required in the exploration phase to determine taxonomic identities, affinities and phenotypic variation patterns between and within species. Obviously the correct identity, nomenclature and origin are essential items of information that should be recorded for all seeds lots and all plantations derived from them.

However, taxonomic studies should not stop at the exploration phase. Similar material (standard herbarium specimens of flowers, fruits, leaves, twigs and bark) should be collected from representative samples in each population in all elimination field trials (juvenile material from all seed sources) and growth trials (mature material from the most promising populations). When compared with and between plantations sites these determine the rigidity of genetic control (e.g. the plastic or conservative nature) of the standard taxonomic traits and hence confirm or reject the hypotheses based on phenotypic variation in the natural range.

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* A taxonomic character is any attribute of an organism which can be evaluated, referring to structure, form or behaviour and which has two or more discountinuous states or conditions e.g. morphological character of the flower such as shape of a petal, stamen number of length or a leaf. Strictly speaking, characters as such are abstract entities it is their expressions or states which taxonomists deal with in their classifications. Plant characters are normally listed in the flora descriptions and the diagnostic ones are used in keys for identification. The value of a taxonomic character is increased if its biological significance has been determined but the significance of most characters is still unknown or poorly understood. Some characters are very stable and show little variation from individual to individual and from generation to generation. Such are those of the flower and fruit in angiosperms and the female cone in gymnosperms and which are used extensively in the identification and classification of these groups. Morphological features of vegetative organs, stems, leaves, bracts, etc. which tend to be much more variable and affected by the environment are important at levels below that of the species, e.g. in describing intra-specific variation.

For a further discussion on taxonomic evaluation see Styles*. In particular he described the categories of population variation including ecospecies, ecotype, cline, deme, provenance and cultivar; he did not include the term "land race", which was described in a previous section and which is commonly used in agriculture; it is virtually synomynous with "derived provenance"

In addition to the morphological characters used in classical taxonomy, chromosomal characters, pollen morphology, biochemical products and anatomical features are becoming more widely used as taxonomic traits since sophisticated analytical methods and equipment are becoming cheaper, more widely available and taught at post-graduate level; these include gas chromatography for primary and secondary metabolic products, electrophoresis and electrofocussing for primary gene products, DNA/RNA analysis for genetic structural components, and both transmission and scanning electron microscopy for fine structure of surface, cells and tissues.

Despite the importance of taxonomy, with many species of MPT's in the early stages of their evaluation a very wide range of useful features, (such as vigour) is found. These differences may be of far greater economic inportance than classical taxonomic differences.

Styles, B.T. 1976. Taxonomic and biosystemaic studies pp. 15-25 in "A Manual on Species and Provenance Research with Particular Reference to the Tropics" (Eds. J. Burley and P.J. Wood) Trop. For. Pap. No. 10. CFI, Oxford.

- and see also Appendix 2 for plant nomenclature.

IMPLEMENTATION FLOW CHART FOR STEPS IN EVALUATION OF MULTIPURPOSE WOODY PERENNIALS.- by P.A. Huxley

The flowchart at the end has been prepared in order to draw together some of the point raised earlier about field trials with MPT's, and to combine these with the usual considerations of planning and resource appraisal undertaken when undertaking an experimental programme.

The steps have been elaborated in some detail much as an "aide memoire ". Clearly some have more weight than others, but they are all part of the logical process of planning and implementing a sound experimental programme. If the researcher wishes to "skip" some sections he may chose to do so, but this should be done knowingly and not by default!

Circles represent inputs (e.g. of information and/or germplasm) rectangles "action steps", parallelgrams are "states" and diamonds are "decision processes". Fig. 1 gives an outline of main flowchart sequences.

Following on from the implementation flowchart presented in Section 2 outlining a national strategy for MPT exploration we can assume that there is at least some assess to existing information about both indigenous and exotic MPT species (and, in fewer cases at present, provenances), together with a knowledge of how to obtain supplies of the required, authenticated germplasm.

The latter may present some difficulties at the present time and the reader can be directed to the Proceedings of the Planning Workshop on MPT Germplasm* for a fuller account of these. Also, to Part 4A of this manual which includes some preliminary ideas about the problems of chosing appropriate species and provenances of MPT's.

Notes on the various steps

1 to 5 These arise from and/or relate to the processes involved in chosing appropriate species/provenances. In particular, for Step 1, the choice of provenance may offer an opportunity to extend the accepted range in which a species is generally found to be adapted in its indigenous state (see Part 4A).

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*Held in Washington D.C. USA June 1983 by ICRAF/IBPGR/CFI/NAS.

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Figure 1: OUTLINE OF MAIN FLOWCHART SEQUENCES
(see back of this chapter for the flowchart itself)

Steps	Process	Results
1 - 5	Information and germplasm acquisition →	Selected choice of indigenous and exotics.
6 - 9	Decide on experimental objectives and match to available resources →	An experimental plan
10-12	Commence field trials to test MPT species and provenances in a logical and properly phased manner →	Sufficient research information concerning survival, adaptability vigour and productivity in relation to site and chosen levels of management
13	Evaluation of the MPT information and experimental evidence to data →	Decision to go on to mixed cropping trials or acquire more information about the MPT's first.
14-17	Examine and update, if necessary, information about other crop components and likely between plant component interactions. Carry out screening trials with mixtures, then more detailed management trials →	Determination of suitable MPT/crop species mixtures and a knowledge of how to manage them so as to optimize required outputs
18	Feasibility and acceptability trials with landuse systems →	Leading to adoption

If a detailed diagnosis is available of the land-use systems for which the MPT's are potentially useful then the "specification" arising from this will have defined the character and purpose of the woody plant component in some detail for Steps 2 to 4 (see Part 6G and refer to the manual on Diagnostic and Design Methodology" for more details of the land use diagnosis and design procedures).

The outcome, then, will be a list of MPT species/provenances which might be considered suitable, after testing as required, for the purposes and sites outlined by an initial specification.

6 to 8 This list might well be rather lengthy and the overall scope of the experimental programme has to be known, or estimated, at this stage in order to further refine it.

Depending also, for example, on the urgency with which results are required and the feasibility of "telescoping" the various parts of the programme, the question of arranging to overlap different phases needs to be carefully evaluated. In many cases it will be likely that the pressure to arrive at practical results as quickly as possible, so as to provide technical answers for development programmes, will almost certainly eliminate the opportunity to procede in a strictly stepwise fashion by completing each phase of the experimental programme before moving on to the next - this may not be strictly necessary, in any case.

Finally, the initial concepts of "end-use", together with the information gap which has initiated the need for an experimental programme in the first place, will have given rise to a set of research objectives which have, at this point, to be weighed against the resources available to achieve them.

The cost-benefit of different possible ways to provide the answers must always be assessed in terms of a) the integrity of the experimental

procedures b) the level of information required in order to achieve a satisfactory technically operational outcome at a practical level and c) the fulfillment of an adequate set of answers tailored to the socio-economic situations in which they are to be used (see also Part 6B). There may, also, be a case for considering the establishment of a sound scientific and/or technical basis for the elaboration of future experimental programmes, if this is clearly apparent at this stage. But the extent to which this can be provided for, if it does not co-incide with current goals, is probably largely dependent upon the richness or otherwise of the experimental resources available (although the possibilities of obtaining some "basic" information, e.g. about plant responses to the simple management procedures, by adding some simple, additional measurements at low cost, should never be overlooked if it can be done without straining the programme as a whole).

Especially with multipurpose tree experimentation, one should always check whether the programme is feasible before embarking on an overambitious scheme that has, later, to be curtailed. This applies, especially, because of the relatively long-term nature of the field trials involved (see Table 1 Part 1A) and the need for a *sustained* provision of experimental inputs. At this stage (Step 8) it is not too late to go back and revise the scope of the experimental plans to take into account the likelihood of future budget cuts, the loss or transfer of skilled project personnel, the breakdown of equipment that is not easily maintained (and on which the acqusition of essential data depends), and so on. Basically, this is an assessment of risk.

9 Experimental plans can be very varied depending, to some extent, on the scope of the programme and the amount of detail to be included that personal preferences and the level of organisational ability of support staff dictate. There are some common features that can be listed as generally desirable, such as stating or defining the following.

- A title
- Project leader/s and other participants
- Location/s and dimension and characteristics of site/s
- Objectives
- Goals (summary of outcome and in what form/s and when)
- Time plan/s of operations
- Support personnel required and when
- Equipment/facilities required and when
- Germplasm sources and plant acquisition/plant raising requirements and provisions (in detail).
- The full description(and map) of the chosen experimental layout.
- Planting out and subsequent plant/soil management procedures to be conformed to.
- Main procedures for data acquisition (mandatory).
- Supplementary data acquisition (intermittent and/or optional)
- Reporting procedures and checks
- Data processing and storage procedures including statistical analysis
- Procedures for disseminating results
- Report and accounting operations

With field trials of MPT's there is a need to be especial careful in planning (apart from choice of species/provenances) over such consideration as:-

- The acquisition of *authentic* germplasm in good time to start the field trials (and the testing of its viability.
- The treatment of young plants to ensure survival and a plant stand with minimum variability (in other than elimination/survival trials).

- Possibilities for gapping up early plant losses (and how best to do this so as to reduce variability and to avoid experimental bias).
- The need to impose a standard tree form through early training
- Assessing the needs to explore the juvenile or the mature growth stages (or both)
- The time at which records should commence (bearing in mind the, usually, high variability in the early stages of field trials with woody perennials)
- The possibilities/desirability of sequential thinning operations
- The effects of intermittent or sequential harvesting of different kinds of plant parts.
- Soil management (including times when the plants are to be coppiced)
- The scale of the field trials (in relation to land and labour resources available and the homogeneity of the experimental site/s)
- The possibility of amending management treatments at a later stage when these might be made more precise and/or more information becomes available (implications for the experimental design)
- The need for guard rows/areas (both external and internal)
- The possible occurrence of particularly adverse weather features during course of the experiment (extreme droughts, floods, cyclones etc.).

- Guarding against the depredations of animals at all times (e.g. browsing animals, birds, rabbits, wild pigs, monkeys etc., and at later stages, of thefts by humans).

- Pest and disease control including termites and other soil-borne pests (in view of the scarcity of data for many MPT species).

- The likelihood of some species growing/developing/ageing faster than others.

- Evaluation of the effects of the development of the plant canopy (especially in trials on communities of plants in plots), and a clear indication of how this is to be dealt with if the extent is not previously known.

- How the yield data are to be handled if "seasonal bearing" is found to be a feature of some species but not others.

- When the trial is to be considered over.

10 to 12 It is here that a decision about some level of overlap will often be necessary. If little or nothing is known about the survival and/or adaptability of an introduced species (and this includes species or provenances indigenous to a country but being grown outside their natural range or area of natural stands). Thus it makes little sense to embark on higher orders of experimental evaluation (Steps 11 and 12) before *at least* one or two seasons of trials to assess the survival and early growth phases are completed. This applies with even more force to embarking on intercropping trials (Step 16).

In practice, more may well be known about some of the species/provenances selected for a field trial and less about others. In this case a decision has to be taken on whether to include a few "unknowns" at the risk of leaving gaps in the trial later if some do not survive, or have to be ignored due to

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the onset of extreme variability, (perhaps using a layout such as the "augmented designs described in Part 3C), or whether to plan for two separate trials for "unknowns" and "knowns" respectively.

The experience gained from elimination trials in industrial forestry research would indicate that merely "matching-up" tree species according to similarity of ecozone in the countries of origin and introduction may not always result in success, and *vice-versa* (This is due to a number of reasons and the reader is referred to some of the papers given in the selected references for further reading).

Nomenclature

An explanation may be required for the nomenclature used in this flowchart (and the manual as a whole) with regard to the main types of trials. (See also "Research Management and Monitoring" earlier on in this Part). Although "Elimination Trials" (Step 10) are coincident in scope with those normally carried out by foresters, being the mass screening of relatively large numbers of species/provenances, the data collection and scope of the subsequent types of trials - "vigor/phenology trials (Step 11) and "Performance/management trials (Step 12) are likely to involve a greater degree of sophistication and research management with MPT's than their industrial forestry equipment - at least in some respects. They are, indeed, more akin to the types of field experimentation (and laboratory back-up) that tree cash crop and range management specialists are more familiar with.

This is because the potential for multiple outputs may require the acquisition of data about the production of leaves, leafy twigs, small stemwood, flowers, fruits, seeds, bark, gums and secreted compounds and medicinal products as major objectives, as well as roundwood. And the sustainability and/or service factors that may be required of MPT's may, additionally,

Steps	Forestry Trial Phases: Nomenclature	Forestry Trial Phases: Scope	Multipurpose Tree Trial Phases: Nomenclature	Multipurpose Tree Trial Phases: Scope
10	Species elimination trials and Range-wide provenance sampling trials	Mass screening in small plots or lines - short-term	Elimination trials	Mass screening in small plots - short-term
11	Species testing trials and Restricted provenance sampling trials	Reduced number of promising accessions only, in larger plots - longer-term	Vigour/phenology trials	Reduced number of promising lines of anything from single tree plots up. Especially to study plant behaviour with a view to helping assess potentials for selection (later) of plant management techniques and for preliminary assessment of output potentials ("multipurpose" traits).
12	Species proving trials and Provenance proving trials	Few selected accessions, large plots and long-term	Performance/management trials	Few selected accessions in either: a) single tree plots (if for wide-spaced systems) and/or b) Small to large plots (if for "crop" situations)
16	Not strictly applicable except, perhaps, trials on suitability of taungya-type plantation establishment methods	-	Screening intercropping trials	Tree/crop interface trials
			Management intercropping trials	Full scale plot trials with intercrops.

TABLE 1: APPROXIMATE EQUIVALENCE OF TERMS USED TO DESCRIBE CONVENTIONAL ORESTRY FIELD TRIALS AND MPT FIELD TRIALS (AS DESIGNATED IN THIS MANAUL)

of information that should be tapped. In the first place, (Step 14) there are probably considerable data available about any agricultural crop components that might be potential candidates one form or another of intercropped systems (the various alternatives in space and time are outlined in Appendix 3). However, it should be remembered that virtually all selection of genotypes for the major agricultural crops has been directed at maximizing yields, and obviating pest and disease damage, *under sole crop situations*, and certainly not for compatibility in tree/crop associations. Nevertheless, some sensible choices can be made in terms of plant stature, length of the growing season and drought and/or shade resistance (if the latter is known). There will, in nearly all cases, be a number of specific cultivars to chose from.

The basic, comparable information about the multipurpose tree will be that obtained from the published literature, communications from those with any experience elsewhere with the selected species/provenances and the results of the evaluation programme that have emerged to date. There may be rather scanty information about the performance of provenances for most MPT species, an exception being *Leucaena leucocephala* which has been the subject of world wide trials for at least a few years.

In such circumstances it is probably wise to investigate intercropping possibilities in two stages so as initially to screen, in a relatively simple way, as many possible combinations of MPT's and crops as may be required to satisfy the specifications of relevant agroforestry landuse systems; or as are required by a purely scientific evaluation of combinations chosen to establish any particular hypothesis (Step 15). This number of combinations can then be reduced to only a few and fully explored in terms of management options in a series of final tests (Step 17).

Both the intercrop screening and management trials can draw on two other sources of information (Steps 16a and 16b): a) data obtained by

interplanting existing stands of selected MPT species with crop species (obviously this tests the combinations only in the mature stages of MPT growth and does not exactly simulate what would have happened if intercropping had commenced, *de novo*, on farmer's fields); and b) information about plant compatibility obtained from detailed inventories of existing agroforestry land use systems in the world using the same (or similar) species combinations. The manipulation of mature stands of MPT's might well be considered, equally, to be in the mainstream of experimental steps in the flowchart. However, because it involves a somewhat different experimental approach to that so far covered in the manual this has not been done. Data from such investigations and from a detailed inventory of existing agroforestry land use systems can be of value to both the intercrop screening trials (to help select appropriate and compatible combinations) and, if enough detail is available, to intercrop management trials (providing guidelines for possible plant and soil management treatments)

15 and 17 The possibilities of obtaining a good deal of information about tree/crop interactions, and the potential performance of each component in the presence of the other at any one site, by "tree/crop interface" experiments is described in another part of the manual (Part 4C). At this level (the equivalent, for intercropping, of "range-wide provenance tests" for foresters, or "vigour/survival trials" for purely MPT testing) the numbers of combinations for study is still likely to be relatively large. In the next step (17) only a selected few would be further examined, but the number of possible management options (spacings, time-of-sowing, degree and time of lopping/pruning, soil management etc. etc) could be large. Possible ways of considering the selection of experimental variables, depending on the objectives of the experiment, are discussed in other parts (Part 3C "The scope and design of field trials"; 4B Compatibility in mixtures and tree/crop optimization.

Part 4D "Considerations when experimenting with changes in plant spacing" and others to follow).

18 A final step to take before implementing the results of any experimental programme is to re-examine all the experimental results in the light of the landuser's requirements. "Do they satisfy the specification obtained from the landuse diagnosis? Or, that conceptualized from the experience and knowledge of qualified informants?"

Where it is possible the plant combinations and their management "packages", should be tested in complete systems under the socio-economic state in which they are, if proved successful, to be implemented and extended. Where some of the previous work has been accomplished through on-farm trials this will clearly be easier than if all the work has been confined to research stations. The merits of achieving technical answers in one way or the other will depend on the type of experiment and the resources available. Only local knowledge of the research and farming situations can be of use here, but most experimental programmes with MPT's will, at least with some steps, involve a mixture of the two approaches.

ANNEX

PART 3A

Appendix 1:
Preliminary list of some international and national organisations that can provide information about multipurpose trees

Appendix 2:
The Scientific naming of plants

PRELIMINARY LIST OF SOME INTERNATIONAL AND NATIONAL ORGANISATIONS THAT CAN PROVIDE INFORMATION ABOUT MULTIPURPOSE TREES*

ISNAR
P.O. Box 93375
2509 AJ. The Hague
Netherlands.

IBPGR
Crop Genetic Resources Centre
Plant Production and Protection Div.
FAO
Via delle Terme di Caracalla
00100 Rome
Italy.

ICRA
P.O. Box 88,
6700 AB Wageningen
The Netherlands.

CATIE
Aptdo. 15
Turrialba
Costa Rica

IICA
Apartado Postal 55
2200 Cornado
San Jose
Costa Rica

ICRISAT
Patancheru P.O.
Andhra Pradesh 502 324
India

ICARDA
P.O. Box 5466
Aleppo
Syria

IITA
Oyo Road
P.M.B. 5320,
Ibadan
Nigeria

SEARCA
College, Luguna 3720
Manila
Philippine

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*For an extensive list see "Institute Study Nitrogen Fixing Trees" from Nitrogen Fixing Tree Association.

UNEP
P.O. Box 30552
Nairobi
Kenya.

FAO
Via delle Terme di Caracalla
00100 Rome
Italy

UNESCO
7 Place de Fontenoy
75700 Paris
France

UNU
Toho Seimei Building
15-1 Shibuya 2-Chome
Shibuya-ku
Tokyo 150
Japan

Chiang Mai University
Chiang Mai
Thailand

CFI
South Parks Road
Oxford, OX1 3RB
England

University Pertanian Malaysia
Serdang,
Selangor
Malaysia

Direksi Perum Perhutani
Jl. Gatot Subroto No. 17-18
Indonesia

IRRI
P.O. Box 933
Manila
Philippines

ILCA
P.O. Box 5689
Addis Ababa
Ethiopia

Beijer Institute
Fack S-104 05
Stockoholm
Sweden

425

VITA
3706 Rhode Island Ave.
Mt. Rainier, MD 20822
USA

Biotrop
P.O. Box 17
Bogor
Indonesia

CARE
660 First Avenue
New York
N.Y. 10016
USA

Dept. of Forestry Research Management
University of Ibadan
Nigeria.

Faculty of Agriculture and Forestry
University of Dar-es-Salaam
P.O. Box 643
Morogoro
Tanzania

Central Arid Zone Research Insitute
Jodhpur 342 003
Rajastan
India

Nitrogen Fixing Tree Association
P.O. Box 680
Waimanalo
Hawaii 96795
USA

CSIRO
Division of Forest Research
P.O. Box 4008
Canberra 2600
Australia

National Academy of Scieces
(Board on Science and Technology for International
Development)
2101 Constitution Avenue
Washington D.C. 20418
USA

- And see list of NAS Grantees in the "Fast-Growing Nitrogen-Fixing Trees" Project.

These entries are far from complete and they form the start of what will be a selected and annotated list.

29. THE SCIENTIFIC NAMING OF PLANTS

The scientific name of most plants consists of two words, e.g. *Quercus robur*, which are Latin in form, or are treated as Latin even though they are derived from other languages. The first word is common to all species of oak and is the name of the genus; the second word, or more rarely two hyphenated words, denotes the species, and is called the specific epithet. All generic names must be written with an initial capital letter and it is recommended that specific names should begin with a small one.

The method of naming plants by two words was first used consistently by Linnaeus in the eighteenth century and is known as the binomial system of nomenclature. It replaced the previous system of naming species by long descriptive phrases. Linnaeus' method is now accepted and used universally.

During the nineteenth century the flood of new species described in various parts of the world often resulted in the same plant repeatedly described as new and under different names. This caused increasing inconvenience to the users of these names, especially because of the lack of any authoritive guidance on how to choose the correct name from those available. In 1905, therefore, the International Botanical Congress then held at Vienna established the first set of International Rules of Botanical Nomenclature, designed to bring order and stability to the naming of plants. These Rules are now periodically modified or revised by a committee on nomenclature at each five-yearly International Congress.

Even to précis the Rules would take too long, but it may be helpful to mention a few of the guiding principles on which they are based. Perhaps the most important are validity and priority of publication. Thus, of two or more competing names for a species, the one published first is normally the correct one. No names before 1753 (the first edition of Linnaeus' *Species Plantarum*) are recognised unless they are taken up by an author subsequent to this date. To be validly published each taxon (genus, species or subspecies, etc.) to be named must be provided with a Latin description or at least some kind of reference to such a description.

Sometimes a new species is described in the wrong genus. When this happens the Rules demand that the second part of the name—the specific epithet—must be retained when the plant is transferred to the correct genus. Thus if somebody proposed to transfer the species *Quercus robur* to another genus, the specific epithet *robur* would have to be maintained.

In scientific works a personal name, in full or abbreviated (known as the *authority*), is often given after the Latin name, e.g. *Quercus robur* L. The "L" is a shortened way of referring to Linnaeus who first described the species *Quercus robur*. This is particularly necessary when a name has been duplicated; for instance, the generic name *Petalonema* has been proposed by botanists for four entirely different genera. A personal name is sometimes bracketed, for example *Chlorophora excelsa* (Welw.) Benth. This indicates that the specific epithet *excelsa* was originally used in a different combination; Welwitsch first described the plant as *Morus excelsa*; Bentham later placed it in its correct genus, *Chlorophora*, keeping the specific epithet *excelsa*.

Each plant therefore (if the International Rules are followed) has one correct name, internationally accepted and applied.

Complaints, too often ill-informed, are made about the frequency with which the names of well-known plants have been changed. Changes may happen for various reasons. Very often it is because the International Rules have not been followed or have been disregarded: the earliest available name, for instance, has not been adopted. This non-adoption may be unintentional through lack of knowledge or research; or sometimes intentional because a writer feels that a name, familiar before the Inter-

national Rules were accepted, should be maintained in preference to the correct name.

A change of name may often be due to a wrong identification of a plant being corrected. It may also be due to other taxonomic research; thus a species in one country may be shown to be the same as an earlier-described species in another country; or a species may be found to be not sufficiently distinct from another, and made a variety or subspecies of it. There are thus many ways in which research can operate to cause name changes.

Very occasionally difficulty is caused by genuine differences of opinion. A genus thought to be distinct by one taxonomist is not considered so by others. These differences are not surprising since Nature herself often leaves her boundaries anything but clearly defined, and variation patterns are often very complex.

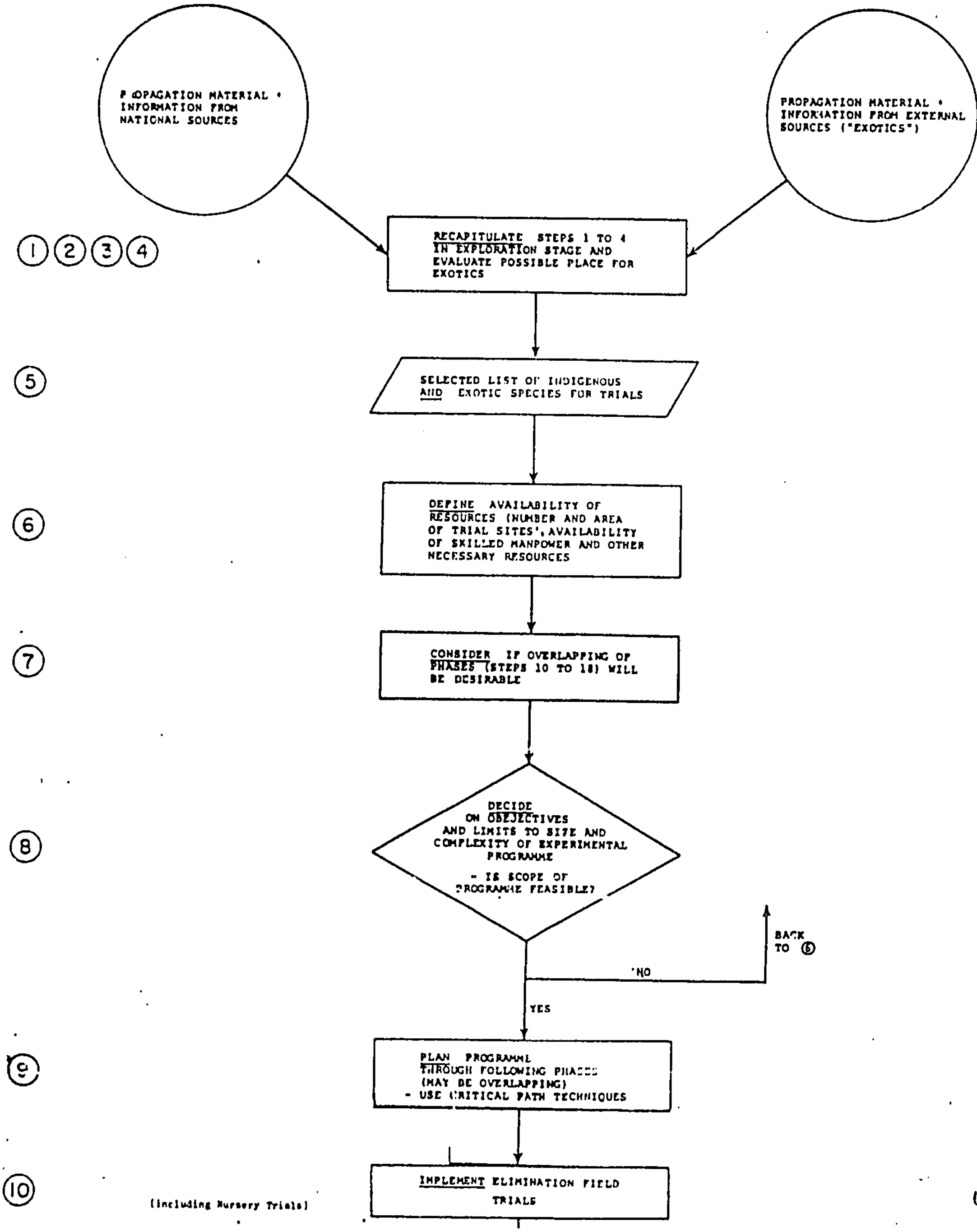
Changes have been unfortunately frequent in the last half-century, but this has been a transition period during which the Rules have been progressively more widely accepted and applied. It was early foreseen that if the law of priority was too rigidly applied, a large number of undesirable name changes would result. In order to reduce the number and ensure some stability a list of conserved *generic* names has been drawn up, and this is constantly being added to. At recent Botanical Congresses attempts have been made to make it possible to conserve the *specific* names at least of economically important plants, but these have always been strongly rejected. Two different standards cannot be used. Foresters and their spokesmen are still trying to have the Rules modified so that greater stability of nomenclature will result, but legislation is only one of the means of promoting stability. Much botanical research still remains to be done, even on some of the commonest and most important timber-producing species, before botanists and foresters are likely to agree as to the correct names of all the trees they are dealing with.

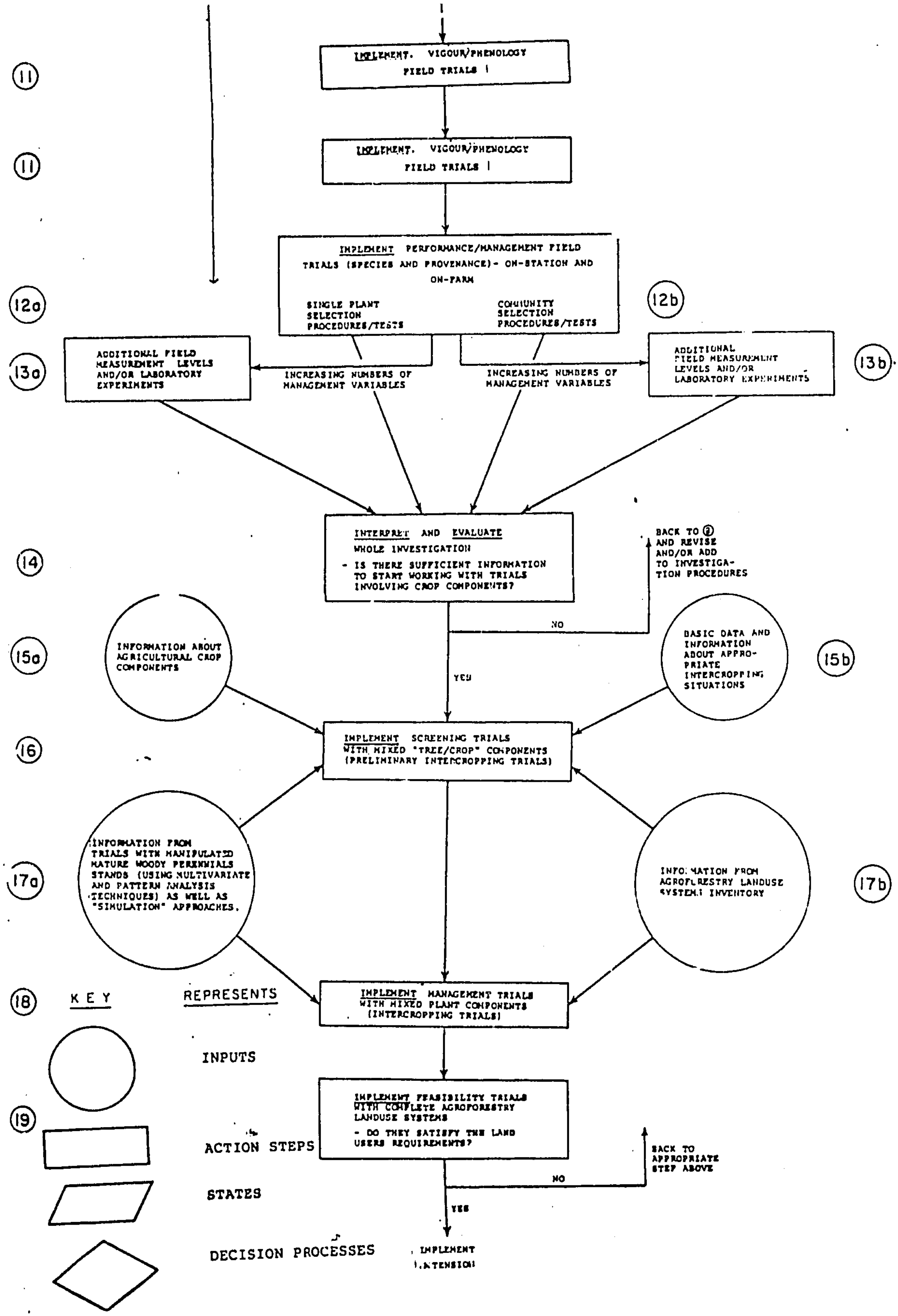
In conclusion, it will do no harm to repeat that the International Rules are not designed to *cause* name changes, but to increase the efficiency and stability of Botanical Nomenclature and to ensure that each plant shall have a single name accepted and used by botanists in all countries.

A simplified account of the principles and Rules of Biological Nomenclature has been published recently: Jeffrey, C. (1973). *Biological Nomenclature.* Arnold, London.

- B.T. Styles
Commonwealth Forestry Institute

IMPLEMENTATION FLOWCHART FOR
STEPS IN EVALUATION OF MULTIPURPOSE
WOODY PERENNIALS





11
IMPLEMENT. VIGOUR/PHENOLOGY FIELD TRIALS I
11
IMPLEMENT. VIGOUR/PHENOLOGY FIELD TRIALS I
IMPLEMENT PERFORMANCE/MANAGEMENT FIELD TRIALS (SPECIES AND PROVENANCE) - ON-STATION AND ON-FARM
12a
SINGLE PLANT SELECTION PROCEDURES/TESTS
COMMUNITY SELECTION PROCEDURES/TESTS
12b
13a
ADDITIONAL FIELD MEASUREMENT LEVELS AND/OR LABORATORY EXPERIMENTS
INCREASING NUMBERS OF MANAGEMENT VARIABLES
INCREASING NUMBERS OF MANAGEMENT VARIABLES
ADDITIONAL FIELD MEASUREMENT LEVELS AND/OR LABORATORY EXPERIMENTS
13b
14
INTERPRET AND EVALUATE WHOLE INVESTIGATION
- IS THERE SUFFICIENT INFORMATION TO START WORKING WITH TRIALS INVOLVING CROP COMPONENTS?
BACK TO ② AND REVISE AND/OR ADD TO INVESTIGATION PROCEDURES
NO
YES
15a
INFORMATION ABOUT AGRICULTURAL CROP COMPONENTS
BASIC DATA AND INFORMATION ABOUT APPROPRIATE INTERCROPPING SITUATIONS
15b
16
IMPLEMENT SCREENING TRIALS WITH MIXED "TREE/CROP" COMPONENTS (PRELIMINARY INTERCROPPING TRIALS)
17a
INFORMATION FROM TRIALS WITH MANIPULATED MATURE WOODY PERENNIALS STANDS (USING MULTIVARIATE AND PATTERN ANALYSIS TECHNIQUES) AS WELL AS "SIMULATION" APPROACHES.
INFORMATION FROM AGROFORESTRY LANDUSE SYSTEMS INVENTORY
17b
18
KEY
REPRESENTS
IMPLEMENT MANAGEMENT TRIALS WITH MIXED PLANT COMPONENTS (INTERCROPPING TRIALS)
INPUTS
19
IMPLEMENT FEASIBILITY TRIALS WITH COMPLETE AGROFORESTRY LANDUSE SYSTEMS
- DO THEY SATISFY THE LAND USERS REQUIREMENTS?
ACTION STEPS
BACK TO APPROPRIATE STEP ABOVE
NO
STATES
YES
DECISION PROCESSES
IMPLEMENT EXTENSION

SECTION THREE

PART 3B

Assessment of experimental sites

PART 3B

CONTENTS

ACKNOWLEDGEMENTS

Chapters 1 and 2

The author (PJR) acknowledges the considerable use made of information already published in Greaves A. and J.F. Hughes 1976, "Site assessment in species and provenances research" in "A Manual on Species and Provenance Research with Particular Reference to the Tropics" (Compiled by J. Burley and P.J. Wood) pp. 49-66. CFI, Oxford.

The Purpose of Experimental Site Assessment - by P.J. Robinson

Site assessment is required for the following purposes.

- To select the locations of trial sites:
  - these should be representatives of site conditions found in the areas where it is felt multipurpose trees are likely to play an important role in land use systems.
- To correlate evironmental factors:
  - either directly with attributes of tree growth and service functions; for example, biomass increment, fodder yield, changes in soil moisture or top soil fertility status; or
  - with an *order of ranking* of production and service of two or more species or provenances. This permits some extrapolation of conclusions reached from established trials or sample plots to unplanted sites.
- To monitor changes in soil conditions, and soil erosion, brought about as a consequence of the trials.
- To indicate to what extent the environmental conditions for the duration of the trials are representative of the long-term average conditions.

Assessment as an aid to planning trials

Unlike species grown in industrial plantations multipurpose trees are likely to be grown on a wide range of sites which may include extremes in the ranges in the following conditions.

- In areas which are particularly fertile there may be such land pressure for cultivation that acute shortages of land for fuelwood are experienced. Trees may therefore, have to be planted on very productive sites in close aasociation with crops.
- Conversely they may have to grow on particularly degraded and/or inherently unproductive land because these provide the *only* sites suitable or available for tree planting to provide specific products and wervices necessary for that area.

The range of tree types optimally suited to different locations in terms of site requirements,

performance (production *and* service attributes), and interactions with crops or animals are likely to be very great. Thus the range of sites in any one country on which multipurpose tree species and provenance trial should be located may well be much greater than for industrial plantation species.

Even so the procedure of experimental site assessment and selection should be a process of progressive division and subdivision to arrive at environmental units useful for the planning and interpretation of trials. Each unit should be a site as defined by Coile (1952). That is:

> "an area of land with characteristic combination of soil topographic, climatic and biotic factors".

The ultimate definitions of these sites will depend on the degree of variability encountered. However, a generalised procedure can be followed, the specific method depending on what information and resources are available.

Two possible procedures are described below: further guidance is provided by FAO in its "Framework for land evaluation". FAO has also prepared guidelines on land evaluation for forestry in cooperation with a IUFRO/ISSS working group on land evaluation for forestry.

Procedure using individual geoclimatic parameters

Classify each proposed planting area by the following:

Latitude

- to, say, nearest degree, and because latitude is related to day length (this may be of less importance for most tropical species).

Rainfall

- According to distribution throughout the year. For example uniform, one dry season, or two dry seasons. If the annual rainfall shows wide variation within any category a secondary division according to mean annual rainfall will be necessary.
- For many species it may be critical to define clearly "summer" and "winter" rainfall regimes.

The boundaries of proposed planting sites can be drawn on maps or aerial satellite photomosaics, preferably using a scale of about 1:50,000. On these maps, or a series of transparent overlays, the following should be marked in the sequence shown.

- Geological boundaries, or the boundaries of generalized soil groups.
- The boundaries of conspicuous geomorphic features, for example, flood plains, river basins, undulating hills, escarpments, dissected plateau.
- The boundaries of major topographical categories, for example, valley bottoms, hill crests, plateaux. The definitions of these categories will depend on the degree of topographic variation encountered Suitable categories should be determined with the aid of aerial photographs (preferably wide-angle 1: 50,000) or large scale contoured maps. They should be suitable for quick identification and not refined to a degree which results in excessive fragmentation of the landscape.

The ultimate units in the classification are, therefore, *units of topographic categories*. These occur in groups, the number of groups depending on the environmental variability encountered during the process of regime and latitudinal range. In these circumstances the additional factors frequently cited for inclusion in the site classification schemes become characterized by a narrow range of altitude, soil conditions, natural vegetation type, exposure, and both marco and micro-climatic factors

If information necessary for the implementation of any of the phases of this scheme is lacking. that phase can be omitted and the resulting less refined level of classification accepted. Alternatively, another factor can be substituted for the recommended one. Thus maps of natural vegetation types may assist with determining the boundaries of vaguely defined topographic units or broad soil groups.

If the area under examination has had an intensive soil survey with subsequent mapping at the soil series level, then the entire classification procedure described here becomes unnecessary. A soil series can be defined as comprising similar soil profiles derived from similar parent materials under similar soil-forming conditions of climate.

vegetation, relief and drainage. Recurrences of the same soil series therefore reflect recurrences of the same environmental conditions and further division becomes superfluous.

The land system procedure

The method described in the previous section depends on a degree of prior knowledge of the area. This is not always available and the time and resources necessary newly to acquire it by ground survey are prohibitively large. An alternative method is required in these circumstances.

Christian and Stewart, faced with the problem of classifying large areas of land in conditions where the standard traverse method of survey was not possible, devised such a scheme.

The basis of their method is the *land system*. This is defined as:

> "an area, or group of areas, throughout which there is a recurring pattern of topography, soils and vegetation"

A change in the pattern determines the boundary of a land system and a land system need not be continuous. Separate examples of the same system may occur, provided that they are within the same general climatic conditions.

The main influence which determines the boundary of a land system is geomorphology. A single system has a common geomorphology throughout its occurrence. It may comprise several types of underlying geology which are no longer recognizable on the surface through overwhelming geomorphic influence, or one geological group may be divided into two or more land systems through the action of different geomorphic influences. Obviously geological material and gecmorphic processes are closely related and their boundaries frequently coincide.

Since this original conception of the land system method of classification further refinement has taken place in that, not only is the land system itself described, but also the components of the recurring pattern which go to make up the land system. These components are called *land facets*. A land facet is defined by a combination of soil topographic position, and vegetation characteristics.

The implementation of the method comprises three stages.

- With the aid of topographic maps and aerial satellite photographs the distinctive combinations of landscape patterns, which constitute the different land systems, are identified and mapped.

- From examinations of aerial photographs the boundaries of the land facets are mapped according to the combinations of vegetation and topography. In defining the land facet the important things to avoid are over refinement to the point of confusion in application, and over-simplification to the point of having a unit with an unacceptably wide degree of variation.

- If the necessary facilities are available a limited field survey is carried out. This usually takes the form of transects planned so as to pass through at least one example of each of the facets. This enables the characteristic soil and associated vegetation of each facet to be described in broad terms.

An example of a land system description is given in Appendix 1.

The scales used for the mapping of the land systems and land facets depend very much on the degree of complexity encountered. Normally land systems can be satisfactorily mapped at scales of 1 :250,000 or 1 : 500,000. Land facets can usually be mapped at a scale of 1: 50,000 but may need a larger scale such as 1 : 25,000 or even 1 : 10,000 in areas of great variation.

It is evident that the final unit of classification produced by the application in full of the procedure described by geoclimatic parameters is closely compatible with the concept of a land facet. It is useful to keep this in mind when formulating an approach for a particular set of circumstances. The land system method is ideally suited to the classification of terrain in which there is one or more distinctive recurring patterns of topography, soil and vegetation. Where there is no such distinctive pattern a compromise approach may be necessary.

Finally, choice of method will depend largely on the facilities available. The time and resources required for the implementation of a land system/land facet classification through to completion should not be under-estimated. It is not unreasonable to require a period of three years for the complete study, and presentation of

results, of a square block of side 64 km (40miles) of mixed savanna types. However, land system classifications have already been published for some regions and these provide an excellent framework for the planning and interpretation of a series of species and provenance trials.

For trials attempting to define relationships between environmental parameters and plant growth and/or plant-soil interactions the land facet approach has its short-comings, not the least of which is the division of what is actually a continuum into a number of discrete units. This is an entirely subjective operation requiring a degree of essential artistry. Some organisations with facilities for field survey and soil analysis may wish to develop more accurate performance prediction models based on the use of continuous scales, rather than discrete classes, for the measurement of environmental variables. This avoids the uncertainties associated with variability within a unit and location of boundaries.

Where organisations have these facilities, or anticipate acquiring them, a logical sequence for any site assessment study is as follows:-

- Classify the sites using the procedure outlined above.
- Locate trials or sample plots as described in the following section.
- From the assessments of these trials or plots reach conclusions on the tree performance that is characteristic of the individual environmental units.
- When circumstances permit, acquire meteorological data and descriptions and measurements of environmental data by field survey. In the case of meteorological data, this is a continuous process.
- When sufficient data are available, investigate the feasibility of formulating a site assessment model with satisfactory predictive efficiency. It is by no means certain that a satisfactory model will be produced, and the investigator may have to fall back on the conclusions reached whilst further research is undertaken. There is, therefore, a need to approach this phase with caution; the desired results may not be forthcoming.

Practical implications

While the previous sections describe procedures which should ideally be used to identify and describe the site differences of land units where multipurpose trees are to be planted, it is realised that it will often be infeasible in the first instance to make such thorough site assessments in order to decide rationally on the siting of trials. This is likely to be particularly so in countries where resourses are limited, detailed information scarce, and where it is essential to establish trials quickly.

The process of planning site assessment and identifying appropriate trial sites can be seen as re-iterative. In any country, enough information is available about its environment and about the problems facing agricultural or forestry systems for reasonable estimates to be made of the following.

- The *broad range* of ecoclimatic variation.
- The areas where particularly important bottlenecks to effective land use exist which may be alleviated by the presence of multipurpose trees.

A start can therefore be made on the establishment of trials to *cover the major agro-ecozones* of a country. Additional trials, to cover more detailed variation in site characteristics can await the availability and processing of more detailed information about geoclimatic and/or land system characteristics.

The Distribution and Location of Trials

The desirable distribution and location of trials clearly depends on many factors including the following.

- The extent of ecoclimatic variation in the region and the extent to which this has been defined.

- The resources available and the resources required to establish, maintain and monitor the trials.

Ideally, a trial should be established in each of the land unit or land facet categories as determined by the land assessment stage. Although there will be some variation in the response of a provenance or species to the conditions encountered within such units, provided good judgement is used in defining the boundaries of the unit, this variation should not be extreme.

However facilities seldom exist for such comprehensive coverage. In which case a compromise between the following criteria should be used to prioritise the distribution and location of trials.

- Choose only the most widely occurring categories of units.

- Select categories of units which are representative of areas where trees are expected to provide the most significant benefits.

- Select categories of units from as wide a range of eco-climatic situations as possible so that some kind of rough extrapolation can be made to sites showing intermediate characteristics to those of trial sites.

- Where frequent environmental and performance measurements are to be made - the sites must be accessible to staff capable of carrying out these measurements. And if resources are scarce, it may be advantageous to have trial sites close to existing climate recording centres (Section 3E describes types of meteorological equipment available).

Environmental Factors - by P.J. Robinson

There is a need to be able to predict objectively from measurements made in trial plots, the responses of the trees to changes in various environmental factors. Only be achieving this, to whatever limited extent, will we then be able to extrapolate the result of a restricted number of trials to much wider areas.

The plant parameters we are considering cover a wide field:

> growth and development, service functions and tree interactions on the site itself associated crop/animal production. There are a large number of environmental factors involved.

Site assessment and environment response studies

Although considerable progress has been made over recent years in the field of plant physiology, the complex interactions between the plant and its environment are far from being fully understood. It is, therefore, impossible to predict plant performance by working from fundamental cause and effect principles in the manner and engineer can forecast power unit performance from a knowledge of the design of the machine and rate of fuel input.

These factors of the environment influencing the performance of a given species, and/or influencing its service function parameters, change with location both in identity and magnitude. Poor performance at a Site X may be because of the presence of a particular factor, its total absence, or the presence of a new inhibiting factor. Consequently, a list of environmental factors known to be limiting to the performance of a particular species on a first site may be completely inapplicable to a second through a change in the basic nature of the environment, and not merely quantitative changes in the magnitudes of its components.

These circumstances imply that:

- It is not yet possible to establish a comprehensive performance model, suitable for practical application, which relates total "tree" behaviour to environmental properties.

- The factors limiting "tree" performance in all environments cannot be described by just one comprehensive set of values.

This has implications that models relating a particular tree species' performance to environment can only be devised by means of identifying significant correlations between the two, for specified tree characteristics and

not from broad cause and effect relationships.

Methodologies for measuring and describing the environment at the site

Several authors have described site environment assessment methods, and recent discussions are available on the problems facing attempts of meaningful assessment in the tropics and subtropics.*

Those studies which have been most successful (when applied to regions of consierable environmental diversity) first eliminate variables that are non-quantifiable, or difficult to measure, by implementing an environmental stratification. Possible limiting factors within the units of the stratification are then measured. The data for individual environmental units are subject to a statistical screening process to identify those variables which will serve as useful predictors of performance either singly or in combinations.

The nature of the preliminary stratification will depend on the accuracy of prediction required. For regional performance studies with the aid of sample plot data, land systems are suitable units. The land facets may be used to plan thorough coverage at the experimental design phase, but ignored in the final analysis.

For very general predictions of performance or preliminary decisions on the most suitable provenance to plant, a more broadly based environmental unit may be adequate, for example, one based on climatic characteristics alone.

What approach?

When deciding which variables to measure within the classification framework one is faced with two possible courses of action. Firstly, knowing the characteristics of a given tree species one can hazard an informed guess as to which attributes of the environment should be studied. Alternatively, one can attempt to devise a list of observations to be made with the intention of observing first, without regard to preconceived plant/environment relationships, and examining for useful trends afterwards.

The first approach is dependent on the prior knowledge and good judgement of the investigator. The second assumes that a manageable, yet sufficiently comprehensive list for all circumstances can be drawn up.

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* See Part 2A and "suggested further reading" below.

Again, the first method establishes well defined guidelines from the outset. Guidelines which, however, may not be vindicated in the final analysis. The second method attempts to preserve flexibility of approach, leaving the investigator with alternatives should his first line of analysis prove unfruitful.

It is for the second method that proposals are made here in the belief that flexibility of approach is of paramount importance in dealing with multipurpose trees (FGNFTs).

The descriptions used here will undoubtely be considered elaborate for many local or regional needs. However, if site description work is to be undertaken the procedures in the following sections should be regarded as the *ultimate* objectives. They will provide a sound data base with which to meet many contingencies. Whether they be the detailed information for local prediction models, or the broader generalities necessary to facilitate a meaningful exchange of data on a given species or provenance.

The classification *framework* has already been described (geoclimatic parameters) but, if a land system classification is available it should be used in preference. Existing ecological classifications may also be used to advantage, but care must be taken in determining their relevance to agroforestry situations. Within a chosen framework we can then procede to the following descriptions.

Trial site description

Many forestry and agricultural research organisations have their own systems of site description which are perfectly adequate. In view of the restricted purposes of this Manual it is inadvisable to put forward proposals which could be construed as an attempt at "standardization" in such a complex matter.

The proposals made here for site description are therefore restricted to observations that can be recorded easily, that can be related to existing and establish procedures in various countries, and that are readily intelligible for purposes of exchange of information between research organisations.

It should be noted that many studies which have attempted to assess the contribution of different environment parameters to the growth of trees,

have shown that the parameters in order of importance are as follows:

- Climate.
- Relief factors (the basis for nature of several important parameters; for example, soil depth, water accumulation zones).
- Rooting depth in soils (a measure of potential soil water availability and of the volume of soil which can be tapped for nutrients).
- Soil parent material - although the latter often accounts for only a small variation in the growth rate of trees and *soil type* is more important.
- An additional overall guiding feature is existing vegetation.

*Climate**: For the local conditions in the vicinity of the trial a detailed description is desirable. An attempt should be made to acquire the following management data. Appendix includes a list of meteorological equipment and addresses of manufacturers).

- mean monthly precipitation (and mean annual totals)
- mean monthly temperatures
- mean and absolute daily minimum temperatures
- mean and absolute daily maximum temperatures
- Evaporation (measured)
- mean monthly relative humidity percentage
- mean monthly wind run (at 2 metres above ground level) (and occurrance of maximum wind speeds)
- incoming shortwave solar radiation

From ch the following derived data can be obtained:

- Potential evapotranspiration (Penman)
- Rainfall reliability (assuming 15-25 years of records are available) e.g. from a newly site, depending on variability).
- Vapour pressure deficits (from wet/dry bulb data).

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* Also see Part 3E.

The number of years of observation on which each of the above categories is based should also be recorded; this will help in calculating the statistical probabilities of occurence of specific climatic conditions occuring at any time.

It is unlikely, except for a very small minority of instances, that climatic data will have been recorded at the actual trial site. Some degree of extrapolation from established meteorological stations will therefore be necessary. Where this is undertaken it is important that the vertical and horizontal seperation of the two locations be noted, as well as circumstances which might indicate a difference in climatic conditions, such as a change in vegetation type, or different locations in relation to topographic features and the prevailing wind which might be the cause of differences, arising from rain shadow effects.

Information on the incidence and general daily and yearly trends in fog, cloud, dew, sand storms, fire and ground frost occurence may help explain certain phenomena of tree performance; such information can usually be incorporated in the daily climate record sheets. And soil temperature measurements (at stated depths) from open sites can also provide useful information.

If it has been shown that, for the region concerned vegetation type or altitude is a reliable indicator of climatic conditions the method can be used, but full references to the procedure should be given. Examples of more advanced ways of describing climatic conditions are given in Appendix

Topography: The general topographic conditions will be accounted for during the preliminary environmental classification.

When the unit of classification, be it land facet or otherwise, encompasses an escapment, or similar topographic feature, defining the trial location according to one of the categories of summit, upper slope, middle slope, bottom, will be useful. If the slope is well defined "percentage distance from the ridge" is a more suitable scale. A similar procedure can be used when the facet comprises an undulating plateau or plain.

Situations can arise where small and gradual variations in the level of the land surface bring a water table close to the surface with consequent marked differences in tree performance. When

this is suspected, attempting to account for the variation with a topographic position classification is undesirable. Owing to the slight and gradual changes the categories are poorly defined and excessively subjective. This condition is more easily measured from observations on the soil profile.

A topographic position may be meaningless in circumstances where there is *no* altitudinal variation. But it may be quite critical where this varies by as little as 200-300m, so causing significant variations in topoclimate and/or a soil catena.

Angle of slope is an excellent measurement for describing this attribute of local topography. It is commonly expressed as slope percentage this being the natural tangent of the slope measured in degrees (for example, on slope of 15° is a "27 per cent" slope). The measurement should be an average reading over a transect aligned at right angles to the contour (not plot boundaries) and passing from one side of the plot to the other.

Aspect can be significant in certain conditions, especially for young plants. It should be recorded in degrees true bearing from north. It is important that it be measured with reference to the characteristics of the unit of environmental classification. Even when dealing with a land system which is essentially a plain, but with minor fluctuations in slope and altitude sufficient to cause localized climatic or micro-climatic variations (for example, through modifiying the influence of a wind damage or solar radiation on planting ridges) the measurements of this variable will not be superfluous.

The criterion for a decision on what to measure must be "Does the variation exist in these circumstances?" And, if so, is it likely to effect the plants at one or more of their stages of growth and development".

Soil description and measurement data: The description of the soil profile is achieved most efficiently by the completion of a tabulated checklist. A suggested format, based on the work of Jenkin , 1973, is presented as Appendix 6 in Part 2A.

Attempts to relate tree performance to chemical content of soils as derived from soil analyses have to be anproached with caution. The more easily

measured soil features such as texture and depth are generally useful. Chemical analysis should be included if local laboratory facilities offer standardized procedures. See Appendix . Information on pH may be useful especially if it is particularly high or low; however, the nature of the parent material should provide a good indication as to the possible range of soil pH. The wide range of soil types on which MPT species will be grown means that other physical and chemical data will often be useful e.g. conductivity, salinity, bulk density percolation rate etc. Notes on these are given in Appendix 6 in Part 2A.

Again, as in previous sections, the underlying principle to this method of description is that classification of the observations should not take place during the compilation of field data. The data, if preserved in this manner, are available for reappraisal and re-classification during the analysis phase, thus preserving flexibility of method. As has been stressed repeatedly, any set of data can be handled in a number of ways depending on the objectives of the investigator, which, in turn, are dependent on the local conditions and, to a certain extent on the background knowledge available. A soil property which appears to be insignificant at first sight might assume greater importance in later years when the factors limiting tree performance in general, or of a certain species in particular, become more fully understood.

This, it is hoped, will emphasize the danger in ignoring some properties of the soil profile (or of designating some as being more important than others) without very detailed reference as to the soil used, in this case performance of a species, for which the properties are being assessed.

For a full description of soil survey procedures the reader is referred to the soil survey manuals prepared by the United States Department of Agriculture, FAO and the Australian Forestry Council.

Vegetation classification: Dansereau* in a critical and very thorough review of the methods of describing and recording vegetation began by

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* Dansereau, P. 1951. Description and recording of vegetation on a structural basis on Ecology 32, 172-229.

stating "The geographer, the ecologist, the taxonomist, the pathologist, the geneticist and others, many others, are interested in encompassing in a classification the living beings on which they work or which presumably bear some relation to a particular organism on which they are working". He continues that there is a necessity to define "the scope of one such (method) and points to the futility of applications exceding it".

Fosberg* echoed these sentiments stating that:

- A uniform technique for the study of vegetation is neither possible or desirable.

- A natural classification of vegetation in one of the ways this term is commonly used is inherently impossible and in the others is improbably feasible, and if possible would be too complex to be readily understandable.

- No single artificial classification will likely be serviceable for all purposes, and that therefore no such classification will be generally accepted.

- A uniform nomenclature of vegetation types, being dependent on a single accepted classification, will not be feasible.

Nevertheless Fosberg acknowledged that classifications are useful and indeed necessary, to facilitate both understanding and communication provided that their limitations are acknowledged.

In this particular instance, it is impossible to devise or select a classification scheme which will provide for all contigencies. For example, where there is diversity in vegetation appearance a physiognomic classification may be most appropriate such as that prepared by Ellenberg. Where there is only one physiognomic type, structure and composition might assume paramount importance.

In these circumstances a method of vegetation documentation is required which will enable the recovery of information at different levels of abstraction to facilitate the appraisal of different methods of classification. It would appear that the system proposed by Kuchler provides a suitable foundation for such a scheme (See Appendix 2 in Part 2A. . It must however be realized that the

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* Fosberg, F.R. 1958. On the possibility of a rational general classification of humid tropical vegetation in "Proc. UNESCO Symp. on Humid Tropical Vegetation" Indonesia UNESCO. Paris.

vegetation on most sites where multipurpose trees are likely to be of prime importance, does not represent the potential of the site; it may therefore not be a good integrator of environmental variables but rather reflect the degree of human impact imposed on the site.

Alterations of site environment by management

In many situations, particularly where some site characteristics are limiting to tree performance, site alterations are likely to be necessary, or desirable, in order to improve the conditions for growth. In some situations these may be necessary to get the trees established and to grow at all. It is, therefore, necessary to record accurately what *site alterations* are made.

The following practices may change to a considerable extent some of the environmental parameters about which the previous sections provided some guidelines for direct or indirect assessment.

- *Microcatchments* affecting:
  - soil water (a greater volume of water per unit surface area infiltrates the soil close to the tree - the soil may even become temporarily waterlogged);
  - night and day surface temperatures;
  - soil fertility (where the inflowing water is loaded with sediment which then becomes deposited in the catchment).
- *Terracing* (and to a lesser extent bunding) affecting:
  - soil water status (surface infiltration capacity increased)
  - daytime temperature
  - soil fertility (the spacial patterns of nutrient leaching and accumulation are altered).
  - wind speeds and turbulance
- *Drainage* affecting:
  - soil water status

- depth of water table
- soil structure
- soil fertility (including surface salt concentration)
- the rooting depth of the tree.

- *Irrigation;* the timing of application, the quantity applied and the specific location of application may influence some or all of the following:

  - tree rooting depth and spread
  - nutrient leaching
  - salt concentration
  - soil temperature

- *Cultivation* affecting:

  - soil moisture (infiltration capacity, water storage, soil surface evaporation)
  - soil surface temperature
  - soil structure (for example, indurations may be broken through).

- *Weeding* affecting:

  - soil water status
  - soil temperature
  - soil fertility

Depending on the weed species concerned, allelopathic compounds may influence the rate of root development and/or the development of micro-organisms associated with tree roots thereby influencing the growth of the tree. Legumes may of course improve soil fertility.

- *Mulching* affecting:

  - soil temperature
  - soil water status (water infiltration capacity increased, and decreased soil surface evaporation; in the medium term increase in soil storage capacity through improved soil surface).

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- nutrient status of the soil (direct influence through nutrient additions at the time of decomposition of the mulch; indirect influence by a probable increase in cation exchange capacity; possibility for nutrient immobilization depending on the nutrient status of the soil and the ratic of carbon to nutrient content of the mulch).

- *Dung/fertilizer applications* affecting:
  - soil structure (and therefore soil moisture)
  - soil fertility.
  - weed growth (and therefore the effects of weeds *per se*, or of extra tillage to eradicate them).

In the case of microcatchments, terracing, drainage, and irrigation, the degree of site alteration for example, the size of the micro-catchment or terrace, or the depth of the drains, will influence the extent to which the environmental parameters are altered. In the case of cultivation, weeding, mulching, fertilizing, the timing of the input in relation to environment events will further influence the effect of the input on the environmental parameters concerned (for example, in relation to subsequent rainfall).

It is unlikely to be feasible to assess the exact degree and extent of alteration of specific environmental parameters which has taken place due solely to any individual management input listed above, but some attempt should be made to measure the overall changes. Certainly, an accurate description of the timing and extent of the management inputs should accompany trial site assessment descriptions so as to give a clue to possible reasons for differences in tree performance on sites with different management inputs.

ANNEX

PART 3B

Example of a Land system description

SUGGESTED FURTHER READING WITH SPECIAL REFERENCE TO SITE/SPECIES OR PROVENANCE INTERACTIONS

Astle, W.L., Webster, R. and Lawrence, C.J. 1969. Land classification for management planning in the Luangwa Valley of Zambia. J. Appl. Ecol. 6, 143-69.

Burley, J. and Wood, P.J. 1976. A manual on species and provenance research with particular reference to the tropics. Tropical For. Pap. No. 10, Commonw. For. Inst. Oxford, U.K.

Coile, T.S. 1952. Soil and the growth of forests Advances in Agronomy 4, 329-398.

Freeman, G.H. 1973. Statistical methods for the analysis of genotype-environment interactions. Heredity 31, 339-54.

Jenkin, R.N. 1973. Forest soil surveying with special reference to the selection of sites for forest plantations. Fed. Dept. For. Res. Nigeria, Technical Note No.26 pp. 36.

Jones, J.R. 1969. Review and comparison of site evaluation methods. USDA For. Serv. Res. Pap. No. RM-51. pp.27.

Leuchars, D. 1965. The planning and practice of trials of exotic species. E. Africa Agric. For. Journal 31, 83-90.

Ralston, C.W. 1964. Evaluation of forest site productivity. Internat. Rev. For. Res. 1, 171-201.

Rennie, P.J. 1963. Methods of assessing site capacity. Commonw. For. Rev. 42, 306-17.

Simmonds, N.W. 1981. Genotype (G), Environment (E) and GxE components of crop yields. Expl. Agric. 17, 355-362.

The reader is also referred to a forthcoming FAO publication on Land evaluation for Forestry, compiled by A.Young and expected during 1984.

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APPENDIX 1

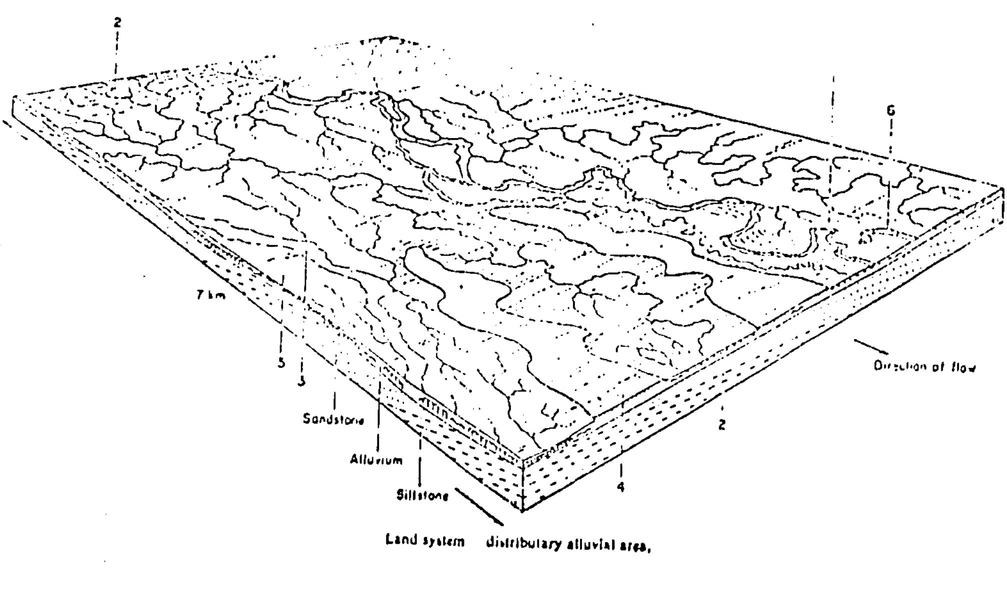
Site assessment methods

Example of a land system description (Astle et al., 1969)

(The permission of Blackwell Scientific Publication, Ltd., to reproduce this page is gratefully acknowledged)

A variable nearly flat landscape in which rivers branch into a number of winding channels separating broad interfluves of old alluvium. Sinuous strips of distinct soil and vegetation mark the positions of former channels. Relief a few metres only.

Land facet	Form	Soils, materials and hydrology	Vegetation
1	CHANNEL. Winding, irregular in plan; 5–50 m wide with gently sloping banks and flat or concave floor.	Variable, more or less stratified, sand to sandy clay loam, usually mottled. Water-logged for all or part of the year. In any one channel water flow varies greatly from year to year depending on the position of the river feeding it.	Single tree wide strip along the banks, [illegible] *microcephala*, *Diospyros mespiliformis*, *Trichilia emetica*, *Khaya nyasica*. Grassland in the channel, *Oryza*/*Echinochloa* spp.
2	CLAY INTERFLUVE. Flat, extensive.	Dark mottled cracking clays or silty clays (vertisols), frequently calcareous and sodium influenced. Waterlogged during wet season and occasionally under water for a few days.	Mopane woodland with short *Echinochloa* grass cover. On wetter sites trees absent and watergrass (*Oryza*) associations present.
3	SAND STRIP. Flat; ribbon-like in plan and usually c. 500 m wide; with large termite mounds (4 m high).	Stratified coarse and fine sand with water-worn pebbles at depth. Freely drained.	Woodland savanna, *Erythrophloeum africanum*, *Terminalia sericea*, *Cassia abbreviata* and *Pseudolachnostylis maprouneifolia*, with a good grass cover of *Digitaria gayana*, *Andropogon amplectens*, *Hyparrhenia dissoluta* [?], *Tristachya superba*. *Combretum* shrubs and Mopane occur on the mounds.
4	SAND INTERFLUVE. Flat; irregular in plan with diffuse boundaries to facet 3; 1–5 km across.	Stratified coarse and fine sand occasionally with small rounded pebbles. Freely drained.	Deciduous thicket, *Combretum obovatum*, *Diospyros senensis*, *D. quiloensis*, *Holarrhena febrifuga*, *Markhamia acuminata*, [illegible].
5	SOLONETZ INTERFLUVE (a) Level to very gently sloping (up to 1°), slightly convex; extensive (1–7 km across), with numerous low mounds (30 cm high and 5 m across).	10–15 cm of greyish-brown sand over very hard compact [illegible] sandy loam or sandy clay loam, calcareous [illegible] (Solonetz).	Tall Mopane woodland with occasional shrubs, *Combretum* [illegible] *Holarrhena* [illegible] short grass cover of *Setaria* [illegible] *Panicum* [illegible].
	(b) As (a) above but without mounds, occurring as small pockets (c. 5 ha) within (a).	0–3 cm of greyish-brown sand over compact alkaline sandy clay loam, calcareous (Solonetz). Drainage impeded.	Scrub Mopane and sparse cover of annual grasses, *Sporobolus*, *Eragrostis* and *Chloris* spp.



Land system distributary alluvial area,

SECTION THREE

PART 3C

The scope and design of field trials

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PART 3C

CONTENTS

N O T E

It is not the intention in this Part to elaborate on the general concepts of experimental design, or to attempt a review of all possible layouts together with the statistical background to their evaluation. This has already been covered in a succint and easily readable form in the CFI "Manual on Species and Provenance Research with Particular Reference to the Tropics" (Tropical Forests Papers No. 10, compiled by J. Burley and P.J. Wood). Further elaborations are readily available in the experimental and statistical manuals of the reader's choice - A selected bibliography of the most relevant and useful of these is given in Appendix 12.

In this Part, and those that follow in Section Three, only the *particular* aspects which have to be taken into account with field research on MPT's (FGNFT's) will be outlined and summarized. And four possible experiments are proposed covering, respectively, Nursery, Elimination, Vogour/Phenology and the early Management stages of investigation. It is assumed that these will be carried out in a phased manner according to the needs of any particular time plan (see Section 3A). That is either separately or as overlapping trials but in any case, as a set of mutually supportive investigations.

Subsequent work to investigate the place of particular MPT species in land use systems, more particularly in mixed cropping agroforestry systems, is dealt with in Section 4 and examples of possible field layouts to achieve particular experimental objectives in MPT mixed cropping research are given there.

P.A. Huxley

Field Trials - Some General Considerations - by P.A. Huxley

Designing trials in relation to the potential role of MPT's

The multiplicity of uses to which woody perennials can be put in land use systems implies that a very wide range of experimental approaches will be used to investigate them, depending upon the plant part, or parts, which are to be utilized. However, because of the permanence of their aerial structures and, sometimes, their deeper-rooting characteristics as compared with herbaceous agricultural crops, they may also fulfil a number of *other* functions. These relate to the maintenance or improvement of their immediate environment.

Trees and bushes, for example, can confer shade and shelter and they may, through nutrient recycling, including litter deposition, improve adjacent surface soil characteristics. Then again, woody species, especially the taller, larger ones will modify rainfall interception patterns ("throughfall and stemflow"). In a practical way trees and bushes can be utilized to aid in soil conservation; provided that the right species are planted in the right spatial arrangements, and if they are associated with suitable gorund layer vegetation and/or appropriate soil modifications (terracing, cut-off drains etc).

Many of these functions can be considered, cumulatively, to confer some level of *sustainability* to any land use system. Indeed, this is one of the prime objectives of agroforestry, and it clearly depends on the woody species used, their age, the number grown per unit of land and the way they are arranged and managed. (See Part 6B). These are all key experimental variables and the extent to which any woody species may enhance sustain-ability in one way or another is an important factor to be taken into considerations in evaluation its worth. In planning experiments, therefore, these variables should be taken into account, both in relation to the experimental layout (see further on, this Section) and with regard to what is observed and/or measured. (See Part 3E).

Dealing with highly variable species

Because many species of multipurpose trees will be outcrossing and therefore, highly heterozygous, the plant material for trials will inevitably be variable, however carefully it has been grown and selected in the nursery (Part 3B). One way to avoid this would be to use vegetatively propagated material (if ways of doing this are already known), but this raises issues concerning the basis on which the parent plant/s are chosen and, it may well be, that insufficient is known about the species at this time to make such a decision. Otherwise it is important to have some information from the Exploration Stage (Section 2) concerning the variability found in natural situations (especially on homogeneous sites), and to limit the more advanced Performance/ Management Investigations (Step 12 in the Evaluation Flow Diagram Part 3A) to plants from carefully selected seed lots.

Earlier steps, Elimination Trials and even Vigour/phenology Trials (Steps 10 and 11, respectively), are more specifically directed to discovering the *extent* of variability. So that these will have to be made large enough to explore this adequately depending on the known extent of variation in either general vigour and form, or for any particular plant character being investigated.

Single or multiple tree plots?

Field trials may involve examining trees as species ("single trees") or in plots, depending on the objectives and the amount of plant material available. For investigation an early survival, phenology or the specific responses of a species to particular management variables (e.g. the effects of pruning, tolerance to pesticides, time-of-planting effects and so on) the study of suitably replicated single, free-standing trees may be perfectly adquate. In effect these are "single-tree plots", or lines, where individual plants are not subjected to any community-imposed stresses. Even where plots are used the early growth stages of young plants are similarly stress free, of course.

Although the ultimate objective may be to grow the species in communities (e.g. woodlots, orchards, or fodder blocks) trials on a single

tree basis can still provide a very cost effective way of obtaining some preliminary information, and species/provenance elimation trials (Step 10 in the Evaluation Flow Diagram) and Vigour/Phenology Trials (Step 11).

Where it is necessary to learn how the species performs in association with its fellows trials on a plot scale are mandatory. In this situation plant population and arrangement will be a primary variable affecting the yield per unit area and the form and dry matter distribution of individual plants. Furthermore, the type of plant required will be different from that required if the ultimate objective is to obtain yields from effectively free-standing specimens. Because multipurpose trees will be grown under both situations this has to be borne in mind when a) selecting provenances and b) planning the experimental programme and chosing a field layout.

The principles for comparing plants, woody or otherwise, which are to be grown separately or in communities are now well known (see Appendix 1). Total biomass and the production of plant parts (fruits, seeds, boles, etc) will be maximised in communities of single species (a) where individual plants experience some level of community imposed stress and (b) where the plant ideotype is *not* "aggressive" that is spreading, with horizontally inclined leaves, etc as distinct from "community tolerant" ideotypes with a more erect form, and erect leaves.

With MPT's (FGNFT's), therefore, and depending on the situation, we may be selecting different ideotypes within the same species not only for different end-use purposes, but also for systems in which they may be either community-grown or effectively free-standing. In addition, on farmers' lands, they may often be part of a mixed cropping situation, but this is specifically dealt with in Section 4.

On-station or On-farm?

Many multipurpose tree species are likely to be highly variable. In addition every country as well as evaluating indigenous species is now interested in testing a range of promising but previously unknown exotics. Both these factors suggest a need to carry out trials at as many sites as possible. In the first case to adequately explore genotype x environment effects (GxE) and, in the second, to test the opinion of land

users with regard to the ways in which species which perform well can best be incorporated into existing land use systems as rapidly as possible. The number of experimental sites attached to research stations is invariably limited and, in any case as "farmer" involvement is itself a useful investigational procedure, there is a powerful argument for setting up at least additional on-farm trials to supplement those carried out on-station.

The kind of investigations required with MPT's (FGNFT's) range from preliminary tests of survival (perhaps involving different planting-out or direct sowing techniques), through vigour/phenologically trials to testing every degree of relevant management. All of these stages can often, advantageously, be undertaken on-farm as well as on-station.

There is really a whole spectrum of on-station to on-farm approaches depending on what the objectives of any particular investigation are. Indeed, exactly the same experimental layou might be sited both on-farm and on-station (provided it fell within the limits of complexity imposed by most on-farm situations), but be much more critically measured at the on-station site.

On-farm approaches related to technology evaluation can be of different kinds with regard to farmer participation. The examples listed below are in decreasing order of farmer participation.

- Investigations which demand a high level of farmer participation in the form of decisions, management, skill and/or understanding at some or all stages (e.g. pruning trials).

- Management "as is" trials. Where the farmer is left entirely, or guided only minimally, with regard to the management programme he choses to adopt (e.g. some on-farm variety trials).

- "Set piece" trials where a fairly straight forward sequence of simple operations are laid down according to a strict timetable (e.g. fertilizer and pesticide trials), and management decisions are not required except at a very simple level (e.g. the weeding practices to adopt).

- "Nil farm management" trials - where

technicians from the research station carry out all essential work, measurements, and the harvest, and the farm is merely used as an additional location for a test.

Where experiments relate to whole agroforestry systems (Section 4) they may be considered as of two kinds (1) testing of complete designs or (2) "perturbation" experiments, whereby one or more components and/or management processes are changed in order to ascertain how this effects the system as a whole. Type (1) can most rationally be carried out within the context of the relevant systems of land use and Type (2) clearly *have* to be on-farm.

Because of the highly socially interactive and preliminary nature of possible land use interventions involving MPT's many on-farm technology investigations may best be initiated with a strong element of "farmer" participation. This may still, advantageously be accompanied by a high level of farm visitation in order to monitor progress, and to take supplementary measurements. If, in these circumstances, the "farmer" departs from suggested trial layouts or operations, then it indicates that the experimenter has something still to learn about the objectives of the investigation, and time has not been wasted.

A good deal has been learnt in recent years about the problems and potentials of on-farm experimentation. Some useful references are given in Appendix 2.

Dealing with unwanted locational variability

In undertaking trials with either single or multiple tree plots there are the usual considerations to be borne in mind.

- Sites should be chosen so that each is as free as possible of unwanted random effects or bias, i.e. it is homogeneous in terms of soil fertility, exposure, and any special "headland" effects.

  - this is often best achieved by using rectangular plots and it is contained statistically, by adequate replication.

- If plots are assembled into blocks because of some known variations in the experimental site, or because the experiment is planted or sown over a period of time, then each block should be made as homogeneous as possible.

  - the advantages of blocking as against loss of some degree of freedom by so doing are discussed elsewhere. If little is known about the area a detailed soil survey should be carried out and it may be wise to run a uniformity trial first, using an annual crop as a test plant.

Plot size

The size of a single plot, in terms of both space and number of plants involved, needs careful consideration. A number of factors are involved and a compromise reached, bearing in mind the following.

- The area of homogeneous land, and the resources actually available for the experiment.

- The genetic diversity of the germplasm

- The types of treatments to be imposed, and the extent to which they can influence adjacent plots.

- Management considerations of how to care for the plants, how to apply treatments, and how to take records or collect data in a cost-effective and efficient manner without disturbing the plants (for example by trampling or the use of machinery).

The actual number of plants per plot will also depend, then, on what is known about the likely variability and the need for a sample variance which will allow adequate tests of significance for differences between treatments. (Increasing the sample size by fourfold will only halve the sample variance under identical experimental conditions). There are some other practical considerations also.

- Newly-planted trees/bushes are much more variable in the first few years than later, when the effects of planting-out have become

less important, and/or imposed treatments (e.g. pruning, browsing) will have "evened-up" the stand. Thus the size of plots may need to be different if the experiment is directed at the "juvenile" rather than the mature stages.

- Where mechanical equipment is used for cultivation etc then the size of plots may have to be modified to satisfy the requirements for doing this effectively. Similarly, if the plots are to be irrigated differentially, then their size may depend on the limitations imposed by the need to apply water uniformly.

Foresters often use 7 x 7 plots for species selection trials but, from what has been said above, it is not wise to use just a "rule-of-thumb" decision. It is better to base a decision on known information about the species and the experimental site(and see CFI Manual, Page 79). Plots in any one trial should be of the same size and shape.

Guard rows

A factor which can increase the experimental area and resources needed, especially for conventional field layouts (randomized blocks, latin squares, lattices, etc) is the need for "guard" plants. These may be just external, to obviate "headland" effects; or both external and internal, where some form of plot-to-plot interference is suspected.

Just to set a single row of guard plants between plots to take care of these factors may not be adequate, and the underlying cause, or causes of bias need to be carefully considered. For example, in experiments involving the spread of pests or plant diseases the distances over which an infested/infected plot of a susceptable cultivar can impose increased hazard to others may distort the results. Then, again, where treatments bring about a large change in plant structure or habit (e.g. pruning, or the application of fertilizers) then the question of possible important differencies in the light profiles at the edge of plots needs to be addressed. Lateral movement of fertilizers, and the

effects of mulch or added water in irrigation experiments, can all be sources of bias. Spacing experiments need especial care*. To avoid bias the between-plot guard areas, or rows, should contain enough plants similar in structure to each adjacent experimental one to eliminate changes in the different levels of interplant interference brought about by any particular spacing treatment. This interference will consist of shelter effects, root spread and its consequences on water use and nutrient uptake, and shading effects in different plant spacing treatments, where the plants will attain different heights. To maintain appropriate light profiles the guard areas surrounding individual plots should allow the same lateral light infiltration to that received by any plant situated in the middle of the plot. In practice this is seldom achieved with tall plants such as trees being grown in small plots, but the consequent errors should at least be aknowledged and, if possible, estimated.

Conventional designs, such as randomized blocks, can be very uneconomical of space if extensive ruard rows are used. As the diagrams in Appendix 3 show, depending on the number of plants per plot and the extent of the guard plants it is unlikely that more than 50 to 60 per cent of the total area could be effectively used for data collection, and it can be much less.

All told, the need for guard plants should be taken seriously but, in most cases, a practical compromise may have to be accepted. In planning an experiment with trees arranged in small plots a careful appraisal of exactly *what* is involved, and how much error this introduces should be undertaken.

Relating results to comparisons the landuser wants to make.

Agroforestry systems of landuse, by incorporating plant species with different spatial requirements and of very diverse economic life span and phenology, provide a better than usual choice of combinations to share the environmental riches available. In agroforestry one is out to *exploit* the heterogeneity of the system, both in terms of space and time. This too has to be borne in mind in

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* See Part 4E

in planning investigations.

Usually researchers in agriculture and forestry try to contain variability in a way which can be easily handled. Thus field experiments express results in terms of means and variances, and layouts do not always facilitate comparisons between potential "packages" of treatments as well as they might. Sometimes there is a good reason for this but, generally speaking, the technical objectives of the researchers take precedence over the need to have data presented in a form which can convince the farmer. For example, in a factorial experiment data should not be presented just as mean effects and interactions, but as yield increase ratios in terms of the "least input" treatment or treatment package. Such a course implies considerations of layout and degrees of freedom for appropriate tests *from the initial planning stage of the experiment.* This approach can be more meaningful in extension and development because farmers do not always wish to maximize yield but rather to remain with a choice of treatment options depending on decisions about available inputs. An example of what is meant is given in Appendix 4.

Choice of experimental layouts - by P.A. Huxley

From what has been discussed so far we might briefly summarize the alternative types of layout which are most likely to be used in MPT field trials. And mention, briefly, the advantages and disadvantages of each. Once again, the reader is referred to the CFI's Manual on Species and Provenance Research (Tropical Forest Paper No. 10) for a practical account, and especially to Section 4 "Principles of Experimental Design" by H.A. Wright and I. A Andrew (pages 67-82), and "A Guide to Field Practice" by J. Burley, P.J. Wood and R. Lines (pages 83-107).

Introduction

Any particular field layouts should be considered in relation to how satisfactorily it achieves an effective compromise between attaining the specific experimental objectives whilst remaining well within the resources available. In most cases, and especially with woody perennials because both the duration of the experiment and the level of research management required are usually greater than with annual crops, it pays to use several relatively simple experiments rather than one or a few larger, more complex ones.

With these factors in mind a pre-requisite for choice of layout is to consider the following questions in the order shown.

- How variable is the experimental plant material? And how much is available?
- How much of the desired information can be obtained by examining single trees?
- If community-grown specimens are required what other factors of plant-to-plant variability are involved in deciding plot size?
- Is some control over local environmental variation needed?

Each of these questions requires careful thought and, if necessary, recourse to available sources of information and/or advice with regard to individual species of MPT's (see ICRAF database). The final choice of layout, and the degree of replication needed, will depend very much on the outcome. Table 1 summarizes the kinds of approaches that might be suitable for MPT trials of different kinds.

Table 1 Selection of approaches for MPT trials of various kinds.

Degree of control over local environment variation	Type of study requires: Single plants	Community-grown plants
None *or* Minimal	Well-spaced fully randomised (individual or lines)	Simple replicated plots *or* systematic designs
Definitely required	Single tree plots	Multiple tree plots

arranged in:

- Randomized complete blocks
- Latin squares
- Rotating designs (e.g. Augmented layouts)

Consider raising efficiency and/or effectiveness by the use of:

- Partial replication (e.g. Lattice designs)
- Split plots/factorial arrangements
- Covariance/Nearest neighbour analyses

Well-spaced fully randomized individuals

Tree crop horticulturalists sometimes use this layout, often for preliminary tests of a range of management techniques. It is:

- Useful for elimination/survival trials, especially when the supply of planting materials is strictly limited and variation occurs in the numbers of plants available.

- Also where local environmental variation (e.g. soil fertility or exposure) is minimal and blocks are considered unnecessary; or where such variation can be eliminated, as in some nursery experiments.

- Particularly economical where one wants just to observe the growth and phenology of different accessions of a "new" species (in vigour/phenology trials).

- Also where intra-specific variation in vigour and habit are not too marked and a number of provenances are being tested.

- It is not suitable where there are marked differences in plant size and form, for example, if large and small species are to be mixed, because of possible differential levels of interference between plants within a standard-spaced field layout.

- This layout is probably mainly of value for general "observations". It can provide a very simple statistical test of differences between means and this can be for samples of different sizes (Appendix 5). Thus *all* available material can be planted and/or if some casualties occur the experiment is not ruined.

Simple replicated plots (or lines)

This is, perhaps, the most straightforward way of handling very limited amounts of plant materials where local environmental variation can be assumed to be minimal otherwise it may have only management and/or demonstration advantages. Some points to note are that:

- If the plants are to be kept for seed then attention has to be given to the breeding systems and the possible need for isolating accessions.

- Statistical evaluations have the same advantages and disadvantages as before, that is considerable flexibility but relatively little efficiency for tests of significance.

Single versus multiple tree plots

- One factor to consider is: what is the purpose of the trial and the nature of the plant material? If the material is homozygus (perhaps clonal), then the purpose of having more than a single tree plot is to confirm the observations being made. If the plant material is heterozygus, and growth is to be measured, then the purpose is to decrease bias caused by inadvertently having sampled from the population extremes.

- Single tree plots clearly can save much space. They are valuable for studying plant behaviour on homogeneous sites, (which are thus easier to select), but of less value for measurement data where a reliable sample mean from multiple tree plots may more than make up for a greater, but less reliable, set of data from single plants. Only some knowledge of the variability concerning the characters to be measured for particular species under trial can help here.

- The amount of plant material available may restrict plot size - but the question then becomes one of whether to carry out the trial at all, in that form, or not.

- Some of the factors to be considered in deciding on the number of trees per plot, and their spacing, where multiple plots are to be used are mentioned in the CFI Manual.

Randomized complete blocks/Latin squares

- These are often necessary in order to account for local environmental variation, (One can use latin squares where there is environmental variations in two directions, preferably at right angles); but considerable care is needed in siting blocks, that is the

local environmental variation *must be known* for blocking to be effective. (See CFI Manual pages 71 and 76).

- Blocks can usefully be used to confound differences due to nursery selection, time of planting out, timing of major management operations for an experiment (e.g. irrigation by blocks) In other words both spatial *and* temporal variations can be assigned to the block residual and removed from between-treatment comparisons so as to make these statistically more effective.

- Randomized blocks may use space inefficiently if guard rows are required (see Appendix 3) and optimum plot size has to be judged carefully to effect a compromise between obtaining effective samples, statistical efficiency and, particularly with trees/bushes, cost-management feasibility.

- Randomised complete blocks are fairly robust, that is some missing plots can be accounted for statistically (CFI Manual, p.120), but non-orthogonal arrangements (i.e. those in which different population samples occur in different blocks without it being possible to make balanced comparisons) are difficult to analyse.

- With few replications (blocks) and treatments there may be insufficient degrees of freedom for the error variance to test mean differences between treatments effectively.

- The relative value of using randomised blocks and/or other methods of controlling or accounting for environmental variation has recently been discussed by Pearce (see selected references).

- In cases where no logical grouping of provenances (or any other set of treatment variables) is possible it is more prudent to use a multiple range test than an ordinary t - test to make statistical comparisons.

Augmented designs

These are a form of "rotating" design (normally used for fitting second

order (quadratic) response surfaces, see Cochran and Cox, p335). As adapted the "augmented" design provides a useful approach to comparing some relatively few preliminary treatments (e.g. completely new species) within a trial where more precise comparisons are required between previously observed treatments (species which have already been initially worked on) (See Appendix 6).

This is done at different levels of statistical precision, but the layout has space-saving characteristics which make it valuable for vigour/phenology or early management trials.

- For example the layout fitted into randomized complete blocks, allows flexibility in block design where not all treatments appear to warrant full replication, but a range of interesting "possibilities" exist to be tested as well.

- Standard, or check, treatments (species, provenances) are replicated fully but a limited number of new selections material from which may be in short supply, are additionally split among the replications (or are left unreplicated).

- Statistical comparisons involve a calculation of an overall mean square for error which excludes unreplicated entries. The means of unreplicated treatments are adjusted and a procedure for estimating standard errors of differences depending on whether treatments we are replicated, unreplicated or in the same or different replications, is undertaken.

Increasing efficiency and/or effectiveness

- Partial replication in the form of incomplete blocks can be useful where some information can be sacrificed and it is essential, because of environmental heterogeneity, to

limit the overall size of each block. If the designs are balanced (and hence comparisions between treatments remain orthogonal) comparisons among all *pairs* of treatments can be made with equal precision. The layouts can be randomised incomplete blocks or quasi - latin squares. The minimum number of treatments and units per block decides the number of replications required - so that these may be very large unless the experiment is a simple one.

- A particular set of partially balanced designs which require fewer replications are lattices. In these designs different pairs of treatments will be compared at different levels of precision and the number of replications are fixed according to the number of treatments ('square' or 'rectangular' lattices - see Cochran and Cox). These designs can be useful for early investigations where rather large numbers of previously untested selections (species of provenances) are to be chosen in a preliminary way i.e. for 'elimination' and/or 'vigour/phenology' trials - and where control over environmental heterogeneity rules out a completely randomised layout. They do not increase statistical efficiency (indeed, the statistical comparison involves the calculation of several different standard errors), but they may well increase cost-effectiveness.

- Split plots or more complicated factorial arrangements can be especially useful where either the *interactions* between treatments is likely to be important or, in the case of split plots, where one group of treatments need to be tested with greater statistical precision than another. This might be because one set of differences is already fairly well established (main plot treatments) and this is not so in the other case (the split plots treatment. Split plots are also used where some treatment can be applied to small plots (e.g. pruning but others cannot be (e.g. soil management treatments or irrigation). In such cases the only feasible way to set out the experiment may be to apply treatments requiring the larger amount of space to main plots and the others to split plots. There are

statistical problems in making comparisons using "split-split" plots and it is more satisfactory to use a fully factorialized layout. The latter are particularly valuable for exploratory experiments, and statistically efficient because of the enhanced level of replication ("interval replication") which occurs. However, because of the space involved they have been used much less with trees than with smaller perennials or annual crop plants (and see page this Section).

- A logical arrangement of different classes (taxonomic or vigour selections etc), species, provenances may help raise efficiency. For example, it may be desirable to confound large between-species effects by assigning each species to a separate block (which themselves are replicated) with the separate provenances in randomized plots within these. This would be where there was little or no inter interest in making statistical comparisons between species and the between-provenances/ within-species comparisons were the important ones. Such an arrangement is basically a split-"plot" design. ("Family blocks" designs, see p. 77 CFI Manual).

- Covariance analysis can be used to increase experimental accuracy where supplementary observations (for example on seedling size at planting out, or on initial plot fertility (according to some measured statistic such as soil organic matter content, etc) can be used to establish correlations with the final performance data being measured. Cochran and Cox, page 82). The effects of these unwanted influences can be accounted for and thus eliminated from the comparison of experimental treatments *per se* (and see P.124, CFI, Manual). In cases where the presence of one plant may markedly influence that of its neighbours (for example in plots of composite mixed genotypes of differing vigour) a "nearest neighbout" analysis may provide useful additional information as Bartlett points out.

*Systematic designs**

- Since these types of layouts were originally proposed by Nelder they have been used extensively with many different kinds of plants, and for a variety of purposes (spacing trials, fertilizer and herbicide experiments, etc). They can be especially

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* and see Part 4F

useful at the early stages of investigation when it may not be quite clear what level of a particular treatment is likely to be "on-target". In particular, systematic designs lend themselves to investigations which involve studying the effect of a wide range of plant spacing. Either when this is the primary variable, or where it is a background treatment against which some other management variable is to be tested (lopping or pruning treatments, for example). Systematic designs are likely to be extremely valuable field layouts for early management trials with MPT's.

- Two kinds of systematic design have been commonly used to investigate sole crop spacing problems from vegetable to tree species. The "fan" design and "parallel row" layouts. Examples are given in Part 4F, and methods for calculating the actual changes in spacing for any one layout are fully described by Bleasdale.*

- Fan designs have a restricted number of plants to sample limited by the number of radii in the fan. Parallel-rows, which are easier to lay out in the field, can be made as long as necessary to achieve a suitable sample size at the wide spacing. But then there is an unnecessarily large sample for close-spaced rows. This can be remedied by successively shortening those rows to make it resemble a 'fan'. More complex designs (log/log) can be used to combine testing plant population *and* rectangularity simultaneously.

- Systematic layouts have the following advantages and disadvantages compared with conventional layouts:

  - they take up very little space even if several replications are laid down (as they should be, with different orientation);

  - they make excellent field demonstrations the results of which are very easily understood by extension workers, farmers, etc.;

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* A microcomputer programme is available from ICRAF.

- they are, however, sometimes difficult to lay out, establish and maintain (not at all 'robust');

- few, if any, statistical comparisons are valid except regression parameters;

- all systematic designs which incorporate spacing as a variable need some additional guard area surrounding the close-spaced treatment rows; otherwise side-effects (especially extraneous light) will completely distort the growth and/or yields in this part of the layout.

- Simple types of systematic designs may well have a place in "on-farm" trials. One such example, in this case to test the results of having different proportional areas of bush to arable land, lopped/unlopped bushes, woody mulch, and tillage, is given in Part 4F.

Comments on and outlines of proposals for four different field trials with MPT's - by P.A. Huxley

Parts 3A, 3B and the first chapters of this Part will, hopefully, all have contributed to a clear definition of what has to be done in the evaluation stage. From this process will arise definite proposals for field trials. The remainder of this Part is devoted to outlines of such evaluation of MPT's (that is from steps to in the flow diagram contained in Part 3A) as they may be carried out by a network of operational researchers.

Although some level of conformity in experimental design is desirable, in that it more readily enables comparisons of results between participants in different locations, there will, inevitably, be local conditions and somewhat disparate objectives which result in individual trials being run in a somewhat different way from one another. Or in some participants deciding to interpolate additional experiments and/or overlap experimental phases more concisely. No co-ordinated programme should discount any such preceived investigated needs, so long as there is a central 'core' of research activity which retains a significant level of commonality.

Checklist on design decisions

First of all, Table 1 gives a useful checklist of questions concerning all aspects of designing an experiment (by J.N.R. Jeffers of the Institute of Terrestrial Ecology, U.K.) to serve as a reminder.

Design proposals

Table 2 then indicates the scope of the four experiments suggested and these are, then expanded in the last part of this chapter.

Design of Experiments

Stating the objectives

1. Have you stated clearly and explicitly the objectives of the experiment and the reasons for undertaking it?
2. Have you translated these objectives into precise questions that the experiment can be expected to answer?

Defining the population about which inferences are to be made

3. Have you defined carefully the population about which you are seeking to make inferences from the results of the experiment?
4. Is the site or location of the experiment representative of that defined population?
5. If not, what do you need to do to find a representative site?
6. Is the experimental material to be used in the experiment, e.g. plants, animals, soil, water, etc., representative of the defined population?
7. If not, how can representative material be obtained?
8. If either the location or the experimental material is not representative of the population about which you wish to make inferences, is it worth doing the experiment at all?

Selection of experimental treatments

9. Have the experimental treatments been defined sufficiently precisely for them to be applied correctly by the experimenter or by those wishing to repeat the experiment, and are they realistic?
10. If the "treatments" consist of species, varieties, or strains of organisms, are they representative of some defined population of organisms?
11. Can the experimental treatments be expressed as "factors", that is as groups of treatments at two or more levels?
12. If so, can all combinations of factors be achieved and are these combinations realistic?
13. Is the number of levels within each factor restricted to two or three?
14. If not, is there any real advantage in using more than three levels to determine the shape of the response curve?
15. Do the levels of any one factor change by a constant amount or in a constant ratio?
16. If not, is there a good reason for departing from linear relationships, or relationships which can be made linear by an appropriate transformation?
17. Is the number of factorial combinations so large that there would be some advantage in considering only some of those combinations, perhaps sequentially?
18. Is there a naturally defined control treatment which should be included in the experiment?

Plot shape and size

19. Is the plot size for the experiment defined by the nature of the experimental material or the site?
20. If not, will the proposed plot size enable the treatments to be applied and allow the desired records to be made?
21. Is the plot shape defined by the nature of the experimental material or treatments?
22. If not, will the proposed plot shape enable the treatments to be applied and allow the desired records to be made?
23. Are the experimental plots all of the same size and shape?
24. If not, are you aware of the problems that may be encountered during the analysis of the results of the experiment?
25. Is there likely to be interaction between the individual plots of the experiment?
26. Can this competition be reduced by increasing the space between plots, or surrounding each plot by a buffer zone?
27. Are the plots of the experiment of the smallest size consistent with the other constraints?

Number of replications

28. Do you have any preliminary estimates of the precision likely to be achieved by the experiment (expressed as a coefficient of variation, for example)?
29. Is it possible to conduct a pilot experiment to determine the coefficient of variation likely to be encountered, and to test the experimental procedures?
30. Have you determined the size of the difference between treatment means which you would regard as of practical importance, if such a difference were to exist?
31. Have you calculated the number of replications that would be necessary to match the size of the differences likely to be detected as significant with the size of differences you regard as of practical importance?

   (E.g. $N = \left(\frac{c}{s}\right)^2$

   where N = number of replications
   c = coefficient of variation
   s = standard error of means)
32. If there is insufficient land or experimental material for the number of replications required to give significant differences of practical importance, is it worth doing the experiment at all?
33. Do the controls need to be replicated more or less frequently than the other treatments, in order to place greater emphasis on particular comparisons?

Layout of the experiment

34. Is it possible to divide the site of the experiment or the experimental material into blocks within each of which there will be less variation than over the experiment as a whole?
35. Is the size of these blocks sufficiently large to contain at least one plot of each treatment and controls?

Table 1. Statistical Checklist "Design of Experiments" by J.N.R Jeffers. Institute of Terr.Ecology U.K.

36. Have you considered the advantages of robustness and ease of analysis of a randomized block design?

37. If the blocks are not large enough to contain at least one plot of each treatment and controls, is there some way of allocating the treatment replications so that the important comparisons are estimated with the greatest precision?

38. If the treatment comparisons are not orthogonal, do you know how the data can be analysed, and will that analysis answer the questions the experiment is designed to pose?

39. Are there any regular trends across the experimental site or material? If so, are these trends in one or both directions?

40. Have you considered the use of row and column designs to remove the effects of one or two-way trends?

41. Is there likely to be any advantage in the use of a split plot design?

42. If so, are the treatments applied to the sub-plots the ones for which the greatest precision is required?

43. Will confounding of treatment factors or interactions with block differences improve the efficiency of the design?

44. Have you planned to use the blocks of the experiments to absorb as much as possible of the extraneous variation in the execution and conduct of the experiment?

45. Is it possible that plots may be lost through accidents or mishaps?

46. If so, does your choice of experimental layout allow for a meaningful interpretation of the results?

Randomization

47. Have the treatments and controls been allocated to the plots of the experiment by an explicit randomizing procedure?

48. Was a separate randomization carried out for each block or row of the experiment?

49. Were the constraints on the randomization correctly applied?

50. Were you tempted to re-randomize any part of the allocation of treatments and controls to plots because of apparently unfortunate coincidences?

51. If so, do you have some knowledge of variation in the site or experimental material which has not been incorporated into the design of the experiment?

52. Does a plan exist, showing the allocation of the treatments and controls to the individual plots?

Recording of results

53. Does each plot of the experiment have a clear number or designation, linking it unambiguously to the plan of the experiment?

54. Have you defined the time intervals at which assessments of the experimental results are to be made?

55. Have you defined the variables or attributes to be counted or measured at each assessment?

56. If so, are the measurements meaningful and relevant to the objectives of the experiment?

57. Are any of the assessments to be made from samples of the experimental plot rather than from the whole plot?

58. If so, has the efficiency of the sampling been tested?

59. Are any of the assessments to be used as covariates to correct for unavoidable but measurable differences between the plots?

60. If so, will these assessments need to be made before any of the experimental treatments are applied, or can take any effect?

61. Have you planned to use the blocks or rows of the experiment to absorb any unwanted variation in assessment, e.g. different observers, assessments on different days or at different times of the day?

62. Have you designed a record form which will ensure that all assessments are complete and are recorded against the correct plot?

63. Have the assessors been trained to measure and count the variables or attributes efficiently and accurately?

64. Is there space on the record forms for observations to be recorded of unexpected changes or effects, and have the assessors been encouraged to look for these effects?

Planning for analysis

65. Have the hypotheses to be tested in the analysis of the results of the experiment, and their alternatives, been defined *a priori*?

66. Are these tests expressed, as far as possible, as null hypotheses?

67. Have any special contrasts to be tested or estimated in the analysis been defined in advance of a first inspection of the results of the experiment?

68. Do you understand the methods of analysis that will need to be used for this experiment and made arrangements for the computations to be done on a computer, or elsewhere?

69. If the computations are to be done on a computer, does the necessary program exist, and do you understand the constraints that the program places on the data set?

70. If not, have you obtained advice from a qualified statistician on the analysis and interpretation of the results, preferably before starting on the experiment?

The final (and most important) question

71. If you are in doubt about the purpose of any of the questions in this checklist, should you not obtain some advice from a statistician with experience of your field of research before continuing with the experiment?

There is usually little that a statistician can do to help you once you have committed yourself to a particular experimental design.

Table 1. Statistical Checklist "Design of Experiments" by J.N.R Jeffers. Institute of Terr. Ecology U.K. (cont')

TABLE 2 OBJECTIVES AND DESIGNS FOR FOUR DIFFERENT TYPES OF FIELD TRIALS WITH MPT'S

Types of trial	Objectives	Suggested design(s)	Comments
1. Nursery	To explore the ways of optimising the plant-raising conditions of selected species using relevant nursery practices.	Fully-randomized plants, or plots; or randomized complete block design.	May also involve separate direct-sowing trials, if appropriate. (Studies on biosystematics, juvenile-mature correlations, seed source identification and specific physiological/microbiological responses would be treated as separate experiments).
2. Elimination/ Survival (= "species elimination" or "Range-wide provenance trials")	To test, in the short-term (2 to 4 years, maximum) the ability of any interesting species (and/or range-wide provenances) to establish and flourish.	Fully-randomized single plants or *small* plots (no guards needed). Split into several experiments if needed to obviate local environmental variation.	The inclusion of some, known well-adapted species is useful in order to have a 'controlled' estimate of potential growth in view of year-to-year climatic variations over the short term of these trials.
3. Vigour/Phenology (="Species testing or "Restricted provenance trials")	To re-evaluate, and critically compare the growth performance of apparently adapted *selected* species (or provenances), and to obtain information concerning plant behaviour.	Depending on whether a) single plant b) community grown assessments are required: a) Fully-randomized or lattice designs or b) Augmented design in randomised blocks.	Species (or provenances) of very different structure should not be included in the same 'community-grown' trial. The repetition of trials in both space and time at this phase will enable GxE evaluation to be started.

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Types of trial	Objectives	Suggested design(s)	Comments
4. Early management ("species or provenance proving")	To compare a selected range of management techniques for one or more chosen species (or provenances) with a view to obtaining *extrapolatable* information on how best to optimize chosen outputs (products and/or services) in a range of practical situations.	Fully-randomized for single-plant studies. Randomized complete blocks (possibly with split-plots or a full factorial arrangement) for community-grown studies. Systematic designs where spacing is a prime variable.	See the 'Evaluation' flow diagram. As more is known about the species (or provenance), and the land use system for which it is destined, then increasingly complex management trials will be required. At this stage vegetatively propagated material can help cut down unwanted variability.

Nursery Trials

Objectives: Although the general objectives will probably remain the same throughout the network of trials (see Table 1) *specific* objectives may well vary, depending on the amount of prior information about suitable nursery practices for the particular MPT species which have been selected. There may also be opportunities to undertake some back-up experiments in the laboratory or in controlled or semi-controlled environments* For example on seed germination, the results of rhizobial innoculation, or for studies on biosystematic and juvenile - mature correlations or seed source identification; all under relatively uniform conditions. Practical "plant raising" issues are likely to need looking at with MPT's, as is involvement in direct-sowing investigations. Only the outline of investigations of possible practical nursery techniques are dealt with here at this time.

The decision on what exact questions these trial (or trials) should attempt to answer will depend on the extent to which any of the following are seen to be relevant.

- Are investigations needed before the species can be economically raised in the nursery?

- If it can be germinated and grown successfully, are there improvements to be made in the reliability of production and uniformity of plant material?

- Are there economies of cost and of labour inputs which can be made through improving nursery practices?

- Is there a need to compare species (or provenances) at the same time, and under the same range of nursery treatments and conditions, in order to select those that most reliably produces seedlings of the best quality?

Planning: Once having decided on a more specific set of objectives the trial or trials can be planned by reaching decisions on the following.

- Where are the trials to be located?
  - On-station or on-farm?
  - What are the merits/demerits of the site for nursery trial work?

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* See Part 5A

- If the seedlings are subsequently to be used in a field trial where is that to be located?

- At what time of season is the trial to be done?

  - Is it a normal period for producing tree seedlings? If not is this likely to matter?

  - What seasonal changes in climate will occur during the course of the nursery trial and at what stage of seedling growth is this to end?

  - Are there any management or administrative concerns arising during the course of the trial (i.e. public holidays, competing work directives etc)

- What species are to be selected for nursery trials?

  - Is it necessary to test *all* the species which may be required for field programmes?

  - Even if the nursery stages of some species are well-explored should some be included as 'controls'?

  - Is there a case to leave out particularly difficult species in order to mount separate and more thorough investigation for these? For example on special germination conditions, dormancies, innoculation etc. etc

  - What is the status of seed acquisition for all the species required? Will they all be available in sufficient quantity, arrive on time, store viably, be free of pests and diseases and be true to type?

- Has the seed been tested recently for viabili and allowance made in the amount to be sown for the number of seedlings required for the experiment? (Preferably x 3 viable seeds sown compared with number needed)

A "standard" trial to explore a range of nursery techniques might select, as thought appropriate, from the following variables

either to chose them as treatments or to standardize them throughout:

- Germination medium? (soil, sand, peat, compost mixture)

- Germination method? (chitted seed, scanfied seed, depth of sowing, soil surface covered/ shaded, watering techniques, pesticide used)

- Choice of sowing/germination/planting out sequence? (i.e. sown *in situ*, sown and pricked-out)

- Choice of seedbeds or containers?

- Choice of growing medium? (What soil mix or compost is to be used? Is fertilizer to be added?

- What additional treatments might be of interest (e.g. undercutting, topping, side-branching etc).

- What type of containers? (if used)

- Choice of seedling watering method?

- Type, duration and management of shade?

- What precautions are to be taken to ensure adequate plant nutrition? (original application of fertilizer or top-dressing; leaf applications. What tests to ensure that nutrition *is* adequate?

- What pest and disease control measures are necessary?

• Choice of layout will depend on the nursery site variability, the resources available and the number and relative importance of the treatments decided upon. One important decision to be made early on will be whether to have a separate trial for each species. If this is done it will make for simplicity and, if the number of other variables to be tested are large, it may be necessary to do this anyway. Factors to be considered in deciding on the exact kind of layout will involve:

  - What limitations of size are there?

  - Are there to be single plant plots? (e.g. if in containers in a fully randomized trial this will facilitate regular re-randomization to help obviate local environmental variation, but them rigid containers are desirable).

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- What to do about blocking? (if this is to be used)
- What should the plot size (number) be if single plant plots are *not* used?
- How many replicates are required?
- What spacing will be chosen? And will it be changed during the life of the trial? (By thinning or by re-spacing containers).
- What is to be done to 'gap-up' failures? (in a seed-bed)

- Records will consist of the following:
  - Details of experimental site
  - Names of experimenter/assistants
  - Origin and all details of seeds
  - Date of sowing and exact methods and conditions.
  - Plan of trial
  - Details of all experimental treatments
  - Additional information and/or observations made at sowing/pre-germination time
  - Dates of germination (seedling emergencies) and sample comments
  - Observations on health and vigour (damaging-off, pest, incidence etc)
  - Dates and kinds of applications of any pesticides applications
  - A diary of daily management treatments with regard to shading, watering fertilizing or soil management etc.
  - Details of any gapping-up - or if any destructive sampling (e.g. for growth analysis)
  - Measurements of height/stem girth at root collar at stated intervals
  - observations of vigour/health at same intervals (leaves, stem and roots)

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- observations on nodulation at regular intervals (position, number, colour, shape).

- Observations (laboratory) on mycorrhizas.

- Observations and photographs of form and branching (designations of buds bud series).

- Direct-sowing trials could investigate some of the following variables whilst maintaining the others at a standard level:

  - Time of sowing

  - Different sites (topography, soils).

  - Site improvements (soil amendments, micro-water catchments etc).

  - Seed treatments (scarification, innoculation, chitting, pesticide seed dressing, pelleting, irrigation).

  - Sowing techniques (soil preparation, depth of sowing, immediate post-sowing soil management).

  - Post emergent treatment (irrigation, pesticides, animal protection).

  - Seedling treatments (as above and thinning, shading, capping).

Elimination/Survival Trials

Objectives: The objective will be to test, in the short term (2 to 4 years maximum) the ability of species (or range-wide provenances) to establish and flourish in the particular ecozone and chosen sites.

Planning: (See CFI, Manual, page 95 on). At this early selection stage many accessions are likely to be compared, and little or no element of plant-to-plant interference or competition is being studied. Any number of accessions (species and/or provenances) can be included depending on the land and research management resources available. We need to consider the following:

- Trial layout (fully-randomized single plants or small plots - minimum 5 tree lines, maximum 5x5) the decision must be based on:

- what plant material is available?
- how variable is it?
- what resources are available to support the trial (or trials)?

- On-station or on farm locations?
- How to minimize local environmental variation?
- What spacing? Depending on the species (early vigour) not less than 1 x 1 and not more than than 2 x 2 meters will probably be suitable (especially if plant arrangement is staggered).
- Careful nursery preparation is required (has seed viability been tested?), and the best available plant raising and planting out procedures should be used.
    - some thought needs to be given as to the appropriate stage for planting out, whether or not young plants are to be given a "start" (fertilizer, initial irrigation). The case for initial help will depend on what might be found later, when the species is to be included in various land use systems but, above all, what is the research objectives.
- Consideration about protection from animals is needed.
    - are the trials to be guarded or fenced?
- Records for such a trial should consist of the following:
    - Information about the site (location and brief details)
    - Names of investigators
    - Meteorological data (daily records throughout)
    - Soil data (soil water status in the rooting profile)
    - Details of nursery treatments
        - . Seed identification
        - . date of sowing

- selection procedures
- layout in nursery
- nursery techniques and management details (diary)

- planting-out details
  - date
  - soil preparation
  - planting details
- Survival records (on several occasions)
- Observation on health and vigour
- Description of form and branching (annually)
- Measurement of stem girth and height (twice yearly or after any growth period)
- Records of phenology
  - Time of growth flushes/flowering/fruiting
  - Leaf senescence details/leaf fall periods
  - observations on extension root growth (soil cores)
  - observations on nodulation and mycorrhizals (laboratory examination).
- Records of plant stress/exposure
  - effects of drought (visible wilting, or by porometer measurements)
  - visual effects after chilling or frost
  - wind or sandstorm damage
  - effects of heat stress after maximum temperatures
- Records of pest/diseases
  - describe symptoms
  - identify casual agents.

Vigour/Phenology Trials

Objectives: The critical comparison of growth performance and plant behaviour of selected adapted species (or provenances). At this stage so as to obtain information about their likely performance in actual land use situations and, if possible, an appreciation of Gx E interactions in order to assess their potential over a range of sites.

Planning: By now a clearer idea of the value of outputs will have emerged (i.e. whether the species is likely to be successful as a potential fuelwood, fodder, fruit tree, etc). If trees are to be grown wide-spaced, because that is how they will eventually be used then fully-randomized or balanced lattice designs will serve (see CFI Manual p. 73, and Cochran and Cox page 483 for layouts) - remembering that the latter will restrict the number of species used to an exact square (16,25,36 etc or, in rectangular lattices, 12 20, 30 etc). For community-grown studies an augmented design suggested by Brewbaker is shown in Appendix 3C - 15.

Additional considerations for this type of trial are as follows.

- The duration can be extended to be longer than for elimination/survival trials - say 4-6 years. Because of this the spacing of plots should be adjusted. Again, depending on species and trial duration, between 2x2 and 3 x 3 meters, with staggered rows, will probably be suitable for most. If early community stress and canopy closure is important then double this plant population with a later thinning regime can be adopted. If this is done then there is an advantage in using a triangular or quincunx planting arrangement (see Part 4E).

- There is a case with vigour/phenology trials for favourably considering introducing some level of inputs at the planting out/plant establishment stages. This will depend on whether the experimental conditions are to be entirely natural, "realistic" (that is kept to a level that the majority of land-users/ tree-planters will adopt) or, for the sake of a complete establishment, afforded some higher level of preparation and plant care.

  This question can only be resolved by a close

examination of the experimental objectives, and it nearly always involves a measure of compromise. In some cases the trial plots might be divided, using a RCB and a split plot design, so as to re-examine survival and early growth under conditions which *exactly* conform to the natural state *also* to simulate what a land-user will do, *and* to provide optimum conditions.

- Even in vigour/phenology trials there can be a case to introduce some simple management investigations in order to discover more concerning the plant's responses to environment and manipulation. These might be carried out on relatively few plants, perhaps in the guard rows. For example, it could be of value to remove some plant parts such as shoot apices, flowers and/or fruits in order to effect growth regulatory processes and/or source-sink relationships. This will help to clarify the phenological behaviour of the plant (and to compare its responses with other species in the trials). More elaborate tests of this nature ("perturbations") would be left to subsequent "advanced management trials".

- A decision should be made on whether or not to allow the trees to fruit, especially where precocious flowering can be expected. Deflowering will help obviate possible large plant-to-plant differences in vegetative vigour, which may occur if young trees or bushes are allowed to fruit heavily. Eliminating flowering and fruiting might also be a treatment to investigate maximum potential vegetative yield in some cases.

- Records for such a trial should consist of the following, if applicable, and depending on resources available:

  - Information about the site (location and brief details)

  - Names of investigators

  - Meteorological data (daily records throughout)

  - Soil data (soil water status in the rooting profile)

  - Details of nursery treatments

  - Planting-out details

- Records of any gapping up needed (a, number trial position)

- observations on health and general appearance.

- Description of form and branching (annually)

  - Including one set of herbarium species of leafy twigs, flowers etc for each of the juvenile and mature stages.

  - Crown dimensions

  - Position and number of fruiting points

- Measurements of stem girth and height (twice yearly)

  - for each stem, (label, 'a', 'b', 'c' etc.)

- Records of phenology

  - Time of growth flushes, flowering, fruiting leaf fall.

  - Analysis of vegetative bud activity (times of bud maturation, description of bud break sequence in relation to climate, sequence of axillary shoot growth.

  - Analysis of average leaf age

  - Analysis of flower bud activity (time of initiation, maturation, anthesis, in relation to climate)

  - Fruit set information (flower bud: early fruit set ratio extent and period of later fruit drop)

  - Root activity (including nodulation, presence of mycorrhizas.

  - Bark formation (timing, and on what internodes)

- Yield data (most to be estimated by non-destructive methods until final harvest)

  - Estimates of total dry matter (and annual increment)

  - Stem wood volume (estimated)

  - Fuelwood assessment (estimated)

  - Leafy fodder yield (estimated)
  - Fruit/seed yield (actual)
  - Litter fall (actual)

- Environmental changes
  - Soil micro-site enrichment
  - Shade (at ground level)
  - Shelter (wind profiles)
  - Rainfall interception/stemflow
  - Soil temperatures
  - Soil water profiles away from the trunk
- Pests and diseases

Early management trials

Objectives: Early trials involving management will compare a *selected* range of management techniques on a *few* chosen species (or provenances) with a view to obtaining information on how best to optimize particular outputs (products and/or services), or sets of outputs.

By the time these trials are started the species' (or provenance) adaptability to ecozone and/or special site conditions should already be tested, the characteristics of the land use system or systems in which they are to be used should be throughly known, and thus some appreciation of the possible ways in which they are to be managed and can be expected to perform will be apparent. In particular, where the trees or bushes are destined for use in multiple cropping agro-forestry systems, the management trials can include some measurements which can at least indicate their likely potentials as intercrops with agricultural species - although this would be tested, thoroughly, latter (See Section 4).

Planning: These trials differ from those previously discussed in as much as the kinds and degree of management technology that can be applied to MPT's will be potentially far-ranging. All the kinds of trials and layouts (and laboratory support) suitable for investigating them will, similarly, be numerous and should be precisely designed for any set of specific objectives. Nevertheless, it is possible briefly to review some of the factors to consider in such management trials with MPT's, and to suggest ways of approaching the experimental procedures.

Early management trials with MPT's are likely, depending on local circumstances, to be concerned with some of the lines of investigation listed in Table 3. The type of layout suitable in designated (FR) = fully-randomized; (RCB) = randomized complete blocks, (S) a systematic design; and simple observational (O).

TABLE 3 Subjects of investigation for early management trials and MPT's

Type of investigation	Comments	Type of layout suitable
Plant management		
Spacing	For all kinds of MPT,s. Consider not only suitable plant populations but also rectangularity and plant arrangement. (See Part 4E)	(S) for exploratory trials followed by (RCB) once "target" spacings identified.
"Lopping"	May include cutting back (coppicing, pollarding) or just the removal of leafy shoots - or combinations of these. For fodder, mulch, fuelwood species. Consider age treatment starts, seasonal timing, plant parts, removal intensity (frequency x amount) and total amount of dry matter removed each year in relation to annual increment. All trials should include a 'control' treatment in order to compare the yield response and phenology of un-touched plants.	(FR) for initial trials followed by (RCB) once main treatments identified.
Spacing x lopping	To discover the optimum combination to maximize yield of parts required and to maintain sustainability.	(S)

TABLE 3 cont.

Type of investigation	Comments	Type of layout suitable
Soil aspects		
Soil management options	Cultivations (or zero/ minimum tillage) Mulch Water collection/water spreading	(RCB) - using split plots or full-factorial.
Micro-site enrichment	Important to obtain such information so as to compare relative value of species - but trial may have to run 8 - 10 years, at least	(FR) (RCB) (O)
Soil conservation	Looking into plant numbers required, planting arrangement and how best to manage.	(O)
Innoculation experiments.	Normally, this would follow nursery (or glasshouse) screening trials Comparing local strains (any natural infection by *Rhizobium*) with strains obtainable from Niftal.	(FR) or (RCB)
Special suitability		
For example for: . Shelter (windbreaks) . Dune fixation . Slope stabilization . Swamp drainage . Land reclamation . Planted fallow . Browse resistance . Drought resistance etc.	All of these would involve some selection of appropriate management treatments. For example: . planting-out techniques . spacing . early training . harvesting	All (O)

Management trials will be relatively long term (8-15 years?) and therefore costly. Plot sizes (where used) will be relatively large (not less than 7 x 7) and there is an advantage in being able to divide them so as to change to a "split plot" design during the course of the trial, should any new management treatments require looking into.

All such investigations should be planned so as to collect adequate (but not superfluous) data on the plant and the environment (see Section 3E for details) throughout the trial. This will be a selection of that listed on page 33 to 35.

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IDEOTYPES - by P.A. Huxley

During the 1960's there was a growing input from crop physiologists, particularly with regard to an understanding on what crop plant attributes contributed to "yield". This led to a close association between crop physiologists and crop breeders in order to seek a more satisfactory way to select new crop cultivars through a knowledge of, and ways of measuring, those actual attributes that made any one cultivar more successful than another.

Plant breeders had, up to that time, as Donald (1968) pointed out, conformed in general to two types of breeding programmes: "defect elimination" and "selection for yield" (on the basis of yields). Donald (see also Donald and Hamblin, 1976) assumed that if enough was known about the plant attributes that contributed to any set of breeding objectives, that is if a "model" could be established, then plant breeding could be made much more exact. He derived the term "ideotypes", that is plant types with model characteristics known to influence photosynthesis, growth and fruit/seed production (in breeding for yield). He postulated that a successful *crop* ideotype model differed from a high-yielding free-standing plant selection type by being less competitive relative to its size - with a greater capacity, in other words, to *share* environmental resources in a community of its own kind. With cereals and other crop plants this was often found to be achieved by plants with a less "aggressive" form or individual plant canopy (among other features). And for a number of crops, by rather less "bushy" plants with more erect branches.

Three types of "ideal" plants can be envisaged.

- Those that do well as spaced individuals ("isolation" ideotypes)
- Those that do well in varietal mixtures ("competition" ideotypes)
- Those that do well in crops consisting of single cultivars ("crop" ideotypes).

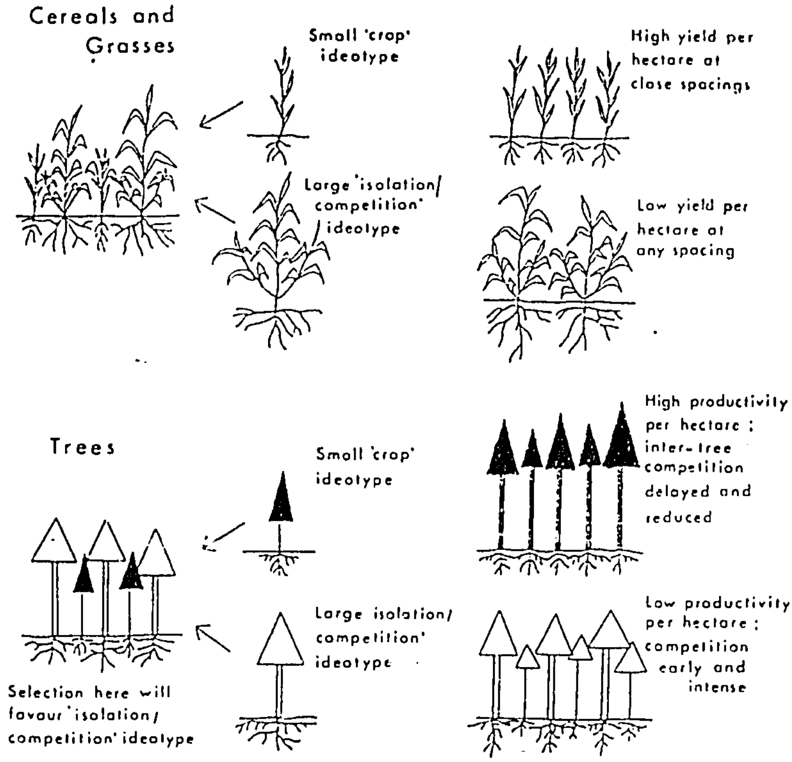

Fig. 1. Possible differences in the performance of various ideal plant types (ideotypes) as spaced individuals (centre), in mixtures (left) and in stands (right) (after Donald 1968; Donald & Hamblin 1976). Note that (a) relationships between individual plant performances and per hectare productivity after canopy closure can be negative (Hamblin & Powell 1975), (b) 'isolation/competition' ideotypes may tend to be selected if the criterion is plant size, and (c) selection for 'isolation/competition' ideotypes may lead to a desirable early spread in tree size frequency distributions.

From Cannell, M.G.R. (1978).

The extension of these ideas to forest tree breeding has been clearly set down by Cannell (1979) - and see Figure 1 - and given credence by some experimental evidence (Cannell, 1982).

With multipurpose trees there is a need to explore, and possibly extend the ideas concerning "competition" ideotypes in relation to the highly variable nature of most MPT germplasm at present. Also, to resource-sharing/yield-optimizing characteristics under management in mixed cropping situations. Although these might add additional complexities the *basic* assumptions made by Donald are most likely to remain as a sound starting point for viewing the attributes of any MPT species or provenance.

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See "On-Farm Experimentation in Farming Systems Research. Rep. of discussions held at IITA, Ibadan, Nigeria 31- May - 4th June 1982. Eds. D.S. Ngambeki and G.F. Wilson.

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The appendices to this include the following:-

	Pages
Flinn, J.C. Constraints Analysis Approach by IRRI	62-64
Zandstra, H.G. On-farm Research to Improve Production Systems	65-80
Collinson, M.P. Farming Systems Research	81-83
Norman, D.W. Institutionalizing the Farming Systems Approach to Research	84-92
McGuire, J.V* Some selected Analytical Techniques for On-Farm Experimentation.	93-101

- this is especially useful for statistical approaches and it gives an example of a balanced incomplete block design.

See also:

Kirkby, R. P. Gullegos and T. Cornicle, 1981. On-farm research methods: a comparitive approach (experinces of the Quimincy-Penipe Project, Eduador) Cornell Univ. Ithican. pp 29.

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Guard rows and effective percentage plot space - by P.A. Huxley

Effective percentage space for plot layouts involving different numbers of plants arranged in single, double, treble etc. rows within plots, and assuming that each such plot is surrounded by a single row of discard "guard" plants at the same spacing ("internal guards") and a single external guard surround.

The family of curves generated shows that:

a) spacing experimental plants in a single row soon results in a virtual upper limit (around 25% of effective experimental space,

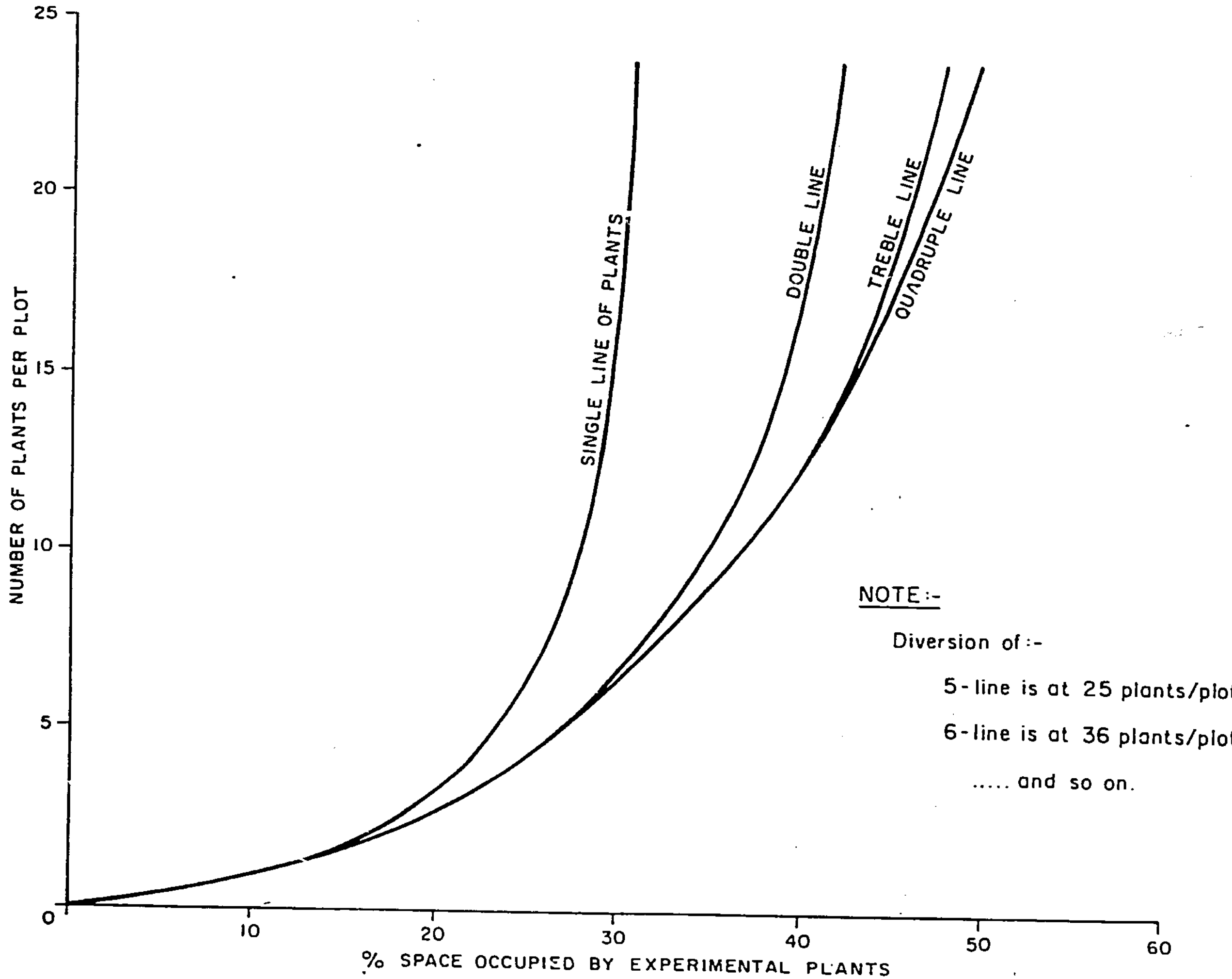
b) doubling or trebling row arrangements as a larger number of plants is used per plot results in an appreciable improvement in effective space, but this improvement diminishes as plot size increases, and

c) even if single guard rows are considered adequate (and they may well not be with trees at different spacings) then even an efficiently-designed plot layout will not utilize more than some 50-60 percent of the available experimental area.

- See also comments on guard rows in:

  Part 4E "Considerations when experimenting with changes in plant spacing", and

  Part 4F "Systematic designs for field experimentation with MPT's".


NUMBER OF PLANTS PER PLOT
25
20
15
10
5
0
10
20
30
40
50
60
% SPACE OCCUPIED BY EXPERIMENTAL PLANTS
SINGLE LINE OF PLANTS
DOUBLE LINE
TREBLE LINE
QUADRUPLE LINE
NOTE:-
Diversion of:-
5-line is at 25 plants/plot
6-line is at 36 plants/plot
..... and so on.

Presenting results in a way that is meaningful to farmers - by P.A.Huxley

Introduction

Any set of experimental objectives must be derived bearing in mind the possible ways in which the results of the experiments laid down will be used. In some cases experiments may be carried out in order to collect data to prove or disaprove a particular hypothesis which is of immediate interest only to other scientists. Much more often, in problem-oriented research related to the development of agriculture, forestry or agroforesty, the results will be needed to assist in making decisions about, and so help implement, a project development related to some improvement of landuse that will bring about benefits for the landuser and improve the level of national resources.

Under the latter circumstances both the experimental designs and the presentation of results need to be carefully considered in order to maximize their "interpretibility" for the user group without jeopardizing the scientific integrity or technical efficiency of the experiment/s. In practice, and unless the experiments are "on-farm" the immediate "target" is more likely to be the extension service whose field operators need to be shown the results of experiments in a form that is easily transcribable to the real situation facing the landuser *and particular in terms of his likely decision making processes*. Thus, in planning field experiments a comparison is needed on the following. They apply particularly to agroforestry research because of the input needed for adoptable answers to immediate development problems and the large number of management options open in agroforestry about which we have little information.

- The precision and experimental efficiency to be gained by using any particular layout in relation to the scientific information required and the practical application of the results.

  - For example, a factorial arrangement of plots (including the split-plot design) can very satisfactorily test main treatment effects and/or interactions (depending on the outcome) and indicate the kind of relationship exhibited by a range of levels

applied to any particular treatment (linear, quardratice, cubic). To do this effectively the experimenter is used to "optimising" (in cost-benefit terms) the plot sizes and arrangements and the numbers of replications of them. The outcome can also be expressed in any of the "packages" of treatments (and/or levels of these) that are relevant practically. This may not always leave as many degrees of freedom for testing difference between such "packages" of treatments, but this can be borne in mind when planning the layout. If a design can accommodate *both* requirements it should do so; and this implies that the research worker understands the landuser's likely requirements before the experiment is laid down.

- The flexibility of the design.

  - There is often a need, particularly in agroforestry trials, to leave some treatment options "open" as, during the cause of the experiment, a particular modification (say, a management treatment, such as lopping) becomes obviously in need of testing. The treatment of plot layout that immediately suggests itself as adapted to this requirement is the 'split-plot' (see Appendix 9) or, where single tree plots are being used in a fully-randomized layout some can merely be converted to the new treatment, as long as sufficient were planted at the start of the experiment

<u>Yield increase ratios</u>

Landusers are more likely to come to decisions about whether or not to adopt any new methods (species, cultivars) on the basis of the likely benefit to be achieved compared with the extra level of inputs (labour, skill, cash, land) required. This ratio - the "yield increase ratio" will seldom be attractive if it is less than 20-30 per cent, and it may be much more depending on the level of "affluence" of the farmer and the degree of risk and level of "innovation" involved. In many of the poorer parts of the tropics and sub-tropics, where agroforestry can be seen to be a feasible alternative to current landuse, the landuser may often be expected to be operating at a minimal level of inputs. What

he then needs to know is exactly what return can be expected by applying, incrementally, the various treatments being suggested to him and the advice should be based on valid experimental evidence that adequately tests each specific set of additional combinations. This approach assumes that a farmer is heavily influenced by his need to see some immediate gain from his efforts, and that events from the recent past weigh more with him than possible future trends.

The example, below illustrates the point using the results of a minimum tillage experiment in which both fertilizer and different kinds of mulch are applied.*

Layout Factorialized arrangement of main plots in 2 replicated blocks.

The crop was a maize/cowpea mixture.

Treatments

(i) Tillage - zero and two levels of hoe tillage (3)
(ii) Mulch - zero and 2 levels of grass and 2 levels of woody mulch (5)
(iii) Fertilizer - zero, N, P and N+P (4)

= 3 x 5 x 4 = 60 plots per block

(The 20 fertilizer and mulch treatments were factorially arranged and each was split for the 3 tillage treatments).

From such an experiment it is possible to provide a great deal of information e.g.

(a) The mean effects of tillage or mulch or fertilizer (i.e. the outcome of the different main treatments averaged over all the other treatments).

(b) The effects of various combinations of "packages" of treatments - from minimum to maximum inputs.

(c) The "sole" effect of any treatment (i.e. at zero levels of the others)

(d) Various interactions (note: if interactions are important there may be no value in deliberating about main effects).

---

* Huxley, P.A. 1980. Report on Zero tillage at Morogoro, Tanzania. II Summary of crop yields over the first 3 years (1975-1977) Faculty of Agric. For. and Vet. Sci. University of Dar-es-Salaam, P.O. Box 634, Morogoro, Tanzania. 26 pp.

The landuser is most likely to be interested in (b) chosing combinations that are meaningful to his actual situation. For example, starting with *no* tillage, *no* mulch and *no* fertilizer he might wish to be told what to expect if he does till (but does not add mulch or fertilizer), and if he adds only mulch, or fertilizer, or both but does not till.

In fact, in this experiment all the different kinds of information (a) to (d) were available but, as there were only 2 plots (i.e. 1 df) for testing differences between any two individual "packages" of treatments they are not tested statistically, very effectively.

As a first experiment this factorial/split-plot layout exemplifies how extremely useful it can be - but subsequent experiments, if more specifically designed to test "farmer" situation, would probably need more emphasis on selected treatment packages. The results could then be indicated to the farmer as 'Yield increase ratios" rather than as actual figures.

Fully Randomized Layouts

(with or without equal sample numbers)

Either as multi- or single-tree plots this can be a very flexible layout to use with MPT's, especially in early testing of species and/or provenances. There needs to be minimum spatial variability (e.g. in soil fertility) over the experimental area, but the design can handle samples of different sizes.

Replicates

5 a's
8 b's
7 c's
9 d's
7 e's
10 f's
5 g's
9 h's

Single trees

a	g	h	b	f	c	e	d	b	f	b	e
b	f	d	c	e	b	f	f	a	g	c	d
f	g	a	h	f	g	h	c	e	b	f	a
d	c	h	d	h	a	f	d	g	d	c	e
d	h	c	h	e	h	b	h	b	e	f	d

or fully randomized strip plots.

b	a	c	b	c	a	d	d	a	b	c	b	d	a

→

Continued →

d	b	c	a	d	c

Analysis

To compare any two means using a t-test.

Calculate the variances of A and B

e.g. SS
$$\frac{S(x^2) - \frac{(S(x))^2}{n_1}}{n_1 - 1}$$

and check that they are not too dissimilar

Then calculate a pooled variance

e.g.
$$\frac{S(x_1{}^2) - \frac{(S(x_1))^2}{n-1} + S(x_2{}^2) - \frac{(S(x_2))^2}{n_2}}{n_1 + n_1 - 2}$$

and use it in a t-test.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{(\frac{1}{n_1} + \frac{1}{n_2}) \text{x pooled variance}}$$

APPLICATION OF AUGMENTED DESIGN IN FIELD CROP EXPERIMENTS[1]

James L. Brewbaker
Professor of Horticulture
University of Hawaii

Tropical crop investigations often involve treatments or varieties at two distinct stages of inquiry. Some treatments will be at a fairly advanced level of inquiry, and extensive replication is desired. Other treatments are preliminary in nature, and it may be unnecesarily expensive and time-consuming to include them in all replications at all locations of the experiment. An experimental design that conveniently incorporates both types of treatments is the "Augmented design" of Federer (Federer, 1956; Federer and Raghavarao, 1975; Federer and Searle, 1976 Neely, personal communication, 1978).

The augmented design was first applied to varietal trials of sugarcane, where it was desired to compare new seedling varieties with older, well-adapted varieties (Federer, 1956). Plots were large and experimental expenses and errors were both high. As Federer pointed out, however, the design has wide applicability where both advanced and preliminary varieties or treatments are studied. This seems especially true for tropical crop experiments, such as these involving multiple cropping, soil amelioration, new varieties or new control measures. It is widely used in Hawaii for Statewide corn yield trials, involving about 20 old, standard hybrids and about 40 new hybrids, with 4 reps in 8 experiments annually.

A simplified example is given here of an augmented randomized block I have borrowed freely from Dr. Federer's papers, and acknowledge his authorship of the design and statistical notation used here.[1]

AN EXAMPLE OF THE AUGMENTED RCB DESIGN

All calculations and interpretations apply to the following set of data, from a randomized complete block (RCB) design with 3 treatments (t_r) in 3 reps. The design was augmented by the inclusion in each replication of 2 unreplicated treatments (t_u).

Table 1. Treatments:

	Replicated				Unreplicated				
Rep	A	B	C	Sub-total					Rep totals
I	8	6	12	26	(D)	4	(E)	6	36
II	9	5	9	23	(F)	13	(G)	10	46
III	12	8	13	33	(H)	10	(I)	8	51
Total	29	19	34	82		27		24	133

[1]The author acknowledges with thanks review and criticism of the manuscript by Dr. W.T. Federer, Biometrics Unit, Cornell University, Ithaca, New York, and by Dr. Douglas Neely, formerly of ORD, Suweon, Korea.

The experiment is seen to include 15 plots, with 3 replications of 5 plots each. Randomization is practiced of all plots in each replication, with no sub-grouping.

PRELIMINARY ANALYSIS OF THE DESIGN

In most instances, the following analysis of variance (Federer's type (b) analysis, 1975) and standard error calculations, using only the replicated treatments, should suffice for augmented designs. Adjustment of unreplicated treatments is required. The basic ANOV (Table 2) ignores data from the unreplicated entries. The computed error variance is then applied in tests of differences among both replicated and unreplicated entries. Referring to the data in Table 1 for replicated entries only, where SS = Sums of Squares, corrected, and CF = correction factor for the mean:

$$\Sigma X = 82, \quad \Sigma X^2 = 808, \quad CF = (82)^2/9 = 747.11$$

$$SS_{TOT} = 808 - CF = 60.89$$

$$SS_{REP} = (26^2 + 23^2 + 33^2)/3 - CF = 17.56$$

$$SS_{TRT} = (29^2 + 19^2 + 34^2)/3 - CF = 38.89$$

Table 2.

ANOV

Source	DF	SS	MS	F
TRT	2	38.89	19.45	17.51*
REP	2 f	17.56	8.78	7.91
ERROR	4	4.44	1.11	
TOTAL	8	60.89		

The analysis of variance results in an error mean square (MS_e) of 1.11. This should reflect directly the dispersion of the 3 replicated varieties included in the 5 plots of each rep; i.e., the MS would normally be smaller if the unreplicated entries were excluded. In normal practice probably no more than half of each rep should be taken over by unreplicated entries.

ADJUSTMENT OF UNREPLICATED TREATMENT MEANS

Before comparing means, it is necessary to adjust the unreplicated treatment values for the effect of the rep in which each occurs. Letting T_u represent the value of an unreplicated treatment in the i^{th} rep, the following adjustment must be made: $T_{adj} = T_u - \bar{x}_{i.} + \bar{x}_{..}$, where $\bar{x}_{i.}$ is the mean of all replicated treatments within the i^{th} rep, and $\bar{x}_{..}$ is the mean of all replicated treatments in the experiment. These values are as follows, based on data in Table 1:

$\bar{x}_{1.} = 26/3 = 8.67$

$\bar{x}_{2.} = 23/3 = 7.67$

$\bar{x}_{3.} = 33/3 = 11.00$

$\bar{x}_{..} = 82/9 = 9.12$

Adjusted treatment values are then obtained as follows:

Treatment	T_u	Rep No.	Rep $\bar{x}_{i.}$	T_{adj}
D	4	I	8.67	4.4
E	6	I	8.67	6.4
F	13	II	7.67	14.4
G	10	II	7.67	11.4
H	10	III	11.00	8.1
I	8	III	11.00	6.1

STANDARD ERRORS OF DIFFERENCES

Standard errors of differences based on the $MS_e = 1.11$ can be calculated to apply to all treatment comparisons as follows, where $r = 3$ reps, $t_r = 3$ replicated treatments and $t_u = 6$ unreplicated treatments:

1. SE_D between any 2 replicated treatments:

   $(2MS_e/r)^{\frac{1}{2}}$ $= 0.86$

2. SE_D between any 2 treatments in the same rep:

   $(2MS_e)^{\frac{1}{2}}$ $= 1.49$

3. SE_D betweem any 2 unreplicated treatments not in the same rep:

   $[2\ MS_e\ (1 + 1/t_r)]^{\frac{1}{2}}$ $= 1.72$

4. SE_D between replicated treatments (averaged over all reps) and unreplicated treatments:

   $[MS_e\ (1 + \frac{1}{r} + \frac{1}{t_r} + \frac{1}{r \times t_r})]^{\frac{1}{2}}$ $= 1.32$

As an example of further calculations, LSD (least significant difference) values are obtained by the formula:

$$5\%\ LSD = t\ (\text{at } df_e = 4) \times SE_d$$

For the four comparisons above, $t = 2.78$ and the LSD's are:

1. 2.39
2. 4.14
3. 4.78
4. 3.67

Discussion

The augmented block design provides a welcome flexibility to block designs where not all treatments appear to warrant full replication. By reducing replication, rep size may be reduced; experimental errors should thus be reduced also.

Greater care can in general be encouraged in the choice of replicated treatments for tropical crop trials. Preliminary evaluation in unreplicated plots, that can be compared visually and statistically with replicated treatments as "controls," permits better choice of treatments for study in advanced trials. Augmented designs might also include such unreplicated treatments as those suggested by junior investigators, extension men and farmers, or treatments chosen largely for demonstration purposes, or treatments representing extremes of treatment combinations. A major advantage of the design is that such treatments, no matter how discrepant their values may be, do not contribute to the experimental error of the experiment. In a replicated experiment, the unwise choice of an extreme treatment may greatly increase the experimental error, damaging thereby the entire experiment.

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96795, U.S.A.

INTERNATIONAL NITROGEN FIXING TREE TRIALS

ABSTRACT

- NFTA coordinates biomass productivity trials that evaluate outstanding nitrogen fixing trees of the tropics for growth and utility as fuelwood, pulpwood and forage.
- The basic trial is an augmented block design of about 1/4 ha in size, including ten or more NFT species.
- Primary data are on heights and diameters on 6-month cycle.

EXPERIMENTAL DESIGN

- Small plots (e.g., 42 trees with 20 internal data trees).
- Field Size: 0.2 ha including border.
- Augmented block with four (4) replicates of outstanding species and single (1) rep of other species or varieties.
- Population density of 10,000/ha or 5,000/ha if preferred.
- Data: Heights and diameters on 6-month cycle. NFTA will assist in computerization and analysis of data.

SPECIES ENTERED IN TRIAL

- REPLICATED

Acacia auriculiformis
Acacia mangium
Calliandra calothyrsus
Gliricidia sepium
Leucaena diversifolia
Leucaena leucocephala
Sesbania grandiflora

(Plus others as desired)

- UNREPLICATED

Acacia mearnsii
Albizia falcataria
Albizia procera
Cassia siamea
Casuarina equisitifolia
Dalbergia sissoo
Enterolobium cyclocarpum
Eucalyptus spp. ("Check")
Mimosa scabrella
Samanea saman

(Plus others as desired)

FOR FURTHER INFORMATION AND SEEDS, WRITE:

- NFTA, Box 680, Waimanalo, Hawaii 96795 U.S.A.

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INTERNATIONAL NITROGEN FIXING TREE (INFT) DEMONSTRATION/TRIALS

ABSTRACT

- NFTA coordinates biomass productivity trials that evaluate outstanding ntirogen fixing trees of the tropics for growth and utility as fuelwood, pulpwood and forage.
- The basic demonstration/trial is an unreplicated design of about 1/10 ha. in size, including ten or more NFT species.
- Primary data are on heights and diameters on 6-month cycle.

FIELD DESIGN

- Field Size: 1,200m^2 including border.
- Field layout: Plot size of 6 x 20m per species with 40 trees sampled per plot.
- Population density of 10,000/ha (1 x 1m spacing).
- Data: Heights and diameters on 6-month cycle. NFTA will assist in computerization and analysis of data.

SPECIES ENTERED IN TRIAL

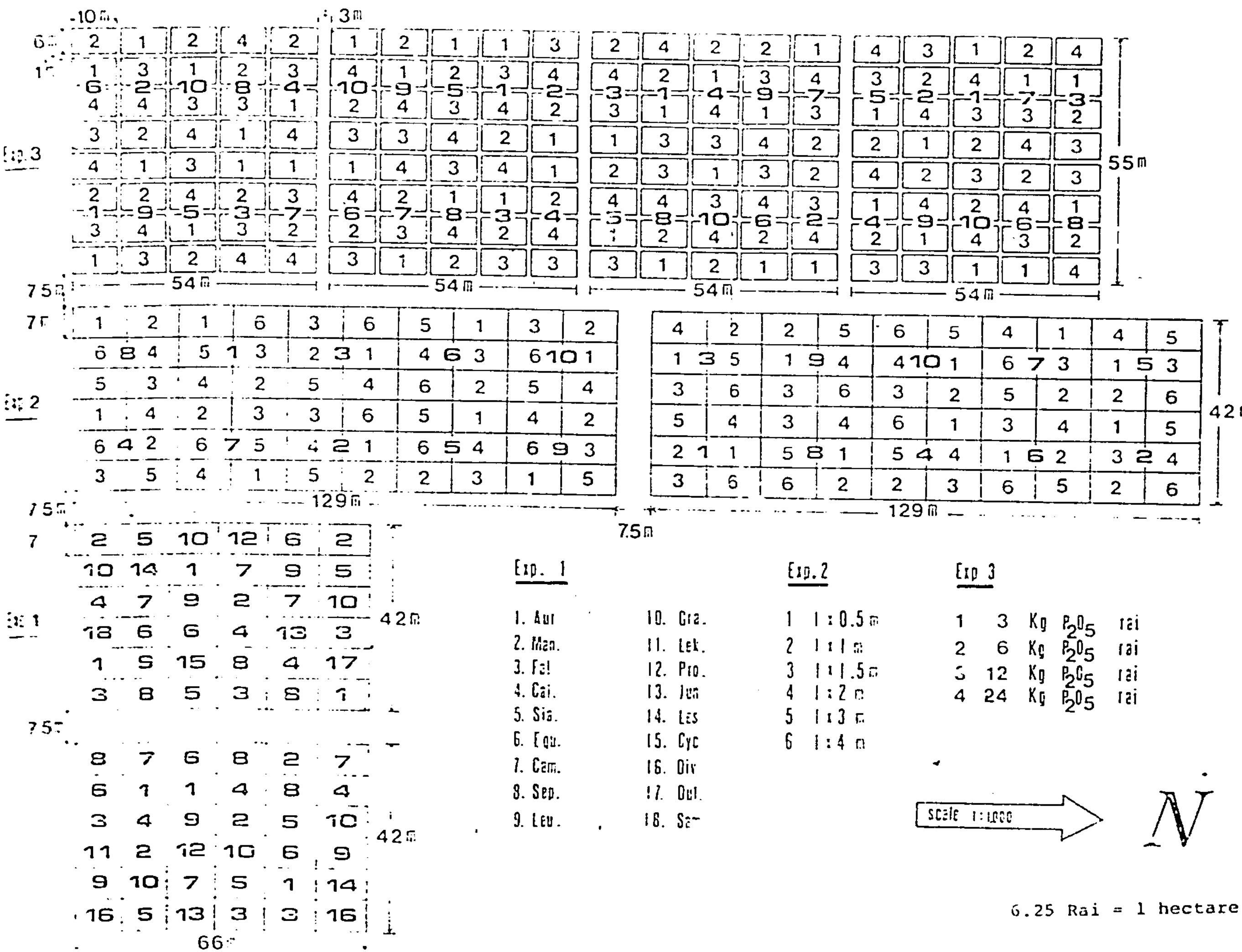
Acacia auriculiformis
Acacia mangium
Calliandra calothyrsus
Gliricidia sepium
Leucaena diversifolia
Leucaena leucocephala
Sesbania grandiflora
Casuarina equisitifolia
Plus locally adapted species

FOR FURTHER INFORMATION AND SEEDS, WRITE:

- NFTA, Box 680, Waimanalo, Hawaii 96795 U.S.A.

NAS ~ FGNFT «CHAN THUEK»

Narong Chamchalow
Thailand



6.25 Rai = 1 hectare

Incomplete block designs

Commonly in population studies, and particularly with provenance trials, the number of populations to be compared exceeds 10 or 12 and, if there are 25-36 or more trees per plot, it is difficult to find a site with sufficient uniformity to accommodate a complete replication. Incomplete block designs have the common feature that the experimental plots are grouped into blocks of less than the total number of populations. In addition, each block has the same number of plots and each population occurs the same number of times in all (i.e. there is constant replication). The arrangement is such that variation between blocks can be estimated and eliminated from the analysis of population differences. An ideal incomplete block design is one in which each pair of populations (e.g. provenances) occurs in a block together the same number of times. Such a design is said to be balanced and allows all population comparisons to be made with the same precision; however, it generally requires a large number of replications. Smaller experiments, with only partial balance are commonly used.

Incomplete block designs are not available for all numbers of populations, particularly if near or complete balance is required. However, the number of populations can often be adjusted to fit a design by either eliminating populations in which interest is low, or by including one or more additional or "dummy" populations (local, mixed collections, say). Increased replication of standard or control populations is also possible. A complete list of available incomplete block designs was given by Cochran and Cox (1957) who also described their construction and analysis in detail.

Extracted from, Wright, H.L. and I.A. Andrew, 1976. pp 67-82 in "A Manual on Species and Provenance Research with Particular Reference to the tropics" (Compiled by J. Burley and P.J. Wood Trop. For. Pap. No. 10. CFI. Oxford.

Appendix 8

Lattice designs

A particular type of incomplete block design is the lattice, in which the blocks are physically grouped in sets which form complete replications of the populations. The number of populations must be a perfect square, k^2 (= 16, 25, 36, etc.), or a product of the form $k(k + 1)$ (= 12, 20, 30, etc.); these designs are known as square or rectangular lattices respectively. In each case there are k (= 3, 4, 5, etc.) plots per block and k (square) or $k + 1$ (rectangular) blocks per replicate. In general a fully balanced square lattice requires $k + 1$ replicates, each arranged in a distinct way; balanced designs do not exist for certain sizes of square lattices (e.g. for $k^2 = 36$, 100 and 144) nor for any of the rectangular lattices.

Unrandomized plans for all the important lattices are given in Cochran and Cox (1957) and in Fisher and Yates (1963); a selection are incorporated in Appendix 5. When the required numbers of populations and replications have been determined the appropriate plan is used to produce a randomized design as follows:-

(a) If the required number of replications is less than that given in the plan select the required replications at random. Thus if four replicates of a 5 x 5 lattice are required select them randomly from the six given in Appendix 5, Table (d). If more replications are required than are given in the plan then two or more of the theoretical replicates must be selected and repeated. For example, if four replicates of a 6 x 6 lattice are required select two from the three given in Appendix 5, Table (f) and use each twice. Note that if replicates are to be repeated the total number of replications must be even. Repeated designs are rather more difficult to analyse than otherwise and any imbalance in population comparisons is magnified.

(b) Randomize the order (sequence) of the replicates actually used.

(c) Randomize the order of incomplete blocks within the replicates.

(d) Randomize the plots within each block.

(e) Assign the populations at random to the treatment numbers in the plan.

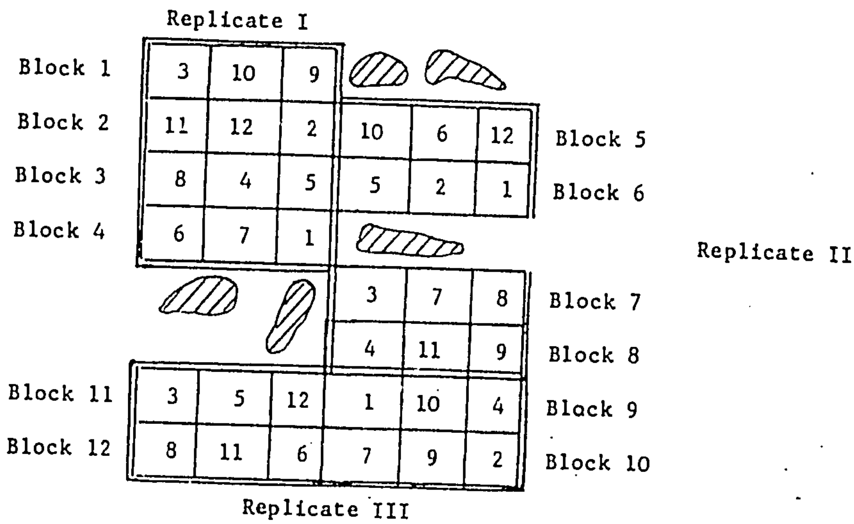
The series of randomizations described above should be carried out using a table of random numbers and permutations. The result is an office layout analogous to that described for an RCB design above (4.21). The principles for laying out of the design in the field follow those given for RCB designs; blocks should be confounded with systematic site variation and plots should avoid obvious extreme irregularities. A possible field layout of three replicates of a 3 x 4 rectangular lattice is illustrated in Figure 4.3; it may be compared with the plan from which it was derived in Appendix 5, Table (a).

The single advantage of lattice designs, or of any other incomplete block designs, is that the precision with which population differences may be estimated is at least as great as with a RCB design with equal replication. The disadvantages are that the designs are complex and their analyses are involved and best undertaken on an electronic computer;

however, a lattice, unlike other incomplete block designs, is arranged in complete replicates and it can be analysed (with some loss of information) as a RCB. This feature can be of considerable utility if one or more populations fail completely, or if there are many missing values. Moreover it permits the experimenter who does not have ready access to a computer to do his own initial analyses by hand.

Cubic lattice designs exist for very large numbers of populations which form a perfect cube (e.g. 27, 64, 125) and where site uniformity is so low that very small blocks (3, 4 and 5 plots respectively) should be used. The use of these designs has been described by Yates (1939).

Possible field layout of three replicates of a 3 x 4 rectangular lattice design



Extracted from, Wright, H.L. and I.A. Andrew, 1976. pp 67-82 in "A Manual on Species and Provenance Research with Particular Reference to the tropics" (Compiled by J. Burley and P.J. Wood Trop. For. Pap. No. 10. CFI. Oxford.

Appendix 9

Factorials

Using a randomised block design each block will contain *all* the combinations and levels of treatments. These can be assembled most easily by drawing a small table. (see below)

For example, if there were 4 species of MPTs (ABCD) each to be subjected to one of 3 lopping regimes (1,2, and 3) to be carried out at one of two seasons (early or late = x or y) i.e. a 4x3x2 factorial.

	Lopping Regime					
Species	1		2		3	
	x	y	x	y	x	y
A	Ax1	Ay1	Ax2	Ay2	Ax3	Ay3
B	Bx1	By1	Bx2	By2	Bx3	By3
C	Cx1	Cy1	Cx2	Cy2	Cx3	Cy3
D	Dx1	Dy1	Dx2	Dy2	Dx3	Dy3

When these are tabulated they provide 24 plots with all the various combinations of treatments to supply 1 replication (block).

An advantage of factorials is their ability to test interactions, and this can be particularly useful in exploratory work when one is not aware if the main effects are additive or not. Factorials also contain a high degree of "internal replication" and are therefore efficient designs.

Analysis

For the above example with just 2 blocks the analysis would, in outline, would be:-

Overall:	df	
Blocks	1	
Treatments	23	- split as shown below.
Error	23	
Total	47	

Treatments

Species (sp)	3
Lopping regimes (L)	2
Seasons (Se)	1
Sp x L	6
Sp x Se	3
L x Se	2
Sp x L x Se	6
	23

The variances of higher order interactions are sometimes used as an "error" variance to test differences between means involved in lower order interactions.

- See any standard text book for details of calculating MSs and carrying out tests of significance.

Split-plot designs

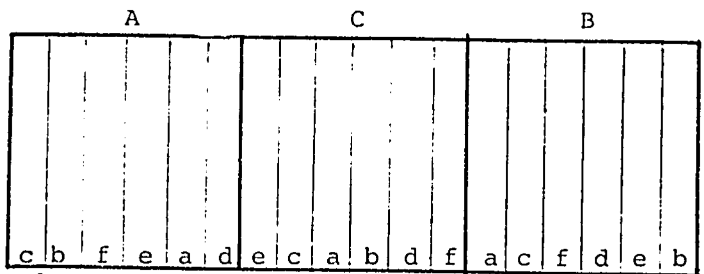
Example. A randomised complete block layout with:

3 main plot treatments - randomised throughout each block (each block contains all 4 treatments

6 sub plot treatments - randomised throughout each main plot, and

4 replicates (blocks)

Main plot treatments   Block 1



Split plot treatments

Analysis

Main plots	d.f.
Blocks	3
Main plot treatments	2
Error (a)	6
Split plots	
Split plot treatments	5
Split x Main treatments	10
Error (b)	45
Total	71

Such a layout gives more precision for testing the differences between the split-plot treatment means (with 45 df as compared with 6 df for main plot treatment means), and this is sometimes the reason why it is used i.e. when the kind of differences to be expected between main plot treatments are reasonably well known but the main emphasis is to discover more about the split-plot treatments and the interaction. A problem can sometimes be that the number of degrees of fredom to test main plot differences is very low and, if the error variance (a) is large, no significant differences will emerge.

This layout is also useful when there are some reasons of convenience for assigning a particular set of treatments to the main (larger) plots, for example, if each is to be subjected to a common tillage treatment and, with multipurposes trees there may be a reason to assign species (or provenances) to main plots and use the split plots to investigate management treatments.

The standard errors for comparing means of different kinds are as follows (from the example given):

Any two main plots means $\sqrt{\frac{2 \times \text{error MS(a)}}{24}}$ with 6 df

Any two split plot means $\sqrt{\frac{2 \times \text{error MS(b)}}{12}}$ with 45df

Any two split plot means within a single main plot $\sqrt{\frac{2\text{xerror MS(b)}}{4}}$ with 45df

The differences between two split plot means for any two main plot treatments $\sqrt{\frac{4\text{xerror MS(b)}}{4}}$ with 45df

The standard error for comparing any two main plot treatments either for any any split plot or for different split plot treatment involves both error mean squares $\sqrt{\frac{2((B-1)MS(b)+MS(a))}{rB}}$

(where r is the number of blocks and B is the number of split plot treatments - No t test is possible).

See also: Abou-el-Fittough, H.A. 1978. Relative efficiency of the split-plot design. Expl.Agric. 14, 65-72.

Appendix 10

Family block designs

If the populations divide naturally into a number of groups it may be useful to keep the groups together in blocks within each complete replication. Typically the groups may be separate species or distinct varieties, with several provenances of each. The number of provenances (i.e. group size) need not be constant. The resulting design is analogous to a split plot layout with groups corresponding to main plots and provenances to sub plots. Family block designs have been called pseudo split plot designs. The advantage of the design, in the specialized set of circumstances described, is that differences between provenances, which are likely to be smaller than those between groups (e.g. species), may be estimated more precisely.

Designing a family block layout is straightforward. The groups are assigned at random within each replication and then the individual populations are assigned randomly within each group. A possible layout for four provenances of each of three species is shown below.

A family block design for four provenances of each of three species.

Replicate I

B_1 (Species B) (Prov 1)	A_2	C_2
B_3	A_4	C_1
B_1	A_3	C_4
B_4	A_1	C_3

Replicate II

C_3	B_4	A_3
C_1	B_2	A_2
C_4	B_3	A_1
C_2	B_1	A_4

(For illustration only two replicates are shown)

Extracted from, Wright, H.L. and I.A. Andrew, 1976. pp 67-82 in "A Manual on Species and Provenance Research with Particular Reference to the tropics" (Compiled by J. Burley and P.J. Wood Trop. For. Pap. No. 10. CFI. Oxford.

Controlling residual variation by co-variance adjustments including adjustment by neighbouring plots

A covariance analysis can be used to adjust observed plot values by adjusting them according to a correlation either with initial values (e.g. some of the young trees) or with some oneasure of the variability of the experimental site (the date from a previously run "uniformity trial") The reduction of experimental error by judging the performance of each plot by that of a neighbours, which also uses a covariance technique.

Analysis of covariance*

Covariance analysis is an extension of the analysis of variance in which observed plot values are adjusted according to their correlation with initial values or with inherent site variability. Thus growth in some plots may be good partly because of high soil fertility; in this case assessment of some aspect of fertility may be used as a covariate to adjust the analysis of variance. (The effects of site variability should, of course, be controlled as far as possible by good experimental design; covariance analysis provides a means of reducing residual variation which cannot be controlled by design alone.) The theory behind the analysis of covariance is, strictly, only applicable if the covariate is independent of population differences, as in the example just described. The method may also be used to adjust, say, fifth year growth data according to variation in initial field height, in order to investigate, specifically, growth in the field. In this sort of analysis the standard significance tests should not be made as they may be seriously in error (Cochran and Cox, 1957); moreover the results of the analysis must be interpreted with extreme care. If adjustment makes little difference to ultimate population differences it indicates that initial growth differences between populations do not have much practical importance. If initial growth is, on the other hand, closely related to ultimate performance the adjustment by the analysis of covariance may obscure important population differences; a provenance may ultimately perform better than its rivals precisely because it grows well initially.

Computations for the analysis of covariance for simple designs are described by Snedecor and Cochran (1967) and by Cochran and Cox (1957). A Statform for the calculation of a randomized block analysis of covariance is given by Dawkins (1975). For square lattice designs the analysis is described by Cox, Eckhardt and Cochran (1940).

* Extracted from, Wright, H.L. and I.A. Andrew, 1976. pp 67-82 in "A Manual on Species and Provenance Research with Particular Reference to the tropics" (Compiled by J. Burley and P.J. Wood Trop. For. Pap. No. 10. CFI. Oxford.

Adjustment by neighbouring plots

This procedure, described in Pearce and Moore (1976) involves calculating then plotting the residuals (residual variance about the overall mean for the experiment) on a plan of the experiment to indicate their spatial relationships, after which a "concomitant variate" is calculated. This is done for any one plot using the residuals of its neighbours and the plot data are then subjected to an analysis of covariance so as to adjust them by the "concomitant variate".

Replication must be adequate in order to leave sufficient degrees o- freedom, after substracting treatment effects to enable a reasonable estimate of residuals to be made. Or, in other words, there has to be enough plots of each treatment to give a reasonably precise estimates of its mean performance over the whole experimental area.

Results are available of a study by Pearce and More (1976) of some 11 situations involving 6 trials on tea, peach, pineapple, grapes and apples, in which the experimental data were adjusted by neighbouring plots using 6 different ways of calculating "neighbours" two of which used double covariance, and compared with ordinary blocking and no attempt to control circumstantal variation at all. Readers are referred to the original paper but, in general, double covariance was more successful than single covariance and the more trees used for adjustment the larger the reduction in error. The technique was particularly successful with the tea experiments but not with apples.

With the high degree of vaiability expected from experiments with most MPT species all possible ways of reducing unwanted variation will be necessary (nursery selection, planting out care etc etc.). In addition spatial variation will need to be contained by blocking - although the size of field experiments will often put a limit on the effectiveness of this. The methods proposed by Pearce and Moore may be particularly suited to MPT field trials especially where, as is often the case, the germplasm is heterrozygous and individual plots will, anyway, vary genetically in their potentials to attain different statures and habits - irrespective of the extent to which environmental variation brings this about.

What is now needed are more experimental data and a closer examination of the technique for use with MPT species.

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APPENDIX 12

Selected and annotated list of books on statistics and field experimental design

- Being prepared -

SECTION THREE

PART 3D

Raising plants for field experiments

PART 3D

CONTENTS

Page

Seed for species and provenance research - by P.J. Wood and P.A. Huxley.

The information and instructions given by the International Seed Testing Association (ISTA) should be followed for all species used in agroforestry if possible. Normally all the seed handling under these rules will be carried out in national laboratories.

Germination tests

The most important sections of the ISTA rules (Appendix 3D-1) relate to the germination procedures and the calculation and expression of results. For these, standard tests of 4 x 100 seed samples are specified. However, for some multiple-seeded species either 400 "fruits" (as with teak) or for small seeded tree species (such as (*Eucalyptus or Alnus*), the weight of each replicate is specified. Clearly the ISTA rules cannot include all possible multipurpose species and, if a "new" species is under trial the procedure for a species with similar seed should be used (similar first of all in size and then in physiology, if this is known).

ISTA rules also indicate the duration of the germination test to the final count for different agricultural and horticultural seeds. Again, many multipurpose species, particularly tropical ones, are not listed, and the nearest relatives should be taken. The prescribed germination period seldom exceeds 28 days. Additional information that is sometimes useful is to obtain an estimate of "seed vigour This is obtained by counting germinated seeds at more frequent intervals and plotting germination percentage against time. The combination of "ultimate percentage germination" and "germination rate" gives a better description of the seed lot than the former alone. A knowledge of "seed vigour" can be useful in calculating the amount of seed needed both for nursery and direct sowing work. When seedlings are being used for experimental purposes it is preferable to use seed batches with good "seed-vigour as "stragglers" will not, in any case, be selected for planting out.

Deciding on the time at which a seed can be considered to have germinated may, occasionally, present difficulties. In most cases, after a seed has imbibed, the extension of 1 centimeter of radicle is a suitable stage. However, sometimes further growth of the hypocotyl (and/or epicotyl) is inhibited for one reason or another. The expansion of cotyledons and the appearance of a

healthy shoot apex (in epigeal seedlings), or the appearance of both a healthy radicle and shoot apex (in hypogeal seedlings) is more confirmatory. The literature on seeds and seed testing contains more information.

The ISTA rules also give maximum tolerated ranges of germination percentages between the replicates of 100 seeds under test, at 0.025 probability. This is given in Table 1.

Table 1

M-ximum tolerated ranges between seed lot replicates

Average percentage germination	Maximum range	Average percentage germination	Maximum range
99 or 2	5	87 to 88 or 13 to 14	13
98 or 3	6	84 to 86 or 15 to 17	14
97 or 4	7	81 to 83 or 18 to 20	15
96 or 5	8	78 to 80 or 21 to 23	16
95 or 6	9	73 to 77 or 24 to 28	17
93 to 94 or 7 to 8	10	67 to 72 or 29 to 34	18
91 to 92 or 9 to 10	11	56 to 66 or 35 to 45	19
89 to 90 or 11 to 12	12	51 to 55 or 46 to 50	20

From ISTA(1976)

Specifications for a range of permitted test substrates including paper towels, the soil and water used are given, together with descriptions of equipment, the use of light and the temperature regimes, etc. Some examples are given in Appendix 3D-2 and sources of other information in Appendix 3.

In very general terms, small seeds which will germinate quickly are suitably tested on seed testing papers (in petri dishes or, better, on a Copenhagen Tank), or in paper towels. These methods are not suited to large seeds or to small seeds that take a long time to germinate because of difficulties in maintaining an adequate and constant water supply to the seed surface in the first case, and, in the second, because the capillarity of the paper deteriorates with time if the duration of the test is prolonged unduly. Large seeds can be tested in free-draining 'flats' or plastic containers filled with a suitable compost, or with coarse, washed sand which has been wetted to field capacity and allowed

to drain at the start of the test. The containers should be kept at room temperature in the shade (or preferably in an incubator at the temperature(s) stated in the ISTA rules). The seeds can be placed in rows on the compost or sand and pressed into it with a piece of flat board. In this way each seed is equally situated in the germination medium. The water status of the medium can be maintained by spraying (with a fine spray) at intervals which can be regulated (a) exactly, by monitoring the weight of each container plus seeds (b) less exactly, by observing the persistence of the condensation film on a sheet of thin polythene laid directly over the seeds as a cover.

Some seeds (but not all) will germinate if placed in a flask in water through which air is bubbled (using an aquarium bubbler) and this method can provide a cheap form of an easily-controlled, and standardized, germination environment. It cannot be too strongly stressed that some form of germination test is absolutely essential before distributing seeds either for experimental or developmental programmes, otherwise costly and unnecessary failures can ensue.

Biochemical viability tests

For a rapid determination of the viability of seed samples, biochemical tests may be used, and for use on International Analysis Certificates strict instructions are included in the ISTA rules. However, for a quick working estimate of viability these may be varied. In addition to such "short cut" viability tests the method may also be used to examine any unusually high proportion of apparently sound ungerminated seed at the end of a standard test. The use of a buffered solution of tetrazolium chloride or bromide makes it possible to distinguish living cells in an excised embryo, and instructions for applying the method, together with diagrams of several examples are given in the Annexes to the ISTA rules.

Seed health

This is an important subject since seed-borne diseases may affect performance in the field and may affect the germination test. In the international context of seed introduction and exchange, quarantine is always necessary. However, only where specific pathogens are known to exist will it be necessary to carry out special tests and these will always be done in pathology laboratories.

Nevertheless, careful examination of the seed sample plus examination of the growing plants should always be carried out as part of the normal process in nurseries and after germination tests. The germination regulations of individual countries will specify the regulations for importing seeds of particular species. In most cases it is necessary to have an accompanying phytosanitary certificate and additional requirements may have to be met (e.g. fumigate with methyl bromide against pests, or strict quarantine examination if plant pathogens or eelworm contamination is suspected. Most countries forbid the import of vegetative materials except through quarantine stations, and the import of plants in soil is usually completely forbidden. Tissue or meristem cultures may require special permits.

Plant raising
- by P.A. Huxley and P.J. Wood

A main principle in testing species is the evaluation of as wide a genetic spectrum as possible. The design and size of experiments is thus critical, and in the agroforestry situation many more variable require testing than in more straightforward forestry or agricultural situations. Since resources are nearly always limited the greatest amount of information should be aimed at for the minimum outlay of resources, but critical decisions to be made early on are how many plants are needed? And how should they be raised in order to produce "standard" material for planting out?

Experimental Nursery Programmes

It may be necessary, when little information is available about plant raising for a particular species, to embark on at least a small programme to inbestigate simple germination and seed raising techniques. The first step towards these is to refer to any information obtained in the Exploration Stage (Section 2).

If further information on germination is required then this might include:-

- Studies of viability:
  - tests of appropriate seed storage methods e.g. combination of different low temperatures x seed moisture content;
  - sealed as against open storage;
  - effectiveness of locally available insecticidal/fungicidal seed dusts, including observations of phytotoxicity and so on.
  - some seeds ("Recalcitrant seeds") do not stand drying or chilling and these need special care.
- Trials on the optimization of germination conditions:-
  - tests of sowing depth, soil temperature, temporary soil cover (light mulch) etc.

    but where seeds will not germinate a viability test should be carried out (see previous chapter)
  - tests of different treatments to overcome dormancies (e.g. scarification, drying, heating, chilling etc.)

- tests for providing special conditions (e.g. wetting/drying as for *Conocarpus lancifolius*, or heating as for *Hakea saligna*)

- Trials for optimising seedling emergence:
  - attention to the soil environment (soil or compost type, texture, water-holding capacity, nutrient status, *etc*) and for FGNFT's inoculation with *Rhizobium*;
  - attention to the aerial environment (particular shade requirements);
  - optimum times for planting out;
  - early plant training requirements (nursery).

Nursery germination

The objectives of germination in the nursery phase include the following.

- the evaluation of germination and plant percent on an operational scale.
- the provision of suitable planting stock for field trials.
- the evaluation of juvenile characteristics.
- the establishment of juvenile/mature correlations using mature characteristics at a later date.

The germination procedure, including pretreatment such as exposure to acid, sun, heat, *etc*, should be kept as uniform as possible throughout for a particular species or provenance.

Routine germination tests should always be standard practice in any nursery, as mentioned above.

Germination can be hastened and the period shortened by pregermination in moist sand, vermiculite or moist blotting paper. For larger seed, viability can also be studied quickly by the nurseryman using simple cutting tests with or without the use of stains, as referred to above. For smaller seeds (e.g. many eucalypts) a smear test between two sheets of glazed writing paper at least identifies full seed, if not necessarily viable seed. For most

multipurpose species it is also desirable to arrive at systems for germination that do not require specialist treatments, equipment or chemicals that might prove difficult to obtain.

Direct sowing in the field

In forestry and horticultural practice, direct sowing is the exception rather than the rule; the reverse is true for agricultural field crops. The advantages of using nursery planting stock relate mainly to increased reliability of survival, and to the more efficient use of seed. Where seed is rare or expensive or of a valuable genetic strain, this is particularly important. Some tree species used mainly for fuel, poles or tanning bark lend themselves particularly to direct sowing - examples are Neem *(Azadirachta indica)*, *Cassia siamea* and black wattle *(Acacia mearnsii)*.

For trials of multipurpose trees in which yield performance is the main parameter to be tested it will usually be best to raise plants in the nursery. If it is desired to test the feasibility of direct sowing, this should be done in separate field experiments.

There are, powerful arguments to re-evaluate the place of direct sowing in view of the very large number of MPT's (FGNGT's) which are needed in order to supply current and future national needs. Where the cost of seed is low, and it is in plentiful supply, some trials might be undertaken to investigate ways of improving germination, survival and early-seedling growth in the field situations that apply.

The variables tested might include the following:

- Germination treatments
  - sowing before or after rainy season begins
  - soil preparations (manure, soil additives to improve water-holding capacity, soil-working, pesticides, micro-water catchments/ "inprinters" and so on)
  - "Pelleting" (but using local materials e.g. dung?) plus stickers in order to improve the seed environment.
  - inoculation with an appropriate strain of *Rhizobium* (FGNGT's).

- Early seedling treatments.
  - micro-water catchments;
  - protection against animals (heaped thorn scrub over sowing site, seed dressings);
  - fertilizers (small amounts to surviving seedlings only).

Nursery methods

Nursery methods can be divided into two main groups, those where the aim is eventually to plant out a complete plant and those where only part of the plant is planted out. These are subdivided as follows.

- Complete plants.
  - Containerized (usually a polythene tube), planted with soil.
  - Containerized, planted with some other growing medium.
  - Grown in open beds, to be planted out with soil.
  - Grown in open beds, but planted out bare rooted.

  All these can apply equally to plants raised from cuttings, from tissue culture, or by grafting.

- Incomplete plants.

  Stumps (plants grown and then cut back to about 20cm root and 2cm shoot).

  Striplings (tall plants with leaves removed to reduce transpiration).

A reliable method for experimental work, and one which is widely practised and understood through out the tropics, is to produce containerized plants with soil. Growing seedlings in beds and planting bare rooted is a cheaper alternative in suitable climatic conditions. Tests of suitability should be the subject of special trials.

Even where containerized plants are to be produced for planting in field trials some attention may be needed to ascertain the best soil mix or compost to use, if this is not already known. The principles involved are well-documented and include the following:

- Attention to a compromise between good water-holding capacity yet free drainage.

- An adequate level of nutrition, bearing in mind the length of time the young plants are to remain in the containers.

- Reproducibility/availability/cost

- Freedom from pests and diseases

The constant watering which container grown plants require soon destroys the structure of ordinary top soils unless they contain large amounts of humus. Furthermore, existing nutrients are fast leached out. Thus most mixtures (composts) for container plants consist of either a natural humic material (forest top soil, peat, palm fibre, compost, vegetable materials etc) or components to assist drainage (grit, or washed (coarse sand of a restricted size grade) and, possibly, added nutrients in the form of well rotted manure, fertilizers or composted vegetable matter. Natural materials are not easy to standardize in the tropics so that attempts to reproduce standard plant raising composts (John Innes Composts, etc) have not usually been successful. Other types of composts which use materials such as vermiculite, or which relate more to sand culture conditions (U.C. Composts), are costly and more suited to experiments where a high level of control over plant nutrition is required.

Even composts which are initially well balanced nutritionally will require supplementary nutrient additions if seedling growth is to remain unrestricted by nutrient deficiences, unless some form of slow release fertilizers have been added to the compost. Top dressing with an appropriate fertilizer mixture (using nitrate as a source of N) at regular intervals and/or applying dilute nutrient solution to the foliage (in shade or at night) are common methods. The extent, amounts and timing obviously depend on individual circumstances. If a drip irrigation system is being used then nutrient applicators can be incorporated in the system.

Watering seedlings

Of all management techniques in the nursery the one most likely to create unwanted variability is watering. Although identical containers can be filled with carefully prepared "compost" to the same amount and bulk density, and initially

equally watered, irregularities in shading, differences in advective energy from the sides seedbeds /standing grounds inevitably lead to different water requirements from one container grown plant to the next. Capillary beds will help alleviate this problem, but not where rooting into the bed is to be avoided (as will happen with long-term nursery stock); and drip or capillary irrigation systems are both costly and need skilled and careful attention to maintain equal flows. Sprinkler irrigation systems are often not accurate enough for most experimental purposes, and mist irrigation may encourage diseases and/or produce "soft"plants. Watering each container with a surplus each time is one way to ensure that the soil or compost is brought back to field capacity but, of course, this can result in severe nutrient leaching which has to be overcome by some form of nutrient application. This can be by top-dressing with fertilizers, but here damage to the young seedlings has to be guarded against. A nutrient solution can be used for watering but this, again, can damage the leaves of seedlings exposed to sun. Weighing potted plants to ascertain the known amount of water to replace is a method few can undertake and, in any case, with large and growing seedlings the dry weight increment of the plant has to be known.

Probably some combination of methods is best, for example, hand-watering plus a mist back-up system. If this is combined with careful supervision to ensure unbiased watering (that is starting at a different point each day) it will help to minimize variability. Two other obvious factors which require attention are: arranging for watering to continue over weekends and holidays; and allowing for more frequent and greater amounts of water as plants become bigger. Although soil water measuring equipment is available (resistance blocks, or capillary moisture water for a "wet" regime) there is probably no substitute for the skilled plantsman.

Shading seedlings

Unlike many herbaceous agricultural crop species, seedlings of many perennial woody species in the tropics often grow better if shaded: but the amount of shading at any particular seedling growth stage, and the time at which to stop shading, many vary considerably with species, site and season. Shading and watering are

closely interrelated in seedling management and, additionally, little-shaded plants will utilize available nutrients to a greater extent than heavily-shaded ones. All three factors - light (shade), water and nutrients - have to be considered together in relation to the local climate, and a suitable balance achieved if growth is to be optimized and plants of the right form and quality produced.

Where little is known about a MPT species some simple shading experiments (degree of light interception, shading more at midday or not, dispensing with shade at different growth stages etc.) will provide useful information. Such experiments can easily be combined with different watering regimes, and the foliar applicati n of nutrients provides yet another set of variables in experiments to reach a "standard" set of nursery practices that apply the information so obtained in more practical ways.

A critical feature in raising tree seedlings for field experiments is to ensure that shading is evenly applied to the whole batch of seedlings and/or young plants at any one time. This is difficult (but not impossible) if natural shading materials (banana leaves, palm leaves, dried grass) are use, but seldom possible if the seedlings are raised under a light, high canopy provided by shade trees - although the latter method might be found adequate for providing production batches of tree seedlings.

Plastic shade netting will provide the most uniform light conditions. Failing that, roll-on/roll-off matting can be used to impose a fairly standard of type of shade over the area, and it, especially, enables regulation of exposure to full sun at times when this is not harmful (i.e in the early morning and evening). In practice, seedling growth is unaffected whether "dappled" or "strip" shading is used as distinct from materials giving a completely diffused light transmission.

A useful compromise is a light level of high (i.e. 2-2.5m) shading with plastic matting, combined with roll-on/roll-off shade mats supported on a system of fence post and wires at waist height. This kind of shade must extend well beyond the seedling area to avoid edge effects and so it should not be placed too much above the seedlings (it will be rolled off for watering). In more sophisticated arrangements the height of such shading is adjusted at intervals, as seedlings grow, so as to be some 20-30 cm above the tops of the young plants. Even then a more uniform batch of experimental plants will be obtained if all the young plants (if in containers) are moved around at random once or twice during the nursery

stage. Where such seedling re-randomization is not possible then edge plants should be either discarded or carefully sorted into classes on the basis of their growth and appearance ("sun"-types versus "shade"-types) - see below.

Uniformity and selection

In the experimental situation the main aim should be uniformity and well grown plants. Even with every attention to environmental and management issues some phenotypic variability will be apparent in any batch of seedlings. Where a species is highly heterozygous this may well be reflected in seedling vigour and habit, so that a decision may have to be made, even at this early stage, to select or cull particular phenotypes.

Bearing this in mind it is also useful for experimental purposes to grade seedlings into size classes based on their apparent vigour. Discarding plants below a minimum, the remaining size grades can be accepted or discarded depending on the level of uniformity required. Within close limits individual size grades can be used in seperate blocks (in a randomized block experiment) - which will include this factor in the block variance. Or they can be equally, or proportionally, distributed among all treatments in plots; which will probably increase the residual error, somewhat, if size in any way affects response to treatments.

For highly *precise* work, selection into size grades on two separate occasions during the seedlings stage may help choose plants which are both equal in size and growth rate.

If a major objective is to estimate the genetic differences between accessions, as might often be the case, then identical layouts can be used in the nursery and the field. In this case nursery blocks are also confounded with field blocks taking care to produce more plants in the nursery than are needed for the field e riment.

Plant type and quality - by P.J. Wood

Scope for nursery experimentation

Because the growth and development of woody perennials are markedly affected by what happens to them in the seedling/young plant stages (for example whether taprooted species are grown to retain the tap root or not; or what early plant form is encouraged) there is a need to establish suitable plant raising/ planting out techniques for the wide range of species now being grown as MPT's (FGNFT's) where these are not already well known. We need, therefore, to consider suitable experimental designs and procedures for testing appropriate nursery and planting out methods and for direct seeding trials.

There is a wealth of existing technology relating to nursery work derived from forestry, agriculture and horticulture to draw on. There are also "new" techniques (seed pelleting, soil amendments, slow release fertilizers, soil blocks, new types of containers, a range of up-to-date watering methods, anti-transpirants, growth regulators, plant handling equipment, etc) as well as new systems of seedling production (fluid drilling, semi-controlled environments, "automatic" plant raising systems, *etc*) from amongst which there might well be the germs of ideas which could be scaled down into appropriate technology packages for improved low cost systems for raising MPT's (FGNFT's). There is, therefore, considerable scope for nursery experimentation. Some improvement in direct seeding might also be of interest and, planting out techniques could be improved through soil amendments, micro-water catchments, plant protection technology, *etc*)

Although the same well known experimental principles govern small scale investigations with seedbeds and/or containerised plants as with experiments on young to adult plants in the field, there are some special considerations which should be borne in mind.

- Spatial variability. Although nursery experiments allow considerable scope for limiting differences with regard to the soil environment they do often involve increased variability in other ways. Experiments with seedlings need to take into account variations in aerial environmental parameters which can often be significant over relatively small distances in a nursery or (glasshouse). These include variation in shading, temperature and evapotranspiration. These often occur

as "edge-effects" (i.e. clines) in small batches of plants and should be allowed for by:

- adequate guard rows;
- increasing the extent (area) of shade in relation to the area of seedlings;
- moving round the containers so that each plant "samples" the whole range of micro-environments imposed (but taking care not to damage the plants).

- Temporal variability. Experiments with seedlings need to take into account the changes which can occur over time.

  The most obvious of these are:

  - differences in within- and between-season weather; and
  - changes in the growth and structure of the young plants.

Because nursery experiments are under semi-controlled conditions it is possible, in many places, to maintain them through the year. However there can be considerable climatic differences, especially in semi-arid and arid regions (incoming solar radiation, ambient temperatures, rates of potential evopotranspiration) which could markedly affect growth rates. The obvious way around this where it is considered important, is to run nursery experiments at the time of year at which the plants would normally be required; or at a similar time each year, and to measure meteorological conditions.

A point to watch for container-grown plants sited above the soil surface is that the growth medium does not get unduly hot. The growth of even warm-season plant seedlings is often adversely affected if root medium temperature rise much above 35°C. Some form of pot-shading may be necessary, or reflective material (or paint) can be used to reduce container temperatures. Alternatively, the pots can be plunged in sand.

As seedlings grow in a nursery experiment some attention should be given to re-spacing them so as to reduce plant-to-plant interference. Especially if the treatments imposed result in different growth rates and/or branching forms. This can only be dealt with by carefully examining the objectives of the experiment, the treatments and the behavioural responses of the species under test. Spacing has often been found to act independently of rooting volume.

Plant quality

Where a complete young plant of a woody perennial species is to be used quality is very important. The required qualities are as follows:

- a good root system, generally a fibrous one.
- a sturdy stem and degree of "hardening-off".
- appropriate proportions of above and below ground parts (a shoot: root ratio which conforms to that growth stage).
- an appropriate form (height and branchi ness).
- freedom from pests and diseases.
- nodulation (for FGNFT's).

A fibrous root system is best obtained by root pruning in the nursery. However, many dry area species (*Cordeauxia* many *Acacias* and *Prosopis*,) produce a very long and rapidly growing tap root, which is difficult to handle in normal nursery practice and which should not be removed or damaged if the plant is to continue to grow well. This should be determined during the preliminary stages of germination testing.

Root pruning also arrests sappy growth and induces the formation of a tough woody stem which is better able to withstand severe conditions after planting. The process of "hardening-off" is critical if plants are to withstand planting out with the least disturbance and (especially in arid and semi-arid regions) by physiological adjustment to the field environment. Hardening-off is achieved by gradually applying increasing amounts of environmental stress. This is done by restricting the seedlings' water supply to some extent, by gradually removing shade, and by increasing the amount of plant nutrients to the rooting zone (especially K). Each species will probably require a different regime of hardening-off if a compromise between plant form and the correct physiological stage underlying restricted growth is to be achieved.

The best proportions of stem and root (shoot: root ratio) can only be determined by experimen . in a particular set of conditions, *Sturdiness index* is an easy parameter to measure in the nursery and is the ratio of height to root collar diameter. In determining the optimum index (and hence the optimum nursery regime) the performance, and particularly the survival of plants in different height classes should be taken first, followed by an evaluation of plants with different "sturdiness indices" within height classes.

Planting out and early care - by P.J. Wood & P.A. Huxley

Land preparation

Ground preparation in agroforestry situations can vary from ploughing and/or sub-soiling completely bare ground, to making judicious openings in the tropical rain forest canopy. This initial cultural treatment interacts very strongly with the need for subsequent tending operations, and its effects on the growth of plants can last for very many years.

Mechanical treatments require more logistical forethought in general than do labour intensive methods, and the constraints of such methods may affect experimental design and layout. In particular, it may be extremely difficult to arrange to have equipment available over a wide range of scattered plots.

Normal attention to soil conservation is of course necessary. This may require contour planting or bunding of waste vegetation in areas of high rainfall. On slopes the use of bench terraces of appropriate width and pattern or of wider traditional terraces in mountainous areas may be indicated.

Water harvesting, or water spreading techniques may be of considerable value but the difficulty here is to ensure uniformity over the whole experimental area. Other soil management approaches to improve water percolation, and to reduce run-off (tie-ridging, trash-bunding, etc.) may be relevant but, again, spatial considerations and uniformity of effect should be given careful consideration with tree crops.

Planting

Planting of woody perennials should follow the "best" practice, or that normally used in plantation agriculture or horticulture depending on the objectives and kind of experiment (e.g. it may be an "on-farm" trial). *Uniformity of treatment* is the most important factor, and this applies particularly to the method and timing of lifting in the nursery, conditions during transport, and timing and methodology of planting. The key to all this is efficient planning and preparation.

The best type of planting material will vary from species to species, many requiring potted planting stock, others being plantable as stumps or striplings or being sown direct.

Replacement of early casualties (except in a trial

which is purely concerned with survival) is an essential operation and it must always be well recorded so as to avoid losing important information on any growth differences (or late survival) at different stages after planting.

Records for planting sites

The identities of morphologically similar species and provenances can easily become lost in a large field experiment, and the importance of clear labelling from the nursery stage onwards cannot be overemphasised. As with most field experiments a detailed planting plan should also be prepared.

Soil inputs

The decision as to whether or not to add fertilizers and/or to irrigate will depend on whether a particular trial is related to "real" conditions, or whether the main objective is to test some scientific or technical aspect which requires optimum, or near optimum environmental conditions. In any case it may be necessary to apply a short initial irrigation to help survival, and a small initial planting dose of fertilizer (especially P) to help both with this and to improve nodulation.

If fertilizers are to be applied then it will be necessary to consider whether these are applied just to individual trees, as is common in forestry or woody cash crops, or to the whole area. The latter may require evaluating in terms of an associated agricultural crop if the experiment is to be converted, later, to test agroforestry crop combinations.

Cultivations for weed control , etc.

Previous or accepted practice of the intensity or type of cultivation methods should be the initial guide and, as a general principle, the best feasible "de luxe" treatment should be given so as to reduce as far as possible the masking of site, climate and crop interaction effects by weak growth or poor drainage.

However, constant top soil cultivation can affect the form and efficiency of the surface-layer of tree/bush roots. The alternative is to use herbicides but great care has to be taken to ensure that no phytotoxic effects occur. There is little information available about the selectivity of currently used herbicides with MPT's (FGNFT's) species. Soil acting herbicides such as substituted ureas and triazines of low but varying solubilities may effect trees differently in wet and dry years, also depending on how the

surface roots have been activated through cultivation or mulch. Contact or Contact/ translocated herbicides (Paraquat and Glyphosate) are relatively "safe" when applied accurately to avoid tree stems, but they can cause considerable damage where any green, photosynthetic stem tissue still exists. Hormone weed killers are likely to be of little value.

For small experimental areas the best comparison is likely to be.

- Really effective land preparation before planting.

- A continued and timely shallow surface weed control regime (best by hand).

- Spot weeding with carefully controlled. contact herbicides.

Irrigation (where used)

The evaluation of species under irrigation calls for detailed attention to water measurement. Broadly speaking irrigation may be used as follows.

- To ensure survival until the roots of young plants reach a moist soil zone, or they are tapping a sufficient soil volume.

- Effectively to lengthen the growing season, or to provide water at a critical development stage (flowering or fruiting), and

- To provide a permanent supply of soil moisture in order to maximize growth and yield.

The methods commonly in use include.

- watering by hand;

- flood irrigation;

- overhead irrigation;

- trickle irrigation;

Only hand and trickle irrigation methods lend themselves to accurate measurement of the water applied, but in all cases special instrumentation is required to measure soil water balances and plant water stress. Whatever method of watering is used however it is important to record the kinds of operation and their timing.

The effects of irrigation need to be thought about carefully.

- Irrigating young trees tends to limit their root extension. This can create problems later on when irrigation is stopped and severe drought periods occur.
- Changes in phenology may occur. Irrigation may bring on flowering, change the time and duration of flower initiation, bring on an early vegetative growth flush and/or prolong vegetative growth. It may also affect fruit set and the duration of fruit growth.
- Regular irrigation will increase vegetative growth and leafiness and this may create pest and disease problems. Sometimes plants may have a rather different form (and certainly a different structure) as compared with unirrigated ones.
- Mature irrigated trees will, normally, require a greater supply of plant nutrients to fulfill their growth potential under irrigation.

One of the difficulties is to decide on an irrigation regime. The factors to consider are the following.

- What are the detailed objectives of irrigating? (See also start of this section).
- When to irrigate? (in relation to seasons)
- How much water to apply ?
- How often to apply it ?

The subject is well covered elsewhere but, very briefly, if water is to be applied at times to obviate some pre-judged degree of plant water stress these can be recognised either by (a) assessing soil water status (directly measuring soil water in the rooting profile or by calculating evapotranspiration and water balance through an empirical equation), (b) by measuring plant water status (for example by a sampling technique and using a pressure bomb to estimate plant water potential, or a field steady state porometer to measure stomatal aperture.)

The methods are well documented in easily available publications but measuring plant water status is the most sensitive, and currently obtainable equipment is relatively cheap and easy to use. This approach also helps, with the question of "How often?" if something is also known about the plants' responses to water stress at different seasonal phenophases and stages of life cycle.

"How much?" is best approached by monitoring soil water status (for example using resistance blocks replicated in a suitable three-dimensional "grid" in the rooting zone so that the wetting front is identified). Cheap equipment for this purpose has now been developed.

All these factors are more readily conceived than achieved in practice due to the difficulties of applying irrigation water evenly to an experimental area. Overhead (sprinkler) irrigation is notoriously uneven; flood irrigation is hard to control and also uneven if the ground is not made very accurately gently sloping; trickle irrigation needs careful maintenance, but is suitable for limited areas; and hand irrigation requires constant supervision.

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SECTION THREE

PART 3E

Assessment

PART 3 E

CONTENTS Page

PLANT ASSESSMENT

L E A V E S

CHARACTERS/CONDITIONS	COMMENTS
1. MORPHOLOGY	
Size/Shape/Form Surface/Margin Petiole/Stipules	For standard taxonomic records. Herbarium specimens should be retained (taking into account both within and between tree variability). In the nursery shape and size of the cotyledons (for epigeal seedlings) can be an identifying characteristic.
Variability - . Juvenile/Adult. . Sun/Shade	Whole plant assessment in the form of reports/photographic records to indicate age and eco-site characteristics. May effect chemical, physical and physiological status.
Area (SLA, SLV) - see also "Canopy"	Single leaf assessments by a) leaf area photometer b) graphic methods c) correlations with dimensions for irregular-shaped leaves. Specific Leaf Area (SLA) and Specific Leaf Volume (SLV) to indicate responses to shading and/or water stress.
2. ANATOMY	
Thickness Tissue kind and disposition Stomata/Enations	In relation to: xeromorphic characteristics and water loss/drought resistance; responses to shade.
3. PHENOLOGY OR STATE	
Age Structure (Different Levels) Stress effects?	Time and duration of individual leaf expansion from apical and lateral buds. Whole plant assessment of leaf longevity, ageing pattern and leaf senesence characteristics. Phenology of of leaf ageing and shedding both in relation to climate (weather) and to vegetate growth and fruiting patterns. Correlations with climatic parameters and soil water status at specific site is desirable, as well as with phenological behaviour of local naturally occurring plant associations. Specifically occuring stress effects (e.g. drought) may give information about the ability of leaves to withstand particular environmental

hazards if observed and recorded. Written descriptions and photographic records are desirable.

4. CHEMICAL COMPOSITION

Organic Matter - Fibre
Oils/Waxes
Crude Protein
Carbohydrate
Ash (N.P.K.Mg. Ca. Na, Si)

Sampling procedures should take into account: leaf maturation/age; position on the tree; exposure; phenophase (especially stage of flowering/fruiting, and amount as well as root behaviour), management (e.g. addition of fertilizers, mulch), and age of plant.

Palatability

Useful Products

May be of value in relation to:

- estimating level of nutrient availability at site
- value for food, fodder, mulch
- taxonomic affinities (oils, waxes, gums)
- Physiological conditions (in relation to management e.g. pruning cycle)
- fertilizer requirements (where used).

On leaves, estimates of available total carbohydrate and/or specific components (starch, sugars) will mostly be related to their potential value for food/fodder. And so will need to be accompanied by palatability trials.

Both plant age and environment will greatly effect the extractable amounts of oils or waxes (younger plants and cooler climates usually increase extractable oils in those species that produce them, (e.g. *Eucalyptus* for oil extraction should be in the juvenile stage)

For medicinal compounds and other useful extracts from leaves. See

5. PHYSICAL

Fresh Weight Dry Weight Water Content	Fresh weight can be very inaccurate Oven drying at an appropriate temperature (see) to a constant weight is best (on a sub-sample if necessary). If volatiles or chemically heat labile compounds are to be conserved small samples can be freeze dried.
Temperature	Estimates of leaf temperatures may be needed for carbon assimilation/respiration and transpiration experiments
Light reflectance/ Transmission	For inclusion in crop growth models and details of light effects on photosynthetic rates..

6. PHYSIOLOGICAL

Water potentials	Most easily and accurately measured by using a pressure bomb apparatus.
Leaf resistance to gas exchange: . Stomatal . mesophyll . chemical	Using a field steady-state porometer
Carbon fixation rates	By CO_2 gas analyser or 14C radio-isotope method.
Source/Sink relationships	14C tracer methods (for photoassimilates
Growth regulation	Bio-assays, application of growth regulations, plant manipulation (or all three).

7. MICROBIOLOGICAL

Phyllosphere population	In humid situations Blue-green algae (nitrogen fixation)

8. MISCELLANEOUS

Epiphytic plants

9. PESTS AND DISEASES

Symptoms	Identifying causal organisms (if possible).
Damage Estimate	

C R O W N / C A N O P Y

CHARACTERS/CONDITIONS	COMMENTS
1. MORPHOLOGY	
Shape	Shape of, the "crown" is a species characteristic but it can be modified depending on competition from associated trees/shrubs, and early training.
Size	Size of single tree crowns can be assessed by linear measurements of depth (maximum/minimum) and diameter by an average of two measurements at right angles.
Community form	In plant communities the "Canopy" (an association of individual "crowns" can be described by a sectial drawing along a transect together with a vertical plan. Very dense plantings may have apparently homogeneous canopies but closer examination will usually show variations. For a single species association Leaf Area Index (LAI - or total area of individual leaves, per unit area of ground , as used by crop physiologists, may helpfully describe changes of canopy structure with time, or variations due to site or management at any one time. The assessment is very laborious for large plants however, and it has to be seen as necessary before being undertaken. Alternatively, spherical photography (with 180" wide angle lens focussed vertically on the ground) can pictorialize canopy changes, in terms of light transmission, and thus may be useful as a record.
3. PHENOLOGY OR STATE	
Seasonal changes	Seasonal changes in the structure (and age) of a canopy, or of individual crowns, can be very important where other under-storey crops (or grasses are to be grown). The effects of these on a) light interception/ transmission b) nutrient transfer to the topsoil through litter deposition and leaching of nutrients from leaves twigs and c) effects on rainfall

interception and throughfall/ stemflow patterns, and the subsequent water balance of the plant association, are critical features for multiple cropping systems. Even in single species communities an understanding of canopy structure and dynamics can help with the interpretation of the factors controlling the growth and development of the stand, and so suggest appropriate management practices (principally plant spacing, thinning, pruning and harvesting programmes).

Site effects	The phenological behaviour of particular species can be affected, sometimes quite considerably, by site characteristics. Other species behave more consistently. Some species (e.g. mango) may exhibit different phenophases in different parts of the tree, depending on exposure and part fruiting patterns.
	All phenology behaviour should be recorded at regular intervals by both written and photographic means.
6. <u>PHYSIOLOGICAL</u>	- See "Leaves" (whole plant crowns, and senescence and observations on plant water status).
Water loss	Water loss measurements from whole canopies may be required for water balance studies of plant associations. Various methods available: Bowen's ratio measurements, net radiation measurements, eddy diffusion techniques, soil water measuring techniques.
Radiation measurements	Total radiation and PAR radiation measurements can provide evidence of the distribution of incoming and outgoing short and long wave radiation, which is of use for both water balance and efficiency of primary productivity of the plant association.

9. PESTS AND DISEASES

Of tree/bush species itself:	These may often be located in different parts of the crown/canopy depending on their etiology. Canopy density will effect the survival and success of soil inhabiting pests by altering the micro-environment.
Of other pests:	Species preference of pest birds to roost should be noted.
	Overall effect of canopy on suitability of micro-site for important pests such as tsetse fly could be important.

B U D S

CHARACTERS/CONDITIONS	COMMENTS
1. MORPHOLOGY	
Type (vegetative or fruit buds) Location/number Size Characteristics (e.g. with or without bud scales	The characteristics of both terminal and axillary buds should be noted i.e. whether with scales or naked, characteristics of scales (if present), whether buds are stalked or sessile, position of axillary buds (pseudo-terminal, sub-petiolar etc), stipular characteristics and type of leaf scar.
2. ANATOMY	
Formation of leaf initials/flower initials	The ability of plants to sprout vegetatively from dormant ancillary buds on old stems is often critical where the mature plant is later to be coppiced, pollarded, otherwise pruned or browsed. The location of an axillary bud series can be confirmed by a coppicing experiment (at different seasons) and the structure of the bud series clarified by anatomical sectioning and observation of gross morphology. Growth: Plastochron (time sequence of development of leaf initials) using microscope sections; or phyllochron (time sequence of young expanding leaves) by observation. Development: Sections of buds to discover time of flower initiation.
3. PHENOLOGY OR STATE	
Occurence of vegetative and/or fruit bud dormancies.	From visual observation combined with weather data
Growth flushes	For information on what effects growth phenophases (species differences weather, site factors, management)
Flower/infloresences development	Development of parts (including short shoots), anthesis, pollination/ fertilization stages, ovule development and early fruit growth (fruit abscission? And why?) - for information on what affects fruit/seed yields. Detailed records of environmental parameters and flower counts

	can often provide a valuable indication of why fruit/seed yields are below potential (and see "Fruit/ Seeds").
5. PHYSICAL	
Bud Temperature	Might occasionally provide information relevant to a study of growth regulation patterns (vegetative buds), or times of anthesis.
6. PHYSIOLOGICAL	
Bud Temperature Water potentials Hormone status	As for (5) above
Bud maturation	Useful observation with regard to selecting material for vegetative propagation.
9. PESTS AND DISEASES	
As for leaves - but also observe for flower eating beetles etc.	Especially thrips, occasionally birds and some plant diseases.

S T E M S

CHARACTERS/CONDITONS	COMMENTS
1. MORPHOLOGY	
Size: diameter and height; taper and volume (and see 'Phenology' below)	Traditional forest mensuration to assess growth rate and yield. Diameter measured at base/breast height and top to estimate taper and volume. For forked or multi-stemmed trees, assess each stem.
Form (Straightness)	Related to sawnwood recovery and ease of harvestial and transport. Assessed by subjective classification or objective measurement of deviations from a plumb-line.
Forking Branching (and crown/ canopy production - which see)	Frequency and height of forking (branching) of main stem/s. Number, diameter and angle of branches influence knots, associated reaction wood and timber strength volume of branch wood is important in fuelwood and fodder trees but notoriously difficult to assess, it requires destructive sampling of a few trees (>20) per species to determine correlation between stem diameter and crown production. Shape of crown is often a species characteristic. Degree of branching is greatly affected by management (training and mature pruning, lopping, browsing), by the degree of concurrent plant association and, to a smaller extent by site factors. Dimorphic branch types should be recorded (photographs). In nurseries height, root collar diameter and early browsing characteristics are often useful indication of species variation.
Bark	Thickness (determined by bark gauge) and rate or pattern of loss are important in species used for cork, fibre, bark extractives.
Thorns	Size and frequency may influence the ease of handling wood. In some species the thorns are used themselves (for carving, e.g. *fagara* species, or toothpicks, e.g *Acacia* species). Record any changes in degree of thorniness with age and/or site.

2. ANATOMY

General wood anatomy	Classically used for taxonomy, identification and prediction of wood properties.
Fibre length, diameter and wall thickness Vessel/Fibre/ parenchyma proportion	Measured by microscope, related to timber strength, pulpwood properties. Particularly important is the pattern of variation within single trees.
Texture	The uniformity or heterogeneity of diameters of axial cells, affecting processing for furniture.
Grain inclination	The angle of fibres to the main stem axis affects timber strength, splitting ability, twisting of poles. Measured by ocular protractor or microscope goniometer.
Figure	The decorative pattern produced on quarter sawn wood; most important in fine furniture and veneers
Heartwood/sapwood proportions	In most species heartwood is more durable than sapwood; it can often be recognised by its darker colour which also makes it more desirable for furniture. Individual elemental composition in wood and ash (see "leaves") Indications of plant nutrient status (as sap analysis), but less often used than leaves. With main roots, an important location for carbohydrates storage which can be affected by site, climate, fruiting load, time-of-year and growth flushes, as well as management factors. Crude protein analysis of green twigs may be important if these are browsed.

3. PHENOLOGY OR STATE

See also 'Buds' (below) Time and extent of bark formation and branch shedding	The within-season occurence of bark formation may be of interest as it is a pest/disease habitat - also as an indication of physiological change. For self-pruning trees and bushes the degree and extent of branch shedding and the season at which it

	principally occurs should be noted. In both cases photographic records are desirable. Where extractives and/or exudates are important the seasonal change in abundance, and management required to increase flow, are relevant (e.g. gum arabic from *Acacia senegal*).
Seasonal periods of elongation versus increase in girth	Linear measures using an accurate tape (branch or stem elongation),
4. <u>CHEMICAL COMPOSITION</u>	
Extractives and exudates; yield and quality	Also important in some chemical pulping processes (e.g. silica in viscose pulp), and where ash is used for fertilizer or the twigs/branches are used for woody mulch. Sometimes useful in taxonomy/identification (e.g silica or calcium oxalate crystals). Some woods react with nails and wires by staining. A wide range of chemical extractives are derived from wood by tapping (e.g. rubber, gum arabic, pine resin, maple sap), or by pyrolysis, distillation. The quantity may be determined in the field; quality is easily determined by analytical techniques such as gas-liquid chromatography in the laboratories. Carbohydrates estimates can indicate conditions of total and transportable reserves in relation to bud burst (vegetative flushing), fruiting or regeneration of shoots after pruning/lopping/coppicing Analysis of major (and minor)elements in woody tissues may also help to highlight deficiencies but leaves or sap are better used to indicate this.
5. <u>PHYSICAL AND PHYSICO-MECHANICAL PROPERTIES</u>	
Colour Density	Particularly important for decorative fine hardwood for futniture and veneers. This is closely correlated with most end use characteristics.

	It can be determined gravimetrically (weight and volume) or by X-ray densitomentry (which facilitates study of within-tree variation).
Calorific value	Although C.V. does not vary greatly between species (18-21,000 KJ/kg) it is a useful indicator of heat yield (when multiplied by wood density). It is assessed by bomb calorimeter.
Fuelwood properties	Desirable properties vary with country and objective but usually include smokiness, tainting of food, sparking, burning rate, moisture content, ash content and composition, and acceptability to local populations.
Strength properties	These vary with density and anatomy of wood and influence suitability for use. Typical properties of sawn wood include bending, compression, shear, tensile and hardness, standard methods of testing exist but usually require large numbers of specially prepared samples. Pole testing of roundwood is simpler and cheaper.
Processing properties	These include sawing, planing , sanding, nail and screw-holding ability. They are also affected by the anatomy of the wood.
Finishing and preservation characters	Woods are assessed for paint and varnish retention, preservative penetration and natural durability.
Veneer and pulp/paper properties	Highly specialised. These industrial uses require large quantities of uniform material
Fire resistance in the field	Considerable variation between species and with age (and management?).
Physical measurements (fresh and dry weights, water content) - as for leaves)	Samples of woody tissues should be chipped or shredded before oven-drying and several days may be necessary before constant weight is acheived. Resinous stems/twigs may have to be ground and freeze-dried for accurate dry weight assessment and the volatiles extracted with a suitable solvent.

	For fairly crude field work an adequate number of small samples (10 to 15) of each kind of woody material (sapwood, heartwood, twigs of various ages etc) can be taken and the dry weight of the total estimated from the whole plant measurements of either fresh weight or volume where these were also accurately measured on the samples. Volumes can be measured direct (e.g. of bundles of twigs, by water displacement in a 44 gallon drum, or by linear measurements (e.g. of trunks).

6. <u>PHYSIOLOGICAL</u>

Water potentials photosynthetic potential of green stem tissues Source/ sink relationships	as for leaves (except water potential by psychrometry)
Sap studies	The hormone contact of the sap may be informative with regard to growth and development patterns and stress-resisting factors (dr ught, chilling).

7. <u>MISCELLANEOUS</u>

Epiphytes

8. <u>PESTS AND DISEASES</u>

As for leaves	Look out for presence of stem cankers, galls etc, or epiphytic parasites (Loranthaceae). Wood-borers and/or bark inhabiting pests. In the nursery, crickets and damping off fungi and/or stem rots. Resistance to termites when used as posts/building poles.

F R U I T S / S E E D S *

CHARACTERS/CONDITIONS	COMMENTS
1. MORPHOLOGY	
Of fruits and Seeds	
Size (linear dimension) Shape (cross sections) Surface characteristics (colour, texture, enations)	Photography combined with linear measurements and written notes
Variability	Within-tree and in relation to light interception of crown/canopy, tree age, season-of-fruiting, management (browsing)etc. Between sites in relation to soil, exposure etc.
2. ANATOMY	
Fruit	
Ovule development	In relation to pollination/ fertilization processes
Young fruits and fruit maturation	Development of desired issues (e.g. development of seeds) in relation to fruit growth/maturation and plant behaviour, development of edible parts, sutures and dehiscing mechanism (to avoid shattering and seed loss). For edible fleshy fruits the between-selection variability in the proportion of edible to non-edible parts needs to be scrutinized.
Seeds	
Seed growth	Noting abortions
Seed characteristics	As an aid to improving handling, seed cleaning techniques,viability and germination, e.g. characteristics of (testa), endosperm and embryo. Relation of seed to fruit growth (by sectioning during fruit growth)

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* Flowers may be important taxonomically

3. PHENOLOGY OR STATE

Time of flowering and fruit set

After flower initiation and flower bud formation and maturation have occured the *time* at which flowering and fruit development occur in relation to season, and the seasonal weather in any one year, can make a great deal of difference to fruit set, fruit development/maturation and to the production of viable seeds. Detailed environmental records just prior to anthesis and through early fruit development, combined with counts of fruit set at labelled fruiting points (continuing from flower bud counts - see "Buds"), can indicate how environmental factors are affecting fruit set.

Pollination

Many MPT's are outbreeding, some may be obligately so through a cross-pollination mechanism (either "mechanical" with a seperation in time or space of the maturation of the stigma and stamens, or through a physiologically acting "S-gene" incompatibility mechanism -(the latter usually breaks down if polyploids are formed). In this case pollinations may (eventually) be required.

Simple tests of removal of stamens from some flowers left to open-pollinate or removal of stamens and hand cross-pollination followed by bagging, can indicate if there are any specific problems. The outcome will be observed from fruit set percentage but some ovule sectioning and staining for pollen tubes and fertilization may be helpful also. Viability of pollen could be a factor in poor fruit set and sectioning and staining of developing anters (to observe proper tetrad formation) could be done; as well as specific hand pollinations, as mentioned above.

Duration of fruit maturation

The normal duration of the fruit maturation/seed development period can vary considerably between species and, within any one species, both the environmental conditions in any one season and the within-plant source/sink-relationship (for carbohydrates)

nitrogen and other nutrients) are important factors in optimizing fruit/seed production, if this is what is required.

Site of fruiting points and source/sink relationships

In the first instance records of fruit growth (linear measurements and weight of samples), estimates of whole plant fruit numbers and some description of the location of fruiting parts in relation to foliation can give comparative data. In any case a clear description of where fruiting parts are located in relation to stem growth should be given (last season's wood, or "short-shoots" on old stems, current season's wood either at stem apices, or lateral apices, or both). This information is essential before any pruning regime can be effectively undertaken in order to maximize or minimize fruiting. More complicated investigations on carbohydrate and nutrient transfers from storage tissues (stem, roots), and of the capacity for current carbon assimilation to provide the needs for the developing fruit loads require a detailed series of experiments on source/sink relationships using appropriate isotope techniques. The outcome can be a clear idea of what type of plant, structurally, is most effectively allocating its resources between vegetative growth and fruiting, and what effects changes in the environment (cloudy weather, droughts etc) are likely to have on the growth of plant parts.

Affects of weather

The actual duration of fruit growth can be profoundly affected by seasonal weather and by site characteristics (shallow soils, exposure etc). If fruit development is curtailed and fruit maturation hastened by inclement conditions, seed size (but not number) is usually less affected than fruit size, especially for fleshy fruits. The amino acid constituents of the seeds may also be changed.

Size of fruiting load

A heavy fruiting load compared with current or stored carbon assimilate, nitrogen and other nutrients can result in a severe depletion in other plant parts, resulting in early leaf senescene (particularly near the fruiting points), and stem and root die-back in extreme cases (e.g. coffee). For this reason flowers are often stripped from young trees/bushes for the first year or so after planting-out in order to a) allow maximum resources to go to building up a sound vegetative structure and b) preventing unwanted variability in growth form and fruiting pattern within an experimental batch. In extreme cases heavy, precocious fruiting can initiate a "biennal bearing" pattern.

4. CHEMICAL COMPOSITION

Standard analysis for N.P.K.Ca.Mg./CP/ fats and oils/fibre/ total carbohydrates, starch, sugars/and other tests

For edible fruits references should be made to standard tests - fruit quality can also be important (sugar/ acid ratios etc) and also vitamin contents. For seeds the amino acid spectrum may be required using an amino-acid analyser. Palatability tests (for humans and animals) may be required. Essential oils and other flower compounds require special procedures. The presence of toxins and anti-metabolites in some fruits and seeds should be considered. Fruits with waxy coats may need careful handling if they are to be stored optimally.

5. PHYSICAL

Fruit and Seed Storage and chemical composition

The storage of fleshy fruits is highly dependent on the stage of maturation and the conditions of storage (temperature, humidity and Co_2, N and O_2 gas concentration as well as the presence of ethylene) Similarly, seed storage is depended on temperature, water content and the presence of oxygen (not all seeds can be dried and/or stored at temperatures below 5°C and still retain viability). Oily seeds often lose flavour qualities if stored in air at ambient temperatures for more than a few months.

6. PHYSIOLOGICAL

Growth rates	Fruit and seeds growth rates (measured by dry weight increase) can reflect genetic, climatic, site and management restraints, as mentioned above. Early fruit growth is dependent on a hormone supply from developing seeds. However, some fruits are parthenocarpic.

7. MICROBIOLOGICAL

Mycotoxins	Damaged fruits and seeds which are stored under damp conditions can be infected by moulds (e.g. *Aspergillus flavus*) which produce mycotoxins which are carcenogenic to man and domestic animals.

8. MISCELLANEOUS

Permits	The movement of fruits and seeds from country to country is nearly always subject to legal restrictions. In all cases the appropriate regulations should be consulted and the necessary permits obtained or quarantine arranged.

9. PESTS AND DISEASES

Occurence	Very many to be expected from mamalian (rodents), and avian to insect, and similarly for plant pathogens. Legume pods are especially prone to insect pests the seeds being high in N. Farinaceous seeds are invariably attacked by bruchids. The susceptibility of fruits (on the tree) and of seeds (in open storage) should be examined and reported on.
Symptoms) Damage assessment)	We need more information and descriptions for most MPT's

ROOTS

CHARACTERS/CONDITIONS	COMMENTS
1. MORPHOLOGY	
Rooting habit Types of roots	In recording root form, data on root types should be obtained i.e. characters of the main roots (branching, thickness, secondary thickness/bark characters, colour); of secondary, tertiary roots, of 'long' roots (if present) rhizoids, prop-roots. Finer roots should be examined in the laboratory for root hairs (and mycorrhizal associations) Photographs and/or botanical drawings should suffice. Overall root form varies according to species but is greatly modified by site (soil) conditions and the management (cultivations, mulching, irrigation). Can be examined by a range of methods: excavation techniques (destructive unless just using a soil core and sampling techniques); root laboratories and/or spaced "visi-tubes", radio-isotope techniques, or soil water measurements (all non-destructive). All methods are laborious and adequate replication is therefore difficult three plants per situation might be considered a minimum but, often, a single "typical" plant has to suffice More knowledge about the rooting habit of MPT's (FGNFT's) is urgently needed.
2. ANATOMY	
Degree of secondary Thickening etc.	Transverse microscope sections can be taken if some special reason occurs, but there is probably little need for such studies at the present time.
3. PHENOLOGY OR STATE	
Evidence of elongation growth, (long roots, branch roots) Evidence of root death (decay)	Can be of considerable importance for management and for helping to explain whole-plant behaviour. But again, difficult and tedious to to obtain such data. However, an

attempt should be made by seasonal sampling techniques (soil cores). Vital to record both above-ground phenophases and at least basic above-and below-ground environmental conditions (standard meteorological parameters and soil water status throughout the rooting profile). Seasonal root growth patterns (when and where)in relation to vegetative shoot growth and flowering/fruiting can vary between species and be affected by both site and management.

4. CHEMICAL COMPOSITION

Organic matter and ash (see "Leaves")	Main roots are important storage organs. Status of transportable carbohydrates in relation to growth of aerial parts can help understand whole plant behaviour and effects of management (pruning, branching etc.)
Extractives	Many medical compounds occur in roots.

5. PHYSICAL

Fresh weights Dry weights (Water content)	The main problem is removing soil and fragments of detritus (dead roots) from the living root sample, especially in soil high in clay and organic matter. In sandy soils correcting dry weights of root samples by re-weighing any remaining sand particles after oven drying is often helpful. The root systems can be divided into fractions but the size limits will most usefully relate to what seems to be their function, and this will be different for different species, e.g. main (and tap) roots (structural) branch roots (exploratory) and fine roots (functional in uptake of water and nutrients). Whatever is chosen some indication of size (diameter) limits should be given.

6. PHYSIOLOGICAL

Root activity	The mere presence of live roots may tell us little about how they are functioning at any one time. For example, elongation growth and increase in girth often occur separately. Again, uptake of

different nutrients occurs at different parts of the root away from the apex and is varyingly affected by increasing soil water potential according to each specific nutrient (access to soluble nutrients such as N is mainly dependent on a low soil water potential, access to insoluble nutrients such as P will depend on continued soil volume exploration by growth of fine roots).

Active water absorbtion may depend on the presence of root hairs and these can be quickly eliminated by a short drought period. During such periods soil shrinkage, which can occur around fine roots, will drastically affect nutrient uptake. Rate of suberization of fine roots may be related to both season and activity of the aerial part. Actively growing roots produce cytokinins and giberellins which are transported to the aerial parts and affect growth regulation(check by bioassaying sap from stump)

A simple approach to studying root activity is to take soil core samples seasonally and examine the separated fine root fraction for viability (Tetrazolium test), root hairs (microscopic examination), suberization, evidence of elongation (young, white root tips), nodulation and mycorrhizae. More elaborate studies require some form of permanent/semi permanent root observation, sequential destructive techniques, radio-isotope techniques, or all three.

A knowledge of the ability of root systems to survive hazards can give information on site-suitability e.g. drought periods (and severe soil cracking), flooding, exposure (when planted in drifting sand), and so on. Also tests of the effects of management (e.g. severe pruning or browsing on growth of fine roots).

In the nursery the effects on root growth and form of compost, fertilizer, watering techniques, container-type and management (shading) can usefully

	be tested and, at planting-out, the timing/amount of previous root-pruning (undercutting) of tap roots (e.g *Cordeanxia*) can indicate the plants requirements vis-a-vis direct sowing or nursery preparation.

7. MICROBIOLOGICAL

Symbiotic N-fixing association (*Rhizobium, Frankia*).	Seasonal occurence of nodules (where, how many) and their visual condition (senecent, healthy and if so, leghaemoglobin or not?) should be recorded (soil cores). Nodule-containing root samples can be tested for N-fixing capacity (per unit fresh or dry weight) using the ethylene-reduction technique. Whole plant assessment of gross N-fixation requires more complicated methods using radio-isotopes and/or cuvette gas analysis, but net N-accumulation in the topsoil may at least be indicative (straighforward total soil-N analysis).
Free-living N-fixing associations *Azotobacter* spp. etc. *Beijerinkia* *Spirillum*	May be helpful in improving the N-balance to a lesser extent. By soil core sampling and testing whole of core by ethylene-reduction technique and relating to root length (volume, or surface area).
General symbiotic associations (mycorrhizae)	By microscopic examination of fine roots (slide section) for presence or absence. More elaborate micro-biological assays required to test functions.

9. PESTS AND DISEASES	Susceptibility to soil-borne plant pathogens (*Phytophthora* root pests) or insect pests (especially root mealy bug, aphids, cutwarms, termites).
	Ability to withstand competition from weed species (allelopathy?).

METEOROLOGICAL ELEMENTS AND THEIR OBSERVATION

- by T. Darnhofer

General

Basic Aspects

- Observations of the bio-physical environment are essential in agricultural research including forestry and livestock. The physical elements of climate are observed in order to assist in the evaluation of actual and future land use potentials and of environmentally caused constraints in agriculture. To meet these requirements, agricultural meteorology needs reliable quantitative data on the relevant climatic elements.

- Indispensable climatic elements in agricultural meteorology include those pertaining to geographical climatology and especially those permitting interpretation of physical processes in the lower layers of the atmosphere and the upper soil layers. Elements pertaining to energy and waterbalance are thus very important, as well as other related phenomena such as humidity, temperature, wind and precipitation.

- In agricultural meteorology macro, meso and micro scale observations are required. While macro-scale observations provide information on the climatic background, most of the agricultural planning and research activities require data on the meso-or micro-climatic scales. Standard instrumentation and standard exposure conditions in agricultural meteorology are important as far as comparability is concerned. However, in research work instruments and exposure conditions not always standard.

Meteorological Stations

- Basic information on the physical environment can be obtained from observations made at stations of the synoptic, climatological and hydrological networks. Since these networks may be restricted in density and in kind of observation it is desirable that they be supplemented by agricultural meteorological stations. Such stations are equipped to perform general meteorological and biological observations and are usually located in areas of particular interest for agriculture, horticulture, forestry, animal husbandry and soil sciences.

- The site of a meteorological station should be located in a place truly representative of the natural conditions in the region concerned. The site should:

- be free from obstructions and fairly level
- have a sod cover if possible or natural cover common to the area
- not be concrete, asphalt, rock
- not be closer to any obstructions (trees shrubs, buildings) than eight to ten times their height
- not be near to areas with cold drainage, flooding and frequent sprinkling
- should be easily accessible for appropriate maintenance

- The lay out of a station will mainly depend on the number and type of observations to be carried out as well as on the types of instruments used. However, it has to comply with the following basic requirements.
  - minimum tampering by animals and people (fence)
  - instruments should as far as possible not be shaded by each other or the fence
  - instruments for air temperature measurements have to be properly screened against direct sunshine.

Measurement of meteorological elements

Temperature and heat flux

- General comments
  - Temperature is the condition of a body which determines its ability to communicate heat to other bodies or to receive heat from them.
  - For meteorological purposes, temperature is referred to the Celsius Scale (^{o}tC). $0^{o}C$ normal ice point; $100^{o}C$ normal boiling point of water.

    The relationship to the absolute thermodynamic Kelvin scale is given by: $t^{o}C \;\; T^{o}K - 273.15$

- Air Temperature

  Air temperature should be measured in representative places at different levels adjacent to the soil in order to allow the study of its vertical distribution which is relevant for the climatic conditions of agricultural crops. As radiation is a serious source of error in measuring temperature, appropriate protection has to be provided. (thermometer screens, small plastic screens, or roof shaped shelters). Another approach to minimize errors, is the use of thermometers having sensitive elements with low response to radiation. (e.g. electrical equipment) Proper ventilation has as well to be assured.

- Soil Temperature

  Soil temperature is of particular interest for energy balance computations, for plant growth and various pest development assessments. The standard depth levels are 5, 10, 20, 50 and 100 cm. Soil temperature is measured under two standard types of soil cover - bare soil and short grass. Its simultaneous measurements under crops and trees shows the modifications of the temperature regime due to the crops and their management.

- Special temperature measurements

  For particular purposes the temperature of:

  . water surfaces and water bodies (including ice and snow)

  . plants (leaves, stems)

  . animals

  can be of interest and have to be measured.

- Heat flux density (unit: cal $cm^{-2}s^{-1}$, $Jcm^{-2}s^{-1}$, Wm^{-2}) is a quantity which is required where detailed heat balances must be ascertained.

● Instruments

- Physical principles of temperature measurements
  To measure the temperature of a body the following physical principles are mainly used:

  . the expansion of liquids and metals

  . the change of electrical resistance with temperature

- the thermo-electrical effect
- chemical reactions
- the black body radiation

- Thermometers and temperature sensors

  - The most common thermometers for standard observations in the air soil and water are the differential expansion thermometers which include the liquid in glass, the liquid in metal and the bimetallic sensors.

  - Different designs of liquid in glass (spirit or mercury) thermometers are: Ordinary thermometers, Minimum and Maximum thermometers and soil thermometers.
    (suppliers: A 1-5, B23, B24)

  - Liquid in metal (e.g. mercury-in-steel) and Bourdon tube devices, make useful temperature recorders with the possibility of remote measurements up to 50 m.

  - Bimetallic strips or helix which change the curvature with temperature are widely used in the construction of mechanical temperature recorders.
    (suppliers: A 1-5, B22)

  - Electrical resistance sensors
    Metallic resistance thermometers are annealed elements, generally of nickel or platinum, whose electrical resistance increases with temperature. Most common are platinum-wire hard-glass sensors with 100 ohms at 0°C. Their resistance temperature response is to a great extent linear. Readings are made with appropriately scaled meters such as power bridges.
    (suppliers: A 2-5, B25)

  - Thermistors are solid semi-conductors with large negative temperature coefficients. They are produced in various shapes such as beads, rods, and flakes. Their small size, high sensitivity and rapid response are valuable characteristics, offset however by their lack of linear response in the resistance temperature relationship. Additional components are therefore required to obtain linear output.
    (suppliers: A4, 5, C22)

- Thermocouples

  Thermocouples are convenient temperature sensors because they are inexpensive and easy to make. For meteorological applications copper-constantan thermocouples are the ones most frequently used. The weak thermal electromotive force response, of about 40 $\mu V/^{o}C$ can be increased by connecting several thermocouples in series, or using suitable d.c. amplifiers. Modern recorders provide for reference junction temperature measurements and/or compensation. With reference to the basic physical principle thermocouple instruments are especially useful for differential measurements.

- Heat-flux plates

  Usually these instruments are thermopiles whose output is proportional to the temperature difference between the sides of a plate crossed by the flux.

- Diodes and transistors

  Diodes and transistors with outputs higher than 1$\mu V/^{o}C$ are used to construct sensitive and accurate thermometers for applications in plant environments.

- Katathermometers

  To measure the cooling effect of temperature and wind, Katathermometers are used. They are spirit in glass thermometers with a rather big bulb of accurately determined area. With these the time required for a fixed amount of cooling, after the thermometer has been warmed, is measured.

- Surface temperatures can be determined by using radiation measurements and applying the physical radiation laws (Stefan Boltzmann, W. Wien), to them. Use of these methods are mainly made in remote sension from aircrafts and satellites.

- The chemical transformation of saccarose to glucose and fructose in a solution is an expontential function of its ph value and temperature. This reaction is used to measure the average temperature or rather the heat quantity received, over a longer period. To measure the state of transformation a polarimeter is used. With respect to the non linear response of the chemical reaction to temperature, satisfactory results with this method is mainly obtained where temperature variations are small (soil, water bodies).

Humidity of the air

- General comments on air humidity measurements

  - physical aspects

    Air humidity is defined by the water vapour contained in the atmosphere. 20 definitions and specifications are given by WMO. The most relevant for agricultural meteorological purposes are:

    - Vapour pressure e: partial pressure of water vapour in moist air of total pressure p. (units mb)
    - Saturation vapour pressure E: maximal water vapour pressure at pressure p and temperature T. (unit: mb)
    - Relative humidity U: Ratio in percent of partial to saturation vapour pressure of a given total pressure p and a temperature T. $U = 100 = \frac{e}{E}$ (unit:%)
    - Dew point temperature Td: Temperature at which the partial vapour pressure becomes equal to the saturation vapour pressure. (e = E; U = 100%) (unit: ^{o}C)
    - Saturation deficit Δe: Difference between saturation and partial water vapour pressure at a given total pressure and temperature ($\Delta e = E - e$; unit: mb)

- Mixing ratio r: ratio of the mass of water vapour to the mass of dry air with which the water vapour is associated. (unit: g/kg)

Note: Distinction has to be made between water vapour over water or ice.

- Observation of air humidity.

  The humidity of the air should be measured in representative places at different levels in the layer adjacent to the soil from ground level up to 10 m. Observations taken for special research projects will vary with the needs of the problems under investigation.

- Instruments

  - Methods of measurement

    - Methods using the change in dimensions of hygroscopic substances (hair hygrometers)
    - Thermodynamic methods (psychrometer) Dry and wet bulb temperatures allow to calculate air humidity.
    - Absorption method using a change of electrical resistance or capacity.
    - Condensation method (dew and frost point hygrometers).

  - Water vapour sensors

    - Mechanical hygrometers and hygrographs. The change in length of hygroscopically sensitive hairs is used to construct "mechanical" hygrometers and hygrographs measuring the relative humidity. Provided that no extreme temperatures and very low humidities (<20%) occur, these instruments meet the general requirements of accuracy (±3 to 5%). Hair hygrographs are the most frequently used standard recording measurements for humidity measurements in international networks. However the following disadvantages have to be noted:

non linear response to humidity changes, changes in zero point requirement for frequent cleaning and recalibration; sensitive to destruction or errors through chemical pollution (e.g. ammonia gases), low response rate at low temperatures.

- There are simple hygrometers for direct readings and hygrographs with adjustable mechanisms for direct recording on clockwork driven cylindric drums. Similar hygrometric sensors have been constructed, where the change in length of the hair bundle operates an electrical potentiometer, which allows for remote control (suppliers: A 1-5, B22).

- Psychrometers

  Psychrometers basically consist of two thermometers one of which is measuring the air temperature (dry bulb thermometer) while the other is covered and kept moist to measure the "wet bulb temperature". For accurate measurements provision has to be made:

  - for appropriate protection against radiation;
  - to avoid error due to conductive heat;
  - to ensure adequate wetness of the wet bulb thermometer;
  - that the thermometers used have approximately the same lag coefficient.

Distiction is made between simple psychrometers without ventilation and artificially ventilated psychrometers.

Non ventilated psycrometers are still in general use at climatological stations, but as ventilation (up to 2.5 m/s) affects the results considerably, the accuracy of these instruments vary with the conditions of natural ventilation. The error usually will be about 5% rel. humidity but can reach 10% in dry air.

Artificially ventilated psychrometers as the Assmann type, the aspirated screen type, the whirling type - are designed to eliminate these errors to a large extent by providing forced ventilation of at least 2.5 m/s. (the sling or whirling type however needs particular attention to avoid radiation caused errors). The general accuracy of these psychrometers - depends mainly on the accuracy of the thermometers and the wet bulb reading. (An error of 0.5°C in the wet bulb reading will cause an error of 44% in rel. humidity at -25°C but only 2% in rel. humidity at +15°C) air temperature.

Psychrometers using liquid in glass thermometers allow for instant readings only. By using electrical temperature sensors and providing for permanent water supply for the "wet bulb" thermometer, recording psychrometers have been designed. Modern microprocessors, by applying the psycrometric formula immediately to the temperature (dry and wet bulb) readings of such psychrometers, allow for continous recording of air humidity in technical units.
(suppliers: A 1-5, B5, B16, C4)

Absorption method

- Electrolytes which change their electrical resistance with relative humidity have been used for measuring and recording the vapour content of the atmosphere. Lithium chloride or sulphanated polystyrene layers are most commonly used for this purposes. The non linear resistance/humidity response of these sensors has to be considered as a disadvantage especially in very dry or very humid conditions. The fact, that these electrolytical sensors are easily contaminated by gases smoke or oil vapours contained in the air, requires great care in handling.
(suppliers: A4,5,B5)

- There are also small humidity sensors which change electrical capacity with humidity. Their size (less than $1cm^2$) and fast response (approx. 1s) is of particular interest for agricultural meteorological applications. With an appropriate micro-electronic circuit, a linear (approx. 1%) D.C. voltage output can be achieved. (suppliers: C2, C5)

- Dew point hygrometers indicate dew point temperature rather than relative humidity. Using the principle of cooling an air sample - which has to be delivered without changing its water vapour content to a measuring unit - until condensation takes place, these instruments are in general more complicated, more expensive but more accurate. One such instrument, an illuminated condensation mirror is alternately cooled and heated by a circuit energised by a photocell relay which maintains the mirror at dew point temperature.

- Peltier psychrometers, using the Peltier effect in chromel constantan junctions are also used for accurate measurement of water potential in plant tissues and soil samples.

Sunshine and Radiation

- General comments

  - Radiation fluxes to and from the earth's surface are most important meteorological elements for heat and energy balance assessments. As the energy conversion from solar radiation mainly takes place on the surface of the soil and of plants. This parameter is of special interest in agricultural meteorology.
  - The duration of sunshine (units: h per day) allows for estimations of the energy available for physical and biological processes. For accurate investigations, measurements of the different radiation (solar and terestrial) fluxes are required. In meteorology, the following radiation fluxes are measured:

  - Solar radiation fluxes (short wave length 0.29 - 4μ)

    - Direct solar radiation is measured at normal incidence.
    - Global solar radiation: downward direct and diffuse solar radiation, received on a horizontal surface from a solid angle of 2Π.
    - Sky radiation: downward diffuse solar radiation received on a horizontal surface.
    - Reflected global radiation: Upward solar radiation reflected by the earth's surface and diffused by the layer between the ground and the point of observation.

      (Albedo: Ratio between upward and downward global solar radiations)

  - Terrestrial radiation fluxes: (long wave - length 4 - 100 μ) By terrestrial radiation is to be understood the thermal radiation of the earth and the atmosphere.

  - Total radiation fluxes

    By total radiations is to be understood the sum of the solar and the terrestrial radiation. The flux of both radiation components passing through a horizontal plane is called net radiation.

- In agriculture, the spectral distribution of solar radiation especially in photosynthesis assessments is of great interest.

- The measuring units of solar energy are:

1 cal $cm^{-2}min^{-1}$	= 4,1868 J $cm^{-2}min^{-1}$	= 0.069 Wcm^{-2}
1 J cm^{-} min^{-1}	= 0.238 Cal $Cm^{-2}Min^{-1}$	= 0.0165 Wcm^{-2}
1 W cm^{-2}	= 14.3 $Cal^{-2}Min^{-1}$	=60.5J$cm^{-2}Min^{-1}$

- In order to ensure the reliability and comparability of radiation measurements the sensors have to be checked frequently and calibrated at regular intervals against reference instruments at national or regional centers as recommended by WMO.

• Instruments

- Physical principles
  . To measure the duration of sunshine to the nearest tenth of an hour, . four physical principles are mainly used.

    heat radiation from the sun is focused to burn a trace in a chart.

    radiation from the sun is made to record a trace on photographic papers.

    thermometric (bimetallic) switches controlling either mechanical or electrical recording devices.

    photoelectrical sunshine switches.

  To measure solar and terrestrial radiation two basic physical principles are used:

    the absorptive and emissive properties of black and white surfaces resulting in temperature changes and differences when exposed to radiation fluxes. These changes and differences in temperature can be measured and give quantitative information on the radiative energy received.

    the photoelectric effects of various semiconductors. (photoresistances, photoelements photodiodes, phototransistors)

- Sunshine sensors

  . To measure the duration of sunshine, the Campbell-Stokes recorder, where the focused radiation from the sun burns a trace in a chart, is the most used one, in international networks. It is also recommended as an interim international reference instrument. (suppliers: A 1-5)

  . To allow for electrical recording of the duration of sunshine, different "detectors" using thermometric switch devices or photo electrical elements are available. However measurements with these instruments should be checked against Campbell-Stokes results and eventually be corrected accordingly. (suppliers: B2, C5)

- Radiation Sensors

  . Pyranometers and actinometers are used to measure the global radiation.

  Bimetallic actinographs are simple self-contained recorders. A mechanical linkage is used to record the temperature difference between a black coated bimetallic strip exposed to the sun and one or two similar bimetallic strips either painted white or shielded from solar radiation. (suppliers: A 3)

  The Moll-Gorczynki pyranometer is a thermopile instrument, having a rectangular receiving surface which is covered by two concentric hemispherical glass domes. The Volachine pyranometer is of similar construction but has a circular receiving surface, hence no attention need be paid to orientation.

  The Eppley pyranometer has two concentric silver rings as receiving surface. One of which is coated black and the other white. The temperature difference between the two rings is measured with thermojunctions.

The Dirmhirm -Sauberer pyranometer uses black and white segments alternatively mounted in the form of a star. Again the temperature difference is measured with thermojunctions which are in good thermal contact with the segments.

The above mentioned thermopile instruments are covered by hemispherical glass domes of 2mm thickness. They are usually well sealed and provision is made that the air inside is kept dry with silica gel. The time required for about 98% response to a sudden change varies between 20 to 30 seconds. The temperature coefficient does not exceed -0.2% per $^{o}C^{-1}$. The sensitivities are about 2 mV/J cm^{-2} min^{-1} Their spectral range includes the wave length is from o.3 to 3μ.

For the standardisation of pyranometers the preferred method is by comparison with a standard pyrheliometer using the sun as a source. More often, one pyranometer is is checked against another. This method requires a high quality reference instrument which is regularly calibrated against a recognized standard.

Pyranometers with an appropriate device (disc or shadow ring) to screen off direct solar radiations are used to measure the sky radiation. For the measurement of reflected global radiation (albedo) pyranometers are exposed downwards.

For measurements of short wave radiation falling from the sun and sky and from soil or other reflection on a freely exposed object, the Bellani spherical pyranometer is used. The radiation is integrated over a spherical surface and over a certain time. Daily total radiation values with satisfactory accuracy can be obtained provided the instruments are scrupulously evacuated before filling with alcohol, properly exposed and well calibrated.

Total radiation (solar and terrestrial) and net radiation (net flux of downward and upward total radiation) is measured with black coated heat-flux photo-sensors, in which thermocouples are embeded to measure the temperature difference between the two sides of a thin uniform plate with well-known thermal properties. Errors due to convection and plate

temperature are avoided by using forced ventilation, appropriate shields and temperature compensation circuits. Most of the commercial net pynradiometers or balance meters use hemispherical windows to cover the circular or square receiving surfaces (1 to 30 cm^2). The material used is thin polythylene, having an integrated transmission in the spectral range from 0.3 to 100μ).

Plastic tube net radiometers are useful instruments for measuring relative values of average net radiation inside crop and forest canopies.

By shielding one of the receiving surfaces and measuring the temperature of the instrument net-pyrradiameters can be used as pyrradiameters or pyrgeometers. (for determination of the downward or upward long-wave radiation).

As the surface has an influence on the terrestrial radiation near the ground, the exposure of a pyrradiometer needs to be chosen with care to be represntative for the neighbourhood.

. For measurements of energy-flux densities in selected spectral bands solid-state sensors (photo-electric cells, photo-emissive elements, photo-resistors) are increasingly used as they produce larger outputs as thermopile instruments with respective filters. The different adaptations of these types of instruments are of special interest in plant canopy research.
(suppliers: B1, 3-6, 26)

Precipitation

- General comments

The amount of precipitation rain, snow/ice and dew which reaches the ground in a stated period, is expressed as the depth to which it would cover a horizontal surface if there were no loss by evaporation, run-off or infiltration, or if any part of the precipitation falling as snow or ice were melted (liquid equivalent).

As precipitation measurements, should as much as possible, be representative for a larger area, the choice of site, the form and exposure of the gauge, the prevention of loss by evaporation as well as the effects of wind and splashing are important points which have to be observed.

The amount of precipitation is measured in millimeters the readings being made to the nearest 0.2 mm, 10 mm should read to 2% of the total. Depth of snow are given in centimeters.

- Instruments

  - Non-recording rain gauges. Ordinary rain gauges usually have the form of a collector above a funnel leading into a receiver. The opening of the collector should have a receiving area of 200 to 500 cm^2. (The most common standards are: 200 cm^2, 324 cm^2 diam. 8 inch and 400 cm^2. However, in many countries 126 cm^2 - diam 5 inch, are still used.) The rim of the collector should have a sharp edge and should fall away vertically inside and be steeply evelled outside. It should be designed to prevent rain from splashing in and out. The receiver should have a narrow neck and be protected from radiation to prevent loss of water by evaporation.

    Weekly and monthly raingauges must have a receiver with a capacity to store the catch over the period. To avoid evaporation losses, a known quantity of oil is placed in the receiver.

  - The rain measures, measuring glass or dip rod, have to be graduated to correspond

to the relative areas of cross section of the gauge orifice. A measuring cylinder should be made of a clear material (glass or moulded plastic), have a low coefficient of expansion and its diameter should not exceed 30% of the gauge diameter. Graduation should be in units of rainfall and at least every 0.2 mm should be marked. Dip rods are mainly used to measure rainfall in monthly or seasonal gauges. However, these measurement should be checked using cylinders as well.

- As far as the exposure of rain gauges is concerned, sites sheltered from wind but not from the rain should be chosen. Eddy disturbances of the airflow due to obstructions and the instrument itself have to be avoided. It is important that the orifice of the gauge is horizontally exposed and is high enough to prevent splashing from the ground. (in different countries standard heights from 30 to 150 cm are used).

- Recording rain gauges

  . Rainfall recorders to record the total amount of rainfall.

  In the float type of instrument, the rain is led into a float chamber, and the vertical movement of a light float is recorded on a chart, when the level of the water raises. To provide a record over a longer period, these instruments are equipped with a device for emptying the float chamber once it becomes full. This is usually a siphoning process which should take no longer than 15 sec. and should start and end abruptly to minimize errors, as rain during this process is not recorded.

  In the tipping bucket type, the rain is led from the receiving collector to a light metal container divided into two compartments. This container or bucket is so balanced that when one compartments holds a predetermined weight of water, it tilts allowing the compartment to empty and the rain to fall into the other compartment. The tilting of the bucket is used to operate either mechanically a counter or recording device, or an electrical switch which allows for recording at distance.

The time the bucket needs to tip over leads to appreciable errors only in heavy rainfall. The discontinous nature of the record is not satisfactory for use. in very light rain as the time of beginning and ending cannot be accurately determined. If detailed records are required the amount of rain per tilting process should be 0.1 mm but in many cases 0.25 or 0.5 mm "sensitivity" will be sufficient.

- For recording rainfall intensities the above mentioned amount recorders can be used provided the recording device allows for a timely resolution of 15 minutes. (5 min for special purposes). There are also instantaneous intensity recorders which utilize the relationship between the rate of flow of water through a restricted orifice and the head of water producing the flow. (Jardi rate of rainfall recorder). To evaluate the amount of rain which has fallen, planimetric measurements of the area under the recorded trace are necessary, which is not an accurate and simple procedure.

- For measuring snowfall, gauges are used where the snow is melted by heating or by mixing with chemical anti-freezers. There are also rain recorders with heating devices which can be used for snowfall measurements as well. Heated recorders should be constructed in such a way to avoid exessive evaporation when the heating is on.

- Rain detectors or wetness detectors are used to record duration of precipitation. Conventional instruments are similar to hygrographs except that the sensing element - a string - is exposed openly to precipitation. Electrical sensors will close or open a switch when precipitation is falling on its surface. To speed up drying of the senoor after the rainfall, heating devices can be built in.

. Measurement of Dew

Dew being essentially a nocturnal phenomenon, and although relatively small in amount, it is nevertheless of much interrest in arid zones. The amount of dew deposited on a given surface in a stated period is usually expressed in the same units as rainfall - mm depth of dew.

A direct method of measuring dew is to expose a weighted plate of hygroscopic material (gypsum, blotting paper) at sunset and re-weighing it after sunrise. This method requires accurate weighing and protection at sunrise to prevent evaporation. Qualitative assessment of dew is obtained by exposing filter paper "sensors" with dye spots. When wetted by dew the spots will spread to an extent which depends on both the duration and intensity of dewfall. Dew duration recorders operate to a far extent in the same way as the above mentioned wetness recorders.

For quantitative assessments, dew-balances are used to weigh the amount of moisture deposited on a surface with similar structure as leaves. The amount of dew on natural leaves can be measured by collecting it with blotting paper which is weighed dry and after being pressed against the leaf. The leaf-surface has, however, to be measured as well.

Wind

- General comments

  - Horizontal pressure differences, caused by temperature variations in the earth/atmospheric system, result in atmospheric motion or wind. Thus, thermal energy is converted to kinetic energy. In the layer near the ground one is concerned with winds of local and micro scale origins, as well as the modifications of airflows, generated on larger atmospheric scales, by the topography and the cover of the surface.

  - In agricultural meteorology, not only the effects of the kinetic energy transfer of wind to the plant/soil system is of interest but as well the effects of its mass transfer, on the energy and water balance.

  - Units

    By its physical nature two magnitudes are required when describing wind; its velocity and the direction from which it blows.

    . Windspeed is usually indicated in: m/sec, km/h, or knots (= 1 nautical mile/h), but occassionally the non linear Beaufort scale is still used, which refers "forces" from 0 to 12, to the effects of wind on smoke, trees or water surfaces.

    . The direction from which the wind blows is either given in accordance with the geographical directions (e.g. N,E,S,W) or in degrees: 1 to 360 (90° = East, 180° = South, 27° = West, 360° = North; 0 frequently stands for Calms .

  - Wind can be conceived to be a vector, which, in the polar system of coordinates, is defined by an azimut and a distance in a unit of time, in representing the wind speed.

    As this system is only for bidimensional representation of the wind, the cartesian system of coordinates (X axis: North/South; axis: West/East; Z axis: vertical) is used when vertical convection has to be considered as well.

  - Observation of Wind

    . As the wind field, speed and direction, near the ground is to a large extent influenced by the topography and the surface cover (vegetation - grass, crops, trees; artificial obstacles - buildings, walls;)

- Observation sites have to be chosen very carefully in order to be representative. For climatological purposes wind should be observed at flat and openly exposed sites (distance to the next obstacle should be 10 times the height of the obstacle; not on top of the buildings which cause turbulences).

- As standard height above ground, 10 m is generally recommended for wind measurements in climatology, but for agrometeorological purposes measurements are very often made at 2m above ground.

- Detailed micro climatic investigations on the windfield near the ground and its modification by the vegetation, will require purpose specific choice of observation sites.

Instruments

Methods of measurements

Basically the following three physical principles are used to measure wind.

- dynamic energy methods
- heat transfer method
- sonic method

- Instruments using the dynamic energy methods.

  - The wind Vane (Direction):
    An assembly of a vane plate (which can have many shapes) and a needle is mounted on a vertical axis, which allows it to revolve freely. As a result of the mechanical action of the wind on the vane, the needle will be turned in the direction, from which the wind blows. As the direction indicated by the vane, oscillates around the equilibrium point of the airflow (which can change direction rapidly over time) big efforts have been undertaken to minimise this drawback by different designs. The axis of the wind vane can be connected to a mechanical or electrical (contacts, potentiometer) device, which provide recording facilities and remote reading of the wind direction.

    Instantanous windspeed can be measured with a swinging plate, placed on an horizontal axis of rotation, provided it is exposed perpendicular to the air flow. This can, to a certain extent, be achieved by a combination of a directional wind vane with the swinging plate.

. Cup anemometers

One of the most common instruments for measuring the wind speed are cup anemometers. A small "windmill" device with cups on a vertical axis of rotation, placed in the plane of the wind, will assume are angular velocity which is a linear (within a large range) function of the wind speed, irrespectively the direction of the wind. The direction of rotation of cup anemometers is always the same. The time, when the equilibrium speed is reached, depends on the moving mass, while the minimum speed, required to start the anemometer, is a function of its internal friction. Cup anemometers with mechanical counting or recording devices are used to measure distances of windrun over larger time intervals, thus allowing mean windspeed to be calculated for this periods.

By using electrical devices to count the anemometer revolutions (reedswitches, photodiodes, etc.) the internal friction of the instruments can be decreased, thus allowing high sensibilities with low starting speeds.

For measuring instantaneous (subject to the reaction time of the instrument) windspeed, cup anemometers are coupled with D.C. generators. The voltage output of which, is a function of the windspeed.

Propeller and Vane anemometers with mechanical or electrical revolution counting devices or DC generators, are also used to measure integrated or instantaneous windspeed. As these instruments require to be exposed perpendicular to the air flow, they have to be coupled with a directional vane, or be used under circumstances where changes in the direction of the air flow do not occur. As the angular speed of a propeller is a function of the wind speed and the sine of the angle between the direction of the air flow and the axis of the anemometer, it is possible to obtain wind data in cartesian coordinates, by using three anemometers mounted in the X,Y,Z axis.

The starting speed of standard cup, propeller and vane anemometers is between 0.5 to 1 m/s but high quality instruments can have treshholds as low as 0.1 m/s.
Suppliers A1-5, B17, B18, D19, C3, C4.

- For very low windspeeds, particles drifting in the air (e.g. soap bubbles, smoke) can be used for qualitative rather than quantitative measurements. Upper air wind measurements use the same method with balloons having a known rate of climb. They are followed optically by theodolite, or by radio or rader waves. The angle from north and the azimuth measured at given intervals, enables one to calculate the winspeed and direction in the upper atmosphere layers.

- Static instruments

  - These types of instruments depend on the hydrodynamic principles of the dynamic and static pressure in streaming gases and liquids.

  - The "PITOT tube", exposed in front of the air flow indicates the dynamic pressure, while a tube exposed parallel the air flow shows the static pressure. By knowing the pressure difference and the specific mass of the air the windspeed can be deduced.

  - With the "VENTURI TUBE", pressure measurements are taken at places having different cross sections. In the narrow section of the tube the air flow is accelerated, thus creating a lower pressure compared with the one in the wider section. Using a differential manometer, the instantaneous windspeed can be measured.

    Both the Pitot tube and the Venturi tube must be placed parallel to the airflow. (Supplier A2)

- Instruments using the heat transfer method.

  - In "hot wire anemometers", an electrically heated wire is cooled by the air flow. As the amount of heat loss is proportional to the windspeed at normal incidence of the air current, this principle can be used to measure the windspeed.

    The heat loss of the exposed wire results in a temperature difference to an unexposed control wire. This differential temperature is usually controlled with thermocouples.

    Either the temperature difference is used to deduce the speed of the air flow, or the exposed wire is heated up to the temperature of the unexposed one, in which case the current required, can be referred to the windspeed.

    Vertical mounting of the measuring wires makes this instrument independent of the direction of the wind in one plane .

    Cross wire sensors are used for measurements of turbulent motion, to separate the wind components.

. The same physical principle is used in the "Hot Bead Anemometer" where the hot wires are replaced by small heated beads. These have the advantage that the heat transfer is less dependent on the direction of the air current, on the other hand their response is slower.

. The small size and high sensitivity, makes this type of anemometers particularly useful for measurements of low wind speeds (down to 0.02 m/s) in plant canopies. (Suppliers A2, A4, A5).

- Sonic anemometers.

. As the rate of propagation of sound waves depends, independently of the temperature, on the displacement of the air, this can be used to measure the windspeed.

If the direction of the sound waves coincides with the wind direction this will result in an accleration of the speed of propagation or vice-versa.

If the air flow does not have the same direction as the propagation of the wave, the latter will thereby be distorted as a function of the sine of the angle formed between the two

Sonic anemometers are composed of four sets of wave generators and receivers, installed on opposite sides of the N-S and E-W axis. Such a set up allows for measurements of average windspeed and direction, within the plane of the dedectors. By adding more sets of wave generators and receivers on the vertical axis, this method can be used to build tridimensional measuring devices.

The important instrumentation (wave generators, receivers, signal analysers computers) and the complex installation of this type of anemometer, makes it not only very expensive but also unsuitable for agrometeorological field applications. (Suppliers C2).

Evaporation

- General comments

As the water loss from a surface depends on a variety of meteorological parameters, such as air humidity, temperature, radiation, wind and atmospheric pressure, an accurate determination of this component of the water balance equation causes considerable problems. Although theoretical approaches, based either on the energy budget or the mass transfer method, allow for estimations of the meteorological parameter, direct measurements are often preferred.

However a common problem to all direct measurements is the representativeness of the installation relative to the "natural" conditions of the above mentioned meteorological parameters.

The amount of water loss is, analogous to rainfall and expressed in mm of height of the water column evaporated.

- Instruments to measure potential evaporation*

  - Piche Evaporimeter

    This evaporation gauge consists of a graduated glasstube which is closed on the upper side. To the lower, open side a disc of blotting paper (usually 3cm diameter) is fixed with a clip. Filled with distilled water, the waterloss from the paper surface is referred to the evaporative demand of the air. Although it is a cheap and widely used instrument, the results are of rather limited value in water budget assessments. Hence it should be used only for special applications of qualitative rather than quantitative nature.

  - Evaporation tanks

    Evaporation pans or open water tanks exposed to the enviromental conditions are most commonly used to measure evaporation. Large number of different designs, sizes and ways of installations are used throughout the world. The most commonly used Pan Typs are:

    - Class A Pan: Round evaporation pan made of stainless steel or galvanised iron sheets. Diameter: 120.6 cm, Height: 25.4 cm. Installation: Horizontally on a wooden grace above the ground approx. 13 cm height.

    - Colorado Sunken Pan: Square evaporation pan Size: 92 x 92 cm, 46cm deep Installation: buried to the level of the ground.

    In most cases evaporation pans have to be protected against animals by wire grids. As this grids modify the windfield around the instrument it becomes necessary to apply correction coefficients to the measurements.

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* (Potential Evaporation: Evaporation from a free water surface)

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The water level is controlled with a graduated hook gauge, set on a still well, or with a fixed point, to which the pan is refilled each time a measurement is made, with a calibrated graduation.

- For continous recording, mechanical water level recorders can be connected to the evaporation pan, or water level gauges with an electrical output can be used with appropriate recording devices.

- For special applications, recording evaporation balances (evaporation surface 250 cm^2, or other devices using porous ceramic discs or spheres have been designed (Evaporimeter "Bellani"., "Livingstone").

- Instruments to measure potential or actual evapotranspiration.*

  - Lysimeters are field tanks of varying types and dimensions containing natural soil and vegetation. Provisions are made which allow a detailed assessment of the water budget inside the tank. (By measurements of the precipitation and the drainage, weighing the entire tank, soil moisture measurements inside the tank).

In order to meet the requirements for representavity and homogeneity, both in soil structure and vegetation, lysimeters should not be too small in size (surface >3 m^2, depth>1 m). Thus, lysimeters require rather high capital input upon installation and further to obtain valid research results, important maintainance efforts as well.
Suppliers A1-5, C6)

- <u>Atmospheric Pressure</u>

  - General comments

    Atmospheric pressure is regularly measured at stations of the international meteorological network for synoptical and weather forecast purposes. In agricultural meteorology this parameter has no direct importance and therefore is not included in the standard observation program.

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* Potential Evapotranspiration: Maximum water loss from a surface covered with vegetation, when water supply to the soil is not limiting.
Actual Evapotranspiration: Water loss from a plant/soil combination under existing meteorological, soil and biological condition.

However, atmospheric pressure data is required for computations such as air humidity and evaporation. Generally, mean pressure values as given by the altitude/pressure relationship is sufficient, or otherwise data from nearby synoptic stations can be used.

RECORDING OF METEOROLOGICAL PARAMETERS

- General

Meteorological data can be obtained by direct readings of measuring instruments, and by instruments providing a continous record of the parameter over time. Instruments for direct readings are usually simpler and cheaper than the latter, but the type of information obtained is of instantaneous character and the amount of data which can be collected depends to a large extent on the availability of trained staff. Recording instruments have been designed for practically all meteorological parameters using various physical principles as described in the previous sections. Generally they can be divided into mechanical and direct recording instruments and in electrical recording assemblies.

- Calibration of meteorological instruments

Just as any physical measuring instrument, meteorological instruments have to be calibrated, to meet the comparability requirements. Initial calibrations are usually made by the supplier of the equipment, but many instruments need to be checked or recalibrated after transport and installation. Recalibrations are a "must" after repairs or replacement of essential parts of the instruments. As the ageing process affects in most instruments the "zero" level and eventually the sensitivity, it is advisable to recalibrate at regular intervals to maintain the equipments accuracy and the comparability of data obtained. The most common way to calibrate meteorological instruments, is by comparison with standard instruments. These are usually kept at national centers and checked from time to time against international standards. However certain instruments and high precision calibrations, require sometimes rather sophisticated calibration equipment and have therefore to be sent to specialised laboratories.

- Manual recording of meteorological data

Observation with instruments which do not have self recording devices are made by individual readings at given observation times. These readings are written into an appropriately designed observation book. (It has to be avoided to note field data on loose leaves and to transfer it later to the observation book). This note book has to be designed in accordance with the observation programme and should in addition provide space for the application of calibration co-efficients to actual measurements and for basic calculations (e.g. humidity, averages, totals etc).

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For stations which do not have self recording instruments, the observation book constitutes the basic document and it is extremely important that it is properly kept and duly completed in accordance with the initial instructions. From this basic document, data can be transfered to monthly summaries and be extracted for special analyses.

For stations having self recording instruments, it is nevertheless important to maintain an observation book although it will serve for control purposes rather than for direct data recording.

- Mechanical recording instruments

  As already mentioned, there are physical principles available to measure meteorological parameters, which result in changes of length of the sensing element or where the sensor exerts a force. This can be transmitted mechanically with or without amplification to a recording system, usually based on a clock driven paperstrip, either of the drum or endless belt type. With regard to the magnitude of the movements and/or the exerted forces and the technical possibilities for mechanical amplification, mechanical recorders have a limited accuracy and the distance between the sensing element and the recording device have to be kept small. The main advantage of mechanical recorders are relatively low cost, easy maintainance and their independence from an external power supply (except that the clock drives have to be wound up in regular intervals.)

  The variations over time of the parameter to be measured, are displayed in graphical form, on diagram chart. Generally these charts have an appropriate time unit imprint to facilitate the analysis. As, in most cases this chart analysis (the transfer of graphical "values" to numerical data) is carried out manually, considerable "man-power" input has to be considered; this however depends on the type of record and the details requested.

- Electrical recording instruments

  Electrical recording assemblies consist of a sensor or dectector component and the recording device. As electrical signals can be transmitted over bigger distances without major problems, such set ups are particularly recommended where "remote" measuring is required, to minimise the interference with natural environmental conditions. A further advantage are high amplification possibilities for electrical signals by electronic circuits, to obtain high accuracy outputs. The power supply on the other hand represents a frequent drawback for electrical measurement units in field applications.

- Electrical sensors

  For electrical measurement assemblies either sensors are used which produce electrical signals "ipso facto" (voltage, differences in potential, resistance) to be referred to the parameters under consideration, or detectors where initial mechanical "signals" (longitudianl changes, rotations etc) are transformed into electrical ones, by appropriate devices (potentiometer, switches etc).

- Recorders

  Depending on the signal output of the sensor. The following types of recorders are used.

  - null-balance potentiometric recorders to amplify d.c. voltage signals.
  - galvanometric recorders, with or without amplification, for current signals
  - wheatstone bridges for electrical resistance measurements.

  Single or dual channel recorders are mainly constructed as continous line recorders. In multiple channel recorders (6-12) channels, the different sensors are consecutively connected (by switches or relays) to the measuring unit, Equipped with a multicolor printing device, these records result in dotted lines. The switching interval can be user determined, but has usually a lower limit, depending on the mechanical inertia of the switching system the measuring and the printing device.

- Analogue to the mechanical recorders the measurement results are graphical displays on a diagram chart, which usually again needs to be analysed manually for further interpretations and/or computations.

  To reduce the chart analysis requirements, electrical recorders with integrators have been designed to integrate signal inputs over a given time interval. To obtain directly mean or total values of continuous observations, some of these integrators allow for a digital outprint of the values, which of course facilitate again the data analysis.

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- Electronic measurement and recording devices

  With the progress in micro-electronic technologies over the last years, more and more instruments using integrated circuits and micro processors are designed for meteorological measurement purposes. While, on the sensor side, this technology has not resulted in major changes, it has largely affected the measurement and recording instruments, including the data handling and analysis.

  - Instruments for direct readings

    Together with electrical sensors the use of integrated circuitry chips has allowed the construction of highly sensitive, low weight, digital read out instruments for most of the meteorological parameters. Their main advantage compared to the classical instruments is the possibility of the build in "conversion" from electrical sensor outputs to technical units, including complex linearizations.

  - Electronic recorders and integrators

    Electronic integrators with very low power consumption and considerable electronic memory capacity for data storage, are available for measurements of radiation, wind, rain and other elements. The stored data can be recalled from the memory manually, but transfer possibilities to magnetic charts or tapes, are frequently built in features of this type of equipment. The power requirements of a few MW allow battery operation over long periods, which makes these integrators in connection with appropriate sensors particularly suitable for use at remote observation sites.

  - Data loggers

    Consequent use of integrated electronic circuits and microprocessor chips had led to the construction of automatic environmental control systems and automatic weather stations.

    Simpler systems do provide for sensor exitation, the conversion of sensor readings into technical units and the recording of this data, on magnetic tapes from where it can be transferred to computers for further treatments (calculation of averages, totals, frequency distributions etc). More complex systems can process the input data (including averaging, totalizing, etc.) in accordance with user defined programmes, before storing it on magnetic tapes, putting it out on paper prints, or transferring it to network centres through telecommunication lines. The advantage of such systems is a higher resolution through higher sampling frequencies. However, with regard to the products offered, there is a wide range of features available for data loggers to meet the user requirements in the field

of meteorological and environmental measurements.

It is admitted that complete environmental control and data acquisition systems will require considerable capital input, but the advantages offered by these systems compared to "conventional" measurement equipment will in many cases justify the investment costs for data loggers.

REFERENCES

WMO: Guide to Agricultural Meteorological Practices WMO Nr.134. 1981. Geneva.

WMO: Guide to Meteorological Instrument and observing practices WMO Nr. 8 Geneva (out of print).

FAO: Agrometeorological Stations, Irrigation and Drainage Papers Nr. 27, Rome 1976.

Seemann, J., Y.I. Chirkov, J. Lomas, B. Primault: Agrometeorological Springerverlag 1979.

Others: Technical informations as provided by various leaflets from equipment suppliers.

List of Companies supplying meteorological Equipment

Meteorological equipment -conventional and mordern electric and/or electronic sensors, as well as recorders and data acquisition systems - is produced by big international companies, as well as by small specialized manufacturers. The latter, especially cooperate in many cases with national research institutes, in the development of new instruments, or get new devices tested and certified by officially recognized institutions. Equipment for special applications is often developed in research laboratories of national meteorological services or agricultural institutions and not produced commercially, and is therefore difficult to obtain.

With higher and higher technological standards many companies offering meteorological measuring systems, tend or need to use components produced by other specialized manufacturers. This applies in particular to modern electronic sensors, recording and data acquisition systems used in agricultural meteorology.

It frequently happens that requirements (sensitivities of sensors, power supply, environmental conditions of operation, type of recorder output) for measuring programs, cannot be met by equipment offered by a single company. So it may become necessary to buy components from different supplies and to "assemble" the meauring plant in accordance with the particular requirements. In this case frequent problems are the "what to buy where". the assessment of the compatibility of different components, the installation "in situ" and the calibration of the equipment.

Another aspect which should be considered when acquiring an environmental measurement unit, is the data analysis. It is advisable to check on the compatibility of the data output and the data processing facilities, either already existing or envisaged to be set up.

The list of suppliers given below intends to assist in addressing requests for detailed descriptions and quotations of meteorological equipment, but must by no means be considered to be complete.

A. Suppliers for a complete range of meteorological instruments

A1. Cassella,
London Ltd.,
Regent House,
Britannia Walk,
London, N1 7ND
U.K. (Telex 261641)

Products: Complete range of conventional Meteorological Instruments.

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A2. Wilh. Lambrecht,
P.O. Box 76,
D - 3400 Gottingen,
GERMANY,
(Telex 96862)
Products: Complete range of conventional instruments and Electrical sensors and recorders; AWS
Speciality: Wind measuring instruments

A3. S.I.A.P.,
Vid. Massarenti 412,
1 - 4040100 Bologna,
ITALY.
(Telex 511197)
Products: Complete range of conventional and electrical met. instruments including AWS.

A4. Weather Measure,
Systron Donner,
P.O. Box 41257,
Scramento,
CA. 95841, WUD 377-310,
U.S.A.
Products: Complete range of conventional and electrical meteorological instruments; AWS, commercializing as well as instruments from other manufacturers.

A5. Weatheronics
P.O.B. 41039,
Sacramento CALIF. U.S.A.
(Telex: 377-395
Products: Complete range of conventional and electrical meteorological instruments; AWS, commercializing as well as instruments from other manufacturers.

B. Suppliers with a restricted range of products

- Sunshine and Radiation Equipment

B1. The Eppley Lab. Inc.,
12 Sheffield Ave.,
Newport,
Rhode Island 02840,
U.S.A.
Products: Complete range of Radiation Instruments.

B2. Haenni Instr.
Ch - 3303 Jegenstorff,
Bern,
SWITZERLAND,
(Telex 32386)
Products: Sunshine Detectors

B3. Li-Cor,
P.O. Box 4425,
Lincoln,
Nebraska 68509, TWX 910 621 8116,
U.S.A.
Products: Instruments for biological and environmental sciences.
Speciality: Photo electrical and Radiation instruments.

B4. Middleton Instruments,
P.O. Box 442,
South Melbourne,
Vic. 3205,
AUSTRALIA
(telex 32486)
Products: Radiation Instruments (Thermopile and Photo electric instruments).

B5. Ph. Schenk, P.O.B. 3,
A - 1212 Wien,
Wien,
AUSTRIA.
Products: Radiation sensors and recorders
Air humidity measurement equipment
Speciality: Radiation sensors (Pyranometers and Pyrradiometers)

B6. Swiss Teco Instr.,
Ctegweg, Eichenwies,
Ch-9463,
Oberrient,
SWITZERLAND
Products: Radiation Instruments (WMO Quality Class 1)

- Soil and plant water potential instruments

B7. P.M.S. Instruments Co.,
2750 N.W. Royal Oaks Drive,
Carvallis, Oregon 97330,
U.S.A.
Products: Plant water potential instruments.

B8. Soiltest Inc.,
2205 Lee Street,
Evanston Illinois 60202,
U.S.A.
(Telex 72-4496)
Products: Large range of testing instruments for agricultural and soil sciences; some conventional meteorological equipment.

B9. Wescor Inc.,
459 South Main Street,
Logan Utah 84321,
U.S.A
(Telex TWX 910 971 5870 WECOR)
Products: Water Potential systems

B10. Westgate Agronomics,
1015 Pitner Ave.,
Evanston,
Illinois 60202,
U.S.A
(Telex - 681422)
Products: Soil measurement instruments.

Miscellaneous (wind, rain, humidity, temperature etc)

B11. Benoit Et Freres,
Rue Marcellin Berthelot,
F-95140 Alfortville,
FRANCE.
Products: Direct reading raingauge (400 cm2)

B12. Environmental Measurements Ltd.,
Raleigh Park Road,
Oxford, OX2 2BB,
U.K.
Products: Rain Recorders (Logger types)

B13. Gulton,
The Hyde,
Brighton,
Sussex BN2 4JU,
ENGLAND.
(Telex 87172)

B14. Th. Haywood and Sons Ltd.,
33 Avery Hill Road,
New Eltham,
LONDON SE 9 2BW.
Product: Rain gauges and Recorders.

B15. Kroneis,
Iglaseegasse 30-32,
A-1191 Wien,
AUSTRIA.
Products: Met. Sensors for Wind, Rain, Humidity Pressure.

B16. J.R.D. Merrill,
Speciality Equipment,
R.F.D. Box 140A,
Logan Utah, 84321,
U.S.A.
Products: Special Psychrometers.

B17. Met. One Inc.,
P.O. Box 1937,
Grants Pass,
Oregon 97526,
U.S.A
Products: Wind sensors.

B18. R.W. Munro,
Cine Road,
Bounds Green,
London N11 2LY,
ENGLAND,
U.K.
(Telex 24130)
Products: Complete Range of Wind Measuring systems, Rain gauges, Barometers.

B19. Northumbrian Energy Workshop Ltd.,
Tanners Yard,
Gilsgate Hexham,
Northumberland,
U.K.

Products: Wind measurement equipment
Speciality: Wind logger

B20. Paulstra-sites,
61 Rue Marius Aufon,
F-92300,
FRANCE.
Products: Meteo Screens (Plastic)

B21. Precis Mechanique,
14 Rue Denis Papin,
F-95870 Bezons,
FRANCE.
Products: Conventional Met. Equipment
Barometers, Rain recorders.

B22. J. Richard,
116-120 Quai de Bezons,
F-95100 Argenteuil,
FRANCE
Products: Conventional Temperature, Humidity, Pressure Recorders.

B23. Thermo Schneider,
Postfach 58,
D-Wertheim/Main 1,
GERMANY.
Products: Liquid in Glass Thermometers.

B24. Freres Thibault.
F-77190 Danmarie Les LYS,
FRANCE.
Products: Thermometers.

B25. Degussa
HANAU,
Germany.
Products: Themometers
Speciality: Platinium resistance themometers.

C. Suppliers for Automatic Weather Stations and Recorders

- AWS 29 - 34

C1. Austrian Research Center,
Seibersdorf,
A-2444 Seibersdorf,
AUSTRIA.
(Telex. 014353)
Products: AWS, Mobile and Stat. Using components other manufacturers

C2. Campbell Scientific Inc.,
P.O. Box 551,
Logan Utah 84321,
U.S.A.
(Telex 453058)
Products: Complete AWS Systems. (using components from other suppliers)
Speciality: Measurement and Control systems (Data loggers and data Processors).

C3. Cimel Electronique,
13 Bvd Rochechouart,
F-7500,
Paris,
FRANCE.
Products: Meteerological Data, Acquisition System.

C4. Didcot Instruments Ltd.,
Station Road,
Abington,
Oxon,
OX 14 3LD,
U.K.
Products: AWS using components from other manufactures.

C5. Vaisala O.Y.
PL 26 SF-00421,
Helsinki 42,
FINLAND.
(Telex 122832 Vsala SF)
Products: AWS including complete data transfer and processing.
(uses partly components from other suppliers)
Speciality: Capacitive Humidity sensor 4MP 14U

C6. Compagnie Industmelle Radioelectrique,
Bundesgosse 16,
CH-3001 BERNE,
SWITZERLAND.
Products: Automatic weatherstations
Lysimeters

D. - <u>Recorders</u>

D1. Rimco,
Analite Pty. Ltd.,
P.O. Box 11,
Oakleigh,
Vic.
Australia 3166,
(Distributed in AUS by "Medos Company Pty Ltd)
Products: AWS.
Speciality: Self contained and rugged recorders for up to 12 month operation

D2. Grant Inst.,
Barrington,
Cambridge, CB2 5QZ,
ENGLAND (Telex 81328)
Products: Chart recorders - Cassette data recorders - Memory recorders.

D3. Leeds and Northrup,

D4. Philips

D5. Siemens

IMPACT OF TRIALS ON SOIL IN EXPERIMENTAL PLOTS* - by A. Young

Introduction

The growth of woody perennials normally has favourable effects on soils. These arise from the well-developed root system; the protection of the soil surface from raindrop impact by the canopy; possibly by the addition of nutrients through tapping of atmospheric dust; and above all, by the fact that the leaf litter is not removed but decays to become incorporated in the soil. In regions where the natural vegetation is woody, trees restore an approximation to the natural conditions under which the soil developed its humic topsoil (Ah horizon)

Trees may thus counteract the adverse effects of continuous arable use on soils, that is, may reverse soil degradation. Measurement of such effects becomes of major importance in trials of species intended for possible use in agroforestry systems.

The effects of trees on soils may be divided into effects on soil physical, chemical and biological properties, and effects on soil erosion. There is an interaction between these, in that erosion removes soil nutrients.

Measurement of these effects should form part of most trials of species intended for possible agroforestry use. The order of importance is as follows:

• Measurement of soil chemical and biological changes	Techniques relatively simple. Should be carried out in all substantial trials.
• Measurement of soil physical change	Techniques more specia lized. Desirable in major trials.
• Monitoring of soil erosion	Requires special installa- tions Desirable in major trials where potential for erosion control is considered important.

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* See also Appendices 2.5 and 2.6 in Section 2A

In all cases, *it is essential to determine soil conditions at the start of the trials*, to provide a basis for subsequent comparison. The initial sampling and measurements form part of the experimental design, and must thus be made on a statistically valid basis.

Measurement of chemical and biological soil changes

The soil is sampled at the start and at intervals during the trials. Samples are analized for organic matter, nitrogen and chemical chemical properties, thus obtaining a record of changes in these properties over time in relation to the growth cycle of the trees.

Timing of sampling: If under natural vegetation, particularly if mature, it is highly desirable for the first sampling to take place prior to clearance. There should be a further sampling after clearance (and burning, if practiced). If more than a year elapses, the soil should then be resampled prior to, or shortly after, planting. Sampling then repeated at regular intervals during the growth cycle, e.g. every 3 or 5 years.

Sampling design: Sampling should include the topsoil (0-20 cm) and at least one lower horizon (45-55 cm is recommended as a standard). Owing to high microvariability of properties, sampling should always be composite (see Appendix 2.6, Composite sampling). For the basic sampling design a rectangular grid pattern is recommended, the spacing depending on plot size and finance available for analysis. A baseline is marked down one side or the centre of the plot, and traverse lines measured from this by compass and tape; the baseline is marked permanently. Composite samples are taken over a 10 m radius around grid points.

This basic design may be supplemented, later in the growth cycle, by micro-transects from close to tree trunks to the soil beyond the canopy (Kellman, 1980).

Analyses

- Organic carbon and/or total organic matter (as ignition loss at 375°C)

- Nitrogen

- Properties of the exchange complex: reaction, individual cations. total

exchangeable cations, cation exchange capacity (specify and standardize whether CEC at pH 7.0, 8.2 or unbuffered, the last preferable on strongly acid iron-oxide rich soils)

- Available phosphorus (specify and standardize method).

By combining soil analytical data with data on litter fall and composition, and rainfall analyses, it may be possible to build up models of the cycles of organic carbon, nitrogen and other nutrients.

Measurement of physical soil changes

Soil degradation under arable use is not confined to organic matter and chemical properties. Deterioration of physical properties can have substantial adverse effects (Lal and Greenland, 1979). Trees will frequently improve such properties, through the root system and by means of organic matter augmentation.

Measurement of soil physical properties requires sampling of undisturbed cores and, for infiltration, field tests. Specialist assistance will thus normally be required and, owing to higher costs, the number of sampling points will be fewer than for chemical analysis. Time intervals may also be longer, for example, at the start and end of the trial only. The following tests are desirable:

- dry bulk density (requires undisturbed cores).

- infiltration capacity (field test, double-ring infiltrometer)

- field capacity and wilting point (usually obtained indirectly by soil moisture retention curves; requires undisturbed cores in special rings, see Appendix 2.5).

Monitoring of soil erosion

There are two techniques for measuring runoff and soil loss by water erosion: run-off plots and wash traps. Both involve continuous recording on the site.

Run-off plots: This is the standard technique for measuring accelerated soil erosion, developed in the US and now found widely on agricultural

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research stations. A portion of the experimental site is selected as a plot. This is enclosed, usually by low corrugated iron sheeting driven into the ground. A pit is constructed across the lower end, from which runoff water and suspended soil particles are collected across a concrete lip flush with the ground surface, and directed by guttering into collecting tanks. The water is measured, then syphoned off and the sedimented soil collected, dried and weighed. As the collecting area is known, the soil loss can be calculated as tonnes per hectare per year. For a full investigation, several plots on different slope angles and of different lengths are required.

Wash traps: These are metal troughs (also called Gerlach troughs) by which runoff water and suspended soil are collected across a metal lip 0.5m wide. Advantages over runoff plots are that wash traps involve less soil disturbance, can be installed anywhere on the site, and are cheaper. The disadvantage is that the collecting area is not enclosed, involving uncertainties in interpretation of the results (Kirkby and Morgan, 1980, p.76).

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SECTION FOUR

Further Evaluation and and Assessment with Special Reference to Mixed Cropping

PART 4A

CONTENTS

INTERCROPPING WITH TREES - by P.A. Huxley

Introduction

Before starting experiments with tree/crop mixtures it is assumed that we are already dealing with well-established agricultural crop components, and that there is sufficient knowledge about the adaptability and behaviour of the tree species or provenances. It will then be necessary to test the ways in which the plant components interact. The earliest stage at which this can be done is after the tree species in question have, at least, been shown to be site-adapted, to possess suitable growth characteristics (vigour and morphology) and to be phenologically suitable. Final selection between or within multipurpose tree species, for example for vigour and yield potential, pest and disease resistance and management, might still continue in field trials carried out concurrently with tree/crop investigations (see Sect. 3A pages 8-11 and flowchart).

There is now an extensive and rapidly-growing literature on agricultural intercropping and some useful approaches to experimental methodology. Anyone starting mixed cropping investigations with MPT's who is not familiar with the selected references (see the section on plant spacing) is strongly advised to look into these before going any further.

Intercropping investigations: cause or effect?

When testing mixtures of different plant components there may be several objectives apart from maximizing overall yield. That is the experimental design, and the exact data collection procedures in experiments involving two or more plant components, have to be very carefully thought out. If they are not the trials will be either just site-specific tests of highly confounded "packages" of several treatment variables, or they will become very large and complex. In the first case (for example, comparing two species in an incomplete set of plant density, species ratio and management combinations) the extent and degree of plant-to-plant interactions will inevitably depend on such environmental factors as soil fertility and the weather experienced during the period of the experiment. The experimenter can certainly determine whether "package A" is better that "package B" but such results are unlikely to be extrapolatable to other soils or climatic conditions; nor will they be sufficiently informative about the reason *why* any particular set of results have been achieved. "Packages" of treatment variables

representative of farmers' alternatives may be useful under some circumstances. For example if the trials are to be carried out over a sufficiently wide sample of the environmental range in which the plant mixtures are to be grown, when extrapolation becomes unnecessary. Or if the experimental programme is just starting and the researcher is trying to simulate what a farmer does in order to establish what the research problems actually are. Otherwise it may be better to break down the problem into a series of relatively small experiments each investigating one or a limited number of *causative* factors.

Trying to decide on the actual causation of the differences observed in the growth and yeild of plants in mixtures may require a fairly detailed level of crop physiological research. This approach can sometimes produce a great deal of unwanted and sometimes uninterpretable data if it is carried out without regard to the more practical issues at stake. However, a *focussed* study of the allocation and effects of environmental resources in crop mixtures (light, nutrients, water) can be of considerable value when considering the possible performance of the mixture under other environmental circumstances. Furthermore, the greater complexity of the crop physiological approach, both in terms of the kinds of measurements made and the number and location of samples of various environmental and plant attributes, may well be offset by the relatively smaller experimental layout required. It largely depends on whether or not the experiment is designed to glean information just about the outcome (i.e. yield *per se*), or whether the objective is to discover what contributes to yield. Of course a complete investigation covers both these aspects, but we may have to settle for one rather than the other.

Plot sizes have to be fairly large to obtain repeatable yield data, but then they may well be excessively oversized if all that is required is an interpretation of plant-to-plant interactions, and vice-versa. Crop physiological investigations may not need very much additional equipment or facilities (see Section 3E) but they will certainly, take more time.

Intercropping with a tree component

The spatial and temporal dimension of an intercropping experiment designed principally to measure yields will, often, when one of the plant components in a mixture is to be a tree or shrub, become quite unwieldy and the cost exorbitant. In these circumstances it is necessary to examine the experimental objectives with even greater care than usual. Can we do without certain data for the time being? And will it cost less to obtain them later, when the number of experimental variables and levels of each are considerably narrowed down? Are they best obtained through simple "on-farm" trials anyway? Is it, perhaps, of more value to know how the crop mixture behaves in terms of each plant component's responses to environmental resource deprivation, so that some predictions can be made when environmental or management circumstances are changed?

If the answers to the questions above are mainly 'Yes' then much smaller field layouts can be used, and the experimental designs can be different from those addressing principally just comparisons of yields. In particular, if we confine ourselves to investigating the *interface* (or *interfaces*) between the plant components in the mixture under test, then the dimensions of the experiment, and hence its cost, can be markedly reduced.

In agricultural intercropping experiments, which are with seasonal plants of relatively similar stature, both the size and investment in any one experiment are usually containable. Hence, reliable data on yields are a reasonable objective and the arguements for the use of factorial combinations with intercropping experiments, both to raise experimental efficiency and to study interactions, are very powerful, as Mead and Stern (1980) firmly point out. With trees as part of the intercrop the theoretical issues still maintain their force, but the infeasibility of handling such large field experiments will often force us to adopt another approach.

Certainly when woody perennials are included the objectives have to be clearly decided (plant responses, or yields, or both?) and, if yield data *are* required, the experimental goals almost certainly will have to be broken down to address feasible component issues. A more practical way will then often be a series of small, phased trials starting with

plant responses (if these are not known) and using these to make sensible yield predictions, at least for the time being. The long-term nature of the tree component will demand, eventually, an equal consideration of plant responses *and* of yields over time. And, indeed, also of system sustainability factors, but these can then be undertaken in a focussed and more cost-effective manner if the choices of experimental variables and levels have already been considerably narrowed down.

Evaluating intercropping experiments

It is not the intention of this Manual to elaborate on the background to intercropping experimentation, this is thoroughly dealt with in the selected references mentioned above. However, there is a need to raise issues concerning field layouts, assessment and the evaluation of results when the inclusion of long-term woody perennials make the practical and/or theoretical approach different from that normally found when handling comparably sized seasonal crops.

Some aspects relating to field layouts and assessments are briefly covered in the sections on "Considerations when experimenting with changes in plant spacing", "The tree/crop interface" and "Systematic designs for field experimentation with MPTs". We should, here, explore the questions relating to the evaluation of intercropping experiments involving trees/bushes.

When evaluating mixtures of any two component plant species the results, in terms of mutual inhibition, mutual co-operation or some form of compensation, will be dependent on a number of factors.

- The extent to which individual genotypes influence the basic "aggressivity" of the species concerned.
  - and here we should remember that many MPTs are often outcrossing and the available germplasm is highly heterozygeus.
- The general level of environmental resource availability.
  - stresses imposed by limitations of water, light or nutrients will each result in different responses depending on the component species requirements, their ability to adapt temprarily, and the manner in which this will affect the distribution of dry matter to the plant parts representing

yield. A change in environmental resources may bring about a different outcome either as a result of differing interactive processes, or though the same interactive processes resulting in an outcome of a different magnitude.

- Site-and season-imposed restraints on resources
  - to the extent that these are different from the mean.
- The level of 'density stress' involved (plant population per unit area and the rectangularity), as well as the "intimacy" of the mixture.
  - in an evaluation process the density stress considerations must apply to the species concerned both as sole crops and in a mixture, which itself can be of different species proportions.

Early work on species mixtures and competition/ interference were carried out with replacement series experiments where a stated total plant population was manipulated so as to give varying proportions of each component species. In practice, in intercropping, the populations of both sole crops and the mixture can be varied and the expected and actual yields of any mixture density (for any proportions of crop mix and levels of intimacy) can be compared with any relevant sole crop densities (usually the optimum for that site).

Where species yield differently the combined yield of mixtures is highly dependent on the proportions of species used. Nowadays, when making comparisons between mixtures containing different species mixed in various proportions this evaluation problem can be overcome by comparing the separate yields of the two intercrops and their combined yield, in terms of the relative land areas under sole crops, (at a stated plant density) that are required to produce the yields acheived in intercropping - the "Land Equivalent Ratio" (LER). These are equivalent to "Relative Yields" and the "Relative Yield Total" of earlier workers. The LER is always less than or greater than 1.0 with mutual inhibition, and mutual co-operation, respectively. And it can be either where one species dominates the other but some level of compensation is apparent.

Thus:

$$LER = L_a + L_b = \frac{Y_a}{S_a} + \frac{Y_b}{S_b}$$

Where: L_a and L_b are the LER's for the individual crop species in the mixture.

Y_a and Y_b are the actual yields of the intercrops, and

S_a and S_b are their yields as sole crops.

Because a change in crop proportions in a mixture will itself change the calculated LER's and the Total LER of the mixture, there is not only an "optimum" Total LER at a particular mixture but a set of "Effective LER's" for different crop proportions[1]. Furthermore, an LER involves a comparison with component species sole crop yields (very likely at plant densities that are not only different from that of the mixture but different from one another, also) so that these must all be clearly stated. This tends to make between-site and between-year comparisons of LER's (or "Effective LERs) less fundamental than they might seem because the optimum sole crop density will itself change with the level of available environmental resources. As will the individual and total crop yields in the mixture (and hence the individual and total LER's) as mixture intimacy is changed.

Recently, a "Competitive Ratio" (CR) has been proposed[2] to serve as a more universal measure of comparative "aggressivity" of species used in mixtures grown under different circumstances, where:

$$CR = \frac{\text{Actual yield of (a) when intercropped}}{\text{Expected yield of (a) when intercropped}} \div \frac{\text{Actual yield of (b) when intercropped}}{\text{Expected yield of (b) when intercropped}}$$

$$\text{or} \quad \frac{Yab}{Yaa \times Zab} \div \frac{Yba}{Ybb \times Zba}$$

When: Yab = yield per unit area of (a) intercropped with (b) (at the plant density and intimacy of the mixture)

Yaa = yield per unit area of sole crop "a" presuably at its optimum and $\frac{1}{bb}$ for "b" likewise.

Zab = porportion of intercropped area initially allocated to crop "a".

Zba = proportion of intercropped area initially allocated to crop "b"

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[1] See Mead, R. and Willey, R.W. (1980) for a full discussion.

[2] See Willey, R.W. and Rao, M.R. (1980).

$$\text{In fact} \quad CR = \frac{LER_a}{LER_b} \times \frac{Z_{ba}}{Z_{ab}}$$

and it is simply the ratio of the individual LERs of the two component crops but correcting for the proportions in which the crops were originally source.

Problems with woody perennials in intercrop experiments

When we come to try to express the results of intercropping experiments in which one of the plant components is a tree or bush there are several problems.

- The normal plant populations per unit area of trees and agricultural crops are of a completely different order (see Figure 15 in "Experimenting with changes in plant spacing").
    - It is much more meaningful to consider the "area occupied" in mixtures of trees and agricultural crops because the number added by the tree component to the plant population total of the mixture will in no way be commensurate with its competitive significance.
- The usual problems exist over specifying sole crop yields for the relationships LER or CR so as to make the comparisons most apt in terms of relevant plant densities.
- MPT trees/bushes will provide, by definition, several products (fooder, fuelwood, timber, food, mulch, medical products, honey etc) as well as "Service functions" that can be difficult to evaluate totally (shelter, soil improvement etc). And yet some of these may well be modified when the tree or bush is grown in a mixture. This "yield" (of widely disparate outputs) may not be so readily compared between sole crop and in a mixture if the ratio of outputs is changed.
- Trees and bushes may provide harvests at different time intervals depending on the part being harvested.
    - For example there may be several intermittent within-season harvests (browse), a seasonal harvest (fruit/seeds), harvests at several-year intervals (fuelwood, building poles)

and/or a final harvest after many years (timber). Some form of averaging (or discounting, if monetary values are of interest) will therefore be needed if comparisons are to be made with the yields of seasonal crop in mixtures.

- The very considerable differences in stature between mature trees and bushes and most agricultural crops is, itself, a condition that can markedly affect "aggressivity" in either positive or negative ways depending on circumstances (and bearing in mind the comparitive phenology of the component species).

  - There is, therefore, likely to be very large differences observable between performance/stature of a tree/bush in a sole crop situation as compared with its performance in a mixture with a (say) dominated agricultural crop. Much more so than where plants of a similar stature are being compared. This raises an issue as to whether intercrop plot experiments are really necessary in the preliminary steps or whether some simple examination of the "tree/crop interface", followed by a study of sole crop yields at different plant densities, will not provide sufficient information for formulating design and management features. (This is discussed further in the two sections "The tree/crop Interface" and "Considerations when experimenting with changes in plant spacing").

- Woody perennials occupying the land for several to many years. Although this need not obviate the use of, say, LER or CR as a tool for comparing different plant mixtures involving trees/shrubs, there is a need to bear it in mind if the comparisons are to be meaningful.

  - Even with annual species there is a case to treat comparisons of LERs between long and short-season crops with caution, particularily in situations where differences in the duration of land occupancy does not make the best use of the environmental resources available. Furthermore, if there is a possibility to manipulate the length of the growing season and/or time-of-planting in relation to cultivars then different cultivars might be, in practice, better suited to either the sole crop *or* the mixture

but not both. Where a long-tenure crop (a tree or bush) is concerned the yields may be accumulated over a much more complete part of the accumulated growing seasons than a series of seasonally sown annual crops could achieve.

- Trees/bushes (even fast-growing ones) are in the ground for considerably longer than any herbaceous seasonal or even perennial crops. During their occupancy they progress from the juvenile state (when they may be dominated plants) to maturity (when they will be dominants or co-dominants), and they can be subjected to various forms of training in their early stages, and of plant management during their production stage.

    - Experiments in intercropping must have clearly stated objectives relating to which growth stages are to be studied. Furthermore the development of the trees or bushes themselves will also be dependent upon the plant associations, soil management etc, that are imposed in previous years.

- Many agroforestry systems exist that have more than two plant components.

    - Some of the most productive man-managed plant associations involve woody perennials and contain number of species mixed together. Conventional intercropping experiments will not encompass the range of variables inherent in such systems (see "The Tree/crop interface" section). Bivariate and multivariate methods have been suggested for the evaluation of intercropping experiments (see references in the section on plant spacing), but the added complexity of agroforestry intercropping is likely still to cause problems of data evaluation.

Bearing these comments in mind it seems likely that some relatively elementary facts about the growth complementarity and environmental resource needs of the proposed partners in tree/crop mixtures will be needed *before* one embarks on yields investigations through more elaborate intercropping trials. These ideas are discussed in the sections that follow.

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SECTION FOUR

PART 4B

The problem of chosing appropriate species/provenances

PART 4B

CONTENTS

Adaptive Behaviour and the Selection of MPTs - P.A. Huxley

Effective selection of MPT (FGNFT) species for testing in elimination trials can prevent a waste of effort later but, if the process is to be more than just the outcome of suggestions from informed opinion, (see page 32, Part 2A and Appendix 2 Part 2B) some additional considerations need to be explored. Some of these are discussed below in relation, mainly to adaptive behaviour and also the concept of multiple outputs.

*Fitness and flexibility**

Environmental selection pressures will, through eventual genetic change, result in different degrees of adaptation to a range of ecological niches ("flexibility") or, in other cases, to a more rigid adaptation to a specific set of environmental variables ("fitness"). Genetic flexibility is an attribute of a particular pool of germplasm and individual genotypes may or may not have the capability to flourish outside the immediate environment in which they are discovered to be well-adapted. Genotypes within a particular taxon (species, cultivar) may, individually, exhibit a narrow or a broad adaptive capacity, irrespective of how heterozygous they are. The capacity of a *single* genotype to grow in a range of environment will depend on its ability to modify the phenotype, through plant anatomical, morphological and physiological characters, and in response to changes in particular environmental variables; i.e. the extent to which it has retained some "buffering" responses within any set of broad genetic instructions. Table 1 indicates the combinations found.

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* See also Pickersgill, B (1983) "Aspects of evolution in herbaceous tree crops relevant to agroforestry"

- Part 2A, Appendix 10.

TABLE 1: Degrees of Adaptability

Type of adaptation of germplasm (genepool) to environment	Controlled by mechanisms which are	Adaptation limits
Fit	Genetical and highly specialized.	*Only* grows in one (or a restricted number) of ecological niches for which its form and function is highly specialized.
	Genetical, but some non-specialised traits remaining.	Grows *usually* in a restricted number of niches (where it has evolved), but has maintained some capacity to be moved to others by retaining sufficient "non-specialization" in terms of anatomical, morphological and physiological traits.
Flexible	Genetically diverse	A wide range of genotypes available which enable some to grow in a number of different kinds of habitat (each genotype restricted to one or similar habitats though)
	Genetically diverse *and* many non-specialized traits.	A wide range of genotypes available from different ecological niches but many of these *also* are individually capable of considerable morphological, anatomical and or physiological modification in response to environmental change.

Survival and resource-sharing mechanisms

Many of the attributes for adaptive change, and the capacity a plant has for either limiting or expressing these in response to changes in the environment, will have evolved during evolutionary history both from a need to ensure *survival* as well as an ability to develop *competitively* in plant associations*. The balance between these two objectives has been resolved in an infinite number of ways by plants. Often, depending on their evolutionary history, by achieving some level of compromise in the size, form and physiological behaviour of particular organs. Once an evolutionary modification has established a more specialized trend, in the form of either a survival mechanism or an enhanced ability to compete (or more correctly to develop a "resource-sharing ability", and where these two are acheived by a different plant modification) then the plant's capability of adapting to another set of environmental conditions has been diminished, however infinitesimally.

As an example, and to make this clearer, we might look at one aspect of the evolution of the plant leaf. Various adaptive structures have evolved to reduce water loss from leaves in arid environments: thicker, fleshier leaves; smaller stomata; hairs; *etc.*, and without these (or alternative) mechanisms the plant would be unable to survive the inevitable prolonged drought periods imposed by such a climate.

Such leaves are very different in character from those of many plants which have evolved in moister conditions, where species can grow relatively closely together, and where the major limiting resource to be shared in such a plant community is not water but light. In such circumstances leaves are aggressive organs and shading out another plant is an adaptive strategy to achieve a greater share of available light. Under these conditions leaves have evolved so as to respond rapidly to reductions of light by increasing their specific leaf area (unit leaf area per unit leaf weight). In other words as the plant is shaded leaves still in a formative stage quickly grow bigger in area, but to conserve assimilated carbon they also grow *thinner*. This is seen to a high degree, for example, in many Cucurbitaceae but it is, clearly, a feature which puts them to a disadvantage if water becomes in short supply.

The arid land plants with thick leaves might well grow vigorously if moved to a situation where

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* These two objectives may overlap in some cases, but not in all.

water becomes more plentiful. But the type of leaf structure to which they are by now genetically restricted will not be of much use in a plant association where the other species have leaves which will respond to shading Equally the survival of the latter, if moved to a desert fringe, would depend, at least in part, on the extent to which they had retained the capacity to respond to dry environments by producing thicker, waxier leaves.

General adaptability therefore becomes a matter of being relatively non-specialised. As distinct from specific adaptability which derives from morphological, anatomical and physiological specialization which are the result of evolution towards genetic "fitness".

Potentials for exploitation

In addition, "success" in any particular community (expressed as the ability of a genotype to increase) may depend on a plant's capacity to acquire, through a whole variety of strategies, a greater share of the available environmental resources than co-habiting species which happen to find themselves there. Rather than on more positive adaptations to fit it to the specific environment. The implications of this in terms of selection for particular products or attributes are rather important.

For example, *Coffea arabica*, at its centre of origin (Ethiopia), is found as a successful understorey shrub producing, under relatively shady conditions, only a modest number of fruits per tree; but sufficient to ensure its survival. Removed from its natural habitat, and grown by man *for its seeds*, it has been found, to yield much more prolifically if grown in full sun; as long as it is provided with a high enough level of plant nutrients to enable it to do so on a regular season-to-season basis. The physiological reasons for this are now well understood and supported by the results of several decades of detailed study.

There are, of course, many other examples of a similar nature in which the attributes for ecological success *conceal* a potential for exploitation by man.

Implications for selecting MPT's

If we understand sufficient about the genetic background of ur MPT species, and have at least a basic understanding of its anatomical, morphological

and physiological adaptive behaviour when exposed to environmental change, we will be better able to chose the correct species for a particular ecosite. And to be able to propose appropriate management techniques to optimise the products we require.

In selecting multipurpose tree species for various uses we are likely to find the whole spectrum of available adaptive strategies. Both in terms of genetic pools of varying degrees of flexibility, and as a consequence of an individual genotype's ability for anatomical and physiological "buffering". However, the task of unravelling the evidence for either (or both) is made more difficult because of the multiplicity of "products" (in its widest sense for which we may select any one species, or provenance. There is, therefore, a need to know and understand, however marginally, the growth and development processes involved in the achievement of "adaptation" to the particular habitats where we propose to grow that species. Also the management to be imposed and, in addition, we must clearly define its uses. Is it to be grown primarily for its leaves? for fuelwood? for building materials? for fruits and/or seeds? And so on. To be productive the species or provenances we chose for a particular ecozone must be either generally or specifically adapted to grow vigously in that particular environment *and* also be suited to it in a way that will maximize the product (or service) that we require.

It therefore makes little sense to attempt to rank, say, "the best 20 MPT's for tropical semi-arid regions". Rather we have to consider what are the most promising in this environment, for *each* of the end uses for which MPT's might be required. We need not a list but a two-way table. Then ultimately, from the results of enough field trials of all the potentially useful species throughout the whole range of ecozones in which each might appropriately be grown, a series of rankings will emerge in each one *according to use*. See Table 2.

We have to take this one step further, however, when evaluating potential species(or provenances) for any particular site because, by definition, MPT's are required for *more* than one use, although we might expect that they are not all equally important. If we can assign priorities for a selected set of multiple uses at a site then it should be possible to devise some form

TABLE 2 Two-way table for tabulating order of suitability of MPT species in different ecozones

	PRIMARY OUTPUTS								
ECOZONE	TIMBER	FUELWOOD	FODDER	FRUITS/NUTS/SPICES ETC.	HONEY	SHELTER	WINDBREAKS	SOIL AMELIORATION	SOIL CONSERVATIO[N]
ARID									
SEMI ARID									
SEASONALLY ARID									
MOIST LOW-LAND									
TROPICAL HIGHLAND									
LITTORAL									
OTHERS (SEBKAS LAKE-SIDES ETC.)									

EXAMPLE

of "selection index" to assist in ranking them. In doing this it would be necessary to give different weightings to each of the combination of uses required, according to the end-user's requirements. And to use this to adjust the actual results of field trials comparing different species in order to derive a single index of suitability. Such a procedure will no doubt have to await the time when a sufficient number of field trials have been established.

Conclusions

The present fragmentary state of knowledge about MPT's together with the large numbers of species (let alone provenances) involved, and the need to get trials started quickly, will all militate against any in-depth evaluation of factors underlying the adaptability of particular species. Nevertheless, where some consideration can be given to this, however briefly, it may not only save resources but assist in the more rapid selection of species for particular end-uses in selected ecozones. Certainly, there has to be a more elaborate process of judging the relative value of different MPT species combined in any early period trials than is usually the case for single-product forest tree, or agricultural crop species.

SUGGESTIONS ARISING FROM THE MPT GERMPLASM WORKSHOP * ON THE PROCEDURES FOR SELECTING MPT SPECIES - by P. von Carlowitz

The suggested procedures presented hereunder are based on discussions at the "Multipurpose Tree Germplasm Workshop" held in Washington D.C. during May 30 to June 3, 1983. Participants and donors alike felt that research and development efforts have to be concentrated on a selected number of multipurpose tree species. The fact that the improvement of MPT germplasm, in going through its various necessary stages, will be not only time-consuming but also restrictively fund-absorbing, calls for a process of short-listing the hundreds of known potentially useful species to a manageable number.

In the course of extended discussions on this basic problem doubts were voiced whether *ad hoc* priority lists of MPTs which vary considerably in their ranking of individual species, constitute an acceptable approach. It also appears that certain species or genera receive a high ranking mainly because more is known about them or - for whatever reason - more interest has been focussed on them. Other genera and species which may have a high potential and which may be used extensively by local people, are neglected because they have escaped the attention of scientists.

The objective of the procedures suggested here are, therefore, to propose an initial process for the rapid selection of multipurpose tree species on the basis of their uses. Further refinements and modification will, undoubtedly, be required.

In order to avoid subjective prioritizing and a biased approach, possible ways and criteria by which MPTs can can be short-listed for further development were discussed. These have been somewhat modified and elaborated here in the form of Tables 1 to 3 below. Each of these represents a step in a rapid appraisal methodology by which any candidate species can be screened against some major selection criteria.

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* Multipurpose Tree Germplasm - A Planning Workshop to Discuss International Co-operation, Washington D.C. 31 May to 3 June 1983. ICRAF/IBPGR/CFI/NAS.

Ranking genera/species by use and ecozone (Tables 1 and 2)

Table 1 has been developed from a similar table introduced during the MPT Germplasm Workshop. The various uses shown in Table 1 are based on a list of productive and service uses prepared in the course of the Workshop. By constructing a simple matrix of information about the full extent of uses to which a selection of genera/species can be put, and by assigning a rank to each of these, together with an indication of the extent to which any particular use is "local", "regional" or "widespread", a subjective choice is made easier.

In the attempt to arrive at a method for singling out the most promising species another proposal* has been to combine use and ecological zone in a simple matrix. The format of this has been slightly modified to prepare Table 2.

Operational procedure

Tables 1 and 2 are intended to serve as an easy-to-handle tool for identifying promising MPT species.

Since the uses, by definition, have to be main criteria for a tree to qualify as a MPT, Table 1 emphasizes this aspect. Any species entered into this table will easily reveal its individual range of productive and service uses. However, the potential uses, as such, do not provide evidence of the economic value and the geographic range of their application; thus ranking codes (0 to 5) have been introduced to rate both of these. For example, species having a wide range of different uses which are highly valued, and which are utilized over a wide geographical range, may rank more highly for selection for inclusion in the stages that follow than species restricted only to a narrow range of uses in limited localities.

Species so qualified can then be entered into the matrix contained in Table 2. While Table 1 concentrates on the uses of the tree species, Table 2 gives more emphasis to the ecological range of these species.

If a tree species which has qualified already, by using Table 1, also shows, in the two-dimensional design of Table 2, a wider-ranging ecological adaptability it has definitely to be

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* by Peter Huxley and adopted at the Bellagio Meeting of the Fast-growing Nitrogen fixing Tree Association, September, 1982 (and see previous chapter).

regarded as a promising candidate for selection and study.

Such species should then be screened by using Table 3, which in a similar form was designed by one of the working groups of the "MPT Germplasm Workshop"*. Using the tabular matrix the present state of knowledge about any given species can be set down and, by doing so, prevailing gaps exposed from which conclusions for priority research requirements can be drawn. In this latter exercise the draft table (May 1983) in Appendix 8 of Forest Genetic Resources Priorities which was drawn-up by the FAO Panel of Experts on Forest Gene Resources (5th Session) can be of great help. The FAO Draft Table provides, for a large number of tree species, an operational priority rating with regard to exploration, evaluation, conservation and utilization.

The MPT data base

Whenever attempts are made to short-list species it should be kept in mind that in the course of scientific studies new multipurpose species and new potentials of known species are bound to be discovered. ICRAF's establishment of a computerized Multipurpose Tree Data Base (see Appendix 1) of which the collection, storage and evaluation of data is a central part, may, for example produce results which could prove relevant in short-listing the numerous useful species. Therefore the prioritization of species for further development has to be an re-iterative process as new, useful information is gathered.

The procedures outlined in this paper can easily and repeatedly be applied whenever the need for prioritizing or re-prioritizing arise, and they may serve as a useful preliminary tool for any scientist who has access to the information required to construct Tables 1 to 3. Such selection procedures are essential if limited research resources are to be assigned to the most promising species.

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* Working Group I.

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An Example of Rapid Appraisal Matrix for Use-Oriented Priority Genera/Species Selection for Research and Development (Example of 7 Genera)

Table 1

Genera/ Species	PRODUCTIVE USES										
	Wood/Timber Industrial Use	Local Use	Fuel	Food	Fodder	Exudations (e.g. oil, gums ambar etc)	Thatching	Fibers	Medicinal	Ornamental	Others
Leucaena	(e.g.) 2/L/b	(e.g.) 4/R/~~e~~c	(e.g.). 5/R/~~e~~c	-	(e.g.) 5/R/a	-	-	-	-	-	-
Prosopis		(e.g.) 4/L/b	(e.g.) 5/R/a	(e.g.) 5/L/a	(.e.g.) 4/R/a	-	-	-	-	(e.g.) 2/L/b	-
Eucalyptus	(e.g.) 5/R/a										
Atriplex		-	e.t.c.	-							
African Acacia											
Australian Acacia											
Coconuts							(e.g.) 4/L/b				

For each Genera/Species and Use apply the following Codes:
Value of Use : 0 ⟶ 5
Geographic Range of Use: L = Local; R = Regional; W = Wide-spread
Reputability of Information: a = Scientific research; b = Observation; c = Common knowledge; d = uncertain/unconfirmed information

(Contin.) Table 1

Genera/ Species	Services, Uses, and indirect products										
	Wind - break/ Shelter belts	Other far/ ourable environ- mental use	Soil im- prove- ment	Erosion-/ Dune Control	N-fix- ation	Mul- ching	Weed control	Livehed- gas/fence pasts	Demar- cation	Fire- breaks	Others
Leucaena	(e.g) 1/L/b	-	(e.g.) 5/W/a	?	(e.g.) 5/W/a	(e.g.) 5/W/a	?	-	-	-	-
Prosopis								(e.g.) 2/L/b			
Eucalyptus										(e.g.) 3/L/b	
Atriplex											
African Acacia				-	e.t.c.	-					
Australian Acacia											
Coconuts											

Table 2

RAPID APPRAISAL MATRIX OF PRIORITY GENERA/SPECIES BY USE AND ECOLOGICAL ZONES

Uses / Ecological Zones	PRODUCTIVE USES						
	Timber	Fuel	Food	Fodder	Fibres, Oil, Resin Gum, Amber, etc.	Medicinal	Others
Rain Forest - Lowland							
Rain Forest - Highland							
Savanna - Lowland	(e.g.) Eucalypts						
Savanna - Highland	(e.g.) Eucalypts	(e.g) Eucalypts			(e.g.) Eucalypts		
Semi-Arid	(e.g.) Eucalypts	(e.g) Prosopis, Euc	(e.g.) Prosopis	(e.g) Prosopis, some African+Austral. Acacia			
Arid				(e.g.) Atriplex			
Sub-humid tropical	(e.g) Euc., Prosopis	(e.g.) African Acacia					
Mediterranean	(e.g.) Euc. Prosopis						

(Contin.) Table 2

Uses / Ecolo-gic Zones	Service Uses (and indirect benefits and products)						
	Environmental Use (windbreak, shelter etc)	Soil Improve-ment	Erosion, Dune Control	N-fixing	Live Hedges/ Fence Posts	Weed Control	Others
Rain Forest - Lowland							
Rain Forest - Highland							
Savanna - Lowland							
Savanna - Highland							
Semi-Arid							
Arid							
Sub-humid Tropical							
Mediterra-nean							

Table 3

RAPID APPRAISAL MATRIX TO ASSESS STATE OF KNOWLEDGE AND PRIORITY RESEARCH REQUIREMENTS (Example of 7 Genera).

Criteria-level of knowledge on: (Answer following questions for each genera/species)	Multipurpose Tree Genera / Species						
	Leucaena	Prosopis	Eucalypts	Atriplex	African Acacia	Australian Acacia	Coconut[s]
Eco-geographic/Environmental Assessment?	some	some	extensive	some	for some spp. yes	starting	Conside[r]able
Historical Uses?	yes	archaic	-	little	some	No	advanced historic[al]
Practised Use: - Productice Use?	yes	yes	yes	yes	yes	yes	yes
Service Use? (indirect benefits and goods)	yes	yes	yes	yes	yes	yes	yes
Known Res. and Dev. on Farmer Acceptability? (even if narrow genetic base)	yes	limited	high (internationally low (farmer)	starting	yes (by land users)	only recently	high
Taxonomy?	yes	starting	yes	little	yes	yes	little
Genetic Variability?	yes	starting	yes	little	No	starting	little
Exploration?	yes	starting	high	minor	yes, with some back-up	Relatively new	very little
Conservation of Primary Gene pool?							
Active Work on Germplasm Enhancement	yes	starting	yes	starting	No	minor	starting
Work and Results Published	yes	some	considerable	some	very few spp	starting	yes
Expansion to New Environment?	yes	N/A	very advanced	modest	No	No	-
Are Germplasm Resources Endangered?	No	No	No	No	some spp possibly	No	No
Principal Financial Background ?	some colonial; limited university	Minor government	Colonial; prir. Ind major government	Large Government/donor	minor colonial people	minor government	people; colonial private; minor government.

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ANNEX

PART 4B

Appendix 1: Multipurpose tree data sheet
- P. von Carlowitz

ICRAF
INTERNATIONAL COUNCIL FOR RESEARCH IN AGROFORESTRY
CONSEIL INTERNATIONAL POUR LA RECHERCHE EN AGROFORESTERIE
CONSEJO INTERNACIONAL PARA INVESTIGACION EN AGROSILVICULTURA
P O Box 30677, Nairobi, Kenya Tel 29867/332304 Telex 22048 Cable ICRAF

Dear Colleague,

In Agroforestry and in relevant land use systems trees and shrubs play an increasingly important and varying role, both with regard to their multiple use and also their ability to provide ecological stability. To ensure that trees and shrubs make an optimum impact it is necessary to know not only about the magnitude of their potential uses but also their biophysical requirements. Failure to consider these inter-related factors may well jeopardize both the reputation of a vital component of Agroforestry systems, as well as the systems themselves and ultimately Agroforestry as such.

We realize that many institutions, organisations and individuals have already done invaluable work in collecting and evaluating relevant information on Multipurpose Trees and Shrubs. However, this has often been directed to selected species only and/or has been concentrated on specific uses. In addition the collection of information has sometimes been limited to certain regions.

In order to collect and to systematically store existing information around the developing world, ICRAF is in the process of establishing a computer-based data bank on Multipurpose Trees/Shrubs. This will enable us to respond in the future to the many requests we receive on where, how and what to plant to meet certain demands (food, fodder at seasonal gaps, fuel, etc.) with a maximum likelihood of success.

Further objectives of the exercise are:

1. To assess the bio-physical range (minimum-maximum-optimum) of Multipurpose Trees/Shrubs.

2. To establish possible variations of tree/shrub characteristics within the bio-physical range covered by individual tree/shrub species.

3. To arrive at a thorough assessment of uses (beyond known commercial uses).

Your co-operation in this exercise would be greatly appreciated. Could you please fill in the attached "Multipurpose Tree Data Sheets" for as many of those species as are growing (naturally or introduced) in your area and which are of importance to the people of this area.

...../2

We have tried to limit the number of questions to the minimum required to meet the fore-mentioned objectives. Nevertheless, we are aware that it might often be impossible to answer all of them. In any case, please do not hesitate to fill in the Data Sheet with whatever information is available to you. We **appreciate all relevant data.**

We are also attaching an example of a completed data sheet to facilitate your job and, hopefully, minimize your effort.

May we ask you to kindly return the completed "Multipurpose Tree Data Sheets" before May, 1984.

Thanking you in advance for your kind co-operation.

Yours sincerely,

(Peter G. von Carlowitz)

Encls.

MULTIPURPOSE TREE DATA SHEET

ICRAF
INTERNATIONAL COUNCIL FOR RESEARCH IN AGROFORESTRY
CONSEIL INTERNATIONAL POUR LA RECHERCHE EN AGROFORESTERIE
CONSEJO INTERNACIONAL PARA INVESTIGACION EN AGROSILVICULTURA
P O Box 30677, Nairobi Kenya Tel 29867/332304 Telex 22048 Cable ICRAF

EXPLANATORY NOTES FOR ANSWERING THE MULTIPURPOSE TREE DATA SHEET

1. In answering the Data Sheet **please be site-specific!**

2. Please fill in Data Sheets only for **those species with which you are familiar and which are of importance in the area you are concerned with.** This will hopefully make it easier and less time-consuming for you and provide us with the necessary site-specific information.

3. If the described species has been grown from seeds collected locally then the question "Source of Seeds, if known" (first box on front page) should be answered as for example, "local, from vicinity of growing site". If the described species is from natural regrowth please state this. In other cases the country and location of seed origin should be stated according to documents received with the seeds.

4. The "Info-Reliability" is regarded as important by us. For each answer to the questions you are requested to use one or more capital letters (A-F) according to the code given on top of page 2.

5. Except for questions 1-9 and 21-27 for which specific data or information are required, only tick in the boxes [ ] wherever appropriate.

6. Questions 23-25: In case there are two "Growth Phases"/"Flowering-"/"Fruit Ripening"-periods per annum please enter these separately in the two boxes indicating the months (e.g. for "Growth Phases": 4(Apr.) - 6(June) in the first box and 11(Nov.) - 12(Dec.) in the second box; for "Flowering"/"Fruit Ripening" e.g. 9(Sept.) in the first box and 2(Feb.) in the second box. If there are more than two phases/periods per annum please enter details under "Comments" (26).

7. In questions 62-73 and 80-85 (Food, Fodder, Other Products) "Months of Harvest" are marked with "(1-12)", meaning January to December. Please note in the appropriate box the number of the correct month(s).

8. For questions 62-95 (Uses) a ranking of importance is requested only for the uses in the area you are concerned with, and/or for the site(s) where the described species grow. Only the first three most important uses may be ranked, 1 being the most important of all indicated uses.

9. **If, for whatever reasons data and information requested under questions 1-61 are not available to you, please enter "n.d." in the appropriate box or space behind the respective question(s), unless questions are competitive (e.g. "evergreen" (34) versus "deciduous" (35/36) or "monoecious" (41) versus "dioecious" (42)) in which case a tick for the one question makes entry of "n.d." for the alternative question irrelevant.**

10. The box on page 4 ("Relevant Publications") should be filled in when you have access to lesser known but relevant publications or unpublished research results.

Species: Family:

Synonyms:

Vernacular Name (state language)

Location (nearest Town, Prov., Country):

Growing Site: Long: .... Lat.: Alt./m.: ....

Source of Seeds, if known (state location, country):

von Carlowitz
ICRAF, Oct. 1983

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Code for Info-Reliability:

A = Scientific Research/Measured — B = Case Study — C = Observation
D = Common Knowledge — E = Best Guess — F = Unknown/Unconfirmed

Bio-physical Data ✓ — Info-Reliability (see code)

1 Mean annual Rainf. (mm) ....
2 nearest Met. Stat. at ....
3 at altitude of .... m,
4 .... km from site
5 Mean max. Temp. °C ....
6 Mean min. Temp. °C ....
7 Absol. min. Temp. °C ....
8 Approx.av. depth of dry season ground water table in m ....

Monthly Rainfall (mm)

9

Jan.	Feb.	Mar.	Apr.	May	Jun.

Jul.	Aug.	Sept.	Oct.	Nov.	Dec.

Soil Texture

10 Heavy (clay)
11 Medium (loam)
12 Light (sandy)

Soil Reaction

13 Acid (p.H. < 6,5)
14 Neutral (p.H. 6,5-7,5)
15 Alkaline (p.H. > 7,5)

Drainage

16 Well drained
17 Seasonal water logging
18 Permanent water logging

Other Soil Characteristics

19 Shallowness (< 50cm)
20 Salinity
21 Soil Type: ....
22 On which Soil Classification:
....

Phenological Behaviour

State months(s) (1-12) of:

23 Growth Phases
24 Flowering
25 Fruit Ripening
26 Comments: ....
....

Morphological Characteristics ✓ — Info-Reliability (see code)

27 Average height of Tree/Shrubs at maturity, being — meters
28 Generally single-stemmed
29 Generally multi-stemmed (as at ground level)
Special Characteristics (describe): ....
30 ....

Canopy

31 Dense
32 Medium
33 Open
34 Evergreen
35 Deciduous, dry season
36 Deciduous, wet season

Root System (cm)

37 Shallow Rooting 10-50
38 Medium Rooting 50-100
39 Deep Rooting > 100
40 Others (state) ....
41 Monoecious
42 Dioecious

Applied Reproduction

43 Direct Sowing
44 Seedlings
45 Coppicing
46 Cuttings
47 Others (state) ....
48 Seed Pre-Treatment
49 Inoculation

Applied Tree Management

50 Coppicing
51 Pollarding
52 Lopping
53 Grafting
54 Budding
55 Others (state) ....

Other Characteristics

56 Shade tolerant
57 Termite resistant
58 Fire resistant
59 Succulent
60 Others (state) ....
61 Problems (e.g. developing into weed)
-state ....

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	USES		Unit, (kg, gr, etc.)	Ann. Yield per tree	Month(s) of harvest (1-12)	Rank importance of use (1-3 1 = most imp.)	Info-Reliability (see code)	Remarks
	Food	✓						
2	Fruits							
3	Nuts							
4	Vegetable							
5	Oils/Fats							
6	Starch							
7	Spices							
8	Others (state)........................							
	Fodder							
69	Leaves							
70	Pods/Seeds							
71	Shoots							
72	Bee-forage							
73	Others (state)........................							
	Wood							
4	Fuel wood							
5	Charcoal							
6	Poles							
7	Timber							
8	Carvings							
9	Others (state)........................							
	Other Products							
	Waxes							
	Essential Oils							
	Tannin/Dyes							
	Gums							
	Fibres							
	Medicinal (state)........................							
	Ornamental							
	Others (state)........................							
	Service Uses							
	Windbreaks							
	Soil conservation							
	Dune Fixation							
	Live Fencing							
	N-Fixing							
	Mulching							
	Hedgerow							
	Others (state)........................							

Relevant Publications:

(Use separate sheet if necessary)

Informant:

Name: ....

Profession: ....

Address: ....

Date: ....

Please return filled-in Data Sheet to:

Peter G. von Carlowitz
International Council for
Research in Agroforestry (ICRAF)
P.O. Box 30677
NAIROBI/Kenya

Thank you for your valuable co-operation

Agro-forestry Extension and Research applied to intensification of Subsistence Agriculture in Papua New Guinea.

John F. Swift

Wau Ecology Institute

P. O. Box 77

Wau, Papua New Guinea

Summary: This background paper reviews the unique characteristics of the Papua New Guinea environment and culture as influencing agricultural development and change. Specific reference is made to Wau, the main research site, at 1200m with 1887 mm of rainfall. Casuarina oligodon, Termanalia Kaerenbachii and Parasponia rugosa are described as traditional agro-forestry species. A summary of the research garden established in 1976 at Wau Ecology Institute is followed by a description of extension approaches for promoting forest fallows, methods to improve gardening techniques and agro-forestry benefits for stressed areas. Eight species of n nitrifying trees are compared by growth rate and insect attack. Leucaena leucocephala at 38cm/month was selected as the best multipurpose species. Extension problems are described relating to establishment and management of trees and the lack of integration of Agriculture and Forestry departments. An intercropping trial with Leucaena and sweet potato, on a 35 degree grassland slope, to quantify the relative spacing and benefits of such an integrated land use system is outlined. A conclusion, recommendations and several annexes are presented.

Presented at:

Environmentally Sustainable Agro-forestry and Fuelwood Production Workshop. East-west Center - Honolulu, November 12 to 20, 1981.

Introduction:

Papua New Guinea contains a wide range of environmental zones, each of an extremly diverse and complex nature. There exist undisturbed rainforests, areas of large anthropogenic grasslands, lowland swamps, to highland valleys where population densities may exceed 100 persons per km^2. The lowland climate has intense rainfall, high humidity and temperatures which can leach or erode a soil rapidly and breakdown the organic matter. In contrast, the highland climate seems very forgiving of rapid yield declines especially in areas with deep volcanic ash soils where some gardens have been continuously cultivated for over 50 years. Agronomic generalizations are of miner value in PNG. New crop varieties require testing before recommendations are made concerning their suitability to a particular environmental zone.

In PNG, 97% of all the land remains classified under "customary ownership" titles. (Yauieb 1979) Land disputes, most common in heavily populated highland villages, occur with regularity through out the country. The current land system inhibits certain groups, especially squatters, from planting permanent crops, since tree planting is viewed as claiming ownership of the land. Larger, more economical plantings of forestry trees for reforestation purposes are difficult to organize due to complex ownership patterns.

There are few severely "stressed" areas in PNG. However with a population growth rate of over 3%, problems of forest and land deterioration, and so declines in food crop production become more immediate. Subsistence farming systems and traditional crops are receiving increased attention in PNG. The subsistence farmer comprises 70-80% if the total population.

Traditional farming groups adapt to environmental change and increased population through the process of land use intensification. (Brookfield 1971) As soil fertility declines, the predominant staple crop usually becomes sweet potato, instead of taro or yams, due to its higher yielding potential. To insure an adequate yield on the less fertile soils, additional labor inputs are required for soil preparation and crop protection. Agro-forestry systems are one way to intensify traditional subsistence agriculture. As change has become more diverse and rapid in PNG, traditional cultural structures capable of reacting to these changes appears diminished. (Bayliss-Smith 1977) Therefore, a demand exists for innovation of viable techniques which the traditional farmer can integrate into his current farming methods to improve his production and prevent deterioration of his land resources.

There are many traditional agro-forestry practices currently used in PNG. The planting of Casuarina oligodon (a non-leguminous nitrifying tree) in highland gardens to improve soil fertility during the fallow period and insure a wood supply for future pig fences is one example. In Gulf province, Terminalia kaernbachii produces a large edible nut and is planted in new garden sites to insure a high survival rate. There are other examples of planted Pandanus spp. orchards, of intercropping staple crops underneath valuable Araucaria species and planting native secondary regrowth trees on grassland sites to insure sustained production on limited land. Modern agro-forestry practices and ideas are starting to circulate while research work is now begining in PNG. (Howcroft 1980) For an agro-forestry system to be successful in PNG, traditional farming practices need be understood, quantified and compared to the

new system so desirable and clear improvement can be demontrated. Only then can new techniques be properly integrated.

The work outlined in this paper represents the relatively dry mid-montane zone (800-1400 meters) of Papua New Guinea. The mean rainfall from nine years data at 1200m in Wau is 1887mm per annum (Gressit/Nadkarni 1978). No precise rainfall intensity measurments are recorded but a heavy storm may only rain 25cm/ hour; a gentle rate compared to the lowlands. The soils are shallow with low fertility, especially on the steeper hillsides. The basic physical texture is a sandy/clay of low plasticity. The region represents a mountainous topography of broad river valleys previously covered by forests.

In 1976, a project began at the Wau Ecology Institute to improve subsistence agriculture by developing an alternative farming system. This work is reviewed while recent extension and research results are presented followed by a description of current on-going research and concluding recommendations.

Agro-forestry Research Garden in Wau:

A composted-contoured ridge garden was established on a grassland site at the Wau Ecology Institute in 1976. (Gagne 1978) The main purpose was to devise a site-stable alternative to the traditional shifting cultivation practices found in the Wau Valley. These farming practices were labeled as the main cause for spreading *Imperata cylindrica* grassland and destruction of the rainforest. From an ecological viewpoint, the traditional farmers were degrading the forest resources and therefore needed to intensify their farming practices to relieve pressure from forest land. A permanent agro-forestry garden, where secondary regrowth trees were permitted to grow as a future firewood supply, where fruit and nut trees were intercropped with a

dense multicrop planting of food crops and where coffee pulp, normally dumped into rivers, would be applied as a soil improving compost; seemed to be an answer to removing the gardening stress from rainforest areas.

The three main reasons causing farmers to shift their gardens are either 1. A decline in soil fertility such that planting an additional crop is not worth the effort. 2. A build-up of pests in the garden which cause excessive damage to food crops. 3. A profusion of competitive weeds which are not worth the extra labor to control.

The specific results from the one 0.2 hectare research garden are presented in several papers. (Gagne 1977, Swift 1981) In brief summary, insect pests tended to reach a balance in the garden as most traditional food crops grew without excessive pest damage. Soil fertility was improved through composting and so able to maintain yields, at a slightly declining, but acceptable level of production. The high labor input demanded by this intensive system maintained adequate weed control. A few specific problems were: 1. The build-up of taro beetle (*Papuana sp.*), which severely damages the Taro corns. 2. The spread of a fungus (*Colletotrichum gloeosporiodes*) causing diebacks on cassava. Avocado (*Persea americana*), a host for the fungus may have initiated the fungus to spread. 3. Serious tree root competition as the secondary regrowth trees have surface feeding roots. The shortage of a balanced quality compost throughout the year.

Traditional Farming Systems Constraints to Acceptance

Preliminary extension attempts to introduce the intensive site-stable techniques to the traditional shifting cultivators emphasized the gaps in our understanding of their system and the

agronomic limitations of our approach. The farmers were eager to establish small intensive gardens near their village houses and learn the associated techniques yet, the methods had no impact on their traditional gardening practices which remained viable due to reasonable yields, lower labor inputs, land tinure commitments and greater social acceptance. The research garden "alternative" to shifting cultivation was not a viable solution as defined by the realistic perspective of the farmers. An intensive system is only useful if it fullfills the demands of the farmers at their current stage of intensification. Composting requires a high labor commitment and becomes a useful agronomic technique only when yields are very low or land very limited so the farmer is motivated to adopt this technique.

On redefining the problem of how to intensify traditional farming methods, three approaches were devised.

a) <u>Promoting Forest Fallows:</u> In areas where land remains relatively abundant, a forest fallow of five years or more is possible. Encourging the forest to regenerate, thereby improving soil fertility, is the best method to sustain garden productivity. In PNG, one secondary regrowth tree (<u>Parasponia rugosa</u>) fixes prodigious amounts of nitrogen (Trinick 1979) and has a light canopy permitting growth of food crops underneath. Retaining these trees un-cut in a garden site would promote rapid regeneration of a highly desirable species and introduce the basic concepts of agro-forestry to the farmers In one area of Enga Province, the technique of pruning and retaining the <u>Parasponia</u> tree in the garden is currently practiced. (Bourke, unpublished). As the seeds of this species have a dormancy period before germination, the farmers have naturally devised a system to encourage this soil improving species to regenerate.

In other areas (Clarke 1971) Albizia falcataria is recognized by the farmers for enriching tho soil and is a dominate species in fallow sites. Improving site selection to protect new gardens from being burned by regular grassland fires would allow tree species to regenerate. The following practices all promote rapid forest regeneration (Grandstaff 1978): Selective weeding, crop diversity, controlled burning, a short garden life, tree cutting techniques which encourage coppicing or the introduction of other productive tree species, for firewood, or building materials, is a possibility.

b) Training and Extension of Improved Gardening Techniques: The process of extending even simple agricultural techniques may take years before they are actually practiced and integrated by the farmer. The key people within a country who can influence change especially teachers, agriculture, health workers, and forestry, must be made aware of and assist in identifying problems and solutions. They can then cooperate in the long process of implementation. PNG is beginning to initiate this type of inter-departmental cooperation and training directed to subsistence agriculture. Establishing the foundations for a dynamic extension base with a training network is a prerequisite to any major improvement of traditional agricultural practices. An agro-forestry training workshop for field extension workers is one direct method to transfer ideas.

c) Agro-forestry for stressed areas: Large areas of grassland have been created in PNG. Some grassland sites have existed for hundreds of years maintained by periodic burning. The Wau Valley is a center for goldmining and has attracted settlers from all over the country. These people, considered squatters, have been gardening on the nearby mountains in progressively

increasing numbers for the past 15-20 years. Many of these mountain slopes are now deforested with grass fallows rarely exceeding three years. The main problems are loss of soil fertility thru erosion plus a greater time investment in collecting firewood from the receeding forest. In these areas compost is in short supply as the grass is normally burnt. The best method to improve soil fertility and reduce erosion would be with the close planting of nitrifying trees along the contour with food crops interplanted between each tree row. But which species of tree? At what spacing? And with which food crops?

Fast Growing Leguminous Tree Species:

For the highlands region of PNG above 1400 meters, the Casuarina oligodon is the most suitable multi-purpose tree if for no other eason than the farmer is familiar with its use, propagation, and benefits. Its adaptation to the environment, moderately fast growth rate, useful wood qualities and nitrogen-fixing potential are a few additional reasons. The farmers have developed a silviculture system for selecting and improving the Casuarina (Howcroft, unpublished). The best individual trees in a garden site are left standing and ring barked to promote panic flowering. The seeds then scatter over the site as food crops are planted. By the time the garden is abandoned a dense regrowth of young seedlings has been established. Wau represents the upper end of the mid-montane zone but the Casuarina is not as prolific in this region. The Albizia falcataria, native to PNG, is found growing along old landslips in the rainforest near Wau. One trial plot of Leucaena leucocephala (K8) as coffee shade has been planted. Hence these three species were selected along with Sesbania

grandiflora, Acacia auriculiformis (also native to PNG), Calliandra spp., Leucaena diversifolia and Alder japonica. I had hoped to include Parasponia rugosa but the seed has a dormancy period before germinating and could not be propagated in a controlled manner. Each of these tree species were planted out at a 1.5 meter spacing between tree and 2 meters within row for a $28m^2$ plot. A properly replicated trial was not possible due to space limitation. Here was also an establishment variation so the results are only useful as an indicator of which trees should be tested in more detail (see Appendix 2).

The results show both species of Leucanena to be the fastest growing tree's for the Wau area. In four separate farmer evaluation trial plantings in areas varying from steep, low fertile slopes to flat ground, Leucanena outperformed other tree species. An exception was one extremely productive Albizia C.F. falcataria which, as an individual, had the fastest growth rate and largest diameter of all trees planted (6.2m and 83mm at one year). Leucaena leucocephala growth rates fluctuated from 38cm/month for the comparative trial to 22cm/mo. on a steep hillside sweet potato garden to a low of 18cm/mo. on poor rocky soil. The average growth rates at a lower altitude in Bulolo at 700 meters were 40-50cm/month. (see appendix 3) These growth rates reveal the variability of Leucaena production with different environments implying the need for proper local assessment before promoting the species. Leucaena should be recognized as having limitations on growth rate, sensitivity to soil ph and suceptibility to fire. Albizia falcataria has one serious pest, a small yellow butterfly (Eurena hecabe) which lays eggs only on Albizia

falcataria. The larvae emerge and either defoliate the entire tree or often a particular branch; causing it to break. The tree does not die but the growth rate is reduced especially if young seedlings are attacked. Albizia is also suceptible to galls of the rust genus Uromycladium. Initially Sesbania performed poorly because the proper Rhizobium for nodule formation was not in the soil (Hardy 1977). Once innoculated, the tree looked healthy but several types of fungus attacked this soft wooded species forming brown splotches on the branches causing them to break off. The base of the tree became unnaturally enlarged causing the dried bark to split. The tree showed an obvious lack of vigour as reflected by its growth rate. The taro beetle larvae (Papuana spp.) killed many newly planted seedlings by chewing the young roots. Several plant chewing and sucking insects caused minor damage to some of the tree foliage. Leucaena leucocephala seeds are damaged by a boring insect and fungus unless collected early. The K67 variety directs much energy for prolific seed production which seems to slow the growth rate and vigour of the tree. Chemical analysis of sweet potato vines were compared between control and Leucanena plots. The Leucaena had a higher percentage of the five major macro-nutrients; particularly nitrogen (Appendix 2). If protein content of tuber's reflect the same trend, then intercropped sweet potato may produce a more nutritious tuber. Further detailed analysis will show if this holds true.

Problems of Extending Agro-forestry Ideas:

Most subsistence farming groups do not plant non-food

trees in their gardens. The whole gardening system, though revolving around the use and exploitation of various tree species, focuses mainly on cutting and burning trees at the garden site. The farmers understand rainforest trees have surface feeding roots which compete with the food crops. Many villagers consider planting trees an active claim of land ownership which causes disputes between clan members or non-traditional land owners. Farmers are familiar with Leucaena calling it Landro or mar-mar but perceive its use only as coffee shade not something to be planted with their traditional food crops. Certain farmers express interest in trying multi-purpose trees to judge for themselves the use and benefit of the trees.

Initial extension efforts revealed problems with the establishment and management of the trees. One farmer wanted to grow a fuelwood orchard near his house. He planted the trees but neglected weeding so the quick growing Imperata smothered most of the trees. Gardens are maintained for only two or three crops so the trees become a planted fallow rather than a beneficial intercrop. With a high risk of being burned during future garden preparation, the energy expended for planting is not justified.

The preliminary extension approach established farmer evaluation tree plantings whereby potentially useful species were distributed, planted and observed by the farmer. The more productive species were identified and a seed supply became available to the farmer for further planting. One farmer collected giant Leucaena seeds and raised his own seedlings in a small bed protected against chickens by a tightly woven bamboo fence. These plantings identified

specific extension problems. For example, what are the best methods of establishing the trees; by direct seeding, with young seedlings or applying a starter fertilizer? Is the proper Rhizobium present in the soil? Which food crops grow best with the trees? These and other basic questions need to be resolved before the general extension agent can promote agro-forestry.

In PNG, agriculture and forestry remain separate diciplines with minor overlap or cooperation (Tisseverasinghe 1980). To structure a productive extension approach will require understanding, integration and motivation for new agro-forestry methods to be linked to traditional farming techniques. This process is just beginning to emerge as more discussion and work is focused on agro-forestry.

The extension priorities of the Department of Primary Industries concentrates on cash crop production but recently more effort is being directed to traditional food crops. Forestry extension promotes the planting of Pinus spp. to rehabilitate unproductive grassland areas thereby improving the site for future plantings of more desirable forest species. In the meantime, Pinus spp. provide a supplementary source of fuelwood. These extension efforts are neither integrated in their approach nor impacting upon the subsistence gardening system. They do not focus on declining garden productivity, loss of topsoil, forest destruction or associated problems which should be addressed and which an agro-forestry land use approach can help answer. Systems which directly integrate trees with agricultural crops need to be designed and tested. Meanwhile, seedlings can be distributed and potentially

desirable tree species identified and propagated. In PNG, the tree Terminalia kaernbachii and impediens produce an excellent nut with high agro-forestry potential. Other species like Finschia chloroxantha, Gnetum gnemon, and Pangium edule have the same potential but little or no work is carried out on these species. The most productive extension focus are school, health center and other communal garden areas where new ideas can be tested, observed and learned by many. For the time being, the agro-forestry extension effort will be on education, field trials and group demonstrations. The state of the art of research makes a large scale extension effort inadvisable for the time being.

Research Focus: An Intercropping Experiment

Research trials become a useful extension tool if carried out in a village setting using the assistence of local farmers. Since agro-foresty experiments inevitably run for a minimum of several years, effort can be saved by involving the farmer during the experimental process. Agro-forestry experiments are difficult to design due to the diversity of mixing woody perenials with herbaceous crop components. Traditional multi-factorial designs demand a prohibitively large trial area. Experimental designs, though, can provide much information with a minimun of space.(Huxley 1979).

The grassland areas around Morobe Province are degraded land sites. The topsoil on these steep, frequently gardened areas is thin and yields of sweet potato declining. The supply of firewood is currently a secondary problem but will become more crucial in the near future. Agro-forestry may be the most

productive land use system for these areas as yields should improve per unit of land compared to sole cropping.

An experimental trial is being established in Wau to quantify the interactions when intercropping <u>Leucaena leucocephala</u>(K8)* with Merikam, a high yielding variety of sweet potato. The spacing between tree rows is one meter with a 70cm by 1m spacing of sweet potato plants; a density equivalent to traditional planting patterns. Finding an optimun tree spacing for maximizing the yield of sweet potato is the major objective. Two pruning and harvesting methods of coppicing and hedge-laying will be compared for their soil retention benefits. The first method, coppicing, cut's down the tree after one year at a 20cm height; removes the wood and permits new sprouts to grow. The second technique is based on the English technique ot hedge-laying which cuts the base of the tree trunk in half laying it horizontal and weaving it between the adjacent tree to creat a thick fence or hedge to protect against erosion. The experiment will run for two and a half years covering five sweet potato harvests(see appendix 4). A similar experiment in the lowlands on a gentle slope will be established near the city of Lae. The main crop for this spacing trial will be <u>Leucaena leucocephala</u> as a fuelwood source for the urban population. Sweet potato will be the interplanted food crop.

If the benefits of intercropping are proved and the right density and best variety and species of <u>Leucaena</u> determined, then specific extension recommendations can be made to promote a more broad based extension effort.

*K-8 was choosen by availability of seed and before the results of appendix 3 were known.

Conclusion:

Papua New Guinea has a wide diversity of environments and cultural patterns. Few areas of the country face serious firewood shortage but most Provinces experience an overall deterioation of land resources caused by the pressures of population growth. The historical pattern of the traditional subsistence cultivators is one of intensifying their farming technology in responce to increased land use pressures. The farmers in Enga Province currently practice sophisticated techniques which promote rapid regeneration of two native, non-leguminous but nitrifying species Casuarina oligodon and Parasponia rugosa. Modern agro-forestry investigations of alternative land use systems which can increase production per unit of land, possibly on a sustainable basis, are being initiated on a small scale. Two formal research trials are being established at sea level and 1200m to compare the effects on yield between different spacings of Leucaena leucocephala and sweet potato. The Agriculture and Forestry disciplines remain seperated in their approach but limited cooperation is begining. Proliminary extension work is continuing, largely with farmer evaluation plantings of potentially useful tree species.

Agro-forestry remains a new concept poorly grasped by most people except some farmers who unconsciously practice the main principals of the technology. With further exposure, discussion and experimentation, agro-forestry should become a more instutionalized dicipline. For the moment it remains both an old and new idea seeking integration with the farming systems evolving in Papua New Guinea.

Recommendations:

1. To increase integration and cooperation of Agriculture and Forestry in the country; especially at the Provincial extension level.

2. Promote training workshops for extension staff into basic concepts and principals of agro-forestry.

3. Introduce an agro-forestry curriculum into Agriculture and Forestry colleges.

4. Distribute seed to rural stations for establishment of trial plots to identify the best species over a range of environments.

5. Identify knowledge gaps and priorities for coordinated research.

6. Compile existing information on secondary regrowth species by botany, regrowth patterns and potential uses.

7. Encourage further research on desirable and potentially useful tree species.

8. Investigate butterfly farming as integrated with agro-forestry systems to provide a cash income.

9. For UPNG to research nitrogen-fixation and mychorrizal relationships in the soil, tree and crop environment.

10. To establish an agro-forestry resource center to compile information from within and outside the country and distribute useful extension materials.

11. Conduct socio-economic surveys in areas with high agro-forestry potential to identify labour constraints, firewood supply and the overall costs and benefits of establishment.

12. Design more diversified Forestry plantations and cash crop gardens which integrate food crops.

Acknowledgements:

To the East-West Center for providing travel funds. To Wau Ecology Institute and the International Voluntary Services for institutional and financial support. To Barry Holmes and Allen Allison for useful editorial comments and thanks to Neville Howcroft for helpful advice and providing seeds.

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Appendix I: A List of Tree Species grown in the Wau Ecology Institute Research Garden.
As of September 1980, the tree Canopy cover was measured at 42 percent of the garden area.

Fruit Trees: Number of:

Annona muricata Soursop - 15

Annona reticulata Bullocks Heart - 14

Annona squamosa Custard apple - 9

Artocarpus altilis Breadfruit - 1

Carica papaya Pawpaw - 10

Citrus spp. - 11

Eugenia malaccensis LauLau - 2

Persea americana Avocado - 18

Psidium guajava Guava - 4

Nut Trees:

Anacardium occidentale Cashew - 3

Cannarium indicum Galip - 2

Macadamia ternifolia - 1

Terminalia kaernbachii Okari - 3

Nitrifying Trees:

Albizia falcataria - 3

Casuarina sp. - 2

Leucaena leucocephela - 13

Parasponia rugosa - 2

Sesbania grandiflora - 6

Secondary Regrowth/Firewood Species:

Actinodaphne sp. - 1

Alstonia sp. - 1

Altoffia sp. - 2

Araucaria cunninghamii - 1

Araucaria husteinii - 2

Ardisia sp. - 1

Castanopsis spp. - 6

Dacrydium sp. - 1

Dondonaea sp. - 1

Dysoxylum spp. - 1

Eucalyptus torrelinana - 1

E. toreticanis - 1

Eugenia sp. - 1

Ficus spp. - 13

Litsea spp. - 3

Parasponia ridgia - 14

Piper sp. - 2

Pipturus spp. - 11

Psychotria sp. - 1

Trema orientalis - 2

Appendix 2: Results of multi-purpose, nitrifying tree trial intercopped with sweet potato.

Alder japonica: seed obtained from the Philippines but due to poor germination only five trees servived. There may be a rhizobium problem as the trees are growing very slowly but appear healthy. Large maple leaf type with serrated edges - size 7.0cm by 4.5cm.

Calliandra spp.: due to profuse low branching structure and poor woody growth, no growth rate measurements could be obtained. The sweet potato vines climbed the thin trunk making this species undersiable.

Trees ranked according to growth rate, uniformity and vigour:

Species	Growth Rate	BHD	Uniformity	Pinnule Size*	Insect Pests
1. Leucaena leucocephala (K67)	38cm/month	32mm	excellent 90 percent	1.5cm-Length 0.3cm-Width	Pod borer, seasonal moth larvae.
2. Leucaena diversifolia (K145)	33cm/month	26mm	good 75 percent	very small	none
3. Albizia falcataria (Indonesia)	20cm/month	20mm	medium 55 percent	1.1 by 0.4	Eurenshecabe
4. Casuarina oligodon	12cm/month	11mm	med./poor 40 percent	needle shape	----
5. Sesbania grandiflora1 (B1245)	15cm/month	15mm	poor Rhizobium problems	3.8 by 1.4	Elastrspidae brachyplatys
6. Acacia auriculiformis	12cm/month	8mm	very poor possibly a mycorrhizal problem	----	----

*In terms of the shade factor, the smaller the leaf the better since a scattered "netting" of shade is best for maximum plant growth. The diversifolia has very tiny pinnules.

For the first sweet potato harvest, two control plots yielded 19.7 kg while two Leucaena plots averaged 25.0 kg. The second crops under the Leucaena, none under 4 m. tall, is not as vigorous, indicating a 1.5m by 2.0m spacing may be too dense.

Soil Sample:

Bulk Density	ph	Phosphorus ug/ml	Extractable Cations me/100mg K	Ca	Mg	Sodium	CEC	Percent Saturation K	Ca	Mg	So
1.05	6.0	32	.31	13	1.56	.09	18	3.5	72	8.7	0.5

Plant Analysis Data:

	Percent on dry basis N	P	K	Ca	Mg	Al	p.p.m. on dry basis Mn	Fe	Zn	Cu	B	Na
Kaukau - Control	3.7	0.57	4.2	0.7	0.4	290	99	1570	31	15.6	2.0	415
Kaukau - Leucaena Plot	3.1	0.60	4.4	0.8	0.8	135	110	825	31	17.6	31.8	160

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Appendix 3:

Giant Leucaena Speices and Variety Plots: Annual increase results.

The following growth measurements were compiled by Neville Howcroft at Foresty Research Station, Bulolo.

Measure Results, August, 1981

Identity	Dami	K28	El. Salv.	Mexican	K8	Local	K67
Mean Ht.	623.5	554.8	554.6	845.8	638.8	256.7	726.9 cm
Inc for 6mo.	165.8	186.5	294.0	315.3	155.3	42.2	214.1 cm
" " 12 "	415.0	435.8	465.9	678.4	436.7	143.8	518.9 cm
Ht Range							
Min	415	413	460	713	534	137	610 cm
Max	834	682	712	966	782	328	815 cm
Mean Dia	602	5.48	4.87	6.12	5.75	---	4.00 cm
Dia Range							
Min (cm)	4.85	4.00	4.05	4.30	3.15	---	4.00 cm
Max	8.95	6.80	6.05	8.25	7.50	---	7.70 cm

Comments

From the measures it is obvious that the Mexican species is performing the best here at Bulolo followed by K67. El Salvadore, K28 and K8 still look promising and trials proposed for the lowlands are still recommended to test these further.

SECTION FOUR

PART 4A

\- SUPPLEMENT -

1

Some field layouts used in mixed cropping trials with MPT's

PART 4A

- SUPPLEMENT -

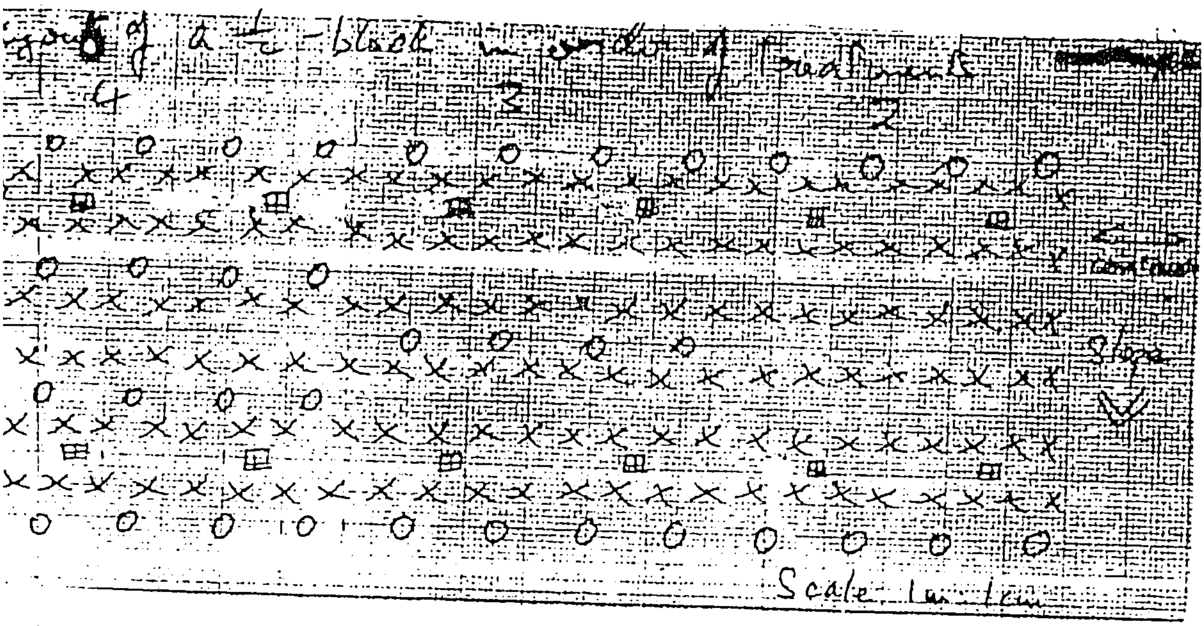
1. Agroforestry extension and research applied to intensification of subsistence agriculture - by J.F. Swift (plus Appendix by D. Morton)

2. Agroforestry experiments at Morogoro, Tanzania. - by J.A, Maghembe

Note: This supplement is in the process of being compiled. Will anyone wishing to have details of their mixed cropping experiments with MPT's included please send full details to:

Dr. P.A. Huxley
I.C.R.A.F.
P.O. Box 30677
NAIROBI
Kenya.

<u>Appendix 4</u>: Prof. Dick Morton of UPNG designed the mixed cropping experiment. The following shows a detailed half block of the eight block design.



O = Leucaena tree   x = sweet potato plant   H = metal stake

The sampling area for sweet potato is within the four stakes: 12m.
For the Leucaena, the two central columns.
Each plot or cell is 6m(row) x 7m(column.
Each half block requires 36 Leucaena seedlings and 144 sweet potato cuttings at 2/mound.

Design by Prof. Dick Morton for [redacted] John Swift of the Wau Ecology Institute of an experiment in mixed cropping of kau-kau and Leucaena

Background:

On the slopes of the hills around Wau valley, as in many similar areas of Papua New Guinea, heavy cropping of root crops, reduced fallow and demands for firewood are causing denitrification and erosion of the soil. The general hypothesis to be tested is that inter-cropping of N-fixing trees among the root crop could arrest this process, permitting more harvests of roots without damage to the soil and providing domestic fuel as a by-product.

Preliminary experiments by John Swift suggest that Leucaena is the most easily established N-fixing tree for the Wau region and that seedlings can be simply interplanted in kau-kau gardens. Kau-kau is known as one of the most soil debilitating of root crops, so that a simple Leucaena kau-kau mixture seems the best material for a first test of the general hypothesis.

In a quick survey of land available at the Wau Ecology Institute, John Swift and Dick Morton preliminarily selected a steeply sloping piece of land above the Wau football field, which we estimated to be at least 50m wide along the contour and close to 100m deep down the slope.

Design:

A ½-block of 4 Block-treatment cells is shown in diagram 1. The spacing of the Leucaena plants along the rows (contours) is 1½m of the kau-kau plants 3/4m and the distance between each kau-kau row (down the slope) is 1m. Each cell includes 4 metal stakes, partly as a measure suggested by Adrian Williams of soil erosion/ accumulation and partly to delineate the sampling area for kau-kau harvests ($12m^2$ = 16 plants), the remainder being treated as guard rows. The sampling units for Leucaena trees are the two central columns of each cell.

The Leucaena spacing treatments are described in the diagram as
7 4 3 2, being the number of Leucaena plants per column but at least there other eummerations of the independent variable are possible, viz
1 2 3 6, the distance between each Leucaena row
½ 1 1½ 2 the mean distance between kau-kau plants and Leucaena trees within the sampling area and
8 4 2 0 , the number of Leucaena trees within the kau-kau sampling area. The chance of describing a simple response curve to one of these versions of the spacing variables or their reciprocals should be high.

Many ways of pruning and harvesting the Leucaena are possible. It is therefore proposed that two contrasting methods be applied as treatments, based on the English practices of coppicing and hedge-laying. The effects of these treatments are likely to be gross on yield of domestic fuel (in favour of coppicing) and soil retention (in favour of hedging), and the work of hedging is much reduced where long runs are possible (and a long run of hedge is a fairer test of its soil retention abilities than several short ones). A split plot design, with hedging or coppicing randomly assigned to ½-blocks, is therefore prefered. Compared to a completely randomised block design, this will make it difficult to detect differences in kau-kau yield between coppiced and hedged ½-blocks, but should improve

the precision of the estimation of the effect of Leucaena spacing on kau-kau yields, which is taken as the most important effect in the experiment.

Effects of time within harvests are to be absorbed into blocks. For this to be effective labour will be required to complete each harvest/planting of each block within ~~two~~ weeks. Assuming that the time from planting to harvest of kau-kau crops at Wau varies from 4 - 6 months according to season, 8 blocks can thus be planted without danger of a double labour shift.

The total layout of the experiment then becomes as diagram 2, requiring a piece of ground 48 m (along the contour) by 75 m (down the slope).

The basic skeleton analysis of variance for single and cumulative harvests is : -

Source of variation	Degres of ferdom	
Blocks (B)	7	
Coppice vs hedge (Ch)	1	
B x Ch	7	
Main plots	15	
Spacing (S)	3	
(S linear (S_l)	1	
S quadratic (S_q)	1	
S cubic (S_c)	1)	
S x Ch	3	
B x S	21	expected to be combinable
B x S x Ch	21	expected to be combinable
Subplots	48	
Total	63	

-two degrees of freedom for error in the subplots may appear excessive. However, it should be recalled that if time (harvest) trends are to be analysed, the correct error term for, say, harvest linear (H_1) x S_1 is B x H_1 x S_1 with only 7 d.f..

Procedure

Eight blocks to be prepared, one per ~~fortnight~~ week over ~~15~~ 8 weeks. (It doesnot matter which block you start with).

1) Each block to be cleared of grass (to be kept as mulch) ~~and about~~ and about 1 - 1½ m metal stakes driven in at positions indicated. Amount of stake protruding above soil to be measured by running washer over stake and using metre rule to measure from washer to tops of stakes.

Kau-kau slips to be planted on mounds over grass mulch (or as ridges as prefered, but stick to one or the other), with rows along contours at 1 m intervals down slope and slips at 3/4 m intervals along rows.

Randomly assign one half of each block to future hedging or coppicing and one of each spacing of Leucaena to each half block. Plant Leucaena seedlings accordingly.

2) First harvest, starting with first block planted, when ready.

Measure stake as 1)
Harvest kau-kau. Within sampling area, divide kau-kau into tops, ware tubers and kaukau bilong pik and weigh each.
Retain tops for mulch, and slips.
Replant kau-kau in same areas as soon as harvest complete.
Harvest blocks at fortnightly intervals in the order planted.

3) Second harvest, as first, plus

a) Coppice every other column of Leucaena in ½-block to be coppiced (choose odd or even columns for each ½ block at random). From central column of each treatment-block cell that is coppiced, separate product into sticks for burning/ and twigs and leaves for mulching and weigh these.

b) Lay as hedge the Leucaena in the other half block. Treat any cut-out from the central half of the hedge (i.e. as if from 2 central columns) in each treatment blocks as in a).

4) Third harvest, as first, plus

a) Coppice the other columns as in 3a)

5) Fourth harvest as second.

Data collection and duration of experiment.

The first harvest will give data on loss of soil from upper and lower parts of each sub-plot, yield of kaukau tubers (ware and long pik) and tops (and hence mulch supplied for harvest 2). It is unlikely that the Leucaena will yet have had any effect, so that this will mainly be supplying the base-line against which to judge subsequent harvests. The second harvest will supply additionally data on yield of Leucaena fuel-wood and mulch-leaves (also applied to third crop). Since at this stage there can be no effect of Ch, there will effectively be 16 blocks to assess the effects of S on yield of kau-kau and Leucaena.

The third harvest will yield the first data on effects of Ch on soil preservation and kau-kau yields, but the Leucaena yield will obviously be artificially different. The fourth harvest will extend the data of the third, and by combining these two will give meaningful data on Leucaena yields, by Ch treatments. By the completion of this harvest we should have

1. Soil retention/erosion
2. Kau-kau yields - a) ware tubers; b) kau-kau bilong pik; c) tops - mulch for next harvest
3. Leucaena yields - a) domestic fuel; b) leaves = mulch for next harvest

If representative samples of 3a) be converted to charcoal (incl. 'before' and 'after' weights) and of 2a) and b) offered for sale, it should be possible to add

4. kina value of take-off harvest.

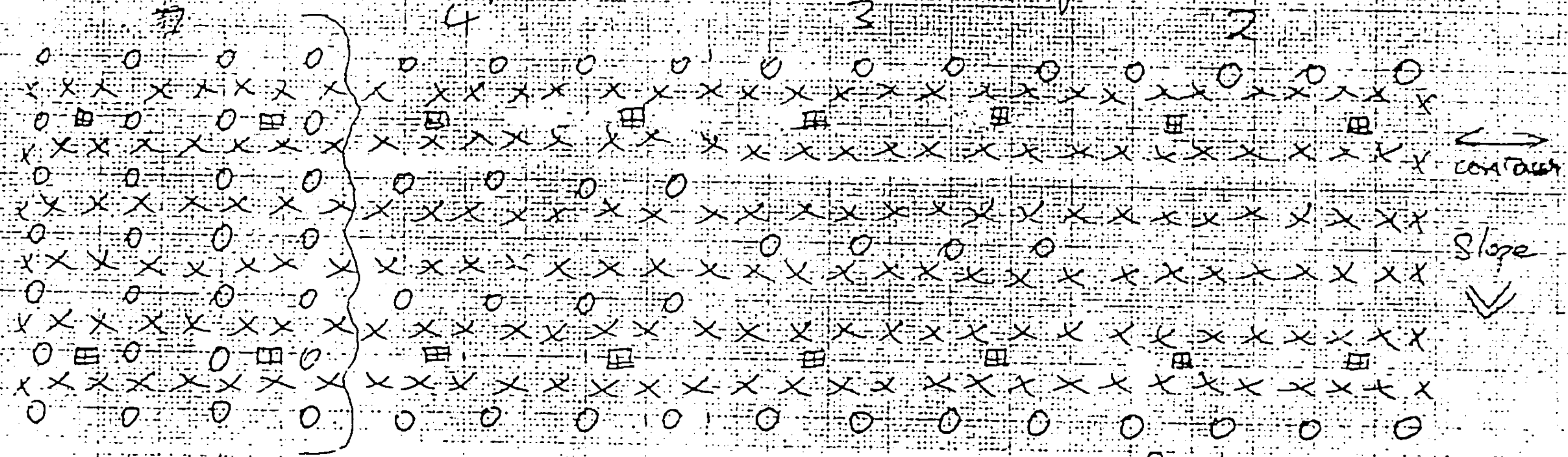
It is anticipated that spacing treatment 7 (S_7) will be too dense for efficient kau-kau production and quite probably for maximum 3a), while S_0 will be too sparse for maximum 3a) and probably for maintenance of soil fertility for kau-kau. The response curves fitted are thus expected to produce intermediate maxima for both 2 and 3. If, as is likely, these do not coincide, an overall optimum spacing could be determined from the maximum of 4. It is also likely that an analysis of covariance could assign the contributions of 1, 2c) and 3b) to these maxima.

Thus after harvest 4, which should be completed by about 2 years from the start of the experiment, a detailed and useful analysis should be possible. It would probably be worth while completing a 5th cycle while the data from the first four are analysed so that sensible decisions could be made on whether to scrap or fundamentally re-organise the experiment in the light of the analysis after about 2½ years.

Dick Morton,
Prof. of Biology

DM/mtes,
16/6/81.

Diagram 1 Detailed layout of a ½-block in order of treatments   4 meters/plot



Scale 1m : 1cm

o = Leucaena tree   x = Kau-kau plant   ⊞ = metal stake

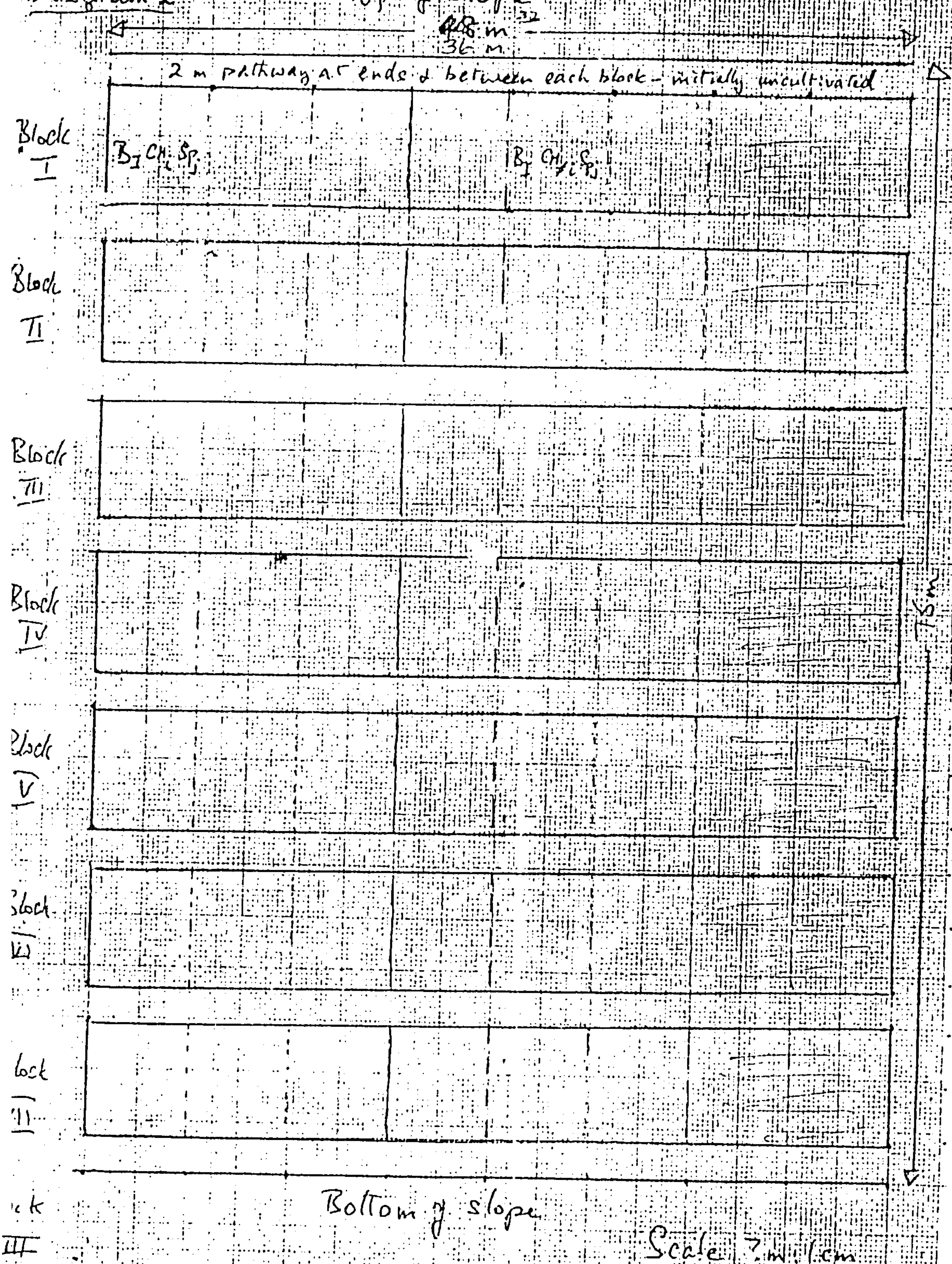
In treatment	7	4	3	2	
the mean distance of kaukau to Leucaena in the sampling area is	½	1	1½	2	metres

The sampling area for kau kau is that contained within the 4 stakes i.e. 3x4 m   4x4 plants/mound
" " " " leucaena is the two central columns of each BxT cell

Each BxT cell is 6 m (row) x 7 m (column)

Each ½ block requires 36 Leucaena seedling & (or 144 of 2/mound) Kau kau slips.

Diagram 2



Outline plan of blocks. Sowing of each block to be completed within a fortnight, starting at top or bottom.

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Assistant Director: Allen Allison, PhD

Michael Greene
Committee on Research and Grants
National Academy of Sciences
2002 Constitution Ave.
Wash, D.C. 20418

December 16, 1981

Dear Dr. Greene,

One of the stated research priorities from the workshop concerned collaboration with intercropping trials to determine the spacing/density relationships between NFT species and food crops. From the preliminary information you had sent to Dr. Gressitt which I read upon my return from Honolulu, you have already begun to coordinate such a research approach.

The main problem I see with using similar experimental designs relate to the variations in farming systems between countries. In PNG, the main priority is soil conservation and improving soil fertility rather than fuelwood production. The tree species should be the same for a spacing pattern to emerge while the food crop will need to be different.

Have you any proposed designs? I enclose the trial we have established in Wau which may be of interest to you. The Institute wants to continue with this line of research as expressed by Allen Allison in his letter to you Oct. 28th.

Please send us more information as soon as possible. If you have yet to design the comparative trials you mention or similar intercropping trials like the approach we are taking in Wau, please let me know..

Thank you for your interest at the Institute.

Sincerely,

John F. Swift

AGROFORESTRY EXPERIMENTS AT MOROGORO, TANZANIA*

BY

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INTRODUCTION

Over 90 percent of the Tanzanian people use wood as their main source of energy. To the rural communities fuelwood is as basic a need as water and it has been collected free of charge for many years. Although there is no land hunger in most savanna areas, continued exploitation of natural woodlands with little concern for replenishment is bringing about serious fuelwood and building pole shortages (Temu, 1979; Mnzava, 1980). See Table 1.

The government has launched an ambitious, village afforestation programme (Mnzava, 1980), but the state alone cannot plant and tend trees on the vast scale needed to avert the impending crisis.

The need to encourage villagers to participate in the scheme through agroforestry systems is very important. This will ensure that trees are planted early in the rainy season, and provided more care in tending and fire protection. But before such a system is adopted widely, it is necessary to obtain suitable tree-crop mixes and espacements, especially for the semi-arid areas.

INITIAL TRIALS

An initial trial (Maghembe and Redhead, 1980) with *Eucalyptus melliodora* had shown that even at the close espacement of 2.5 x 2.5m, good crops of maize (1260 kg/ha) and sorghum can be obtained in the first year. However, maize yields fell by 92 percent in the second year and the crop failed to flower in the third year. Sorgham yields followed a similar pattern. The yield of beans was reduced by a bad attack of an unidentified fungus in the first year. In the second year the bean yield was 150 kg/ha but for the third year the bean plants were etiolated and their yield was insignificant.

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* Reprint from "Proceedings of the Kenya National Seminar on Agroforestry" (Ed. L. Buck) pp 435-442, 1981. ICRAF, Nairobi.

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After 30 months, the mean heights of *Eucalyptus melliodora* was between 6m and 8m, already large enough for rafters of village houses. Overall volume production ranged from $5m^3$/ha in unweeded *E. melliodora* monoculture plots to $35m^3$/ha where intercropped with beans.

It is clear that normal crop yields could be expected in the first year with little effect on the tree crop in case of *E. melliodora*. But for intercropping with food crops in subsequent years, wider espacement of trees was necessary.

FOLLOW-UP TRIALS

This section presents preliminary first year growth observations of follow-up trials with *Leucaena leucocephala, Eucalyptus camaldulensis* and *Acacia albida* intercropped with maize and beans. The species have been chosen to test the multipurpose production of fuel, fodder and poles at various espacements and their influence on crop yields.

The trials were established from January - March, 1980 at the Mafiga Forestry Experimental Area of the University of Dar es Salaam's Faculty of Agriculture, Forestry and Veterinary Science at Morogoro, Tanzania. They have been carried out by J.F. Redhead, L.L.L. Lulandala and J.A. Maghembe. More detailed accounts are available in the Faculty's Research Reports (from which this account was summarized. Ed.)

There were four trials involving:

1. *Eucalyptus camaldulensis* for fuelwood and poles
2. *Leucaena leucocephala* for fuelwood
3. *Acacia albida* for fuelwood and poles and
4. *Leucaena leucocephala* for fodder.

All four were laid out as split-plot designs with crops (maize and beans) and weeding regimes (clean weeding and spot weeding) as the main plots, and tree espacements forming the sub-plots.

PRELIMINARY RESULTS

The different tree espacements ranging between 3 x 3m to 5 x 5m in *Leucaena* and *Eucalyptus* and 4 x 4m to 6 x 6m in *Acacia* did not show significant influence on tree height nor did they cause significant variations in maize and bean yields. This is because in all the experiments the trees were still too young to pose effective competition. This may show up in subsequent years, especially when the canopy closes.

Unfortunately, it was only in experiment No. 4 that maize and bean yields were normal. In experiments 1 to 3, the crop planting time and maize flowering coincided with severe drought so crop growth and yield were both poor and uneven.

The yield of maize in investigation No. 4 ranged between 1400 to 1800 kg/ha which compared favourably with yields of maize monocultures at Morogoro and is twice the national average (Acland, 1971). The mean yield of beans was 401 kg/ha, an average yield by peasant standards (Acland, 1971).

On the other hand, maize caused significant height growth increases in all the tree species tried and in all experiments; see Table 2. *Leucaena* intercropped with maize was not only the tallest, but also had straight and unbranched stems. In contrast, the *Leucaena* in the beans, clean weeded or spot weeded plots were shorter and branchy and many had multiple leaders. These trees also flowered and set abundant pods only 15 weeks after planting out, whereas the taller *Leucaena* amongst the maize had not flowered. It is apparent that intercropping *Leucaena* with maize would be advantageous if the objective was to produce a proportion of poles as it precludes the common habit of *Leucaena* of heavy branching and multiple leaders from near the base of the tree.

Measuring height only in an intercropping situation may not reflect changes in actual dry weight because of a possible change in form brought about by mutual shading. Clearly more data are needed and these will be obtained in subsequent years.

TABLE 1:

Forecast of supply and consumption of fuelwood and poles in some regions of Tanzania by 1985

	Estimated mean annual increment $m^3 \times 10^4$	Estimated annual Consumption $m^3 \times 10^4$	Deficit $m^3 \times 10^4$	Deficit as a percentage of demand
Arusha	75	200	125	63
Coastal and Dar es Salaam	57	210	153	73
Dodoma	84	212	128	60
Kilimanjaro	11	210	199	95
Lindi	117	117	-	-
Mara	9	174	165	95
Morogoro	134	193	59	31
Mtwara	36	187	151	81
Mwanza	11	315	304	97
Shinyanga	117	384	267	70
Singida	127	145	18	12
Kagera	23	190	167	88

Source: Forest Division, Ministry of Natural Resources and Tourism, Dar es Salaam, 1978.

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TABLE 2:

Height (cm) of *Eucalyptus camaldulensis*, *Leucaena leucocephala* and *Acacia albida* intercropped with maize and with beans compared to clean weeded and spot weeded treatments at various times after field planting.

Tree cropping system	*Eucalyptus camaldulensis*		*Leucaena leucocephala* (for fuel)		*Leucaena leucocephala* (for fodder)		*Acacia albida*	
	18 weeks	24 weeks	17 weeks	23 weeks	13 weeks	19 weeks	17weeks	23weeks
Intercropped, maize	120	145	129	161	160	194	56	81
Intercropped, beans	103	138	107	139	104	160	49	75
Monoculture, clean weeded	87	114	112	140	114	153	47	66
Monoculture, spot weeded	90	110	91	112	-	-	-	-
LSD 0.05p	9	13	8	12	11	15		
LSD 0.01p	12	19	11	16	15	22		

SECTION FOUR

PART 4C

Optimising tree/crop combinations

PART 4C

CONTENTS

OPTIMIZING TREE/CROP COMBINATIONS

- by P.A. Huxley

Introduction

The selection of plant components for any land use system, in the first instance, involves two main considerations:

- First a choice of genotypes known to be well-adapted to the agro-ecological zone under study including the soil type(s) present).

- Then a critical selection of potentially adapted plant components to fit the broad requirements of the existing, or projected, land usage.

  - *These two choices will be based on what is known or can be discovered, for example either through currently informed opinion, or through a more exact process of landuse diagnosis, of both the biological-environmental and the socio-economic potentials and restraints of the sites under consideration. Here, again, the MPT components may need to be chosen at this stage on the basis of what we know about their possible values whereas, for crop plants, a process of closely matching environmental crop requirements to climatic and soil suitability*, and to local preferences and marketing possibilities, will be feasible.*

In practice, these two decision-making processes can be invoked in a close, re-iterative sequence, resulting in an initial combined list of potential MPT and crop selections. However, these will still only be broadly suitable as possible candidates for a further more exact process of selection, both for different site, requirements (environmental and management) and for an evaluation in terms of between-component compatibility. The latter will be needed so as to ascertain,

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* For a procedure to do this see "Report on the agro-ecological zones project, Vol.1 Methodology and results for Africa/FAO, Rome.

as precisely as possible, the relative potentials of any pair in whatever mixtures, arrangements and management sequences may logically be proposed.

As background reading some basic issues underlying the reasoning for chosing/selecting genotypes of one kind or another are elaborated in Appendix 1, the possibilities of applying various forms of manangement and arrangements in space in Appendix 2, and considerations for chosing phenologically suitable plant components (i.e. "matching" in time) in Appendix 3. Some of the factors underlying the success or otherwise of plant mixtures as compared with sole crops are to be found in the list of selected references; but the subject is too extensive to be dealt with here.

The remainder of this manual part is concerned with outlining a simple sequence of steps (Figure 1) which can be used to select tree/crop combinations from biological/environmental and management standpoints. This is based on a broad agronomic/silvicultural approach at this stage and, clearly, can be ultimately refined through the development of the more precise modelling of the processes involved. The alternatives which emerge would need to be further evaluated for their economic viability and social acceptability and, overall, for their potential adoptability.

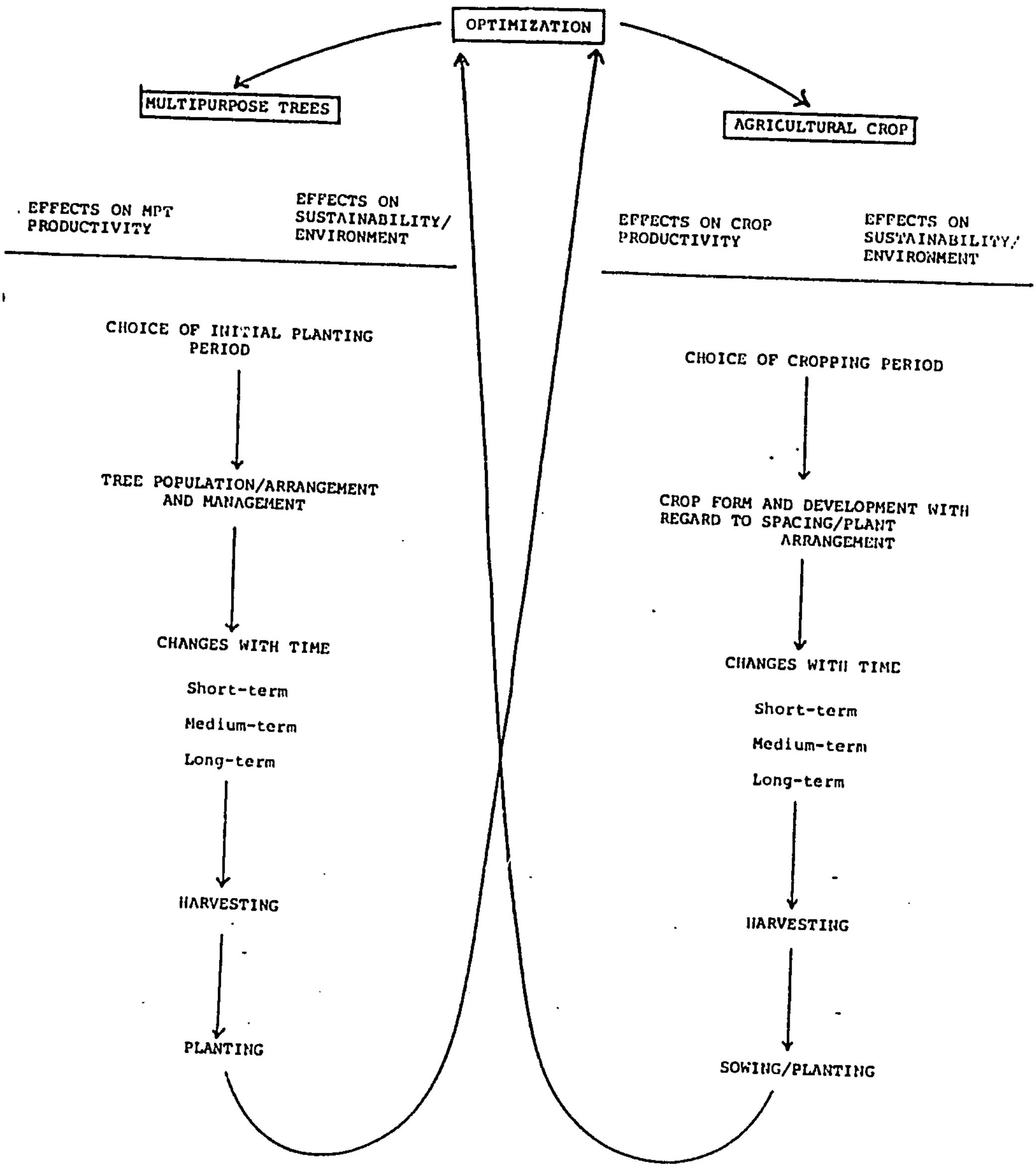
An implementation flowchart for deciding on appropriate tree/crop combinations

The procedures are based on first providing a list of potential plant components, as outlined above. The right hand side of the flowchart (a pair of columns) deals with the agricultural crop or grasses, the left-hand side with the MPT. Where the crop is also a woody perennial species the a left-hand pair of columns can be substituted, or some combination of steps, as appropriate. Within each column pair the factors to be considered are set out under main headings.

Agricultural crops:

- Choice of cropping period
- Factors related to the form of the crop

FIGURE 1



FLOWCHART SHOWING STEPS TO CONSIDER WHEN ATTEMPTING TO OPTIMISE MPT/AGRICULTURAL CROP COMBINATIONS THROUGH A GENERAL AGRONOMIC/SYLVICULTURAL APPROACH.

Pairs of tree/crop selections can be considered at any one time, treating these successively if there are more than two plant components. Start with the agricultural crop and then "match" the MPT as well as possible, reiterating the process as necessary.
The steps are described more fully in the text that follows.

(revised version of an ICRAF in-house paper by P.A. Huxley, June 1979).

plant (bushy, prostrate) and its requirements for successful development (that is the flowering/fruiting behaviour, if appropriate) and so to consider plant spacing and arrangement.

- Considerations of changes with time (within-season, between-season and long term).
- Harvesting requirements.
- Planting/sowing needs.

The choice of growing period in relation to the choice of genotype (a short or long-season crop), and the probability of any particular rainfall/temperature regime, are key issues for agronomists when selecting crops for particular sites, and so this assessment is put first. It is assumed that the other key issue - the suitability of the crop chosen for the soil type at the site - is one that has already been decided when selecting suitable potential components.

In considering the various steps, sequentially, within each of the above sections consideration is given to both

a) the direct effects and/or the indirect implications of the factors involved on the *productivity* of the crop itself (left-hand column of the pair) and

b) the effects on the *sustainability* of the system and any consequences for changes in topo (local) environment.

Under some headings only one column is used as the process is considered always to be equally important for both immediate plant productivity and for sustainability/topo environmental changes.

Multipurpose trees

This general layout applies also to the sequences for the MPT, which can be addressed after the first 'likely' choice of agricultural crop has been considered, using the outcome to compare with alongside the MPT species' characteristics. The process can be a re-iterative one either by manipulating the

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available management for the original pair, or by replacing one or another components of the original tree/crop combination in order to see if a better set of possibilities exists. Similarly, other pairs of choices can be put through the same procedure until all the combinations have been examined and the most promising have emerged *together with an understanding and appreciation of why they are so.*

The comparable sequence of main headings for MPTs is similar except that there will be less emphasis on the first step ("choice of planting period").

In most cases it is probable that tree seedlings will have been nursery-raised in containers and there may, therefore, be a somewhat more extended choice of planting-out time (or even season where two rainy seasons exist) than is desirable with an agricultural crop if optimum yields are required. When MPT's are to be direct-sown then the timing will be equally critical as for an agricultural crops.

The main headings for the sequences to be considered for a MPT are therefore as follows.

- Choice of planting out period
- Tree form and development with regard to spacing with yield of parts required.
- Changes with time
- Harvesting requirements
- Land preparation and planting

These are similar in scope (but not detail) to thos being considered for the agricultural crop and, at each point, cross references to the outcome of any restraints imposed by that crop needs to be made, and vice versa in any reiteration.

Explanation of steps

Because of restrictions of space the flowchart itself is presented only in a very abbreviated form. It needs to be read in conjunction with the following notes which, themselves are only illustrative and in no way comprehensive.

EFFECTS ON PLANT PRODUCTIVITY

EFFECTS ON SYSTEM SUSTAINABILITY
TOPO-ENVIRONMENT

Choice of cropping period

Effects on plant productivity:

Will there be enough rain, and will the soil be in a suitable condition for germination of the particular crop chosen: (soil temperature is also important here). Bearing in mind the expected rainfall, temperature and seasonal solar radiation income what is the *potential* growth rate for the crop and how will it fit into the seasonal environment changes expected? In what way will any particular cropping period affect the likely incidence of pests and diseases? If planted on a certain date when is the crop likely to mature and what is the weather likely to be at that time*.

* The methodology outlined in "Rep. on the Agro-Ecological Zones Project Vol.1 FAO, Rome." provides a detailed sub-routine to be followed here, if required.

Effects on system sustainability:

From an "environmental" point of view - how will the cropping period chosen affect plant cover in relation to soil erosion? How will N-fixation processes be affected by the chosen cropping period (especially if it is a legume) as compared with some other? What are the likely changes in overall soil factors (e.g. humus formation affecting percolation rates, temperature, biota etc.) to be expected from one cropping period to the next? Will there be any pest (or parasite/predator) carry over?

Spacing/Plant Arrangement (= Plant Population)

Effects on plant productivity:

How will the plant population chosen affect the within-season potential *crop* growth rate? For example, at what time will stress for limiting factors (water, light, nutrients) be likely and how will the choice of plant population and plant arrangement affect this? Can anything be assessed about overall plant interference/competition processes for the crop, season and plant arrangement chosen?

How will the choice of plant population/rectangularity/arrangement affect dry matter distribution and the yeild.

Effects on system sustainability:

To what extend will plant population arrangement affect the distribution of roots in the soil and hence the exploitation of nutrients and water, and the build up to soil structure?

How will the particular shading pattern of the crop affect soil degradation processes and soil losses?

How will the application of pesticides (if used) affect biota and residues?

Changes with time due to the crop chosen and its management

a) Short term changes (i.e. within a single season (involving both plant productivity and its sustainability/ topo-environment effects).

What forms of management (soil tillage, weeding, etc) are desirable and what effects will they have on the immediate productivity of this season's crop as well as the status of the soil? (in particular, when proceeding through the MPT sequence, what interactive effects will these have on the MPT and/or how will the requirements for the MPT restrict optimum handling of the crops?).

Are there any allelopathic effects?

b) Medium term changes (between seasons or over a few years)

What effect will the maturation/ senescence pattern of any single crop have on any associated agricultural crops (in mixed cropping).

When, how much and what kind of litter/residues will the crop (or the mixture) contribute to the soil? Are there any particular detrimental effects on particular crop residues on crop that may follow?.

c) Long-term (Several to many years) Will the changes in soil brought about from year to year by the particular cropping pattern affect soil fertility/soil losses and so increase or decrease yield potentials? (Particularly relate this to any potential improvement by association with MPT's)*

Will any site require a change in choice of crops at a later stage (rotations or species/cultivars that better suit the changed soil conditions)?

Will there be any build up of pesticide residues (if used), or of long term soil fertility due to the use of any particular form of fertilizer (if used).

* See also a procedure for predicting the effect of various proportions of tree/crop mixtures in "The Role of Trees of Trees in Agroforestry - some comments" - Appendix 4.

Harvesting

No effects on immediate crop because it is just removed (but optimize time and manner with reference to the MPT).

In what ways will litter, root residues, soil nutrient status and soil losses be changed by different forms of harvesting? What will be the effects on residual weed populations and/or on weed seed residues?

Sowing/Planting

What is the expected condition of the seed bed under the crop management decided upon up to now? (and will it be affected by the presence of MPT's ?).

What effect will sowing/planting methods have on soil structure, permeability etc?

At this point one should proceed to the top of the MPT sequence and progress through it, examining not only how the factors affecting the productivity and influence on the environment of the MPT itself, but also how they will interact with the outcome of this set of considerations.

EFFECTS ON PLANT PRODUCTIVITY

How will all this affect dry matter distribution and the proportion of desired harvestable parts of the trees?
How will particular management practices affect the development of tree form?

How will plant arrangement affect plant-to-plant competition at the root level (and how will all this affect yields and tie in with soil management of the crop?)

How will this affect growth rates and potential production per unit area of land?

* See M.G.R. Cannell "Plant Management in Agroforestry" in Appendix 1 and "The Role of Trees in Agroforestry in Appendix 4). And see Part 4C "The tree/crop interface approach"

(Bear in mind what has already emerged from considering the agricultural crop)

<u>Choice of planting period (this will only occur once in a cycle)</u>

How much flexibility is there? What prior preparations are needed (nursery production of plants in containers, bare rooted, stocks - how is it to be organised?). Is there a case for direct sowing?

This has also to be optimized with reference to both the environment <u>and</u> the labour and other resources <u>needed</u> for sowing/planting the agricultural crop and any possible benefits of combining these (taungya practices).

<u>Tree population/arrangement & management of tree form</u>*

EFFECTS ON SYSTEM SUSTAINABILIT. TOPO-ENVIRONMENT

How will the development of the tree canopy affect factors such as shade/shelter/through-fall, which can affect the environment beneath?
What effect will the trees have on the residue and build up of pests/diseases and weeds?

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Changes with time due to the MPT chosen and its management

a) Changes with time (short and medium term)

What options for tree management are there (training, thinning, pruning or lopping, spraying etc?). Will these affect the phenology of the tree and/or modify the environment in that season (short-term), or in subsequent seasons (medium-term).

b) Changes with time (long-term)

How will time-dependent processes affect productivity and environment during the whole period up to maturity of the tree?

In general, what opportunities and/or restraints will be imposed by the development of the tree canopy.

How is the tree expected to age? And what will the site factors and association crops do to hasten or hinder this?

How will the tree be affecting the site over decades?

Harvesting

What is the most productive way of removing the tree parts required? And how can it be done with the least disturbances to associated crops? Will harvesting be a) seasonal b) intermittent or c) one final harvest?.

Will harvesting procedures affect soil (compaction)? Add more litter? Bring about pest/disease problems? Cause mechanical problems of disposal?

What will the sudden changes in the aerial environment (caused by removal of trees, or tree parts) do?

What will the long-term effects of the removal of harvested parts be on the fertility of the site?

Planting

Are there any re-plant problems for the trees (specific and/or general?).

Will there be soil erosion problems between harvesting and planting again?

Return to Agricultural Crop to re-iterate process and/or change plant components under consideration

SECTION 4C ANNEX

Appendix 1: The influence of genotype and environment on dry matter distribution in plants
- by F.T. Ledig

Appendix 2: Plant management in agroforestry: manipulation of trees, population densities and mixtures of trees and herbaceous crops.
- by M.G.R. Cannell.

Appendix 3: Phenology of tropical woody perennials and seasonal crop plants with reference to their management in agroforestry systems
- by P.A. Huxley

These papers are reprinted from "Plant Research and Agroforestry" (Ed. P.A. Huxley), 1983, ICRAF, Nairobi.

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THE INFLUENCE OF GENOTYPE AND ENVIRONMENT ON DRY MATTER DISTRIBUTION IN PLANTS

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ABSTRACT. Plants distribute growth among competing sinks in such a way as to retain a functional structure. When photosynthate is limiting it is used in the canopy and little, if any, is available to the roots. When water or nutrients are limited they are intercepted by the roots, growth of the canopy is restricted, and photosynthate is available for root growth.

Because most changes are adaptive, environmental effects are predictable. High levels of irradiance increase root growth relative to shoots, and low levels increase shoot growth relative to roots. Especially in temperate perennials short photoperiods signal a cessation of shoot growth, subsequently favouring root growth. Infertile soils and low water potential inhibit shoot growth proportionally more than root growth. The effect of temperature cannot be generalized as easily because it depends not only on the temperature regime to which the plant is adapted, but also on the climatic correlates of temperature.

Life form is intimately connected with the shoot - root balance and with reproductive allocation. The shoot:root ratio in annuals increases with time, and the reproductive allocation is a high proportion of total biomass. In woody perennials the shoot:root ratio generally declines with age, and reproductive allocations are usually less than those in annuals.

Within species the variation of growth distribution, and hence plant architecture, as a result of population adaptation to latitudinal, elevational, edaphic, and moisture gradients is well documented. Variation within populations is less well studied and estimates of heritability are rare.

INTRODUCTION

It is reasonable to assume that plants can adjust their architecture to fit their environment. Animals have behavioural modes to accomplish this. If they find themselves too warm, they seek the shade of a burrow; if too cold, they bask in the sun. Analogous responses in plants would be the differential allocation of growth to the stem in order to seek the sun when they find themselves in partial shade, or the allocation of growth to roots when the soil water status or nutrient environment become limiting to biological function. This is not a teleological argument. These responses have been fixed by natural selection: those individuals capable of adjusting their growth to seek a more favourable environment were better equipped to survive and reproduce than those that did not.

But the ability to respond to environmental stimuli entails a metabolic cost, and plants, with their limited capacity to sense stimuli, can err in their growth response when confronted with fluctuating environments. The bounds to environmental response, called phenotypic plasticity or individual adaptability, therefore, are not without limit. Plants have adapted to meet the demands of the environmental rigours that they most frequently encounter, and to respond to changes within limits around the mean.

The allocation of growth is a broad topic. It includes the division between reproductive and vegetative efforts and the distribution among vegetative organs: leaves, stem, and root system. Within organ systems there are also trade-offs: for example, long tap roots with few laterals versus fibrous, multibranched root systems.

This paper is primarily a review of the patterns of distribution among vegetative organs, but also refers briefly to trade-offs within organ systems and to reproductive allocation.

MODELS FOR THE DISTRIBUTION OF GROWTH

Thornley (1972a, b, 1975, 1977a, b) and Hunt (1975, 1976, 1977) discussed models for the partition of photosynthate in which the balance between rate of nutrient and water uptake by the root and CO_2-fixation by the leaves determines the allocation of carbohydrate:

$$\text{root mass} \times \text{rate}_{(\text{absorption})} \propto \text{leaf mass} \times \text{rate}_{(\text{photosynthesis})}$$

If conditions limit photosynthesis (for example, low light) then most or all of the current photosynthate will be used near the source, and leaf and stem growth will exceed that of root growth until the canopy is capable of producing sufficient photosynthate to exceed its requirements. This agrees with most observations on translocation. For example, translocation of carbohydrates from the shoot is lowest when shoot growth is most active (Lister *et al.*, 1967). If nutrients limit growth, then photosynthate cannot be used in the canopy and it will be available for translocation to the roots. The limited nutrients that are absorbed will be used near the point of entry, the roots, so that root growth will exceed stem and leaf growth until the root is capable of exporting nutrients to the canopy. The model would

predict that periods of root growth should alternate with periods of shoot growth which, in fact, is the situation for many species even under constant conditions in growth chambers (Fig. 1 from Ledig *et al.*, 1976), or in tropical trees growing in an aseasonal climate (Borchert, 1973). And it has long been observed in the field (for example, Kienholz, 1934; Webb, 1977). Rhythmic growth patterns in pines are parallelled by rhythms in short-term translocation patterns as indicated by distribution of photosynthetically fixed ^{14}C (Shiroya *et al.*, 1966; Schier, 1970).

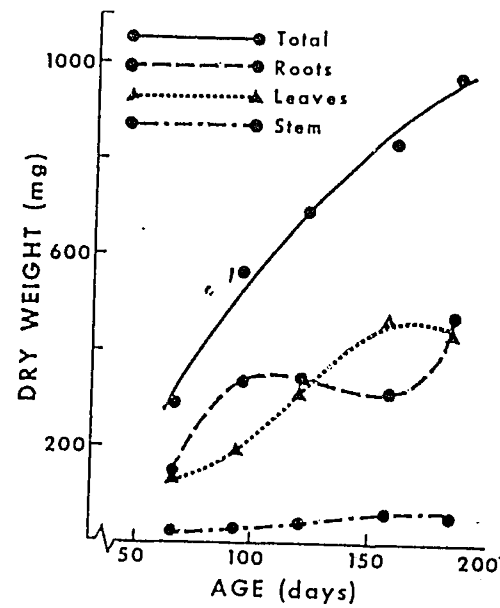

Fig. 1. Peaks of root growth activity alternate with peaks of shoot growth in seedlings of pitch pine (*Pinus rigida*) grown under constant conditions (Ledig *et al.*, 1976).

DEVELOPMENTAL PATTERNS

The shoot:root ratio increases with age in herbaceous plants and decreases in woody perennials, at least in seedlings (Figure 2). Rooted Monterey pine (*Pinus radiata* D. Don) cuttings from physiologically mature trees have lower shoot:root ratios than seedlings of the same size (Fielding, 1970). In general, the greater degree of perenniality (that is, the longer lived), the greater the root growth relative to shoot growth (Troughton, 1960). Because of developmental changes it is difficult to evaluate treatment effects by comparing proportions or ratios. It is better for many purposes to compare the parameters of the allometric equation (Ledig and Perry, 1966; Ledig *et al.*, 1970):

$$\ln Y = a + b \ln X.$$

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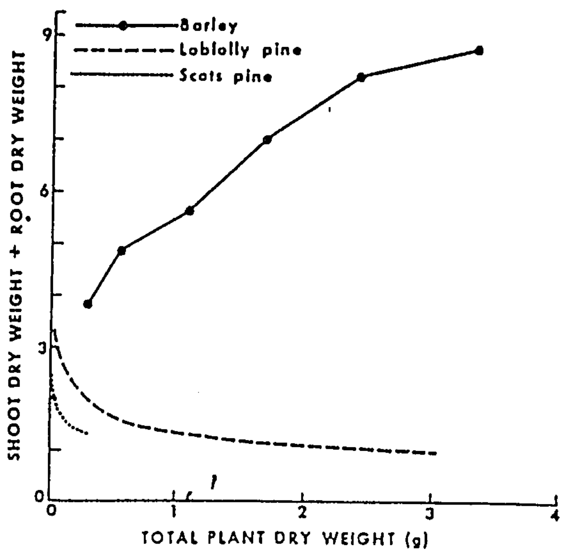

Fig. 2. Shoot:root ratio generally declines with age in woody species and increases in herbaceous species (Turner, 1922; Ledig *et al.*, 1970).

In the equation, lnY and lnX may be the natural logarithms of two organs, or one organ (lnY) and total dry weight (lnX). Allometric relationships among vegetative organs are constant until the onset of flowering, at least in grasses (Troughton, 1956, 1960). In tree species, the relationship seems to hold for at least three years, and perhaps much longer, for example, 15 years in peach (*Prunus persica* [L.] Stokes) (Chalmers and van den Ende, 1975) and 55 years in Scots pine (*Pinus sylvestris* L.) (Ledig *et al.*, 1970).

After perturbation, such as root pruning or shoot clipping, differential growth returns shoot and root to the relationship existing before disturbance (Brouwer, 1962). The relationship between shoot and root is obviously altered after leaf abscission in deciduous trees, but apparently returns in the following spring to levels that continue established trends (Figure 3). Photoperiodic responses in woody species cause alternating growth of shoots and roots, resulting in swings around the allometric relationship (Figure 4); nevertheless, over a sufficient period of time a consistent trend is obvious (Cannell and Willett, 1976).

Although environmental stimuli cue changes in the developmental pattern, controls on the distribution of growth are probably hormonal in nature. Certainly, the strength of reproductive organs as a sink for both nutrient elements and carbohydrates is the result of hormonal control rather than external limitations to growth of the leaves, stem, or roots. Changes in leaf or root activity change hormonal balance. And because subsequent growth

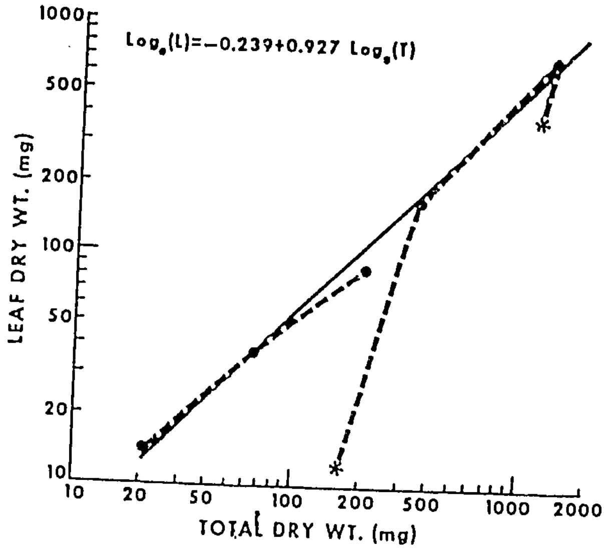

Fig. 3. After winter dormancy the relationship of leaf dry weight to total seedling dry weight tends to return to the patterns established in the first growing season in the deciduous European larch. Asterisks (*) indicate values during early spring when leaf growth was just beginning and in autumn after leaf fall had begun.

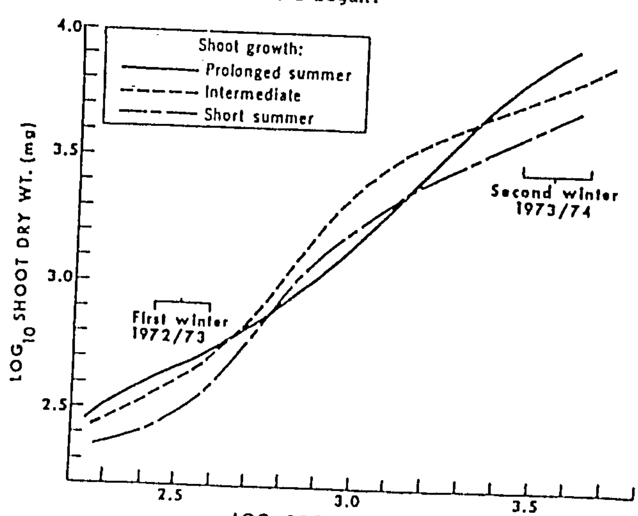

Fig. 4. Oscillation in the shoot:root relationship in lodgepole pine (*Pinus contorta*) provenances as affected by their duration of shoot growth (Cannell and Willett, 1976).

response to correct the imbalance is adaptive, hormonal control and control by limiting factors are indistinguishable in effect. Hormonal control is necessary to maintain growth along adaptive lines despite environmental noise.

ENVIRONMENTAL INFLUENCES

Physical environment

Light. If light has an effect on partitioning of photosynthate it is to increase root growth relative to shoot growth at higher levels of irradiance. Shading reduced the relative growth of roots in grass seedlings (Troughton, 1960), but had no effect on the relative growth of root to shoot in several tree species (Ledig *et al.*, 1970; Doley, 1978). Light *per se* had no effect on the allometric relationships in perennial ryegrass (*Lolium perenne* L.), but under a combination of shading and high levels of nitrogen fertilization, tops grew at a relatively greater rate than roots (Table 1 from Hunt, 1975). Based on the proportion of new growth accounted for by leaves, stem and root the allocation to leaves remained a constant proportion in chrysanthemum (*Chrysanthemum morifolium* Ramat.) irrespective of irradiance; and similar responses were cited for other species (Acock *et al.*, 1979). Under a combination of high light and high moisture Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) had relatively greater shoot growth than root growth compared with other combinations of light and moisture treatment (Ledig *et al.*, 1970).

Table 1. Effect of nitrogen and light on relative root to shoot growth in ryegrass (Hunt, 1975).

Treatment	Allometric constant
High nitrogen - high light	0.838
Low nitrogen - high light	0.953
High nitrogen - low light	0.694
Low nitrogen - low light	0.727

As expected, shoot:root ratios in several woody species were higher in shade than in full sun (Kozlowski, 1949; Huxley, 1967; Gordon, 1969; Carpenter, 1974; Patterson, 1980), but investigations based on the final proportion of dry matter in leaves or roots after extended periods of growth are difficult to interpret. Because shoot:root ratios change with ontogeny, developmental differences are confounded with treatment effects. In several studies of shoot:root ratios, the effect of irradiance may also be confounded with moisture stress (for example, Gordon, 1969; Carpenter, 1974).

Root growth response to illumination of the leaves resembles photosynthetic light response curves in some woody species (Richardson, 1953); that is, there is a light compensation point, a rapid increase in root growth with increasing irradiance, and finally an approach to an asymptote or saturation level. The response time was in the order of 12 to 24 hours in silver maple (*Acer saccharum* L.) seedlings, but substantially longer in red

oak (*Quercus rubra* L.) (Richardson, 1956). Studies on translocation of ^{14}C-labelled carbohydrates also indicate an increased export to roots with increasing irradiance. More labelled carbohydrates were translocated to roots after exposure at high irradiance than after low irradiance in Italian ryegrass (*Lolium temulentum* Lam.) and barley (*Hordeum vulgare* L.) (Ryle and Powell, 1976). The response is immediate, but not fully expressed until two or three days at high or low levels of irradiance. In some pines, and in sorghum (*Sorghum sudanense* [Piper] Stapf), translocation to the roots was greatest following several days of preconditioning under high irradiance (Shiroya *et al.*, 1962; Wardlaw, 1976).

The results agree with the hypothesis that requirements for shoot growth are satisfied first and, as the needs of the shoot are saturated, the carbohydrate gradient increases and the roots receive an increasing share of assimilates. If nutrients or water are limiting then carbohydrates cannot be utilized for shoot growth, and the root will receive a disproportionate share. Therefore, shoot growth should be saturated at a lower irradiance than root growth. In fact, for western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and Douglas fir, shoot dry weight was greatest when seedlings were grown at 50 to 75 per cent of full sunlight, but root growth was greatest when seedlings were grown without shade (Brix, 1970). For ryegrass and barley, the amount of ^{14}C-labelled products retained in the leaves was constant, so increased assimilation under high irradiance primarily favoured the roots (Ryle and Powell, 1976). Whether short-term change in translocation has an effect on developmental patterns is less certain. Short-term experiments do not always separate temporary storage products from structural growth.

Many species respond to levels of irradiance by changes in leaf and stem morphology without changes in the allocation of dry matter growth between tops and roots (Figure 5). Internodes are longer and/or leaves are broader and thinner when shaded, for both woody perennials and herbaceous species (for example, Jackson, 1967; Ledig *et al.*, 1970; Carpenter, 1974; Doley, 1978; Acock *et al.*, 1979).

Photoperiod. Without exception, the effect of lengthening photoperiod is to increase shoot growth relative to root growth in temperate perennials (Bourdeau, 1961; Giertych and Farrar, 1961; McNaughton, 1966; Read and Bagley, 1967; Eliasson, 1971; Heide, 1974; Anon., 1976; Immel *et al.*, 1978; Kinloch, 1980). Temperate plants respond to long photoperiods by extending their shoot growth period. Because growth is episodic roots elongate after shoot extension and leaf expansion slow down. Thus, extended periods of shoot growth result in an increase in shoot: root ratio. Tropical plants, not photoperiodically adapted, should show no response, or an erratic response, to variation in photoperiod.

Temperature. The effect of temperature on the allocation of growth is difficult to generalize about (for example, see literature reviewed in Acock *et al.*, 1979). Shoot:root ratios, or relative shoot growth to root growth, increase with temperature in some species (McNaughton, 1966; Cooper and Thornley, 1976;

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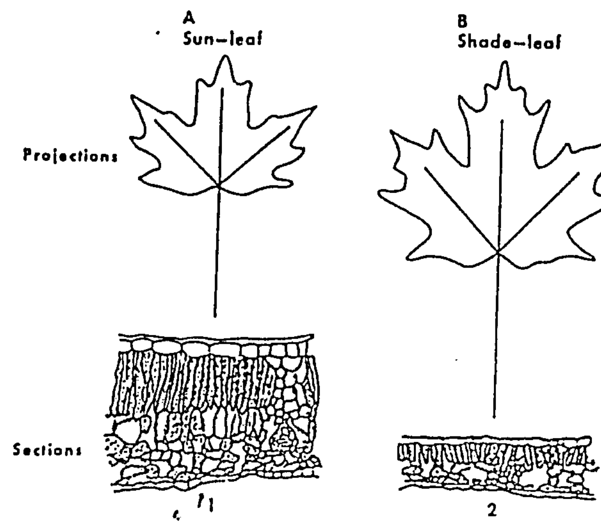

Fig. 5. Drawn for sugar maple (*Acer saccharum*). Shade leaves and sun leaves. Shade leaves are broader and produce higher concentrations of chlorophyll than sun leaves which are thicker and have higher levels of carboxylating enzymes.

Gur *et al.*, 1976; Hodgkinson and Quinn, 1976; Gowin *et al.*, 1980) and decrease in others (Troughton, 1961; Mahon *et al.*, 1976; Gottlieb, 1978; Acock *et al.*, 1979). Part of the problem may be the lack of temperature differential between shoots and roots in controlled environment experiments; an unusual situation in nature where variables such as light, photoperiod, soil water status and mineral nutrition impinge directly on one or the other of either the shoot or the root. However, temperature treatments in most controlled environments are usually applied to both simultaneously, and root and shoot responses and interactions are complex. For example, photosynthesis is partly a temperature insensitive photochemical reaction, while photorespiration increases with temperature as a result of the temperature dependence of leaf ribulose-1,5-diphosphate carboxylase/oxygenase activity. Therefore, as temperature increases, the rate of root absorption should increase more rapidly than the rate of net photosynthesis.

Thornley's model would, indeed, predict that shoot:root ratio will increase as root activity increases. However, this hypothesis was not borne out in several species of trees when root temperatures were varied from 19°C to 27°C and shoot temperature was held constant at 22°C (Heninger and White, 1974). Shoot:root ratios did tend to increase at 31°C, perhaps because of rapid rates of root respiration. Shoot:root ratio decreased with change in temperature from 19°C to 15°C in species with apparent growth optima of 19°C or above, which can be explained either by reduced root activity or by the observation that the optimum temperature for root growth is lower than that for shoot

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growth (Nielsen and Humphries, 1966; Davidson, 1969a). The results suggest that the effect of temperature is directly on growth rate and not on relative activity.

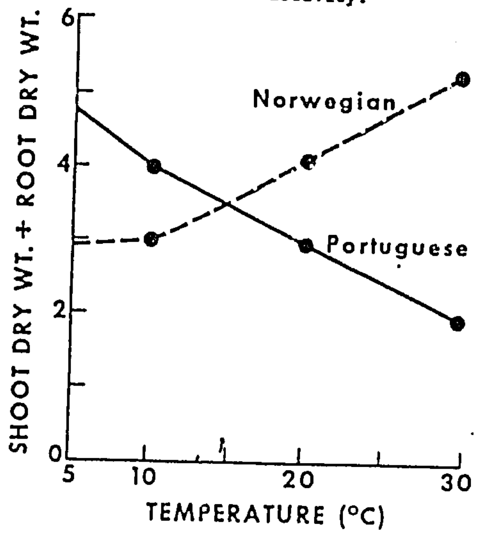

Fig. 6. Shoot:root ratio in a Norwegian race of orchard grass (*Dactylis glomerata*) increased with increasing temperature but decreased in a Portuguese race adapted to summer drought (Eagles, 1967).

Temperature responses may vary among species as a result of differences in climatic adaptation. For example, allometric root to total dry weight growth increased with increasing temperature in the subtropical species cassava (*Manihot esculenta* Crantz) (Mahon *et al.*, 1976), but decreased in several temperate species (McNaughton, 1966; Cooper and Thornley, 1976; Gur *et al.*, 1976). In orchard grass (*Dactylis glomerata* L.) relative shoot-to-root growth increased with increasing temperature in a race from a climate with a cool, moist growing season and decreased in a race from an area with summer drought (Figure 6 from Eagles, 1967).

If seasonal change is signalled by a difference in temperature its effects will also depend on the precipitation regime to which a plant is adapted.

Soil water status. Greater available soil water often reduces root growth relative to shoot growth (Figure 7 from Gales, 1979, and see Harris, 1914; Satoo, 1956; Troughton, 1960; Steinbrenner and Rediske, 1964; Zelawski *et al.*, 1969; Read and Bartlett, 1972; Barlow *et al.*, 1976; Timmis and Tanaka, 1976; Silvius *et al.*, 1977; Fisher and Turner, 1978; Blake *et al.*, 1979). Relatively few studies, however, have shown a change of the allometric coefficient in response to soil water status (Pearsall, 1927; Troughton, 1960; Ledig *et al.*, 1970).

In soybean (*Glycine max* [L.] Merrill) a condition of water

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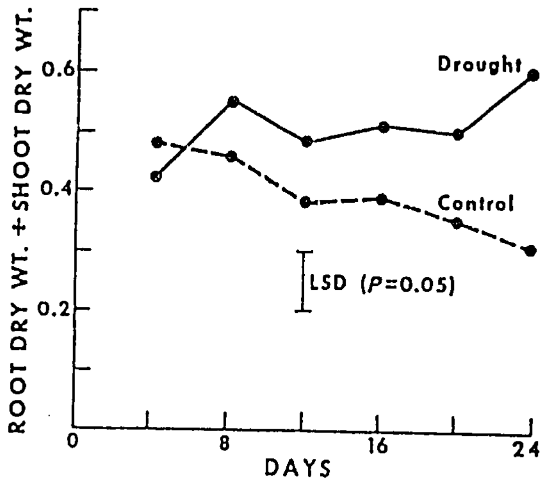

Fig. 7. Increase in root:shoot ratio as a result of drought treatment in ryegrass (*Lolium perenne*) (Gales, 1979).

stress as compared with adequate watering resulted in greater translocation of photosynthetic products to the roots, except during the period of pod-filling (Silvius *et al.*, 1977) because reproductive demands have priority of resources in annuals. Genotype can interact with drought treatment. For example, in cottonwood (*Populus deltoides* Bartr. ex Marsh.), or loblolly pine (*Pinus taeda* L.), clonal or family interactions with a water stress treatment were observed (Farmer, 1970; Cannell *et al.*, 1978). Even when effects of soil water on shoot:root dry weight balance appear to be lacking there are changes in root morphology (Penka, 1965).

Evans (1980) has suggested that the input of energy in the form of irrigation may permit the breeder to shift growth from the roots to the top to increase merchantable yield. Furthermore, this trend would reduce respiratory losses because roots can account for a high proportion of a plant's carbon loss through respiration. In addition, allocating a greater proportion of carbon resources to leaf growth would increase the growth rate (Ledig, 1976). Without irrigation the optimal shoot:root balance will necessarily be less than that where irrigation is practised. Furthermore, on dry sites, Cannell *et al.* (1978) have found a negative association between volume growth in loblolly pine families and high relative shoot-to-root growth.

Nutrient level and soil structure. The response of shoot and root growth to fertilization conforms to the expectations of Thornley's model. High levels of nutrients increase growth of shoot relative to root in both herbaceous and woody species (Figure 8 from Shamsi and Whitehead, 1977, and see Harris, 1914; Turner, 1922; Pearsall, 1927; Mitchell, 1934; White, 1937; Williams, 1948; Troughton, 1955, 1956, 1977; Vose, 1962;

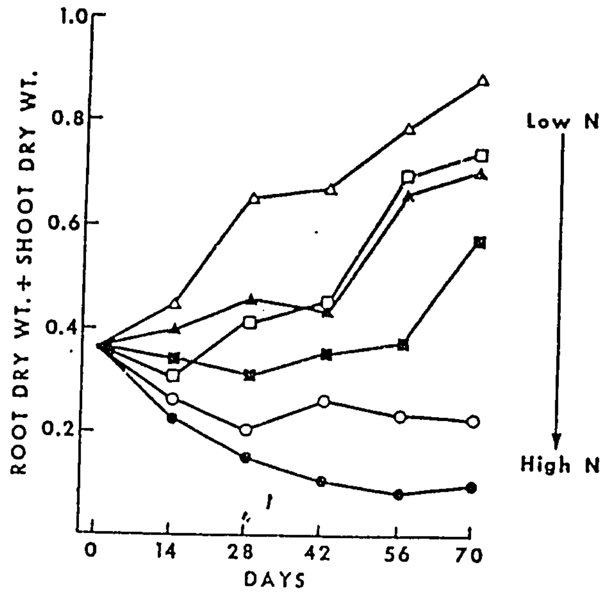

Fig. 8. Change in root:shoot ratio with various nitrogen concentrations in *Lythrum salicaria* (Shamshi and Whitehead, 1977).

Steinbrenner and Rediske, 1964; Davidson, 1969b; Blackmon, 1970; Giertych, 1970; Evans, 1972; Mathews, 1972; Drew *et al.*, 1973; Hunt, 1975; Haines and Dunn, 1976; Stribley and Read, 1976; Will, 1977; Joiner *et al.*, 1980; Maynard *et al.*, 1980). However, in some other examples nutrient level had no effect on the shoot:root balance (for example, Shamshi and Whitehead, 1977; Anderson and Ladiges, 1978; Joiner *et al.*, 1980). Perhaps because the range of fertilizer treatments was not broad enough to cause a measurable response. Potassium is less effective in altering the shoot:root balance than nitrogen or phosphorus (Vose, 1962; Shamshi and Whitehead, 1977; Bouma *et al.*, 1979; Joiner *et al.*, 1980).

Not all genotypes respond to changes in nutrient level to the same degree. For example, the relative shoot-to-root growth of various provenances of Norway spruce (*Picea abies* [L.] Karst.) was affected differently by changes in phosphorus level (Giertych, 1970). In European larch (*Larix decidua* Mill.) fertilization prolonged the shoot growth period (Pineau, 1968), a possible mechanism whereby nutrient level may influence shoot:root ratio in some tree species.

There is less information on the effect of soil structure on shoot:root balance. Root growth is retarded by compaction and lack of aeration, probably because of inhibition of root respiration. As a result shoot:root ratio may increase. In ryegrass and clover (*Trifolium repens* L.), shoot growth was favoured

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against root growth in waterlogged soils (Davidson, 1969b). However, Ladiges and Kelso (1977) found no effect of waterlogging on shoot:root ratio in ribbon gum (*Eucalyptus viminalis* Labill.) or swamp gum (*E. ovata* Labill.).

Biotic competition

The effect of plant population is variable. A greater plant population may increase (Kamel, 1959), decrease (Troughton, 1955, 1956), or not affect the distribution of growth between shoot and root (Troughton, 1956; Rennie, 1974). This variability may result from differential effects of plant population on above- versus below-ground competition, depending on the species and levels of stocking used. Results that show an increase in shoot:root ratio in woody species with increasing nursery bed population, or under grass competition, are suspect because effects are confounded with developmental changes (Fober and Giertych, 1971; Wilson and Campbell, 1972). Changes under interspecific competition seem to be complementary. If shoot:root ratio is increased in one species it is decreased in the other (Troughton, 1955).

GENETIC VARIATION

Species patterns

Shoot:root ratios decrease from the annual to the herbaceous perennial habit, and to seedlings of woody perennials (Table 2 from Abrahamson, 1979, and see Monk, 1966). Tuber crops are exceptions having a high proportion of growth in below-ground organs (Bray 1963; Penka, 1965). Within the woody life form there is a trend for species of early seral stages to have greater shoot-to-root growth than those from later ones. Species like pin cherry (*Prunus pennsylvanica* L.), trembling aspen (*Populus tremuloides* Michx.) and red alder (*Alnus rubra* Bong.), which are geared to temporary occupancy of a site, distribute more growth to leaves and stems than to roots, and they enter the reproductive stage at an early age as contrasted with longer lived species such as beech (*Fagus grandifolia* Ehrh.) and sugar maple (*Acer saccharum* Marsh.) (Zavitkovski and Stevens, 1972; Marks, 1975).

Table 2. Per cent of biomass in vegetative and reproductive organs in herbaceous wildflower species from the eastern United States by life form (Abrahamson, 1979).

Life form	No. of species	Below-ground %	Stem %	Leaf %	Flowers %	Shoot: root
Field annuals	9	14	43	24	20	6.14
Field perennials	24	29	31	28	12	2.45

Habitat related gradients also are observed. Species specific shoot:root ratios increase along gradients from xeric to mesic habitats in both herbs and trees (Bray, 1963; Mooney *et al.*, 1978). Desert species have the lowest shoot:root ratios

(Mooney and Bartholomew, 1974; Evenari *et al.*, 1975). Apparently root morphology may vary as well. For example, from predominantly taprooted, in eucalypt species native to dryer habitats, to shallow fibrous-rooted, in species from mesic habitats (Zimmer and Grose, 1958). Shoot:root ratios may decrease from high values in species at low latitude and altitude to low values in species native to high latitudes and altitudes (Wiegolaski 1975).

Intraspecific variation

Ecovariants. When the pattern of dry matter distribution varies among populations within a species the trends can generally be interpreted as adaptive. For example, two populations of ribbon gum and mugga (*Eucalyptus sideroxylon* (A. Cumm.) Benth.), native to areas with low rainfall, had lower shoot:root ratios (that is larger root systems for their size) than populations representative of high rainfall climates (Zimmer and Grose, 1958; Ladiges, 1974; Pederick, 1976). Seedlings with relatively larger root systems were less susceptible to wilting when water was withheld, and recovered from stress more rapdily than seedlings from populations characterized by high shoot:root ratios (Table 3 from Ladiges, 1974). Similar examples have been reported in a variety of species (Bey, 1974; Baldwin and Barney, 1976; Venator, 1976).

Table 3. Shoot:root ratios and drought damage for 3-month-old seedlings of ribbon gum (*Eucalyptus viminalis*) (Ladiges, 1974).

Population	Leaf material dead %	Plants killed %	Dry weight (mg)	Shoot:root ratio
Dry sites:				
Anakie granite	20.8	10	172	2.22
Anakie basalt	65.1	10	230	1.96
Mesic sites:				
Trentham	69.0	50	189	2.94
Mt Cole	73.0	40	230	2.56

Latitudinal trends in the distribution of growth are quite consistent in tree species. In uniform garden experiments provenances native to northern latitudes have relatively more root to shoot growth than provenances from southern latitudes (Kriebel, 1963; Gordon, 1966; Brown, 1969; Schultz and Gatherum, 1971; Brown and Cech, 1972; Farmer, 1975). Apparently, the proximal cause is photoperiodic. Growth is extended in provenances from areas south of the test location because photoperiods are longer than those to which they are adapted, and/or they are adapted to an inherently longer growing season. While the reverse is true for provenances from areas north of the test location. Shoot growth, therefore, continues longer in southern provenances. And by the time buds are set little time is available for root growth before temperatures become restrictive.

In northern provenances of lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and black cottonwood (*Populus trichocarpa* Torr. et Gray), where

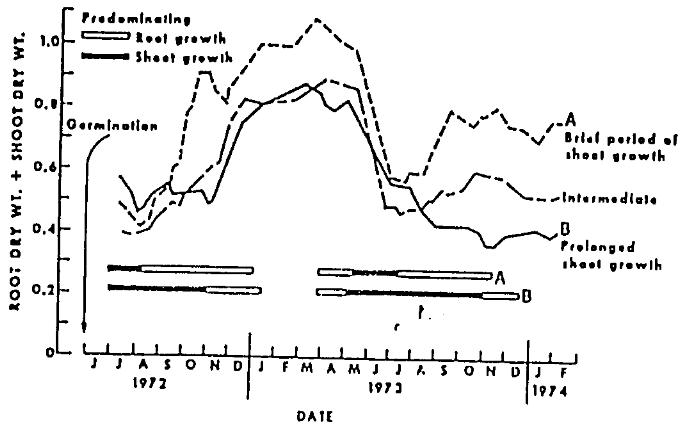

Fig. 9. Seasonal fluctuation in root:shoot ratio in lodgepole pine (*Pinus contorta*) provenances. The longer the period fo shoot growth, the less time for root growth and the lower the root:shoot ratio (Cannell and Willett, 1976).

terminal buds formed earlier, periods of root growth were longer and shoot:root ratios lower than in southern provenances (Cannell and Willett, 1976, and also Sweet and Wareing, 1968). However, more detailed analysis indicated that this compensation occurred in the spring. So for periods measured in years rather than months, the allometric relationships were similar for all provenances of Sitka spruce and black cottonwood (Cannell and Willett, 1976). The pattern of greater root growth relative to shoot growth was retained in lodgepole pine because shoot growth was not as strongly linked to photoperiod. In lodgepole pine current growth was fixed by the number of primordia laid down in the bud the previous year.

On the basis of trends for latitudinal races, and when grown in the same environment, provenances from high altitudes should have greater root growth relative to shoot growth than provenances from low altitudes. In fact, little information is available on relative shoot and root growth with relation to altitudinal transects, and it is conflicting. In lodgepole pine, shoot:root ratio was lower in montane provenances than in coastal provenances (Roberts and Wareing, 1975), but in Norway spruce shoot:root ratio increased with elevation (Holzer, 1966).

Not all differences among provenances are of the fixed or constitutive type. Different populations of the same species may differ in their environmental response, or even in the degree of their response, exhibiting phenotypic plasticity. As an example of differences in environmental response the shoot:root ratio of a Norwegian race of orchard grass increased with increasing temperature, but that of a Portuguese race decreased (Figure 6). For the Norwegian race, which evolved in a climate characterized by summer rainfall, higher temperatures favour water and mineral absorption by roots, so the shoot is free to grow. But for the Portuguese race, higher temperatures signal summer drought, and

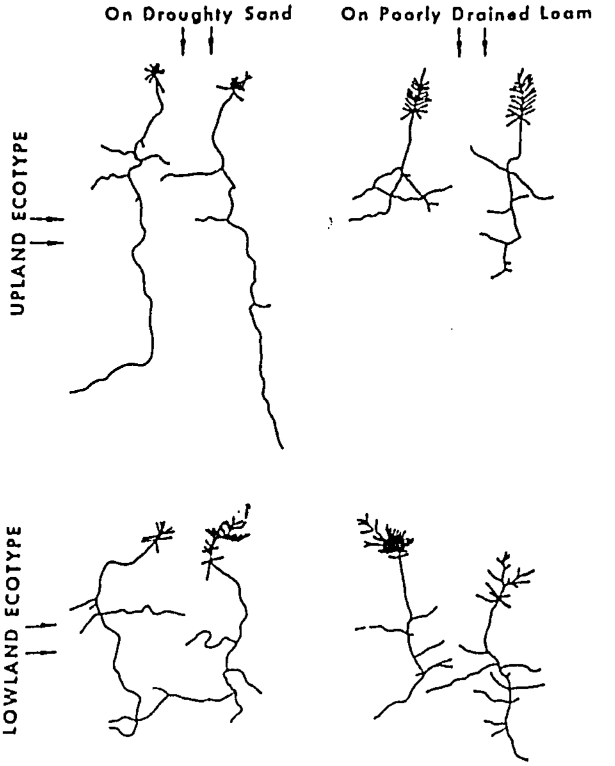

Fig. 10. The root system of seedlings from northern white cedar (*Thuja occidentalis*) growing on the uplands responded plastically to soil moisture conditions in an otherwise uniform environment. Seedlings from parents native to poorly drained lowlands lacked the ability to respond adaptively (Habeck, 1958).

survival depends on an extensive root system. The classic study of Habeck (1958) on upland and swamp ecotypes of northern white cedar (*Thuja occidentalis* L.) has demonstrated genetically determined differences in plasticity (Figure 10, from Habeck, 1958).

In addition to simple differences in the distribution of growth among organ systems, there may be differences among provenances in the way available carbohydrates are used within an organ system. For example, growth of roots may be dominated by formation of a taproot or by a much ramified and fibrous structure. Examples of variation in root morphology include provenances of Scots pine and black cherry (*Prunus serotina* Ehrh.) (Brown, 1969; Brown and Ceck, 1972).

Intrapopulation variation. Much less is known about variation in growth allocation within populations. Ledig and Perry (1966)

and Cannell *et al.*, (1978) found differences among families in loblolly pine. In Cannell *et al.*'s (1978) sample, families having a high relative rate of root growth compared to shoot growth in the seedling stage produced the greatest wood volume at eight years when evaluated on a droughty site (r varied from -0.5 to -0.8), but not on a site with a high water table. Cottonwood clones vary in relative growth of shoot to root and in their interaction with moisture stress treatment (Farmer, 1970). Variation in shoot - root relations among varieties of ryegrass, orchard grass, and tall fescue (*Festuca arundinacea* Schreb.), was also related to differences in growth and yield (Troughton, 1963; MacColl and Cooper, 1967), but gains were predicted for selection of varieties with greater top growth (Troughton, 1977). The only report of heritability uncovered was 0.32 for shoot: root ratio in bread wheat (*Triticum aestivum* L.), and effects resulting from dominance variance were also significant (Kazemi *et al.*, 1978).

REPRODUCTIVE ALLOCATION

The induction of reproductive structures results in a decrease in allocation to vegetative organs (Leonard, 1962). In peach trees diameter increment, or dry weight growth of vegetative organs drops 80 per cent within four years after fruiting (Chalmers and van den Ende, 1975). Fielding (1960) estimated that 7-year-old Monterey pine allocated 16 per cent of current dry weight to sexual reproduction. Dwarf ecotypes of pitch pine (*Pinus rigida* Mill.) grow at almost the same rate as normal pitch pine for their first few years, and the distribution of growth between shoot and root is similar. But the dwarf forms are reproductively precocious and rapidly fall behind in stature after flowering begins (Good and Good, 1975; Ledig and Little, 1979). Dwarfing rootstocks are used to change allocation patterns in fruit trees to favour fruit at the expense of roots. Apparently phloem transport is checked in some graft combinations but, in others, swelling below the graft union suggests that there is an accumulation of carbohydrates in the roots (Sax, 1958). Therefore, more than one mechanism may be responsible for increased reproductive allocations. Rootstock - scion interactions are known (Tubbs, 1980).

In their wild state, annuals devote a greater proportion of photosynthate to reproduction than flowering perennials (Pitelka, 1977; Abrahamson, 1979). Annual allocation to fruit may be very high in domesticated perennials once they reach reproductive maturity; allocation to fruit can be greater than 60 per cent of annual increment in peach (Chalmers and van den Ende, 1975). However, the annual increment is only a fraction of the total accumulated dry weight in roots and stem, so fruit weight is a small proportion of total dry weight. Plants growing in more rigorous habitats and under limiting conditions allocate less to sexual reproduction than those more favoured, although the former may allocate more to vegetative reproduction through increased growth of below-ground parts, such as rhizomes. Thus, in a sample of native North American herbaceous species those indigenous to open habitats allocated 14.5 per cent to flower production and 24 per cent to below-ground organs, but figures for

Table 4. Per cent of biomass in vegetative and reproductive organs in herbaceous wildflower species from the eastern United States by habitat type (Abrahamson, 1979).

Habitat type	No. of species	Below-ground %	Stem %	Leaf %	Flowers %	Shoot:root
Fields	36	24	36	26	14	3.2
Woods	16	40	18	34	8	1.5

those from woodlands were 8.1 per cent to flower production and 40 per cent to below-ground organs (Table 4 from Abrahamson, 1979). Temperate plants growing under rigorous conditions at high elevation may depend on vegetative reproduction, allocating less to sexual reproduction but more to below-ground parts than those at low elevation (Jolls, 1980). However, for species relying primarily on sexual reproduction, reproductive allocation as a proportion of total growth may increase with elevation (Kawano and Masudo, 1980), because less time is available for vegetative growth in shorter growing seasons.

According to some authorities, natural selection may modify wild plants along an r- and K-selection gradient (Solbrig, 1971). For example, dandelions (*Taraxacum officinale* Weber) from frequently disturbed habitats enter the reproductive phase early, while those under severe competition in unmown fields devote considerable growth to leaf production before flowering (Solbrig, 1971); little bluestem (*Andropogon scoparius* Michx.) from older fields, fully stocked with competitors, devoted less to reproduction than those from recently abandoned fields (Roos and Quinn, 1977); and grazed colonies of raspberry (*Rubus hispidus* L.) put more growth into leaves and less into reproduction than ungrazed colonies (Abrahamson, 1975).

APPLICATION TO AGROFORESTRY

In many instances, the distribution of growth in temperate plants, particularly the partition between vegetative and reproductive growth, is regulated directly or indirectly by photoperiod. Photoperiod induces flowering and cues shoot growth cessation by inducing resting buds. Agriculturists and foresters in the tropics and subtropics use many introduced species from temperate zones. The lack of photoperiodic or climatic signals can disrupt their customary growth patterns. The short photoperiods typical of the equatorial regions induce precocious flowering in short-day plants and may prevent flowering entirely in long-day plants. However, these patterns are readily susceptible to modification by breeding. For tropical species, the signals for change from one growth phase to another are less well understood, and the subject is in need of a major research effort.

Responses to limiting factors, such as light, water, and nutrients are adaptive and enhance survival and growth. With intercropping, the patterns of dry weight distribution in understorey crops are likely to change in the direction of increased leaf and stem growth and reduced root growth as a response to

shading. However, root competition for water and nutrients could be compounded because of reduced transpiration under shading, and the net effect warrants study. Certainly, flowering and fruiting will be reduced by growth below an overstorey.

The effect of intercropping on the overstorey is less obvious. Root competition from pasture grasses may increase the distribution of growth to the roots in trees, but once past the seedling stage, competition between roots of annuals and perennials may be less important with respect to dry matter distribution. Species should be chosen that use different rooting zones. If we assume that trees intercropped with low plants will be grown at wide spacing, it seems likely that light will not be limiting to the overstorey and the relative distribution of growth to stem and roots will be greater than when they are grown in a closed canopy.

The types of studies needed to fill our information gap are empirical and practical in nature. In particular, we need more information on the effect of competition, especially comparisons of growth in pure culture versus performance in mixed crops of overstorey and understorey plants.

SUMMARY

The distribution of growth among vegetative parts can be modelled by reference to limiting factors: when photosynthate is limiting, it is used in the canopy and little or none is available for root growth; and when water or nutrients are limiting, they are used at their point of entry, the roots. The mechanism is adaptive because it corrects functional imbalances.

During the period of vegetative growth, relationships among leaves, roots, and stems can be described by the allometric equation, although oscillations around the relationship are observed in response to seasonal demands. The consequence of allometric growth is an ontogenetic change in the proportion of dry matter accumulated in different organs.

Because most changes are adaptive, environmental effects are predictable. High levels of irradiance increase root growth relative to shoot growth, and low levels increase shoot growth relative to root growth. In temperate perennials (and a few tropical ones) short photoperiods signal a cessation of shoot growth, subsequently favouring root growth. In annuals flowering is often keyed to photoperiod and will signal a switch from vegetative to reproductive growth. The effect of temperature cannot be so easily generalized because it depends not only on the temperature regime to which the plant is adapted, but also on the climatic correlates of temperature, such as the association between high temperature and drought in Mediterranean climates, versus high temperature and precipitation in climates with summer maxima. Infertile soils and low water potentials inhibit shoot growth proportionally more than root growth. In addition to changes in plant architecture there are also trade-offs within organ systems; for example, narrow, thick leaves versus broad, thin leaves, as in the sunleaf - shadeleaf dichotomy.

Life form is intimately connected with the shoot:root balance and with reproductive allocation. The shoot:root ratio

in annuals increases with time, and the reproductive allocation has highest priority. In perennials, the shoot:root ratio generally declines with age and reproductive allocations are less than those in annuals. Perennials adapted to a pioneering role are relatively short lived, and generally put less growth into root systems than perennials typical of late successional stages.

Variation in plant architecture within species is well documented. There are examples of population adaptation to latitudinal, elevational, edaphic, and moisture gradients. Variation within populations is less well studied, and estimates of heritability for the shoot:root balance are rare.

In agroforestry, the complex effects of species mixtures on light, water, and nutrients and, therefore, on plant proportions, will depend to a significant degree on the particular combination of species chosen and the number and kinds of plants per unit area. Choice of species will require careful research.

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DISCUSSION

LEYTON - How many of your examples of root:shoot ratios were obtained indoors and how many under outdoor conditions? Also, has your equation taken into account presence versus absence of mycorrhizas, since infection by these can lead to a substantial reduction in root:shoot ratio because improved uptake of phosphorus and water means that the plant can survive with a smaller root system?

LEDIG - In all my own experiments the seedlings had mycorrhizas.

CANNELL - It is difficult to achieve absence of mycorrhizas even in pot-grown plants, and all field plants would have had mycorrhizas.

OLDEMAN - *Hevea* shows rhythmic growth in the upper parts while underground growth is continuous. I suggest a model relating photosynthesis and cambial activity which gives a more complete picture than the model you presented.

LOOMIS - Thornley's model shows a balance depending on a variable resistance, which is difficult to think about. Brouwer's model shows that under conditions of water stress shoots cannot grow but roots can, whereas under carbohydrate stress shoots can grow but roots cannot.

LEDIG - I am not wedded to Thornley's model. It does break down in certain conditions.

HUXLEY - What about complementary changes in root:shoot ratios in mixtures of crops? Do the ratios for both components become higher, since there is often deeper rooting of both components in mixtures?

LEDIG - No. Root:shoot ratio seems to increase in one component and decrease in the other, but the data are fragmentary.

KIRA - There are some dangers in the interpretation of some of the data you have presented. First, it is dangerous to base generalizations on work with young seedlings, since over a period of 20 to 50 years the root:shoot ratio decreases. Second, density of stand is important as, for example, dry matter partition to reproductive organs greatly decreases under overcrowded conditions. Isolated plants should therefore not be compared with plants in dense stands. Third, it is dangerous to depend too heavily on allometric relationships, since even when there is no flowering the log-log linear relationship is not always maintained over long periods of time.

LEDIG - There are many problems with the allometric constant, but it does hold for long periods of time. For example, for 15 years in peach and 55 years in Scots pine. However, you are right that the root:shoot ratio seems to decrease in older trees, although this may be due to our inability to reach the entire root system in older trees.

LOOMIS - Kira raises an important point, in that functions must be balanced (mass of roots × water uptake must equal mass of leaves × water loss) and we should consider the activity of the balance, that is not root mass but root surface, water uptake, and so on.

The ordinary allometric equation deals with the change in the ratio between two different dimensions of an organism with time. However, the changes caused by such growth factors as light, nutrients and water can also be formulated by the same equation. In terms of differential equations, the former is given as

$$\frac{1}{S} \cdot \frac{dS}{dt} \propto \frac{1}{R} \cdot \frac{dR}{dt}$$

where S and R are shoot and root weight, while the latter is

$$\frac{1}{S} \cdot \frac{\partial S}{\partial f} \propto \frac{1}{R} \cdot \frac{\partial R}{\partial f}$$

where f is the level of a certain growth factor. The allometry in the latter sense is much more stable and highly useful.

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PLANT MANAGEMENT IN AGROFORESTRY: MANIPULATION OF TREES, POPULATION DENSITIES AND MIXTURES OF TREES AND HERBACEOUS CROPS

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ABSTRACT. A review is given of some plant management practices that alter dry matter production and distribution, and hence the yield, of trees and herbaceous crops. The topics covered are: (a) the manipulation of individual trees for vegetative and reproductive yield; some principles and methods of tree pruning, and some problems and techniques of fruit tree culture; (b) effects of increasing plant population densities; some general principles involved, and some implications for agroforestry, and (c) the likely effects of manipulating tree/herbaceous crop mixtures; the principles of resource sharing, and some speculations on the management, in agroforestry, of trees grown for different purposes.

INTRODUCTION

This contribution draws together information relevant to tropical agroforestry on some of the ways in which the production and distribution of dry matter, in trees and herbaceous crops can be altered by management practices. Practices involving the time of planting and seasonal phenology are described by Huxley (this volume), and the whole subject of soil management (tillage, fertilization, mulching, use of N_2 fixers, etc.) was dealt with at a previous ICRAF meeting (Mongi and Huxley, 1979). Consequently the scope of this contribution will be limited to (a) tree pruning and tree fruit culture, (b) effects of altering the population density (plants per hectare), and (c) the likely effect of growing various types of trees and herbaceous crops together in mixtures. The emphasis is on spatial rather than temporal aspects of plant management.

The objective is to summarize the main principles involved in the different forms of management, and then to consider some of the options relevant to tropical agroforestry. The merits of the different options will be judged, in this paper, by their

effects on yield per plant and per hectare. This is not to say that it will always be possible, or desirable, to maximize yields per hectare. One of the main objectives of agroforestry is to maintain soil fertility, usually with low inputs, and tropical farming systems need to be designed to meet socio-economic needs, to reduce risks of crop failure, to prevent soil degradation, and so on, all of which may limit the ability to maximize yields per hectare. Nevertheless, it is important to know what the options are for increasing yields.

This paper is divided into three sections. The first deals with the management of individual plants, and concerns exclusively the management of trees for leaves, wood, fruits and nuts. The trees in agroforestry systems are almost bound to demand, or benefit from, individual management, because of their persistence, size and dominance, because they may become too large or unfruitful if unpruned, and because various products may be harvested from them over many years. The second section deals with relevant aspects of the effects of plant population density on crop performance and should be read in conjunction with the second paper (Cannell, this volume) on the responses of different types of tree and herbaceous crops to density stress in monocultures. For many crops this is the best information available on their responses to density stress and so it has to form part of the foundation for speculation on the likely responses of different crops to resource deprivation in the various mixtures contemplated in agroforestry. Also, there may often be some practical and yield advantages in growing particular crops as monocultures, in 'zones', or groves, as part of agroforestry farming systems. The third section considers the principles of manipulating crop plants in mixtures, and presents some speculations on how trees and herbaceous crops may be grown together in different arrangements to influence the yield per unit area of fuel, fodder and food.

MANIPULATING INDIVIDUAL TREES

Horticultural herbaceous vegetable and flower crops can, in some cases, be profitably manipulated as individuals; for example, tomatoes, cucurbits and chrysanthemums. Experiments have shown also that defoliation, shoot thinning and tipping of cotton, cowpeas and cassava, can divert assimilates to the yield portion (as occurs in tomatoes and cucurbits), but for most field crops the increased yield is small per unit of labour (e.g. Ezedinma, 1973). Trees on the other hand, often need to be managed individually. The principles and practices involved obviously depend on whether the product is a vegetative part (wood, leaves, resin etc.) or a reproductive part (fruits, nuts, etc.).

Vegetative yield

Pruning of any sort can alter (a) tree shape, (b) total dry matter production per tree and (c) dry matter distribution within the tree, all according to a general set of principles which need to be understood before judging the outcome and merits of different pruning practices.

Principles regarding tree shape (Fig. 1a). Many woody perennials

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can be trained and pruned to a variety of shapes and sizes quite unlike those they assume in nature. The author's experience with temperate-zone broadleaved trees, fruit trees, and crops such as tea and coffee, would suggest that the morphological responses of many angiospermous trees conform to a general set of principles. However, these principles will need to be tested on any new species used in agroforestry, with due regard to each species' 'architectural model' as defined by Hallé *et al.* (1978).

(i) Pruning stimulates the outgrowth of dormant buds that are often present at old nodes over the whole shoot system.

(ii) Distal buds, near the cut ends, are stimulated to grow more than basal buds ('acrotony') and more shoots grow than would normally do so (sometimes producing more fruiting points).

(iii) The length to which the new shoots grow depends on their position: pruning near ground level produces longer shoots than pruning higher up ('topophysis', Molisch, 1916; demonstrated on apple, Maggs, 1964; *Eucalyptus*, Maggs and Alexander, 1967; explained by Mullins and Rogers, 1971 and Wareing, 1977). Notching the bark on old woody stems stimulates bud outgrowth in the same way as pruning.

(iv) In a sense, pruning reverses tree ageing: the new shoots are 'vigorous', less periodic in growth, have fewer short shoots and greater apical dominance, all possibly resulting from increased supplies of root cytokinins and nutrients per shoot (e.g. peach, Chalmers and Van den Ende, 1975).

(v) There is a tendency for new shoots, derived from resting buds, to grow orthotropically, that is vertically, where branches in that position would normally grow plagiotropically. This is not the case, however, on a few species, such as coffee, where the buds on branches are irreversibly plagiotropic ('propriété fixée', Champagnat, 1954), and cuttings rooted from such branches produce horizontally spreading trees.

(vi) The highest upwardly directed orthotropic shoots attain dominance, especially in nutrient deficient conditions (Wareing, 1968), and left alone these shoots will reconstitute the tree in its juvenile form ('réitération, Hallé *et al.*, 1978).

(vii) Bending shoots horizontally checks their elongation and stimulates buds to grow on their upper sides, especially those buds at the highest point on the arched shoots nearest the root systems ('gravimorphism', Wareing and Nasr, 1961; 'epitrophy', Hallé *et al.* 1978).

Principles regarding dry matter production (Fig. 1b). Pruning usually decreases total dry matter production per tree because leaves are removed, and root pruning has the same effect because new foliage development is checked. However, the decrease in productivity may be less than expected because there can be an increase in net photosynthesis by the remaining leaves, possibly owing to increased sink/source ratios, and because the leaves become better illuminated and receive a greater share of root-originated metabolites (e.g. *Betula*, Sweet, 1966; *Liriodendron*, Madgwick, 1975). Indeed, if only old, shaded foliage is pruned, there may be no decrease in dry matter production at all: basal branch pruning in closed forest stands has little effect on

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volume increment (Zavitkovski *et al.*, 1974), 75 per cent of the leaves of young *Populus* can be removed in early summer without any effect on height growth (Bassman and Myers, 1979) and tea yields can actually be promoted by removing the older leaves (Magambo, pers. comm.). Thus, whenever foliage is to be removed from trees for fodder or mulch, there is an advantage in removing only old shoots, especially from closed stands.

Principles regarding dry matter distribution (Fig. 1c). There are three relevant points that should be made with regard to the effect of pruning practices on dry matter distribution within trees.

First, the proportion of dry matter devoted to bole wood as opposed to leafy shoots depends on the size of the bole cambial sink relative to other sinks. If the trees are kept small, and branching is encouraged, a relatively small proportion of the total dry matter increment will be used to produce bole wood, whereas if the trees are allowed to grow tall, and branching is discouraged (by pruning or competition) a larger proportion of the total dry matter increment will be used to produce bole wood. Accordingly, the proportion of current dry matter increment going to stems in forest trees increases during stand closure (see below); the proportion of dry matter going to thick woody stems is decreased in tea by pruning and plucking (Magambo and Cannell, 1981), and *Prosopis cineraria* (syn. *spicigera*) yields more fodder and less wood when completely lopped than when only partly lopped (Tejwani, 1979). Thus, by manipulating the height and branchiness of trees, one can alter the proportion of dry matter devoted to leafy shoots as opposed to large diametered fuelwood or timber.

Second, it should be realized that the relative growth rates of the stems of trees are proportional to the relative growth rates of both the roots and crowns; that is, there are strong stem - leaf and stem - root allometric relationships; just as there are strong shoot - root allometric relationships. The cambium is an integral part of the total vegetative structure. This fact has been discovered and rediscovered many times: Maggs (1962) suggested that radial growth was proportional to extension growth in apple; Dawkins (1963) and many others in forestry have related bole diameters to various crown dimensions; trunk sapwood cross-sectional areas are positively related to total leaf areas per tree (e.g. Grier and Wareing, 1974); the summed cross-sectional areas of branches at one level can be linearly related to the leaf area above (distal to) that position (the 'pipe model

Fig. 1 (*Opposite*) Diagrammatic representation of some responses of trees to pruning.

(*a*) 1 and 2 illustrate topophysis and acrotony; 3 réitération; 4 dominance and the effect of notching; 5 epitrophy and gravimorphism.

(*b*) This illustrates the partial recovery of open-grown trees from pruning (see text).

(*c*) (i), (ii), and (iii) illustrate relationships between crown size and stem diameter· (iv) allometric relationships with diameter (D) and height (H); (v) effects of root and shoot pruning, and (vi) effects of lopping on height - diameter relationships.

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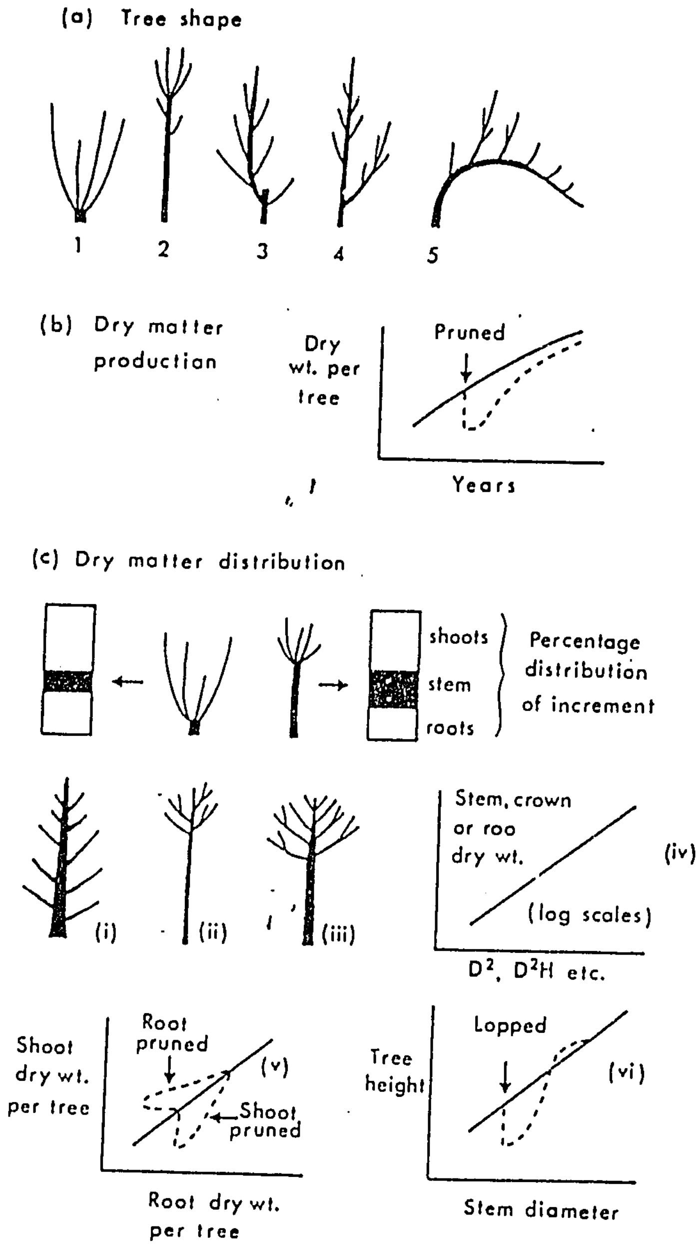
(a) Tree shape
1
2
3
4
5
(b) Dry matter production
Dry wt. per tree
Pruned
Years
(c) Dry matter distribution
shoots
stem
roots
Percentage distribution of increment
(i)
(ii)
(iii)
Stem, crown or roo dry wt.
(log scales)
(iv)
D², D²H etc.
Shoot dry wt. per tree
Root pruned
(v)
Shoot pruned
Root dry wt. per tree
Tree height
Lopped
(vi)
Stem diameter

Figure 1.

theory' of Shinozaki *et al.*, 1964); and many workers have related root, crown or total tree biomass to some function of stem diameter (notably diameter squared times height, Ogawa and Kira, 1977). In short, this means that (a) it is not possible to permanently change the growth rate of one part of the vegetative structure without simultaneously changing the growth rates of all other vegetative parts, and (b) the diameter increment and taper of the stems will depend on the size and disposition of the crowns (Figure 2c).

Third, and following from the above, neither shoot nor root pruning can permanently alter shoot - cambial - root *allometric* relationships. Shoot pruning temporarily checks root growth, and root pruning temporarily checks shoot growth, in both cases in proportion to the amount of shoot or root removed and for as long as it takes the original shoot - root allometry to be restored (apple, Maggs, 1965; orange, Alexander and Maggs, 1971; peach, Richards and Rowe, 1977). Root pruning never diverts assimilates to the shoots, it diverts them to the roots. Severe lopping increases the *proportion* of dry matter taken by new leafy shoots (Maggs, 1960), it does not alter the allometric relationships between roots, cambium and leaves.

Pruning practices. For convenience, pruning practices can be divided into four types, three of which are illustrated in Figure 2: (a) operations which spread the trees laterally, namely, bending and coppicing, or multiple-heading, (b) operations which lop off the main stem and encourage branching, (c) operations which limit branching but leave the main stem intact, and (d) root pruning. Of course, there can be many combinations of these four operations.

Two *tree spreading operations* are shown in Figure 2a. Both bending and coppicing increase the ground cover per tree so that fewer need to be planted, or greater use can be made of those already growing - an advantage if planting stock is in short supply. Also, the vertical shoots can be repeatedly harvested, they are rapidly replaced by new shoots, there is less need to weed than when replanting, and one has all the other advantages of ratoon cropping (Plucknett *et al.*, 1970). Regular coppicing will also keep the leafy shoots accessible for harvesting or browsing, and by restricting the development of the boles and woody frames, coppicing will increase the proportion of dry matter going to new leafy shoots.

However, there is often some difficulty with coppicing systems in promoting the growth of new orthotropic shoots or suckers, because the existing shoots shade the suckers and exercise apical dominance over them. One solution can be to bend the existing shoots horizontally, or to notch them, but if this does not work they will need to be cut off altogether. This means that new growth has to rely entirely on root reserves, which is successful only when the individual stumps and root systems are large, implying a minimum tree size and spacing, combined with timely coppicing and a minimum coppice cycle. There are no rules about this: many willows in Europe can be coppiced annually at very close spacings; tea in the tropics can be coppiced every 4 to 6 years, while sweet chestnut and aspen in temperate regions yield most on coppice rotations of 10 to 25 years (e.g. Berry and

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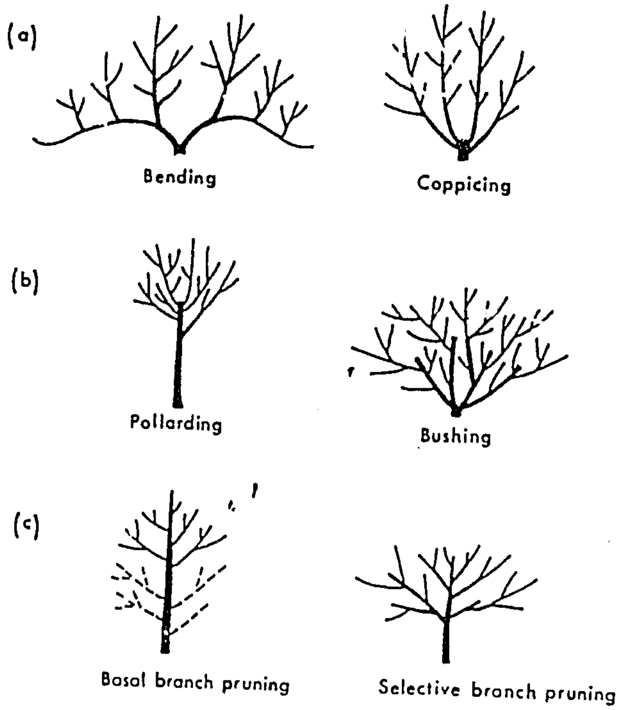

Fig. 2. Diagrammatic representation of trees, illustrating the effects of (*a*) pruning operations which spread the tree canopies, (*b*) lopping, and (*d*) selective pruning of branches.

Steill, 1978). By analogy with grasslands, the optimum cutting frequency may be shorter with increased mineral nutrition. Each species brought into an agroforestry system for fodder or mulch production will need to be tested.

Two basic *lopping operations* are shown in Figure 2b. Pollarding is no more than elevated coppicing: high pollarding will produce trees with a greater potential for wood production and the development of large individual root systems, while low level pollarding and lopping will produce spreading bushes with a greater potential for fodder production. The regrowth of new shoots will be less vigorous with increased distance from the roots. As with coppicing, the optimum cutting frequency to ensure survival and rapid recovery will depend on the species, environment and amount of foliage left. *Prosopis cineraria* growing in dry areas of India can be killed if lopped for fodder more often than every three years (Bhimaya *et al.*, 1964). Bearing in mind that pollarded trees have more reserve capacity left after cutting than coppiced ones, trees which recover poorly after coppicing may recover better after pollarding. However, pollarding itself may be preferred, for instance, to keep the new

foliage out of the reach of animals, and to allow some timber and thick fuelwood production.

Branch pruning (Figure 2c) may involve simply the removal of lower branches, as in intensive forestry (for example, poplars for matchwood or *Pinus radiata* for high quality sawlogs in New Zealand), thereby lessening stem taper and decreasing the number of knots in the bolewood without greatly decreasing bole volume increment. This is a highly desirable operation in forests grown for high-value timber, and yields some small diameter brash and firewood. Alternatively, branch pruning may be highly selective, as in tree fruit culture, restricting height growth, encouraging the development of spreading, shallow, well-illuminated canopies, enhancing fruit bud production (see below) and allowing some light to reach herbaceous crops beneath.

Although *root pruning* checks shoot growth, apparently in direct proportion to the amount of roots removed (Richards and Rowe, 1977), it can have two beneficial effects: (a) enhanced flower bud production, apparently as a direct result of checked shoot growth, and (b) the regrowth of a more fibrous root system, with greater access to immobile soil nutrients, and occasionally, in P deficient soils, temporarily enhanced tree growth. In the case of nursery seedlings, the more fibrous root system produced by undercutting or wrenching helps them to survive after transplanting.

Fruit and nut yield

In general, woody perennials present many more problems than herbaceous crops when grown for fruits or seeds, rather than for some vegetative product; a feature related to their life strategy and evolutionary history. On the one hand woody perennials may need to be intensively managed to encourage them to bear fruits. For example, it may be necessary to overcome prolonged vegetative juvenile periods, poor floral initiation, poor pollination, poor fruit set and fruit shedding. These are all mechanisms evolved to ensure that the potentially very powerful reproductive sinks do not usurp all assimilates and threaten the survival of the perennial vegetative structure. On the other hand, management is needed to limit the fruit load so as to maintain a satisfactory balance between fruit and vegetative growth, and to safeguard future yield.

Consequently wherever trees are grown specifically for fruits or nuts they will generally benefit from intensive care. An enormous amount has been learned about fruit tree culture which could be applied to fruit trees in tropical agroforestry. All that can be attempted here is a summary of the main problems, their causes and possible cures, all of which are elaborated in the following volumes: Ferwerda and Wit, 1969; Williams, 1975; Alvim and Kozlowski, 1977; Tomlinson and Zimmermann, 1978; Brooks *et al.*, 1965; Luckwill and Cutting, 1970; Pereira, 1975; Landsberg and Cutting, 1977.

Juvenile vegetative period. Small, juvenile trees do not flower. For instance, few flowers are produced for 1 to 2 years in open-grown coffee, 5 to 8 years in citrus, and 30 to 40 years in many forest conifers, depending on the cultivar. Recommendations to shorten the juvenile period may include any combination of the

following three general management techniques: (i) to promote early growth by growing the trees on the most fertile patch of soil, applying fertilizers, mulch and irrigation, and removing competition; (ii) to graft on to flower-promoting rootstocks, as done routinely in apple, mango, orange, walnut and many other fruit trees; and (iii) if all else fails, or the trees have been neglected, to partially girdle, root prune, or bend the stems horizontally; all measures that could be used on old trees before they are destroyed for fuel.

Floral initiation. This is inhibited as much by shading in trees as it is in cereals and legumes (Jackson and Palmer, 1977). But, whereas herbaceous crops need to be well illuminated at critical stages of development, many tropical perennials need to be well illuminated all the time, because they initiate flowers over most of the year. The numbers of floral initials produced within the canopies of apple, citrus, cashew, grape vine, oil palm and coconut have all been related to some measure of solar radiation receipt and, in oil palm, shading reduces the proportion of female to male flowers. High insolation must occur during the periods of potential floral initiation and at the points in the trees where the initials form. Some species and cultivars are more light-demanding than others: coconut is particularly shade intolerant, whereas coffee, naturally an understorey shrub, produces some flower buds in deep shade. In fact, for fruit trees like coffe, some shade may be desirable on infertile sites, in order to keep the fruiting load in balance with limited nutrient supplies (Willey, 1975). Also, trees which fruit on young shoots, that is, on the outside of the canopy, like mango, may need less intensive pruning than trees which fruit on old wood. However, for most fruit trees overstorey or mutual shading depresses yield.

Consequently trees grown for fruits or seeds are traditionally grown in the open, widely and preferably evenly spaced, often trained when young to produce a well-distributed 'scaffold' and regularly pruned and 'handled' to maintain low, accessible, shallow canopies with limited within-tree mutual shading. However, precocious fruiting species can also be tried in closely spaced, short-duration systems which are renewed either by cutting down or replanting before the canopy becomes too dense.

The details of pruning for maximum fruit bud production (and adequate fruit size and ripening) differ for different species, but my impression is that many trees used in agroforestry naturally grow either too tall, too upright (with vigorous vegetative orthotropic shoots), or too densely branched, for efficient fruit production. The contrast between an unmanaged and a managed cherry tree is illustrated in Figure 3.

Pollination. With exceptions such as clove and coffee, most tropical fruit trees are at least partially self-incompatible or self-unfruitful. Poor cross-pollination can be a major cause of poor fruit set, for three reasons: (i) the flowers may be poorly developed or 'effectively' receptive for only a very short period (the 'effective pollination period', Williams, 1970), for instance 3 to 4 days in oil palm and mango, 2 days in cashew, 1 day in avocado; (ii) there may be insufficient pollen,

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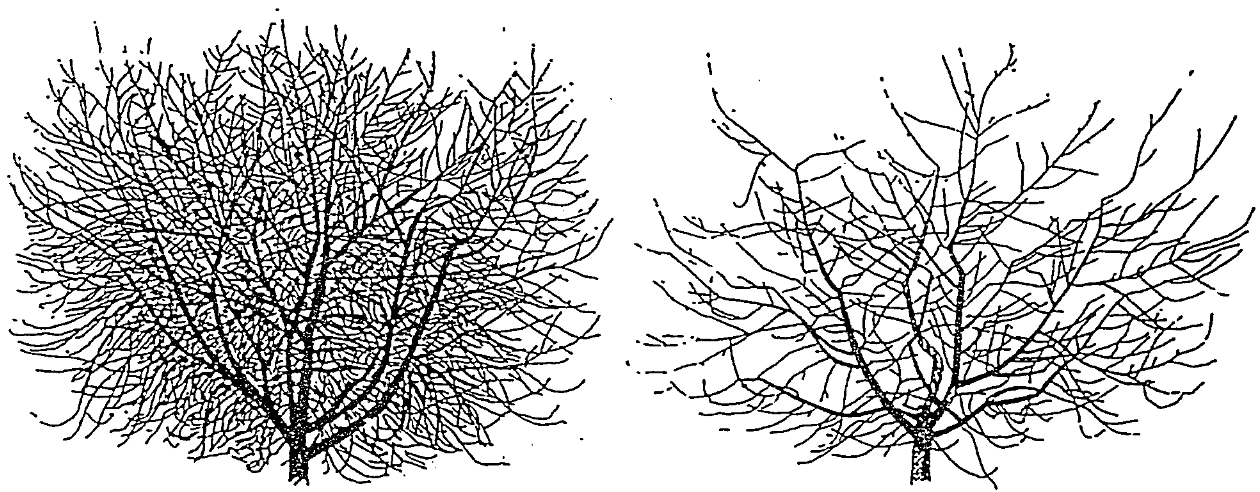

(a) (b)

Fig. 3. Ten-year-old cultivated European cherry trees (cv. Morello) (*a*) completely unpruned, and (*b*) pruned to develop a spreading, open crown favouring fruit production. Taken from Hilkenbäumer (1976)

sometimes due to an imbalance between male and female flowers; or (iii) there may be too few general or specific pollen vectors (e.g. midges for cocoa) or hostile weather conditions for pollen transfer, especially heavy rainfall. The obvious answer to these problems is to select self-fertile or parthenocarpic cultivars, but even these may benefit from measures which enhance cross-pollination. These measures include: growing the trees reasonably close together, interspersing with pollinator trees, withholding insecticides, keeping bees, timely and selective pruning to phase flowering with favourable weather conditions and, in the last resort, supplementary hand pollination.

Fruit shedding. Having obtained a good fruit set, a large percentage (up to 80 per cent, or more) of the fruits can be shed before they mature. June drop of apples in Europe has counterparts in cherelle wilt of cacao, abortion pf button coconuts, citrus and coffee fruit drop 2 to 4 months after anthesis, grape drop 2 to 3 weeks after anthesis and mango drop throughout the period of fruit development. At one stage or more, young tree-fruits seem to be weak sinks for nutrients and carbohydrates compared with the shoot tips, especially when there are synchronous leaf flushes or environmental stresses, especially droughts. The preventative measures are to alleviate water stress and/or internal competition for nutrients and carbohydrates by irrigating, applying fertilizers, removing shade, synchronizing the sensitive stages of fruit growth with favourable climatic conditions, usually by selective pruning, and by removing shoot tips at critical stages when fruit shedding is anticipated (for example, grape, citrus apple, Coombe, 1962; Quinlan and Preston, 1971).

Irregular bearing. Biennial or irregular bearing is a feature of many woody perennial plants, especially as they get older. It is a serious problem in some cultivars of apple, citrus and mango and is a characteristic of nut tree crops such as pecan, hazelnut, walnut and almond. It is especially common in trees with prolonged periods of fruit development, where fruiting overlaps with both vegetative growth and floral initiation for the next season's crop. Cashews, with only a three-month period of nut and receptacle development, usually bear regularly. In nature, irregular bearing may have subtle adaptive advantages, for instance in combating seed predators, and so it should not be regarded as simply a mechanism to balance fruit and vegetative growth. And in seeking explanations for irregular bearing we have to look further than the well-established fact that the fruits utilize reserves and divert assimilates from vegetative parts, particularly the roots (Maggs, 1963; Rogers and Booth, 1964; Cannell, 1971; Chalmers and Van den Ende, 1975; Heim *et al.*, 1979). In many instances it seems that the fruits directly inhibit floral initiation, perhaps by producing growth regulators (apple, Luckwill, 1970; orange, Moss, 1971). One obvious preventative measure is to partially deblossom or thin the fruitlets, but this assumes that one knows how many fruits will be shed, anyway, or lost to pests and pathogens. The best solution is to select regularly bearing cultivars. If that is not possible, selective pruning can be done to obtain a balance of 'on' and

'off' trees, or a balance of 'on' and 'off' branches, for instance on mango (Scarrone, 1969). Heavily bearing 'on' trees may, in fact, use environmental resources efficiently: net photosynthetic rates, and possibly root activity, will be enhanced by the large sink capacities (see Avery, 1975; Richards- et al., 1979), the fruits will meet some of their own assimilate demands, and some assimilates will be off-loaded into seeds, which have lower maintenance respiratory rates than new shoots and roots. The ideal may, in fact, be a half 'on' tree, half 'off' tree system, where fruits are able to draw assimilates from leaves on the other side of the tree (at least one metre away in apple, Hansen, 1977) but are too far away to inhibit floral initiation - a technique developed on some cultivars of apple (Parry, 1974).

Other problems. To complete this list, mention should be made of (i) replant problems possessed, for instance, by peach and citrus, (ii) the need to produce virus-free stock, (iii) the problems of fruit ripening and storage, as well as (iv) nutritional, pest and disease problems.

Concluding remarks. Many of the management techniques developed for fruit trees and palms for plantation culture could be transferred directly and *immediately* to fruit trees growing on tropical smallholdings, with no need for further research. This is important because the fruit trees often occupy the best land; also if there were sufficient improvements in yield and quality, many fruits could become cash rather than subsistence crops, given adequate marketing and processing facilities. Some of the 1000 or more 'new', potential agroforestry fruit and nut trees (Weaver, 1980) may have immediate appeal but there is need for caution: fruit trees are expensive to grow, tend to be labour-intensive, and are clearly problem-prone. A lot needs to be learned about each species before it can be introduced to greatest effect with minimum risk of failure.

MANIPULATING SOLE CROP POPULATIONS

So far we have considered the management of trees as individuals, essentially by altering the relationships between assimilate sinks within the plant. Another way to alter the shape and yield of crop plants is to alter the plant population, by altering the degree of density stress (or environment resource deprivation) experienced by each individual. Again, there is a vast literature on this subject, and my aim is to select only those concepts and examples that are relevant to tropical agroforestry. The accompanying paper (Cannell, this volume) provides a background on the main effects of plant population density on the performance of individuals and communities of different crop types. From that paper, and from the literature on population density effects, I shall, first elaborate some relevant general principles and second, draw some specific implications for agroforestry.

General principles

Asymptotic and parabolic yield-density relationships (Fig. 4a). In general, total dry matter production per hectare, and 'vegetative yield' such as storage roots, wood or leaves, increases with increase in planting density to a plateau, which remains constant regardless of further increase in plant population, barring lodging, disease, drought stress, or in the case of trees, arrested development following severe inter-tree competition early in life (see Cannell, this volume, his Figures 1 and 3). By contrast, 'reproductive yields' such as grains or fruits tend to be greatest at specific plant populations, above which yields decrease and then level off (see Cannell, this volume, his Figures 2 and 4).

Reciprocal yield relationships (Fig. 4b). Once there is inter-plant competition mean individual plant weight decreases (relative to open-grown plants) and becomes inversely related to plant population, often conforming to the reciprocal equation

$$\theta/\text{wt per plant} = (a + b \text{ (plants per hectare)})$$

where a and b are constants, and θ is either 1 for plateau-type relationships and less than 1 for parabolic-type relationships. In both cases θ is approximately the slope of a line relating total plant weight to the weight of the yielded part (that is, the allometric relationship, Willey and Heath, 1969; Harper, 1977). This relationship applies to trees as well as herbaceous plants (Cannell, 1980) and, as long as it holds, then the mean weights of individual plants, or vegetative parts such as storage roots and woody stems, can be manipulated simply by changing the plant population, without decreasing total dry matter production per hectare. Also, the relationship between individual plant weight and planting density, and hence between yield per hectare and planting density, can be found using only two or three spacings, with substantial savings in research costs.

Economic optima (Fig. 4c). The most profitable planting density is not necessarily that giving the greatest yield. Indeed it is almost always less than the optimum for yield when either, the planting material is expensive, as with grafted fruit trees, yam setts (as opposed to yam vine cuttings) and pulse seeds (see Cannell, this volume, his Figure 4), or there is a premium on large sized products, such as graded potatoes, pineapples for canning, and timber for sawlogs (see Cannell, this volume, his Figure 1).

Size-frequency distributions (Fig. 4d). The weights of individual plants within populations are not uniform: plant weight-frequency distributions become positively skewed with increase in density stress, giving a preponderance of small individuals. Tree diameter-frequency distributions are less skewed and can become bimodal when two-tiered canopies develop (Ford, 1975), while height-frequency distributions often remain or become normal in both tree and herbaceous crop stands (Harper, 1977; Mohler *et al.*, 1978).

Self thinning (Fig. 4e). When competition becomes intense, the

smallest individuals or ramets die, often following the relationship between mean individual plant weight and plant population shown in Figure 4e. Although this so-called -3/2 power law of self-thinning may not hold the value of exactly -3/2 in all environments, for plant parts, or for ramets of clonal perennial herbs (Westoby, 1977; Mohler *et al.*, 1978; Hutchings, 1979) it is of some practical value. It defines the maximum number of plants that can possibly exist of a given mean size, so it can be used as a point of reference to determine the degree of stocking and the stocking density at which plants are likely to die because of competitive stress rather than other causes (Drew and Flewelling, 1977; the concepts of limiting tree basal area, Dawkins, 1959; and stand density index, Reineke, 1933).

Rectangularity (Fig. 4f). Per hectare yields can be substantially greater, and occur at higher plant populations, with uniform square or hexagonal planting rather than with rectangular, row or 'hill' planting (Berry, 1967; Willey and Heath, 1969) (see Figure 4f). Competition is a spatial process and will of itself tend to give rise to an even dispersion of large and small plants (Ford, 1975). However, the depressive effect of spatially uneven planting may be small in crops which can spread by profuse tillering or branching, especially in wet, fertile conditions (for example, potatoes and vining legumes). And in many crops, like potatoes, groundnuts and cereals, row planting offers considerable advantages for ease of planting, fertilizer placement, weeding and harvesting, although these advantages will be less with hand cultivation on tropical smallholdings. Finally, where rows are used there can be a benefit in north - south orientation, even in the tropics (Donald, 1963).

Plant environment and habit (Fig. 4g). The optimum plant population is often lower in conditions of nutrient or water shortage than in wet, fertile conditions, and the optimum is lower and less critical for spreading and profusely tillering genotypes as opposed to single stem, determinate or erect genotypes. There can, for instance, be 100-fold differences in the optimum densities for different legume cultivars (for example, cowpea, Erskine and Khan, 1976), and marked genotype - environment interactions, which call for large numbers of local spacing trials.

Plasticity of plant characters (Fig. 4h). Not all plant characters are affected equally by competitive stress, and some effects tend to be species and environment specific. However, some general points can be made, illustrated by Cannell (this volume) as effects on yield components.

Fig. 4 (*Opposite*) Some principles regarding the effects of planting density on the growth and yields of crop plants. (*a*) to (*e*) θ, a, b and c are constants; ρ is population density in numbers of plants per hectare; (*f*) apple data are for years 5 to 8 after planting in western Australia, from Cripps *et al.* (1975), where 1 = square planting; 2 = spaced x by 2x; and 3 = x by 3x. Pea data are for dried peas in England, from Willey and Heath (1969) where 8, 16, and 24 refer to row widths in inches.

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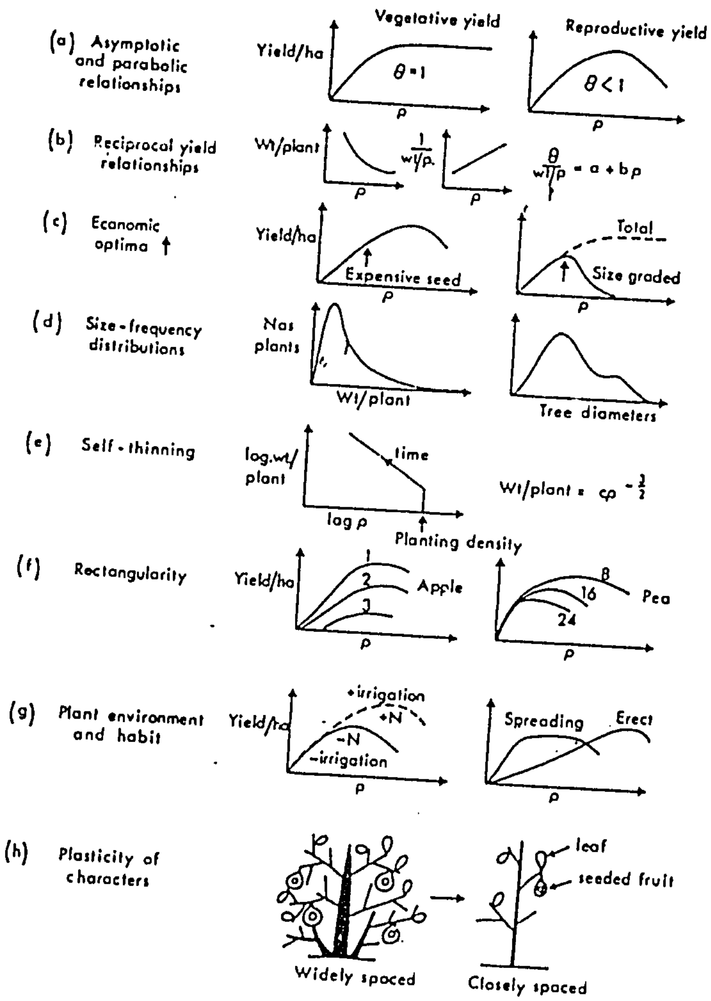
(a) Asymptotic and parabolic relationships
Vegetative yield
Reproductive yield
Yield/ha
θ=1
θ<1
ρ
(b) Reciprocal yield relationships
Wt/plant
1/wt/ρ
θ/wt/ρ = a + bρ
(c) Economic optima
Yield/ha
Expensive seed
Total
Size graded
(d) Size-frequency distributions
Nos plants
Wt/plant
Tree diameters
(e) Self-thinning
log.wt/plant
time
log ρ
Planting density
Wt/plant = cρ^-3/2
(f) Rectangularity
Yield/ha
1
2
3
Apple
8
16
24
Pea
(g) Plant environment and habit
Yield/ha
+irrigation
+N
-N
-irrigation
Spreading
Erect
(h) Plasticity of characters
leaf
seeded fruit
Widely spaced
Closely spaced

Figure 4.

(i) Lateral spread by branching and/or tillering (suckering, sprouting, etc.) is always suppressed by density stress, be it in cereals, potatoes, legumes, bananas or trees. Consequently, all the components of yield associated with lateral spread such as numbers of branch nodes per plant, ears per plant and branch-borne fruits or pods per plant, are all decreased (see Cannell, this volume). But conversely, a greater proportion of the total dry matter is devoted to stalks and stems, and as discussed above, in trees there is an increase in the proportion of the total increment devoted to bolewood.

(ii) Mutual shading further decreases the number of fruits which form on the stems and branches which do develop. The degree to which fruiting points are shaded depends on where the fruits are borne: it is obviously less on wheat than on maize, and less on palms than citrus. Also, the fruiting points most likely to be shaded are those which develop in the axils of old nodes during the later stages of plant development, for instance on indeterminate legumes, or trees which fruit only on 'old' wood.

(iii) Density stress has relatively little effect on the heights of trees and herbaceous crops - they may increase or decrease - but it always greatly decreases the diameter growth of trees (in accordance with the above-mentioned decrease in branching, crown size and allometric relationships).

(iv) The weights of individual fruits, fleshy roots or tubers are decreased by density stress (Cannell, this volume, his Figures 2 and 3) but individual seed weights (for example, nuts, grains and pulses) are characteristically relatively little affected (Cannell, this volume his Figures 2, 3 and 4; Salisbury, 1942; Harper *et al.*, 1970), although exceptions can be found, notably sunflower (Clements *et al.*, 1929).

(v) There is some evidence that the root systems of closely-planted forest and fruit trees tend to be denser per unit volume of soil and grow deeper than those of widely-planted trees (Adams, 1928; Atkinson, 1973). However, shoot/root biomass ratios may change relatively little (Rennie, 1974).

Implications for agroforestry

Solé or mixed cropping? It should be stated explicitly that, for most crops, the greatest yield per hectare is obtained when each individual is under some critical level of 'density stress', that is, deprived of some light, water or nutrients by its neighbours. In agroforestry, where crops will be planted at different times in complex mixtures, it will be almost impossible to ensure that each individual of each crop species experiences its optimum level of density stress throughout its development. For some crops the sacrifice in yield may be small, or may be compensated by other considerations, such as soil protection and weed control, but for other crops this may not be the case, and these crops might be better grown as sole crops at their optimum densities. I would speculate that this could be so for (*a*) trees grown for wood and (*b*) some herbaceous crops grown for reproductive yield.

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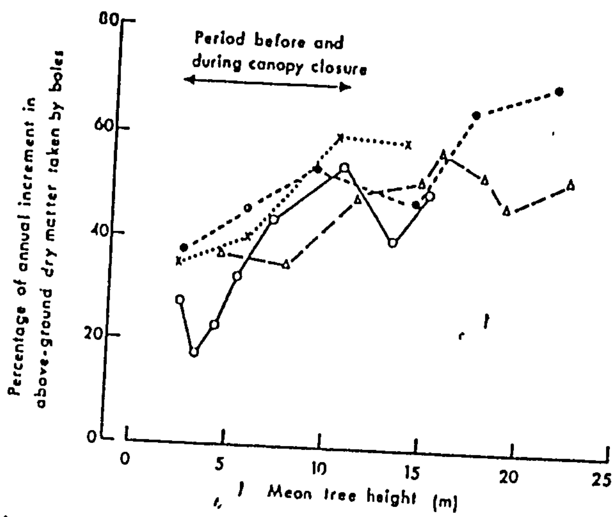

Fig. 5. Increase in the proportion of the annual dry matter increment taken by the stems in temperate forest plantations during canopy closure.
O - *Pinus sylvestris* in England (from Ovington, 1957);
Δ - *Cryptomeria japonica* in Japan (Ando *et al.*, 1968);
• and X - *Pinus radiata* in New Zealand and Australia (Madgwick *et al.*, 1977; Forrest and Ovington, 1970, respectively).

(*a*) Most trees produce more stemwood, and possibly more total wood (stems plus branches; Adams, 1928) per unit leaf area, and per unit of intercepted light, when 'density stressed', that is in forests or groves, rather than when grown as widely-spaced individuals. The proportion of the total annual dry matter increment per hectare taken by the main stems of trees increases from about 30 per cent to 60 per cent during the periods of stand closure (Fig. 5). This is partly because the trees get taller, partly because branching is suppressed, and in some instances because mutual shading suppresses fruiting: as a result the size of the stem cambial sinks is increased relative to the size of the other sinks (shoot apices, fruits and roots). Consequently, if the objective is to produce wood, especially large-diametered wood for slow burning (because the ignition time of wood varies inversely with its surface-to-volume ratio), or for building materials, stakes, tools, etc., then the most efficient way to produce it is to plant the trees in groves or plantations.

It should be added that where the objective is to produce large-diametered sawlogs, the trees need to be widely spaced and regularly thinned, thereby losing some of the benefits of density stress (increased stemwood production per unit leaf area, branch suppression, weed suppression and reduced knot size). 'Taungya' systems of agroforestry offer some obvious advantages here, because many of the above benefits can be provided by the farmer if he cultivates the land between the trees and prunes the lower

branches for fuel and improved light penetration. Obviously these systems have thrived because both the forester and farmer have benefitted.

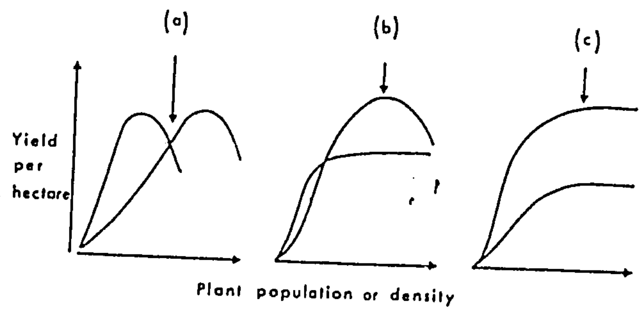

Fig. 6. The optimum plant population (or degree of density stress) for mixtures of (*a*) two crops with reproductive yield having parabolic yield - density relationships; (*c*) two crops with vegetative yield having asymptotic yield - density relationships and (*b*) a mixture of the two. The downward pointing arrows mark the optimum population for each mixture.

(*b*) The problem of obtaining the critical level of density stress needed for maximum yield efficiency is likely to be greatest when growing two or more crops together, each of which has a very different specific optimum population density as a sole crop. This is most likely to occur (i) when growing mixtures of herbaceous crops with reproductive yield, such as grain legumes and maize, (ii) when the crops are planted and harvested at the same time, (iii) when the crops differ in stature and habit, and (iv) when one or more of the crops has a compact habit, and so is unable to spread by tillering or branching, perhaps because it has been selected for high density, sole cropping (for example, some maize and sorghum cultivars). In such cases, it may be impossible to manipulate the total plant population, and the proportions of each crop, so that the overall yield of the mixture on a given land area is as great as the sum of the yields of pure stands of each component, each at its optimum spacing (Fig. 6; Donald, 1963; Willey and Osiru, 1972). In such cases it might be better to grow each component crop in monoculture, if yield were the only objective, as was suggested by Huxley and Maingu (1978) for maize and cowpea in Tanzania.

The problems of maximizing yield will be less for mixtures which include crops with vegetative yield, such as storage root crops, and perhaps also for some cultivars of cereals and legumes which can spread by tillering and branching. This is because these crops have less critical optimum population densities. Indeed, as mentioned above, storage root crops will require only some minimal level of density stress for maximum yield per ground area (Fig. 6). Consequently, there may be less yield penalty in growing, for instance, maize and sweet potatoes together rather than maize and grain legumes.

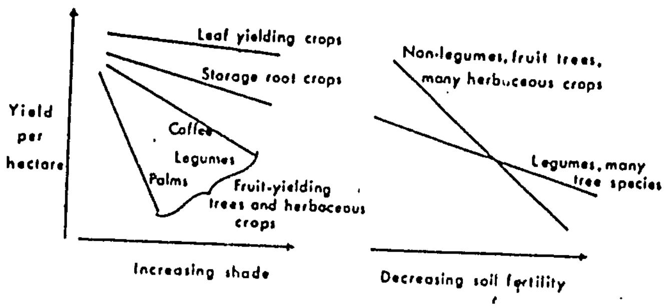

Fig. 7. Diagrammatic representation of general crop differences in response to shading and soil fertility.

Different crop responses to resource deprivation (Fig. 7). The responses of different crop types to density stress give some idea about how they may respond to interference from neighbours in mixtures; although their exact responses will be different, depending on the timing and kind of interference that occurs. For instance, wheat and rice are tolerant of density stress as sole crops, but they are very intolerant of shading during the periods of ear initiation and grain filling. Nevertheless, the following inferences may be drawn from the literature on sole crop population density effects.

First, most fruit-yielding trees and palms are very shade intolerant (for fruit yield). The pruning and management of fruit trees will often be made more complicated by close spacing and, as mentioned above, dense shade will markedly decrease the number of fruits, decrease the size of the fleshy parts, hamper ripening, and probably exacerbate pest and disease problems. Also, anything that hampers individual tree growth will delay the onset of fruiting. This is also the case for bananas under coconuts (Tai, 1977) and density stressed oil palms. Like many plants, oil palms produce fruits only when their vegetative structures have reached a minimum size (Cannell, this volume, his Figure 2), and any form of interference, including pruning, that decreases individual palm growth tends to occur at the expense of fruit production rather than of vegetative growth.

Second, it should be restated that fruit and seed yielding herbaceous crops are also shade intolerant and should, where possible, occupy open spaces, or be able to grow to the top of the canopy in a mixture. Tall or climbing legumes might be better in mixtures than prostrate ones; the ancestors of peas (*Pisum sativum*) were climbers, quite unlike the short statured cultivars selected for monoculture.

Third, the crops that will suffer least from competitive interference, or shading beneath trees, will be those that yield some vegetative parts. The most shade tolerant crops will probably be those yielding leaves, including trees grown for fodder or mulch, and crops like tea, tobacco, forage grasses and legumes. Shading will decrease total dry matter production but this will be partially compensated by an increase in leaf area ratio and shoot - root ratio, ignoring for the moment the soils aspects and other effects of shading (Willey, 1975). Silvo-

pastoral systems are evidently successful in many parts of the world (Tejwani, 1979). It is also worth noting that most trees, especially late successional ones, are very shade tolerant during their juvenile stages and will make efficient use of low intensity radiation (Jarvis *et al.*, 1976) and so will grow satisfactorily beneath tall herbaceous crops such as maize. Coffee seedlings grow better in shade than in full sunlight (Huxley, 1967). Storage root crops are also reasonably tolerant of mutual shading at high population densities and the shading of taller plants. The bulking rates and yields of sweet potatoes, cassava and cocoyams, like those of European potatoes, are regulated principally by the size of the storage sinks, and yields can be unaffected by up to 50 per cent shade in the tropics, provided the conditions during storage root initiation are satisfactory (that is, there are short or cool days, and N fertilizers are withheld; sweet potato, Hahn, 1977; cassava, Wholey and Cock, 1975). Consequently, there may be little yield penalty in growing climbing cocoyams under trees, and sweet potatoes and cassava among fruit or multipurpose trees.

Fourth, crops differ in their responses to poor nutrition, and the harmful effect of competition for light and water may be either diminished or amplified by a shortage of mineral nutrients. As mentioned above, the optimum degree of density stress may be lower under low nutrient conditions. On the other hand, crops which already yield little because of poor mineral nutrition may not suffer much loss in yield as a result of overstorey shade (for example, coffee and cacao, Willey, 1975). And obviously, legumes and other crops that form dinitrogen-fixing symbiotic associations, tend to be more tolerant of N-deficient soils than non-N-fixing crops provided there is adequate P and K, although their capacity to fix nitrogen may be seriously impaired by light deprivation.

MANIPULATING CROP MIXTURES

So far we have considered some of the ways in which trees can be managed as individuals; how different crop types respond to competitive stress; and how competitive stress can be exploited to maximize the yield per unit area of ground. In practice, however, a subsistence farmer may be better able to maximize yields by *avoiding* competitive stress rather than by exploiting it. To do that he needs to alter the relationships between crops in the horizontal, vertical and temporal dimensions so that the different crops share environmental resources of light, water and nutrients (that is, there is annidation, Trenbath, 1976) in a way that minimizes mutual interference and maximizes resource sharing (commensalism, Bunting, 1976). In this section, I shall consider some of the principles governing this form of crop management, that is, the management of crop mixtures, followed by some speculations on ways in which tree crops might be mixed with herbaceous crops to meet some of the objectives of agroforestry.

General principles

De Wit (1960), Donald (1963) and others (see Harper, 1977) developed models to evaluate two-species herbaceous crop mixtures

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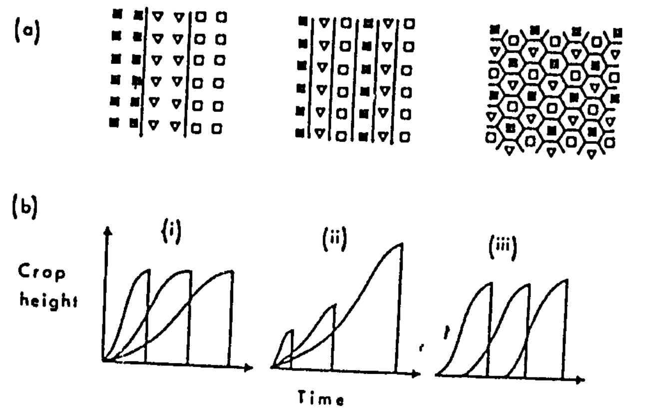

Fig. 8 Differences in spatial and vertical arrangements of three crops. (*a*) Three spatial arrangements with a 5-fold difference in area of interface between different crops (marked with lines). (*b*) Three ways of managing mixtures so that each matures at the top of the canopy (i, ii, and iii as described in the text).

which describe the effects of changing the proportions and populations of the two components. In these models, indices such as 'relative yield totals' or 'land equivalent ratios' that are greater than one indicate that mixtures yield more than their components would as sole crops on the same area of land. These concepts have been helpful in discussions on mixed cropping restricted to two species of herbaceous crops, but only Donald's model copes with the problem of differential optimum populations discussed above (Huxley and Maingu, 1978), and none of the models cope with the complex three-dimensional situation in agroforestry. Consequently, this discussion will be limited to the general concepts and principles of resource sharing in three dimensions, without going into details on inappropriate two-species models.

Resource sharing in the horizontal dimension (Fig. 8a). Environmental resources of light, water and nutrients can be shared in the horizontal dimension by altering the spatial dispersion of different crops in a mixture and by altering the proportions of each crop. Having decided what crops are to be grown in an agroforest, and where they are to be grown (depending on soil fertility, slope, objectives, etc.) one needs to focus on the areas of land occupied by each type of herbaceous crop - tree *boundary* or *interface* and to determine how the yield of each component is altered along each interface (Trenbath, 1976; Huxley, 1981). Appropriate steps could then be taken to maximize the desired yield of the different components by altering their spatial dispersions and proportions as much as possible in such a way as to maximize the area of profitable crop - tree interfaces and minimize the unprofitable ones. Let us consider this further.

The minimum areas of interface between herbaceous and tree

crops will occur when each is grown in monoculture in 'zones' and when fewest different types of crop are grown (Huxley, 1980). The maximum area of interface will occur when there are many crops and each is evenly dispersed in a hexagonal arrangement. Between these two extremes there will be clumped, multiple row, random, single row, rectangular and square planting arrangements giving progressively smaller areas of interface. In this way the area of herbaceous crop - tree interfaces could be changed 3- to 5-fold (Figure 8a; Trenbath, 1976).

The changes in yield of the trees, and of the herbaceous crops growing beneath them, need to be explored, perhaps using the designs suggested by Huxley (1979). Not only will some crops be more shade tolerant than others, but some may benefit more than others from the nutrients in tree litter, any changes in soil pH, water relations, shelter from wind and rain, and so on. In some instances there may be no effects on either herbaceous or tree crop yields, for instance where forage legumes are grown beneath trees on fertile soils. In other instances, herbaceous crop yields may be depressed by allelopathic toxins produced by the trees, or tree yields may be depressed by competition for nutrients, poor mycorrhizal development, or because the trees along the interface are not subjected to competition by other trees. In each study one would need to determine the yield of the herbaceous and tree crops along the interface compared with their yield within similar areas of monoculture (within the stable agroforest system) preferably with some auxillary information so that one could explain the results in terms of annidation, allelopathy or mutual interference for given environmental resources.

Then, by altering the area of each type of herbaceous crop-tree interface it will be possible to alter not only the total yield, but also the balance of yield obtained from the two components. The greater the area of interface, the more opportunity there will be for the dominant component to benefit and the weaker component to be suppressed. Consequently, the proportions of yield taken from the different components will diverge more and more from the proportions 'expected' on the basis of the land area allocated to it (Huxley and Maingu, 1978). Thus, with increase in interface area, more land has to be devoted to the weaker component in order to obtain the proportions of herbaceous and tree crop yield expected.

This approach could, of course, be applied to tree - tree and crop - crop mixtures, but for the latter it is usually too difficult to quantify interface and non-interface areas, and de Wit-type models still serve some purpose if the crops share the same land over the same time period. Also, the optimum design of herbaceous crop mixtures is difficult to predict because the relative dominance of the component species is often itself dependent on the plant populations and proportions in the mixture (Osiru and Willey. 1972; Harper, 1977).

Lastly, I should repeat that the spatial configuration of trees and crops in agroforests will be influenced by many factors other than those considered here. Very likely the soil will be heterogeneous, some trees and crops may thrive only in certain areas, some may need to be near homesteads or boundaries, and so on.

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Resource sharing in the vertical dimension (Fig. 8b). If light is the main limiting environmental resource, then leaves become organs of aggression, and the dominant crop will be that which is tallest. One of the most potent ways of resource sharing is to plant crops so that they each become tallest in turn. Five ways of doing this spring to mind (Figure 8b): (i) by planting crops together which attain similar heights but with different life cycles; (ii) by planting crops together which attain different heights such that the shorter ones mature before the taller ones; (iii) by planting crops at different times; (iv) by planting crops which can climb up the stalks of crops that mature before them; and (v) by minimizing the shade cast by the tall crops, by using erect-leaved crops (for example, maize), by pruning trees or by planting deciduous trees. Baker (1979) describes examples in the tropics where cereals have been mixed so that each spends the latter part of its life at the top of the canopy, and in most instances there is a substantial increase in total yield. By contrast, when cereals with similar stature have been planted and harvested simultaneously, the yields in the majority of studies have been no greater than the yield of the highest yielding cereal in monoculture (Trenbath, 1974).

If we regard the soil as part of the vertical dimension, then we can include here the sharing of soil nutrients and water by planting deep-rooted 'nutrient pumping' trees like some *Acacias* with relatively shallowly rooted crops like millet, sorghum and sesame. And to complete the list we should include the mixing of legumes with non-legumes as a means of sharing atmospheric and soil nitrogen (see Mongi and Huxley, 1979).

Resource sharing in time. If no one crop fully utilizes environmental resources available throughout the year, then yields will be increased by skilfully phasing the growth cycles of different crops. The skill is required in (i) chosing the species and cultivars according to their phenology, stature, habit, product, etc., and (ii) staggering planting or sowing, relay planting, etc., so that soil water resources are fully utilized, the soil is protected from rain, weeds are suppressed, erosion is prevented, crops with reproductive yield are not overshadowed after the onset of floral initiation, and so on (Andrews, 1972, 1974; Baker, 1978, 1979; Fisher, 1977, 1979). Subsistence farmers are apparently very skilled in this way, and much could probably be learned from them (Bunting, 1980; Okigbo, 1980). No more needs to be added here because this subject is treated elsewhere in this volume (see Huxley, p.503).

Tree - herbaceous crop mixtures

Before speculating on some ways in which trees and herbaceous crops might be managed to advantage in agroforestry systems, it is important to recall the many possible objectives of agroforestry beside that of maximizing yield. First, in order to conserve the soil and its fertility it may be imperative to have a minimum number of trees, perhaps deeply rooted ones or dinitrogen fixing ones, and a continuous ground cover. Second, to spread risks it may be necessary to grow low-yielding hardy crops (for example, sorghum instead of maize, or drought-deciduous trees) and also to reorder one's ideal priorities on how much land is

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devoted to food, fuel, fodder and cash crops. Third, to control weeds it may be desirable to grow crops which establish large leaf areas quickly, such as cucurbits and pioneer tree species. Fourth, to further ease the workload, it may be important to stagger planting and harvesting, to grow low yielding but problem free fruit trees, or root crops (which have a high yield per unit of labour), to minimize transport distances and the use of ladders, and to provide shade for animals or to make field work agreeable. Fifth, to control pests and diseases it may be preferable to plant crop mixtures, even if sole crops yielded more, to mix crops with differing heights, smell, colour and susceptibility, and to provide shade (for example, to lessen banana leaf spot or cacao capsid damage). And to these rational objectives may be added the 'irrational' ones of tradition, culture, religion, division of labour within families and so on. Clearly, with so many factors to consider, it would be foolish to offer general management prescriptions. As I have said above, all that can be usefully done here is to consider some of the options with respect to yield per unit area.

Let us suppose that trees were grown in agroforestry systems as multipurpose trees, or for timber, fodder, as planted fallows for fuel, fruit or shelter. For each of these purposes, how could the trees be managed to advantage, and what herbaceous crops might be grown with them, bearing in mind the foregoing discussion on tree pruning, effects of spacing and resource sharing in mixtures?

Multipurpose trees (Fig. 9a). Multipurpose trees, and all the other kinds listed below, should be established by underplanting beneath herbaceous crops such as beans and maize. As the trees grow taller and cast more shade the best companion crops might be 'vegetative' crops such as cassava and forage crops, climbers such as yams, or tall 'reproductive' crops such as bananas. Where possible all tree and herbaceous crops that have 'reproductive' yield should be relatively unshaded or at the top of the agroforest canopy.

Multipurpose trees could be grown as widely spaced individuals, in small groups or rows, but should not be in closed stands if they are required to yield fruits and browse as well as wood. 'Multipurpose' might mean 'multimanagement'; some trees might be pruned for fruits, others lopped for browse, others allowed to grow tall for shade and ground cover; trees for different purposes might be planted on different patches of soil; fruit trees might become 'multipurpose' if poorly managed; some trees might be culled for fuel and continuously replaced; and old trees might be girdled to obtain a last crop of fruits before felling. The management options are legion.

Timber trees (Fig. 9b). As discussed earlier, the forestry enterprise most compatible with tropical subsistence farming is high value sawlog production. Wide spacings and the pruning of basal branches benefit the forester by improving the timber quality and shortening the time to maximum mean annual increment (see Cannell, this volume), and provide the farmer with fuel or mulch and open ground for agriculture. Obviously a wide range of crops can be grown in the early years including cereals and

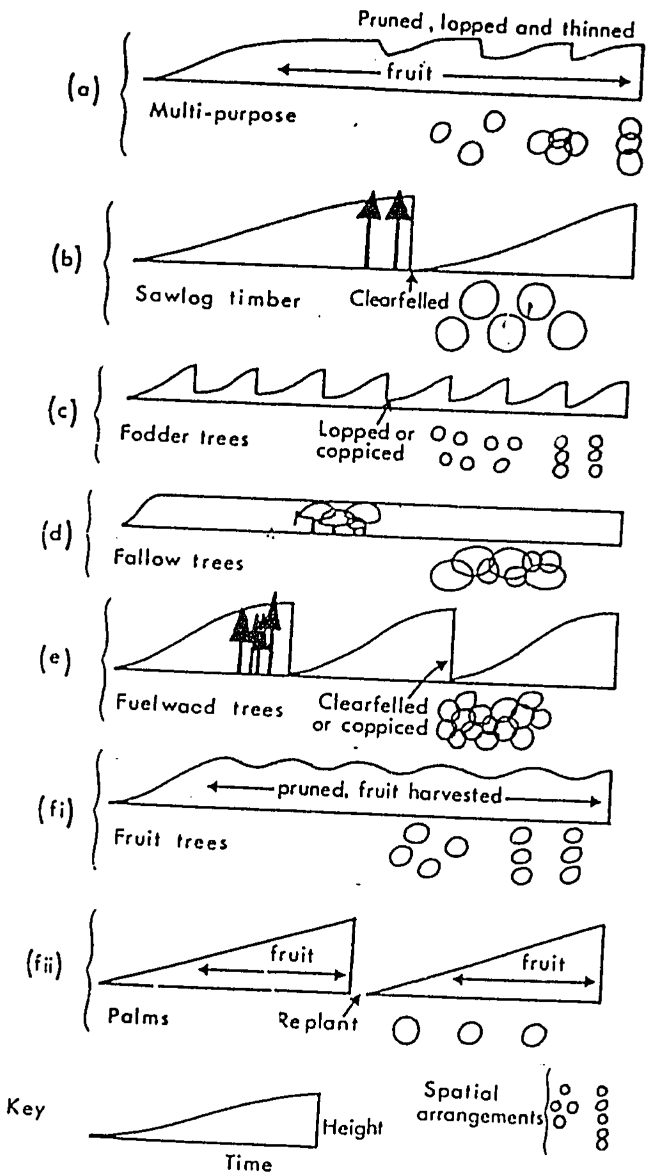

Fig. 9. Diagrammatic representation of the suggested management of trees grown for different purposes in agroforestry. For each tree type a diagram is given of the change in height of the trees with time, and their spatial dispersion at maturity (see text).

legumes, provided the growth of the trees is not severely checked and their leaders are not damaged. In temperate regions, where wheat and barley have been grown among widely spaced poplars, and soybeans among walnuts, tree growth has been checked where crops were grown within about one metre of the trees after the first year. But shallow-rooted crops may be less harmful to the trees than deeply rooted ones; for instance, *Poa* spp. check apple tree growth less than *Lolium* spp. The tree canopy can be kept open by thinning, or by growing seasonally deciduous species, but in most cases the choices open to the farmers will become restricted to vegetative crops and eventually to the grazing of animals.

Fodder trees (Fig. 9c). Trees grown for browse, fodder or mulch should be coppiced, or if animals are grazed beneath them, pollarded. They will recover from coppicing best, and yield most, if widely spaced or in rows or small groups, possibly alongside paths or roads, so that the fodder can be accessed, or the mulch easily carried to nearby fields. Coppicing and lopping could be phased to coincide with the interplanting of field crops such as maize and cassava, in the same way that ratooned sugar cane can be intercropped (Pillay and Mamet, 1978). Short-statured coppice might be grown permanently with bananas or small shrubs and, being a vegetative crop, coppice could be grown with overstorey shade from fruit or multipurpose trees.

Planted fallow trees (Fig. 9d). The species suitable for short forest fallows in shifting agriculture should obviously be highly competitive pioneers, able to grow in nutrient deficient soils, be dinitrogen fixers and soil improvers which will quickly cover the ground and oust weeds such as *Imperata* grass. They should ideally have low spreading canopies, low density wood, large leaves and continuous aperiodic shoot growth, such as the natural pioneers *Musanga* spp. in West Africa and *Macaranga* spp. in south-east Asia. They should also produce large quantities of seeds and be easy to germinate or propagate. Apart from their role as restorers of soil fertility they could be sources of fodder and mulch, and of edible seeds, but their low density wood would not be ideal for fuel.

Fuelwood trees (Fig. 9e). Arguments were presented above for growing fuelwood trees as sole crops, in groves or large clumps, where the trees would be allowed to grow tall and there would be inter-tree competition. There would be little opportunity to grow anything other than herbage crops with them, except during the early years, so evergreen fuelwood species could be used, and the groves could occupy the poorer land with limited animal grazing. The wood should have a high specific gravity, and the trees should be spaced to produce stems and branches of the desired diameters in the shortest time. The outer edges of the groves might be planted with fodder-producing trees, or coppices, which would yield satisfactorily in the shade of the taller fuelwood trees and would also provide some competition for the outer fuelwood trees. This would be better than planting the groves alongside paths or fields or herbaceous crops, or using the edge fuelwood trees themselves for browse.

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Fruit trees and palms (Fig. 9f i and ii). As mentioned above, fruit trees should be widely spaced, yet be within reach of pollinators. Palms, which are circular, benefit from lateral illumination on all sides, whereas angiospermous fruit trees could be grown in rows. The trees should occupy the most fertile land, perhaps near homestead refuse or a source of animal manure, and should be subjected to little competition of any sort. The trees need to be regularly visited for pruning (except palms), harvesting and probably pest and disease control, so there needs to be access, which might be given by planting alongside paths, within animal pastures, homestead gardens or field boundaries. The fruit trees should be small, without overstorey shade (except perhaps unfertilized coffee, cacao and a few shade tolerant species) and should have open canopies, enabling legumes, cereals and bananas to be grown close to them and perhaps climbing plants to be grown on them. Other points regarding fruit tree management were covered above.

Shelterbelts. Where there are strong winds or there is strong advection or wind erosion, shelterbelts increase crop yield, especially of vegetables and legumes. Work on strip intercropping, summarized by Radke and Hagstrom (1976), has shown that the shelterbelts should be perpendicular to the prevailing wind, spaced at intervals 10 to 15 times their heights and should be wind porous. Crops sheltered in this way often grow taller than they otherwise would, produce more dry matter and larger fruit and vegetative yields, mostly because of improved water relations.

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DISCUSSION

KOZLOWSKI - When trees are widely spaced they produce conical stems. They should, therefore, be closely spaced, so that they

produce cylindrical stems, then thinned.

CANNELL - Wide spacing and basal pruning have proved beneficial in agroforestry situations where other products are also required.

BUDOWSKI - Studies in South Africa have shown wide spacing and intensive pruning to be preferable to thinning, but the decision depends on the labour available.

LOOMIS - Dr Cannell's presentation is a most elegant demonstration of a systems type analysis for cause and effect.

CONNOR - Dr Cannell previously asked how systems analysis could handle situations where there was a range of objectives. Systems analysis is the only way in which all the objectives can be met, but for any particular system the objectives must be specified clearly. For example, to maximize the yield of one particular component, with the constraint of no soil erosion and some element of aesthetic function.

BRUNIG - If you take the information of Figure 5 of your paper to infer in Figure 9(b) that options are narrower, you disregard the interactions between the various compartments of the stand as an ecosystem. For example, if you keep your tree density in the early phases as low as possible with respect to your objective functions, you will change the structure and functions of the trees. At the same time, you will change the understorey, and the nutrient, water and energy regimes. There are means available to describe and predict these reactions of the system in ecological and economic terms which would also be useful to agroforestry. An example is the model hierarchy which I described in my paper.

HUXLEY - It is necessary to consider the optimum populations of mixtures separately from optimum populations of sole crops. The optimum population of a mixture is not necessarily the mean of its two components.

RAINTREE - Linear programming is another good tool for handling situations with multiple constraints and multiple variables.

NAIR - The cultivars used in agroforestry are often not those applicable to marginal areas. Experience with high input cultivars has to be used in the agroforestry context because there is as yet no other experience available. This could, however, easily lead to wrong conclusions.

ALVIM - There is now a tendency to use wide spacings, for example box planting in Malaysia. Economic species are not currently used for the box, but this could be done. Planting patterns of this type are necessary for crops which do not withstand much wind, such as cacao.

CANNELL - There are many constraints on spatial arrangements of trees other than those which I mentioned, as you rightly point out.

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PHENOLOGY OF TROPICAL WOODY PERENNIALS AND SEASONAL CROP PLANTS WITH REFERENCE TO THEIR MANAGEMENT IN AGROFORESTRY SYSTEMS

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ABSTRACT. Adapted plant species should be 'matched' in agroforestry so that they complement one another in their time dependence for environmental and management resource sharing. A knowledge of phenological mechanisms and responses has, therefore, considerable practical value.

With tropical woody species the onset of rest may be decided, primarily, by the ageing of leaves. It will thus be regulated by *any* environmental or endogenous stresses that hasten leaf senescence: for example by drought or by fruiting. With such a system renewed vegetative growth can then be centred on times when the environment best suits it, and a generalized growth regulating mechanism of this type is well adapted to the vagaries of tropical climates. It does not preclude additional specific regulation through, for example, photoperiodic control. Tropical herbaceous crop species, or cultivars, need to be selected for particular growing seasons and with special reference to the water budget and to day and night temperatues. Cotton, maize and cowpea are given as examples. Matching the woody and herbaceous components is the final stage of finding effective plant combinations.

Recording plant phenophases in relation to environmental change in the natural, indigenous state is easily accomplished; it provides information about adaptability, as well as possible phenological complementarity. Once genotypes are chosen the next most important concern is plant manipulation and how this modifies phenology. For woody perennials manipulations are limited to relatively few processes; removal of plant parts at appropriate times in order to entrain subsequent phases of growth and flowering is likely to be the most effective. For herbaceous annuals time-of-sowing is the most influential time-related procedure. The need for more information about juvenility - maturity - ageing sequences, and about 'below-ground' phenology for the wide range of multipurpose tree species being used in agroforestry is noted. All agroforestry field research should include simple plant phenological studies wherever possible.

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INTRODUCTION

Phenology is the descriptive study of the behavioural characteristics of organisms in relation to their environment. Phenometry being the quantitative measure of life cycles or specific phenophases. Their value with regard to ecosystems analysis lies particularly in the understanding they provide of plant responses to climate (Lieth, 1970, 1974).

Stone Age man was a good practising phenologist — he had to be in order to gather plant products effectively, and to know where and when the animals he hunted would be feeding. For more modern land users a knowledge of phenological relationships also affords the opportunity to select plant genotypes and management practices in a way which will optimize plant productivity, and/or obtain particular products from the land at the time of season at which they are required.

When plants of different kinds grow together the effective sharing of environmental resources depends on both their spatial and temporal patterns of distribution and actitivy. The spatial relationships have been dealt with in detail by Cannell (see p. 489, this volume). My contribution deals with temporal relationships, but it is not intended as an in-depth review of tropical plant phenology as such (for example, see extensive references in Alvim, 1964; Huxley and Van Eck, 1974; Lieth, 1974; Whitmore, 1975; Borchert, 1976; Alvim and Alvim, 1978; Hallé *et al.*, 1978; Putz, 1979). It is, rather, a summary of some relevant aspects which are briefly related to the design and management of agroforestry land use systems in the tropics and subtropics.

THE BACKGROUND

Different plant species have evolved a wide range of behavioural strategies to enable them to occupy various ecological niches in all kinds of climates. However, in over 200 years of continuing investigations on climate and plant productivity it is only recently that our knowledge of the effects of individual climatic factors on particular plant processes has taken a significant step forward (for example see Rees *et al.*, 1972; Evans, 1975; Monteith, 1975; Cannell and Last, 1976; Alvim and Kozlowski, 1977; Goodall *et al.*, 1979). Much remains to be learnt, however, especially concerning the interactions of climatic factors (see also Kozlowski and Huxley, this volume), and the effects of climatic 'noise'. There is also a dearth of specific information for hundreds of useful species, including many of the multipurpose trees which can be valuable in agroforestry systems.

The tropics and subtropics are exciting places in which to study phenology because of the very wide range of climatic zones which exist, involving aseasonal, wet tropics to highly-seasonal, semiarid and arid regions, with either winter or summer rainfall and a variety of temperature regimes. These provide a complex climatic matrix within which to investigate the behaviour of vegetation or of particular component species. Climatic complexity is increased further by the large season-to-season variations which often exist, as well as the wide range of topoclimatic changes which may occur within a comparatively short distance in broken or undulating land (Huxley and Beadle, 1964).

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Against this background it is not surprising that a number of different hypotheses have arisen to account for the recorded behavioural responses of tropical vegetation to changes in particular climatic variables — especially with regard to tropical trees. In the next section I want first to summarize these.

TROPICAL TREES AND SHRUBS: PHENOLOGICAL TACTICS FOR E. IRONMENTAL STRATEGIES

Exogenous/endogenous controls

Some degree of vegetative growth regulation is a feature of many ligneous tropical species. The initiation of growth has been attributed to the occurrence of rain (Richards, 1952; Holttum, 1953), an increase in air temperature (Murray, 1961; Sale, 1970) or an increase in the level of incoming solar radiation (Alvim, 1964), a decrease in air temperature followed by a rise (Jeffers and Boaler, 1966), and to fire (Hopkins, 1970b). As well as to combinations of these factors which, in any case, are sometimes confounded. The onset of rest has been attributed also to numerous climatic factors. For example, to seasonal drought (Koriba, 1958; Alvim, 1964; Hopkins, 1970a, b), low atmospheric humidity (Wright, 1905), photoperiod (Njoku, 1964; Longman, 1969; Hopkins, 1970a, b) and thermoperiodism — more particularly low night temperatures (Longman, 1969).

Many early workers, in addition to evoking exogenous 'cues' for particular growth and development phenomena, pointed to the apparent existence of endogenous rhythms in tropical woody perennial species (Richards, 1952). A premise which we know, from experimental work in uniform environmental conditions, to be valid (for example, Greathouse *et al.*, 1971, with cacao). Models of plant growth have since been proposed (Thornley, 1972a, b; Borchert, 1973) which would result in such rhythms, based on feedback mechanisms between shoots and roots. Finally, the dependence of many species on photoperiod to promote flowering, even within the relatively small daylength changes which occur in tropical regions, is very well documented (for example, Vince-Prue, 1975).

A flexible strategy for the tropics

What we have been outlining up to now are the tactic which plants adopt to achieve particular adaptive life strategies, that is patterns of growth and development which enable them to survive and to retain their share of resources in association with other plant species. To be successful in many tropical regions with year-to-year climatic variations, these strategies may best depend on alternative sets of tactics. Or at least not be too inflexible if the timing of growth and flowering is to be optimally adjusted to tropical climatic vagaries. Huxley and Van Eck (1974) suggested that such a scheme is fulfilled if there is a general underlying control of vegetative growth which is regulated by the physiological ageing of the leaf canopy as influenced by *any* environmental stress factor, as well as by endogenous factors. Effectively this will regulate the activity of shoot apices by controlling the balance of growth promoting and growth retarding hormones (Borchert, 1978). After the onset of

rest, renewed growth may depend, at least for some species, on no more than the occurrence of the next set of favourable climatic circumstances. This sequence will tend to centre periods of maximum vegetative growth on times when the environment best suits it, either for individual species (see details in Huxley and Van Eck, 1974) or for the woody vegetation as a whole (Fig. 1).

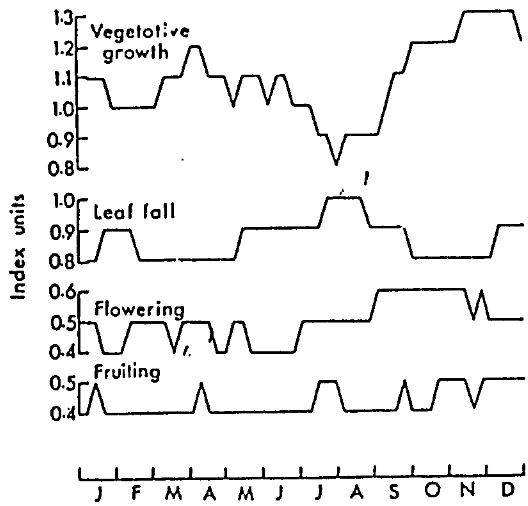

Fig. 1. Overall seasonal trends in vegetative growth, leaf fall, flowering and fruiting of woody perennial species near Kampala, Uganda. Mean values of all recorded specimens from Huxley and Van Eck (1974). The phenology of individual species varied considerably even to the extent of different specimens being out of phase with one another (see original paper for details).

Such a generalized scheme in no way precludes further regulation by additional mechanisms involving specific environmental requirements. For example, daylength (*Hildegardia barteri*, Njoku, 1964) or relief of high plant water potentials (*Coffea arabica*, Browning, 1973).

Many tropical and subtropical species of trees and shrubs flower on current season's wood, and subsequent fruit development is, therefore, supported by a relatively fresh canopy of photosynthetically active leaves. The exhaustion of the plant's carbohydrate and nutrient reserves during fruit maturation will itself then bring on leaf senescence; a sequence which 'entrains' the subsequent cycles of vegetative growth and fruiting (for example, in coffee, Cannell, 1971).

Manipulating woody plants in tropical climates so as to optimize production through 'entrainment' is one of the most demanding of management techniques, and one which is very relevant to the proper use of trees and shrubs in agroforestry systems.

vegetative growth and synchronize the time at which adequate numbers of relevant sinks are created (that is for carbon, nutrients and hormones) in relation to the development of the appropriate sources. This can be done only within the limits of genetic control, and by a limited number of management practices. The first requirement is an appraisal of the 'natural' phenology of the various plant components in the system, the second a stochastic analysis of the extent of between-season climatic variability, the third is an understanding of the degree to which various management practices can affect particular phenophases in the species concerned, and the fourth a knowledge of species interaction. At this stage trying to optimize source/sink relationships in the individual species in agroforestry mixtures, by simple deflowering/defruiting, or by lopping vegetative parts at carefully chosen times, is probably all that can be done.

A major feature of management in agroforestry must be to maintain the appropriate balance between output of products from the woody and herbaceous components. To do this the population and arrangement of woody plants has to be chosen with the future management of the trees/shrubs firmly in mind. The capacity of the chosen woody species to tolerate pruning, lopping, pollarding and browsing, or some other form of removal of leafy twigs or leaves, is fundamental to this. Here the question is not only what to remove, and how much, but *when*? Removal of apical buds from deciduous trees/shrubs which show some form of growth regulation will interrupt natural growth phases least if it is done just prior to a growth extension phase. And the same applies to evergreen species. Such removal of apical dominance during a rest phase can, depending on the species and the timing, bring about renewed growth, although shoot removal in a severely dry season can sometimes result in branch dieback. Species will differ considerably in their response to this treatment depending on the environment they are in, and simple but extensive field tests are necessary. Cultivators of our major tropical woody perennial fruit and beverage crops are well aware of the optimum season for pruning, according to their particular climatic expectations, but this has been optimized only after a good deal of research (for example for tea, Carr, 1972; coffee, Maestri and Santas Baros, 1977).

Removal of leafy shoots or leaves (particularly old ones, Browning, 1973) during a natural vegetative growth period may sometimes help extend the period during which a tree or shrub maintains shoot extension and hence a greater proportion of actively photosynthesizing canopy. Alleviating stress by irrigating and/or applying fertilizers, particularly nitrogen, can also do this.

All these management procedures demand increased inputs, however. Either in terms of skills, or materials. And results depend very much on the timeliness of application. Woody plants can sometimes be grown successfully completely outside their normal climatic range providing sufficiently skilled management is applied. A good example of this is the vine. Cultivars differ but in its natural habitat in Europe or America it is subjected to winter rainfall and winter chilling, and the dormancy of the apical bud in each bud series is broken by a period of cold. Fruiting then occurs on the lateral leafy shoots arising from

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rest, renewed growth may depend, at least for some species, on no more than the occurrence of the next set of favourable climatic circumstances. This sequence will tend to centre periods of maximum vegetative growth on times when the environment best suits it, either for individual species (see details in Huxley and Van Eck, 1974) or for the woody vegetation as a whole (Fig. 1).

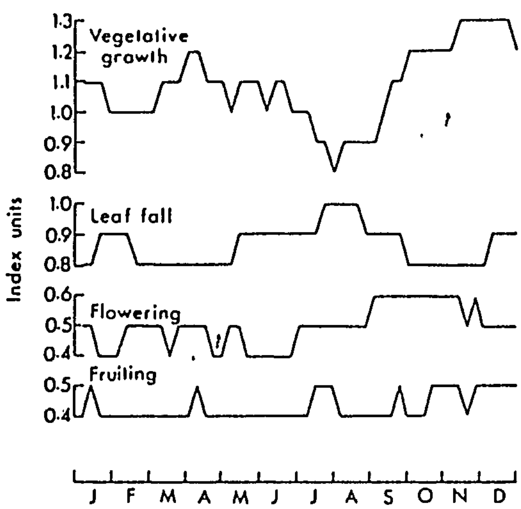

Fig. 1. Overall seasonal trends in vegetative growth, leaf fall, flowering and fruiting of woody perennial species near Kampala, Uganda. Mean values of all recorded specimens from Huxley and Van Eck (1974). The phenology of individual species varied considerably even to the extent of different specimens being out of phase with one another (see original paper for details).

Such a generalized scheme in no way precludes further regulation by additional mechanisms involving specific environmental requirements. For example, daylength (*Hildegardia barteri*, Njoku, 1964) or relief of high plant water potentials (*Coffea arabica*, Browning, 1973).

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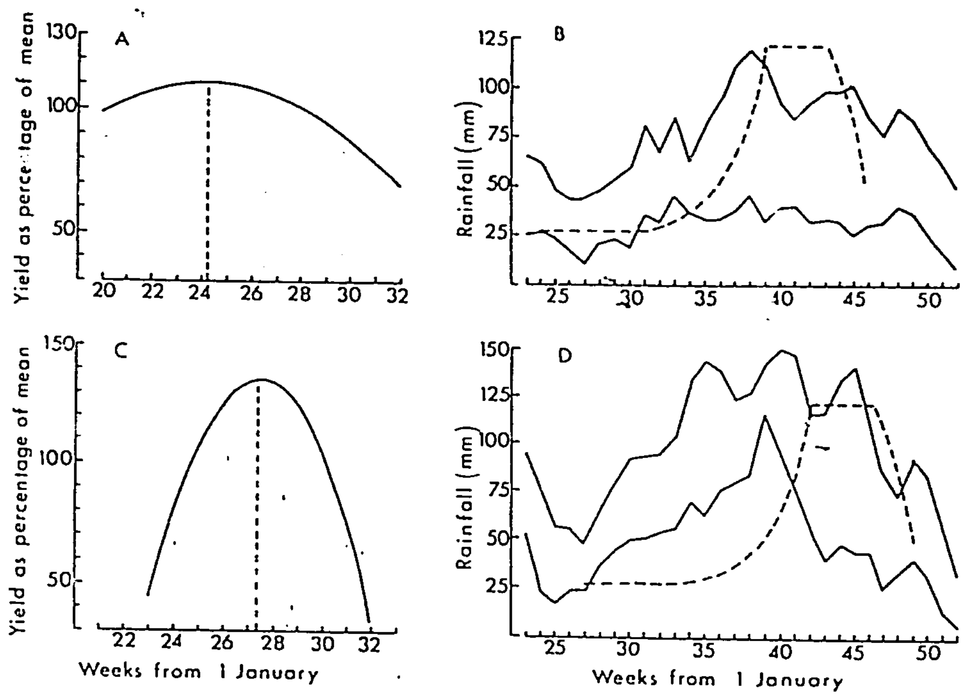
A
Yield as percentage of mean
130
100
50
20 22 24 26 28 30 32
B
Rainfall (mm)
125
100
75
50
25
25 30 35 40 45 50
C
Yield as percentage of mean
150
100
50
22 24 26 28 30 32
Weeks from 1 January
D
Rainfall (mm)
150
125
100
75
50
25
25 30 35 40 45 50
Weeks from 1 January

Figure 2.

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problem to resolve (late planting yield loss); and cowpea, to note the very detailed studies of the climatic factors affecting all stages of growth and development which need to be investigated, through both field and controlled environment studies, if a thorough understanding of the effects of climate are to be achieved.

Cotton and water availability

The classical work done at Namulonge, Uganda, during the 1950s to relate cotton growth and development with water use and availability is a well-known example of matching a crop's needs to a major climatic factor (water), using a stochastic approach (Rijks, 1967).

Rijks defined the optimum sowing date, or period, as the time during which a crop must be sown in order to be likely to experience the most favourable combination of factors that are relevant in obtaining maximum yield. In agroforestry the complex of factors involved must of course also include the interactions — biological and managemental — with one or more woody perennials and, perhaps, with other crop species. In fact, no single environmental factor decides yield and even if the rainfall/evaporation regime is seen as a major influence, there are others of considerable significance. For example, with cotton, the incidence of pests and diseases and the effect of climate on these is always a crucial issue; and solar radiation and the temperature regime are clearly important, even though they have been less well studied.

Figure 2 shows, from some of the earlier work, how yield and the water regime were related at two specific sites; presenting the data in such a way that the probability of receiving rainfall at these sites is clearly brought out. The result of this work, by the then Empire Cotton Growing Corporation, enabled cotton breeders and agronomists to select cultivars for particular climatic areas with much more precision and understanding then would otherwise have been the case.

Maize and heat units

Maize provides another good example of a crop species where yield is highly dependent on timely sowing, as numerous field studies have shown (Cooper, 1975). Indeed, this restraint is commonly found with many long-season tropical crops grown under summer rainfall regimes. With maize, at least, this is partly due to the plants' needs for continuous, relatively high, ambient air temperatures, and partly due to the adverse effects of cool soil temperatures, especially in the seedling stage (Cooper, 1979).

Fig. 2 (Opposite) Change in yield with change in sowing date and rainfall pattern at a station with unreliable (Kawanda) and reliable (Bulindi) second rains. A - yield and sowing date for Kawanda. B - 1:1 confidence limits of rainfall at Kawanda during the cotton season and estimated crop water requirement (broken line). C - as A, for Bulindi. D - as B, for Bulindi. After Manning, unpublished. From Rijks (1967).

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Growth, development and maturation of maize have been found to be broadly correlated, for any particular cultivar, with the number of 'heat units' received. In view of the complex relationships between climatic factors and plant growth and development which detailed investigations invariably uncover (see cowpea, below), it seems remarkable that the relatively simple integration with time of mean temperature above a base can provide a means for predicting the duration of various stages of plant development and the time to final maturation. Even more so when it is clear that in tropical areas the heat balance is very variably correlated with incoming solar radiation, because this relationship depends on the weather in the previous period and factors affecting net radiation and its partition into sensible heat and evapotranspiration (Huxley, 1973). Nevertheless, for maize and other crops, agriculturists do find the heat unit concept a useful albeit somewhat crude tool, and it has been the subject of much evaluation (Arnold, 1959; Wang, 1960; Allison, 1963; Brown, 1963, 1969; Dijkhuis, 1971; Caprio, 1974; Carr, 1977).

Measuring the integration of temperature with time can be both cheap and efficient, for example by using the sucrose inversion technique (Berthet, 1960; Lee, 1969; Jones, 1972) with, perhaps, a 'roving' statistical sampling as suggested by Wilm (Rieley *et al.*, 1969). There is much to be said for such a pragmatic approach to measurements in predictive phenology and we need to simplify techniques and adapt them to be less costly.

In agroforestry the effect of the trees or shrubs on the environment of the associated agricultural crop species can be highly relevant. Changes in soil temperature being a case in point. However, each situation has to be considered carefully. For example, although low soil temperatures can be detrimental to the early growth stages of maize, with soya and other grain legumes unduly high soil temperatures at germination are to be avoided (Singh, 1975). The situation in any agroforestry system will be complex, and it requires detailed study in relation to time of season and the stage of growth of accompanying crops, using all the available information that can be gleaned from the literature.

Cowpea and integrated climatic response

Extensive studies both in the field and in controlled environments have contributed to our knowledge of phenological responses to climatic factors for this species. It provides a good example of the value of combining these two experimental approaches (see Kozlowski and Huxley, this volume). Yield potential in cowpea, as with other grain legumes, is critically affected both by the development of the plant's vegetative structure and the initiation, growth and maturation, at the appropriate times, and for the optimum duration, of the reproductive elements. These processes are markedly affected by daylength, day temperature and night temperature (Huxley and Summerfield, 1976) (see Figure 3).

Daylengths below the critical will shorten the vegetative phase of the plant affecting adversely the potential number of fruiting points which can develop; warm day temperatures can increase vegetative growth in the period up to flower initiation

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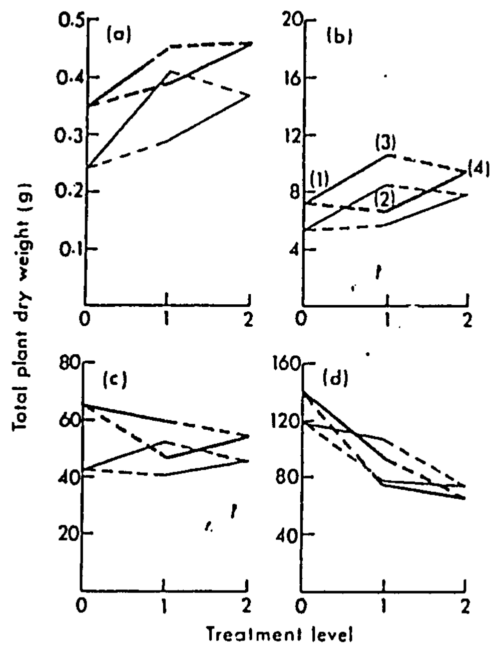

Fig. 3. Effects of treatments on dry matter production (g $plant^{-1}$) of cowpea cv. K 2809 at various stages of growth. (*a*) and (*b*) - Pre-flowering 11 and 25 days after sowing. (*c*) - Early/mid podfill 47 days after sowing. (*d*) - Final harvest 77 to 105 days after sowing. In these interaction diagrams the solid thick lines represent the effect of raising the night temperature (——) and dashes that of raising the day temperature (---) in the 13 h 20 daylength. Equivalent thin lines represent these effects in the 11 h 40 daylength, thus the relative positions of the various day-night temperature combinations (°C) are denoted by (1) for 27-19, (2) for 33-19, (3) for 27-24 and (4) for 33-24, as indicated in (*b*). From Huxley and Summerfield (1976). This was one of the early, significant results of a programme initiated by P.A. Huxley and the late A.P. Hughes in 1971 at the Plant Environment Laboratory (PEL), University of Reading, UK, (funded by the British Overseas Development Ministry), which has subsequently expanded to cover investigations on the climatic responses and the nitrogen nutrition of several grain legume species. Readers interested should write direct to the PEL.

but also shorten the period of seed maturation; warm night temperatures can reduce the period to flower initiation. Further work (for example, Stewart *et al.*, 1980) has helped to explain the detailed effects of climate on flower and fruit development. Warm days can reduce the number of nodes at which peduncles are

formed, they increase the number of peduncles aborting or growing poorly, as well as the number of flowers and pods which abscise. Cool nights following warm days increase flower abscission, but cool days followed by cool nights enhance flower retention.

Resolving the climatic needs for all the complex stages of growth and development of plants as complicated as the grain legumes, in which nitrogen supply is additionally dependent on a symbiotic association and interaction with rhizobium may seem a hopeless task. But the results of a combined approach of laboratory, controlled environment and field work has now enabled us to determine the pattern of programming and response for this group of plants to a point where it is feasible to fit the species and cultivars so far investigated to specific environments and production systems. Or, conversely, to arrive at reasoned explanations for their climate-related success or failure on any one site, or in any one season (Summerfield and Bunting, 1981). This type of detailed knowledge will clearly not be available for all but a few of the species of interest, but whenever such information can be obtained it will help to make the design of agroforestry systems infinitely more precise, their management more rational, and the outcome more predictable.

The agroforestry situation

These three examples — cotton, maize, and cowpea — illustrate, in increasing detail, how complex the many stages of growth and development are and, in no small measure, the reason why in the field it is often far from easy to explain the gross effects of weather. Furthermore, the *time* at which environmental changes are imposed is, in many cases, critical in relation to particular development phases of the plant. Thus the complex environmental interrelationships affecting the phenology of the woody and herbaceous species in an agroforestry mixture will not always be easy to identify or to quantify. Nevertheless, as our knowledge of the influence of one agroforestry plant component on another builds up, through tree/crop interface studies, a useful level of prediction is likely.

One other point. Many of our most successful crop plant selections are not just those well adapted to grow, flower and fruit vigorously in any particular climate but probably, also, those less likely to suffer from environmental stress. For example, with cowpea growth cabinet studies have shown that, in terms of overall seed yield, some cowpea cultivars are insensitive to daylength changes, or to night temperatures, or to both (Huxley and Summerfield, 1976; Summerfield and Wien, 1979). Cultivars of herbaceous crop plants which are high yielding but have a small genotype × environment interaction (G × E) could, perhaps, be the safest choice for agroforestry systems, particularly where marked temporal microenvironmental changes are likely to be imposed on the lower storeys.

THE VALUE OF STUDYING NATURAL PHENOLOGICAL STATES

Plant phenological studies can be of the simplest kind, involving only a series of observations of the plant accompanied by meteorological and soil data (soil water status and soil temperatures, if possible). Obviously more sophisticated measurements

Table 1. Although completely interdependent (*a*) aerial growth, (*b*) root growth, and (*c*) flower and fruit development can usefully be considered as each progressing through separate steps of phenophases. These will occupy different real-time periods and sequences will overlap. In agroforestry phenological complementarity involving the tree/agricultural crops implies optimizing the sharing of environmental resources throughout the growing season so that minimum stress is imposed on any plant component at critical stages of its growth and development as represented by the steps listed.

(*a*) AERIAL GROWTH (Time sequence for (*a*) ↓)

Initiation of buds/leaf initials.
↓
Stem growth
↓
Leaf expansion
↓
Maturation of leaf → Branching (repeats main sequence)
↓
Leaf senescence
↓
Leaf fall

(*b*) ROOT GROWTH (Time sequence for (*b*) ↓)

Root initiation
↓
Root growth (A) (elongation and formation of root hairs) → Branching of roots.
↓
Root growth (B) (secondary thickening)
↓
Cessation of root growth

(*c*) FLOWER/FRUIT DEVELOPMENT (Time sequence for (*c*) ↓)

Formation of flowering wood
↓
Flower/inflorescence initiation
↓
Flower bud development
↓
Flower bud dormancy
↓
Anthesis
↓
Pollination
↓
Fertilization
↓
Early fruit growth
↓
Fruit maturity
↓
Fruit ripening

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can be made to help elucidate specific plant responses. For example, one might wish to check plant water potentials, or bud temperatures, and so on. For the current level of agroforestry research a weekly or fortnightly record of the state of vegetative growth (shoot growth occurring or not), leaf fall, flowering, the presence of fruit and whether or not root extension is occurring in the topsoil, may well be sufficient. Table 1 gives a more complete list of phenophases and it serves also to remind us of the complex and parallel series of steps which have all to be completed for any plant to achieve maturity.

There is a very extensive literature relating types of tropical vegetation to particular climates (e.g. Ellenburg and Mueller-Dombois, 1967; Walter, 1973, 1977) and, apart from hot, wet, aseasonal climates, a rather important division needs to be made between climates with rain during the cool season, and those receiving mono- or bimodal rainfall in the hottest part of the year; either as a consequence of a true monsoon-type air circulation, or through the north-south transition of a convergence zone (winter or summer rainfall climates). This is because a considerable body of evidence suggests that perennial woody species, and grasses from these two types of climate may often possess somewhat different growth regulation syndromes.

Woody species adapted to winter rainfall regions have often developed a vegetative growth regulation mechanism which is broken, naturally, by a greater or lesser amount of winter chilling. Chemical means (for example, using di-nitro ortho-cresol), or end-of-season defoliation can sometimes achieve the same effect (see Ruck, 1975 for fruit trees). Moving such species to summer rainfall areas may, obviously, bring problems. Some of our promising species of multipurpose trees (for example, *Ceratonia siliqua*, *Brosimum alicastrum*) originate in winter rainfall areas and this should be taken into account when including them in trials in summer rainfall climates. Some simple comparative phenology should quickly indicate whether there are any difficulties.

The reverse process of moving summer rainfall species to winter rainfall areas involves less a problem of growth regulating mechanisms than of achieving optimum temperatures for carbon fixation, distribution and utilization during the time of available water supply.

Some tree species useful in agroforestry appear to be very widely adapted. For example, species of *Acacia* such as *A. tortilis*, see Kazmi (1979), or *A. albida*, see Halevy (1971); *Ficus benjamina*, *Schinus molle*, *Grevillea robusta*, and some *Eucalyptus* species, see Food and Agriculture Organization (1976), to name but a few. Foresters are well versed in 'provenance testing' but appropriate selection procedures for multipurpose species to be used in agroforestry should be carefully borne in mind, and some evaluation of the genetic fitness or flexibility of different species needs to be undertaken. The separation of genetically and environmentally induced phenological responses is critical (Flint, 1974), but work on potential agroforestry tree components is not well advanced and only fragments of information are available (for example, Peacock and McMillan (1965) for American *Prosopis* and *Acacia*, and Halevy (1971) for *Acacia albida* in Israel).

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In such investigations not all woody species will show obvious indications of non-adaptability in the form of an out-of-sequence vegetative dormancy or growth flush, but their phenological behaviour may still provide some evidence of unsuitability. For example, an increase in frequency of growth flushes (for cacao, Sale, 1970) is just such an indicator. As may be early leaf senescence/leaf fall, early or intermittent flowering/fruiting, and either premature or unduly delayed fruit maturation. All that is needed to obtain such data is a carefully conducted set of field observations and some meteorological data. If the phenology of a woody species is carefully studied in relation to the climate in its area of natural distribution some useful pointers immediately become available as to its management in other, supposedly suitable climatic zones.

PHENOLOGY AND PLANT MANAGEMENT IN AGROFORESTRY SYSTEMS

Phenological complementarity

Much of what has been said so far has emphasized the importance of the behaviour of the woody component in an agroforestry system. Because at maturity these are, almost invariably, the dominant partners in an intercropping situation with herbaceous crops the selection of appropriate genotypes is a crucial one. This choice, with an eye both to possible resource sharing capabilities as well as the potential for microsite enrichment and environmental amelioration is, clearly, the first management consideration once production outputs have been decided upon.

The choice of an agricultural crop is, in practice, likely to be limited to that which the local population, or established markets, require. But within these limitations, phenological compatibility can be sought. The important variables being the length of the growing season, the time of sowing in relation to the environmental resources likely to be available, and the natural phenophases and/or potential management treatments (such as lopping) of the trees and shrubs. The various kinds of temporal relationships which can occur (crop sequences) are set out in Figure 2 of the paper 'Comments on agroforestry classification: with special reference to plant aspects' (see p.161, this volume).

Some tree species, for example *Acacia albida*, produce a leafy canopy *prior* to the onset of rains and lose these leaves during the early part of the rainy season (Felker, 1978). This enables crops such as millet and groundnuts to be grown around or even beneath the trees, where they can derive benefit from top soil microenrichment, but environmental resource sharing is otherwise separated in time. This almost complete temporal separation of growth periods is an ideal one, but there are probably only limited opportunities to modify the natural phenology of most woody species to any extent through management practices in order to simulate this.

Optimum yield of vegetative parts will be obtained if flowering and fruiting are avoided. For example, the usable yield of *Leucaena leucocephala* (fodder, fuelwood) could, perhaps, be increased by some 20 to 30 per cent if sterile or scantily-fruiting cultivars could be found. However, to maximize total yield, including fruits and seeds, it is necessary to optimize early

vegetative growth and synchronize the time at which adequate numbers of relevant sinks are created (that is for carbon, nutrients and hormones) in relation to the development of the appropriate sources. This can be done only within the limits of genetic control, and by a limited number of management practices. The first requirement is an appraisal of the 'natural' phenology of the various plant components in the system, the second a stochastic analysis of the extent of between-season climatic variability, the third is an understanding of the degree to which various management practices can affect particular phenophases in the species concerned, and the fourth a knowledge of species interaction. At this stage trying to optimize source/sink relationships in the individual species in agroforestry mixtures, by simple deflowering/defruiting, or by lopping vegetative parts at carefully chosen times, is probably all that can be done.

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these apical buds. In summer rainfall tropical regions fruiting can be brought about on the shoots arising from lateral buds in the axillary series, if apical dominance is removed by pinching out shoot tips (Shalitin, 1973). Such complex management procedures are unlikely to be of much use in handling multipurpose trees in low input agroforestry systems, however.

Long-term changes

The changes which occur in woody plants over the longer term have also to be considered. That is, the changes from juvenility to maturity and, finally, to various stages of ageing. Borchert (1976) points out that the various aspects of physiological ageing can best be understood by considering them as consequences of the increasing complexity which arises when viewing the tree as a growing system.

Although the onset of flowering in herbaceous plants is related to early growth rate (number of leaves), the extent of the juvenile phase in woody perennials can, in practice, be unduly delayed by such practices as early pruning or an excessive supply of nitrogen. Some degree of environmental stress is therefore likely to promote early flowering. The process of ageing in plants in general (Wareing and Seth, 1967; Carr and Pate, 1972; Woolhouse, 1972) and its morphological expression in trees in particular (see Wareing, 1968) is now fairly well appreciated. In agroforestry systems it is the juvenile phase of the woody component(s) which is most likely to be dominated by associated agricultural crops and, during this period, special care is needed to ensure phenological compatibility, as well as spatial regulation, if the trees, shrubs or vines are to be properly established. 'Taungya' practices take these facts into account (for example, Buchele and Conn, 1981). In some circumstances, an optimum solution may be reached by adjusting the geometry of the system with time. For example, by sequential whole-plant thinning, or the increasing removal of stems and branches from the woody species in an originally thickly planted stand.

BELOW-GROUND PHENOLOGY

Root systems and root growth and activity in relation to agroforestry are discussed by Huck (elsewhere in this volume), and in several recent general reviews (Lyr and Hoffman, 1967; Sutton, 1969; Cooper, 1973; Drew, 1979, 1980). Some emphasis does need to be given, however, to the *time* at which different activities occur.

A consequence of a constant allometric relationship between roots and shoots would be an alternation of root and shoot growth (see Ledig, this volume), although, in practice, a measure of overlap in time is to be expected. However, the mechanisms which initiate a phase of root elongation in tropical woody perennials are not clearly established. And whether a root elongation phase precedes a leaf flush, and is cut short by this, or whether it occurs subsequent to leaf flushing, may depend on the species concerned. Certainly, present field evidence is inconclusive (Huxley and Turk, 1976). It is a matter of considerable practical relevance in agroforestry mixed cropping because in order to understand, and optimize, such management practices as

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cultivation, fertilizer application and pruning, lopping and browsing, an appreciation of the state of activity of the roots of the woody components is essential.

Another feature of below-ground phenology should be mentioned. Many of the most promising multipurpose trees are legumes (National Academy of Sciences, 1980) and effective nodulation and dinitrogen fixation is important if they are to play their full role in a productive and sustainable agroforestry system. The various factors which can help to optimize dinitrogen fixation in herbaceous legumes are well established (Roughley, 1980), but much less detail is known about the woody species of the family. In particular the extent, time and duration of nodulation and fixation phases in trees. In this respect we have to consider, also, the possible symbiosis with mycorrhizas (Redhead, 1979), the presence of which have been shown to enhance the dinitrogen fixatio activity of rhizobium (Daft and El-Giahmi, 1976). Also the possibilities of free-living dinitrogen fixers associated with the rhizosphere (Dobereiner *et al.*, 1972a, b) may be of some considerable significance.

In seasonally arid regions where tree/shrub species are showing distinct growth phenophases, the activity of associated micro-organisms is also likely to be a periodic phenomenon, perhaps occurring within relatively short time scales. As with the state of activity of roots, we need to be aware of at least the broad outline of not only what is happening but *when*, if we are to make the most of compatible plant associations in agroforestry systems.

SOME CONCLUSIONS

The choice of appropriate plant genotypes which fit not only the climatic limitations of the site but also match one another's resource demands is a critical factor in optimizing both productivity and environmental benefits in agroforestry systems. This applies to all plant components, but it is especially important for the woody ones which are not easily changed. Unfortunately, many of the woody species we are now interested in are comparatively little studied. Phenological complementarity should be a major objective in the design and management of agroforestry land use systems. Once the genotypes have been chosen with this in view then herbaceous species can be regulated to some extent through manipulation of time-of-sowing and woody perennials through the removal of parts.

Phenological studies, including the collection of meteorological data, are indispensible and should accompany all agroforestry field investigations. These should be of two complementary kinds in any particular environmental situation. First, observations of the free-standing, untouched plant. Second, experiments involving various types of simple management treatments. The indiscriminate collection of data is merely time wasting, but careful observations of plant behaviour will undoubtedly help to explain both the level of environmental adaptability of the plant species concerned, as well as the opportunities they may offer for temporal resource sharing in any agroforestry system.

More detailed approaches to phenology/phenometry are

likely to have a place once preliminary plant component selection has been done. For example, treatments designed to test the capacity for changing the entrainment sequences of a woody species (or cultivars/selections) and to modify times of flowering/fruiting, timing of plant part removal in order to optimize offtake or, combined with herbaceous crops, time-of-sowing experiments. Such trials are all relatively simple to design and carry out. Table 1 reminds us that they may not be so easy to interpret, however, because of the complexity of plant growth and development. The phases of these are not only highly interdependent, of course, but may proceed along different real-time sequences. The objectives of phenological study must be clearly defined and, in the case of agroforestry, will usually be limited by practical goals rather than a desire to understand the plant's whole set of relationships with the environment.

We should always remember, too, that an appreciation of the levels of phenological adaptability to the environment, and complementarity in an agroforestry system, is but one part of the understanding required to evaluate that system holistically. The short- and long-term time dependent factors involved must include those related to management and socioeconomic considerations.

A PLATE illustrating this paper is elsewhere in this volume.

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DISCUSSION

CANNELL - Opportunity exists for increasing yield by avoiding competition in time. I would suggest that the emphasis is on yield as opposed to growth in agroforestry systems.

HUXLEY - Resource sharing in time is essential but with trees the first management choice is the genotype. In agricultural crops resource sharing in time is equally vital, but the additional management option of 'time-of-sowing' can help optimize this. Yield or growth, or both, may be affected by time-dependent stresses; it will depend on circumstances. Many trees seem to have conservative growth strategies. In nature, they flush or flower sooner or later than we would wish when they are cultivated. Optimum strategies for yield in cultivation may not be the same as for survival and reproduction in nature.

LEYTON - While discussing the time of flower production to what extent can you relate this to insect problems, particularly pollination?

HUXLEY - There is a need to look into when exactly the tree starts to initiate flowers and the character of the wood on which this happens before actually relating these to insect problems (pollination or pests). In coffee, for example, bud dormancy is regulated by temperature and water stress.

LAMPREY - In dry regions the great majority of the trees and

shrubs are insect pollinated. This is true for the herbaceous plants, except grasses and palm trees which are wind pollinated. Wind pollinated plants flower first and then the insect pollinated ones. Grasses also come into flower at different times and grow very quickly. Root growth is genetically programmed. It goes through stages which are related to the above-ground parts.

BRUNIG - The phenology of seemingly uniform plants is affected by fertility and climatic factors; for example by water availability. Do you consider stress to be an important factor?

HUXLEY - Individual plants have basic endogenous rhythms, but there will be a definite response to a particular stress depending on what it is, to what part of the plant it is applied, and when.

BRUNIG - Timing of events in plants is conservative and based on survival mechanisms.

HUXLEY - It is certainly important to record the phenology of untouched, free-standing plants in their natural environment before any manipulations are carried out.

BUDOWSKI - It would be useful if we could obtain a better understanding of the environmental or management triggering mechanisms which promote particular phenophases. Classification of plants on triggering effects would greatly assist in management.

CANNELL - In my view there are many more opportunities to increase yield by phasing crops so that they share environmental resources in time rather than by manipulating them in space. It is important to fill the year not just with growth but with yielding activities. To do this effectively, particularly critical stages of crop development may need to coincide with specific conditions. For example, high light intensities will be needed by most herbaceous and tree crops at the time of floral initiation in order to establish sinks for potential yield. And these critical periods of floral initiation and fruit setting will be shorter in determinate crops than in indeterminate ones.

SECTION FOUR

PART 4D

The tree/crop interface

or

Simplifying biological/environmental study of mixed cropping agroforestry systems.

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PART 4D

CONTENTS

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(Also circulated as ICRAF Working Paper No. 13).

The tree/crop interface

- or simplifying the biological/environmental study of mixed cropping agroforestry systems.

Introduction

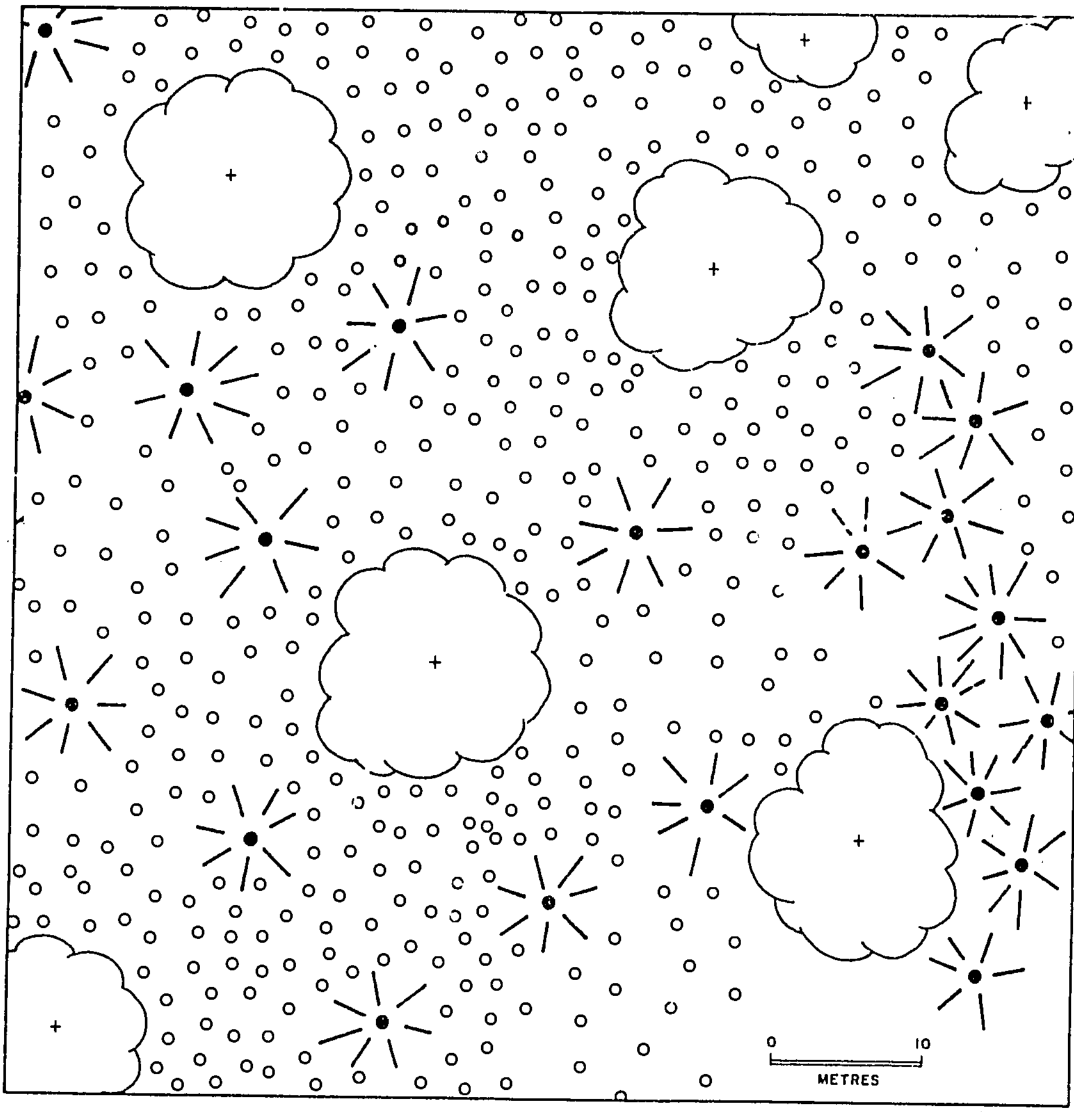
Agroforestry land use systems are relatively complex and the analysis and understanding of them, even if just in biological and environmental terms, can be difficult. Figure 1 shows a plan view of an agroforestry system, well-established in Costa Rica, that involves 3 plant components. There are many examples of much more complicated systems, some even involving up to 20 to 30 species in an extremely complex space-time continuum with a multitude of interactions.

The multistoried system in Figure 1 consists of *Cordia alliodora*, as an upper-storey timber tree, which is generally self sewn and relatively widely scattered; *Erythrina poepigiana* in the mid-storey, which is established from large cuttings and used to provide shelter, shade and nitrogen-rich mulch; and *Coffea arabica*, the understorey, planted in relatively close-spaced rows as a cash crop. In this example all three species are woody perennials.

Such an indigenously-evolved system needs first of all to be described in detail. But how, then, is it to be further studied in order to develop an adequate enough knowledge for its improvement and development? On what basis can proposals for optimizing some or all of the output products be made? How is the best management of the *Erythrina* determined? And so on. To reach such answers some evaluation of the effects of each species on the growth and development of the others is required, and of the influence of existing or optional management practices. This can be done either by *in-situ* investigations or from studies made in specially-planted experimental plots.

A sufficiently detailed analysis of the responses of the component plant species to major environmental limitations (water, light, nutrients) can be carried out *in-situ* using relatively little space, although some level of instrumentation is usually required. This is basically a study of how the environmental resources are shared and to what extent. And under what circumstances species interfere with one another. An excellent example of such a study is that conducted to investigate the effects of shade trees on tea

Figure 1. Plan view of a 3-component, multistoried system. Varying distances are involved between the same species and between any two component species in this relatively complex form of land use.



K E Y

Species A - a tall tree.

Species B - a small tree or shrub.

Species C - a low growing agricultural crop.

in Kenya, which can serve as a model for this kind of approach.(see refs).

In some more complex systems the relative importance of a whole range of different factors relating to the plants, the environment and the interactions between these may first be examined through the use of multivariate analysis of one kind or another (see refs). Nor is it difficulty to modify the existing field situations and devise a programme to investigate the effects of changing selected management variables in the overall *in-situ* situation.

Such investigations, following initial description, will help to establish the main plant-to-plant interactions and the seasonal environmental resource-sharing patterns and limitations. But how can this information then be further elaborated and tested in simple easily-managed, experimental layouts? If we are starting with a potentially useful, but previously unknown mixture of plants (trees and crops), or a list of potential candidate species, the same problem arises. How do we obtain the necessary details and yet contain the size and extent of the experiments?

The tree-crop interface

In Figure 2 the heart of the problem is shown in the lines at A-C, B-C and A-B. These are the *interfaces* between the three plant species in the mixture: *Cordia/Coffea*, *Erythrina/Coffea*, and *Cordia/Erythrina*. If we can understand what is happening at the three interfaces then we have gone a long way towards understanding how the system is operating. We might also want to investigate the intra-species interactions for *Coffea* as well, in order to complete our picture. Certainly, in screening the potential "Physiological combining ability" of selected tree/crop species mixtures during the early stages of an agroforestry research programme the possibilities of limiting the size of the investigation in this way, whilst still obtaining highly extrapolatable information, should be very attractive.

Figure 3 reminds us that there are both above- and below-ground interfaces, the influences of which, of course, extend further than shown in either direction and include a complex set of interactions relating to radiation exchange, the water balance, nutrient budgets and cycling and shelter and other microclimatic modifications (see Figure 4).

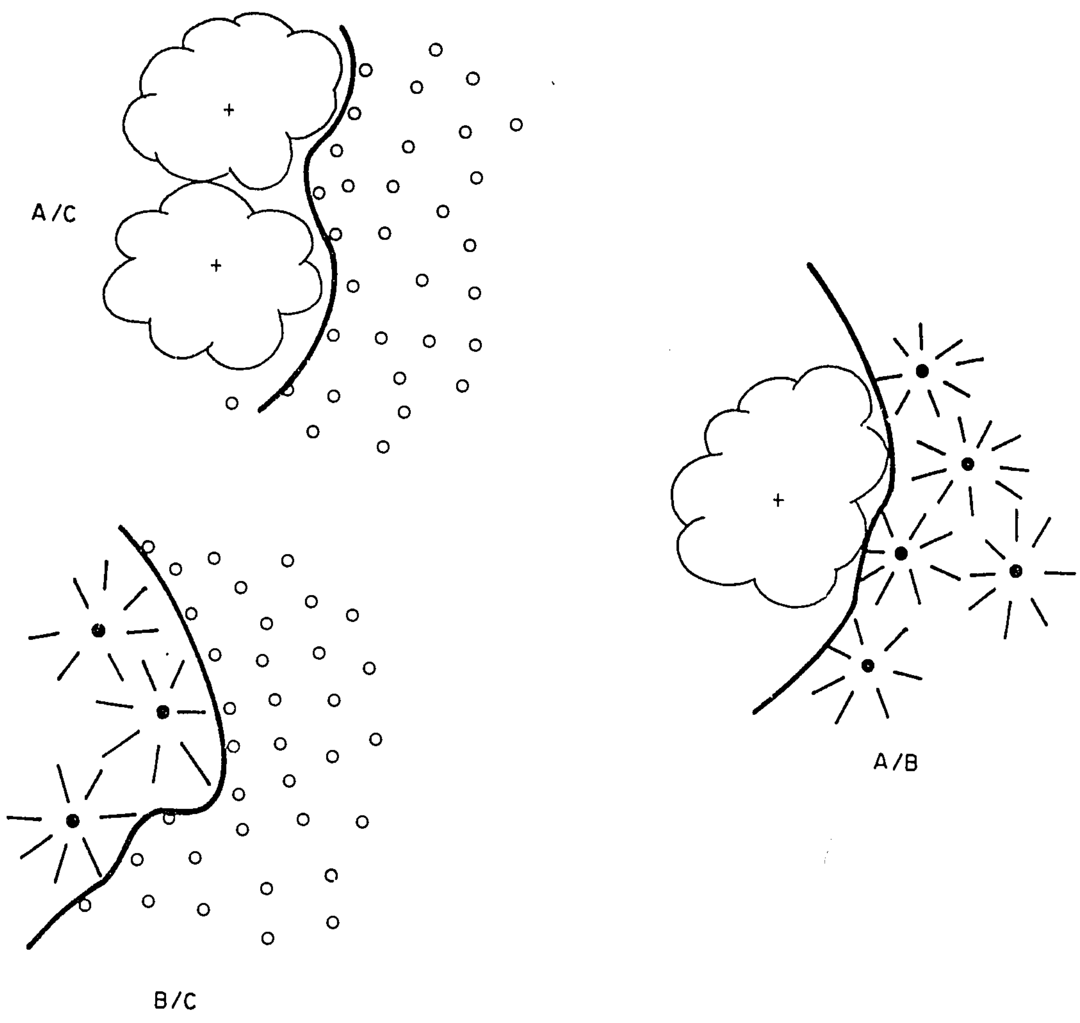
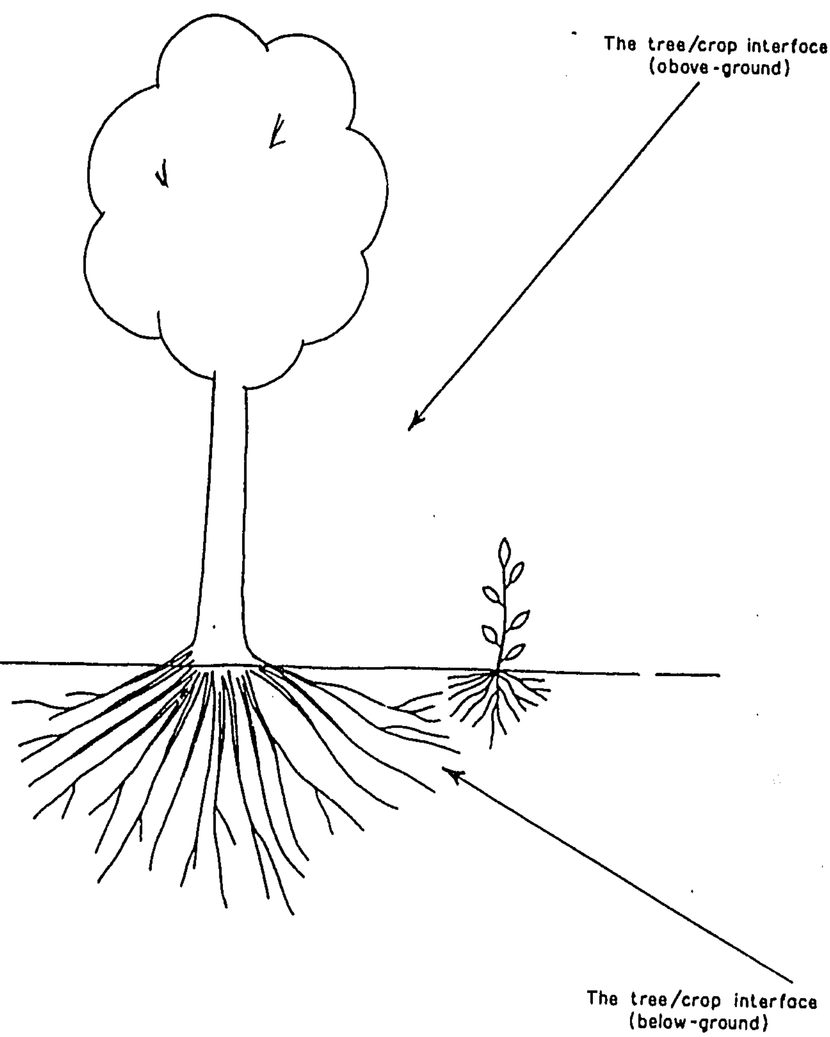


Figure 2. The key to understanding the complex agroforestry system shown in Figure 1 - the interfaces between pairs of component species. It may also be of interest to examine the sole crop interactions (A/A, B/B and, certainly, C/C).

Figure 3. A tree/crop interface - at its simplest



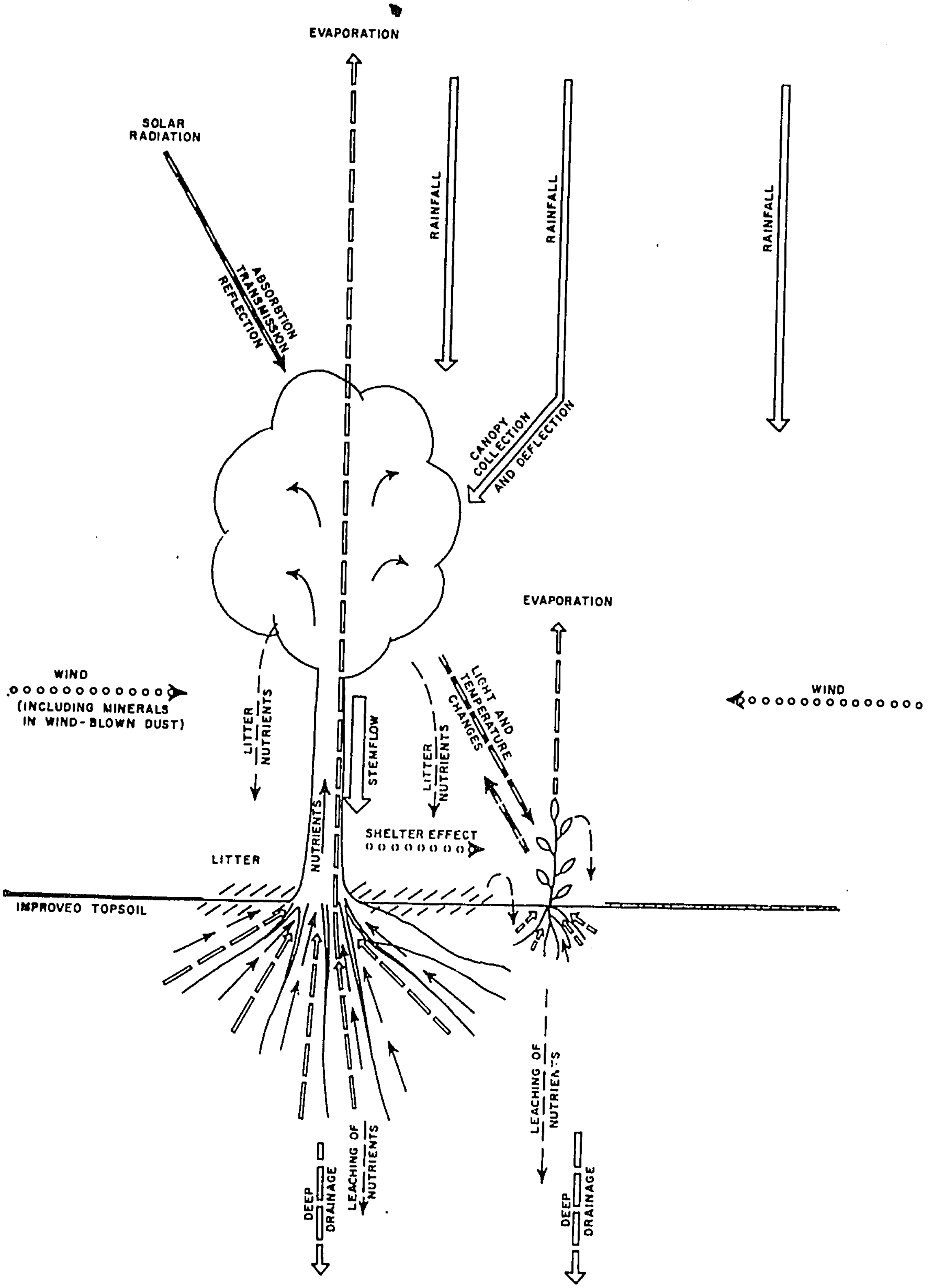


Figure 4. Tree/crop interactions will result in, and be a consequence of changes in environmental resource pools, shelter effects etc.

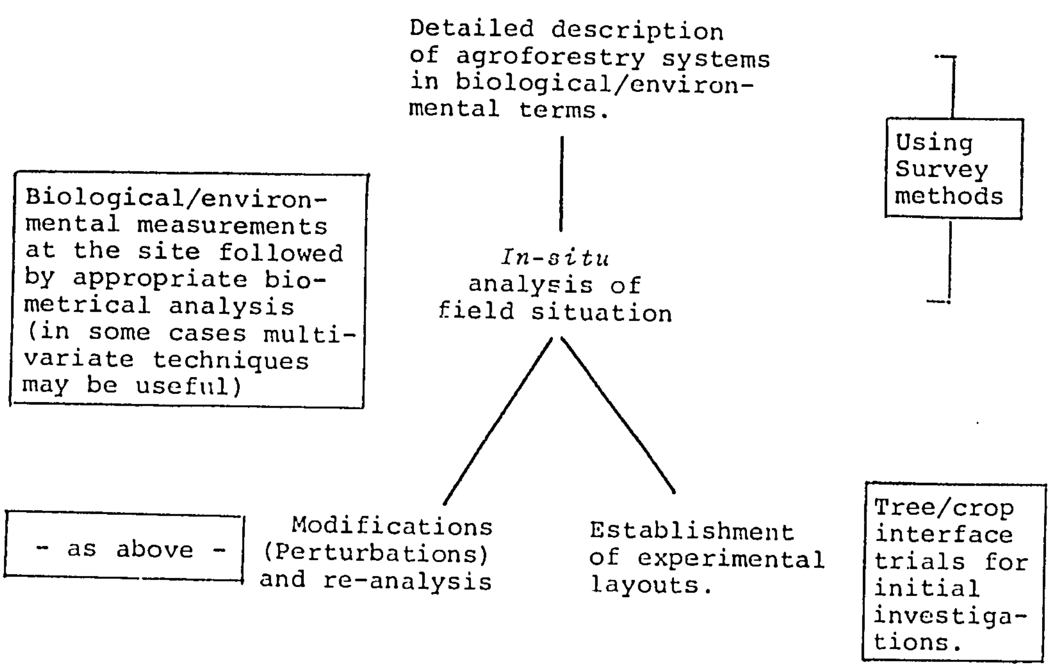
The scope of tree/crop interface investigations can be extended to accommodate a wide range of research objectives including those that contain management alternatives. Let us suppose that we require answers to the following kinds of questions.

- Is *Prosopis cineraria* a good tree species to associate with groundnuts in a particular region?
- How close to *Leucaena leucocephala* should we plant maize in an alley-cropping scheme at Site X (1200mm summer rainfall altitude 30m), or at Site Y (1800mm rainfall, 600m altitude)?
- What are the optimum design spacings for *Acacia cyanophylla* browsed (or lopped) at the end of the winter if chickpea and barley are to be grown as well?
- When should we start harvesting *Sesbania grandiflora* (or *Calliandra calothyrsus* etc) for fuelwood when you grow it with sweet potatoes (or yams, or upland rice, cowpea, maize etc)?
- When tree species X is planted on different soils in various rainfall regimes what are the distances over which it will compete with interplanted agricultural crops?

The quickest, and best way of discovering an *initial* answer to these, and many other similar questions, is to set up a simple experiment to look at the respective interfaces.

Table 1 indicates the successive steps involved in breaking down the problem of the analysis and understanding of the biological and environmental complexities of existing agroforestry land use systems. Tree/crop interface studies can, of course, form an initial step in acquiring information for the design of new systems.

Table 1: Steps in understanding the biological/ environmental complexities of agroforestry land use systems.



Suitable experimental designs for studying tree/crop interfaces

Tree/crop interfaces can be studied wherever they occur. That is we can utilize stands of a selected tree species, or we can plant up a tree/crop combination on a new plot, or both.

The issues are whether we wish to study mature or juvenile (i.e. newly-planted) trees, and seasonally-planted or 'permanent' crop species. Where the experiments are directed towards discovering facts about the possibilities of farmers intercropping among existing trees, the establishment of tree/crop interface experiments starting with newly-planted trees is obviously irrelevant. This is because the root systems of a mature stand of trees will have already occupied the ground, usually to at least the

extent of their canopies, or well beyond it in semi-arid and arid regions. If the "mature tree" situation is the one to be investigated then existing stands can be utilized (perhaps of different ages) and tree/crop interfaces can be created by sowing or planting the relevant agricultural crop species around them.

For the "juvenile tree" approach *any* set of experimental plots containing the appropriate plant mixtures will serve, and these could, of course, be ordinary yield plots in a conventional or a systematic design. However, if yield data are not (as yet) the first objective then much simpler "Geometric designs" can be used that will take up very little space (see Figure 5). If more than two plant components are to be studied then each combination of pairs of species can be tested separately.

Figures 6 and 9 show some examples of the outcome of some hypothetical tree/crop situations which can be of the kinds listed in Table 2, below.

Table 2

Possible kinds of interface effects
(each comment applies relative to the performance as a sole crop)

A. Tree grows better - agricultural crop grows worse.

B. Tree grows worse - agricultural crop relatively unaffected.

C. Both tree and agricultural crop do better than expected.

D. Both tree and agricultural crop adversely affected to some degree or another e.g.

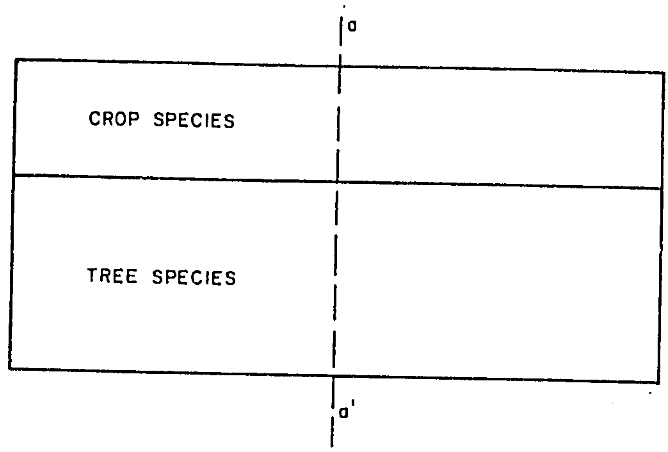
a) only moderately, or
b) severely

What to observe and measure?

A great deal can be learnt about the way two plant species interact by just observing carefully and critically how they grow and develop throughout the season. If equipment is also available to measure various plant and environmental factors then more detailed information

Figure 5. Two simple geometic designs. In either the tree/crop interface can be studied along transects a to a' (a"). The circular design takes intc account bias introduced by orientation (sun angles, prevailing winds etc).

1.



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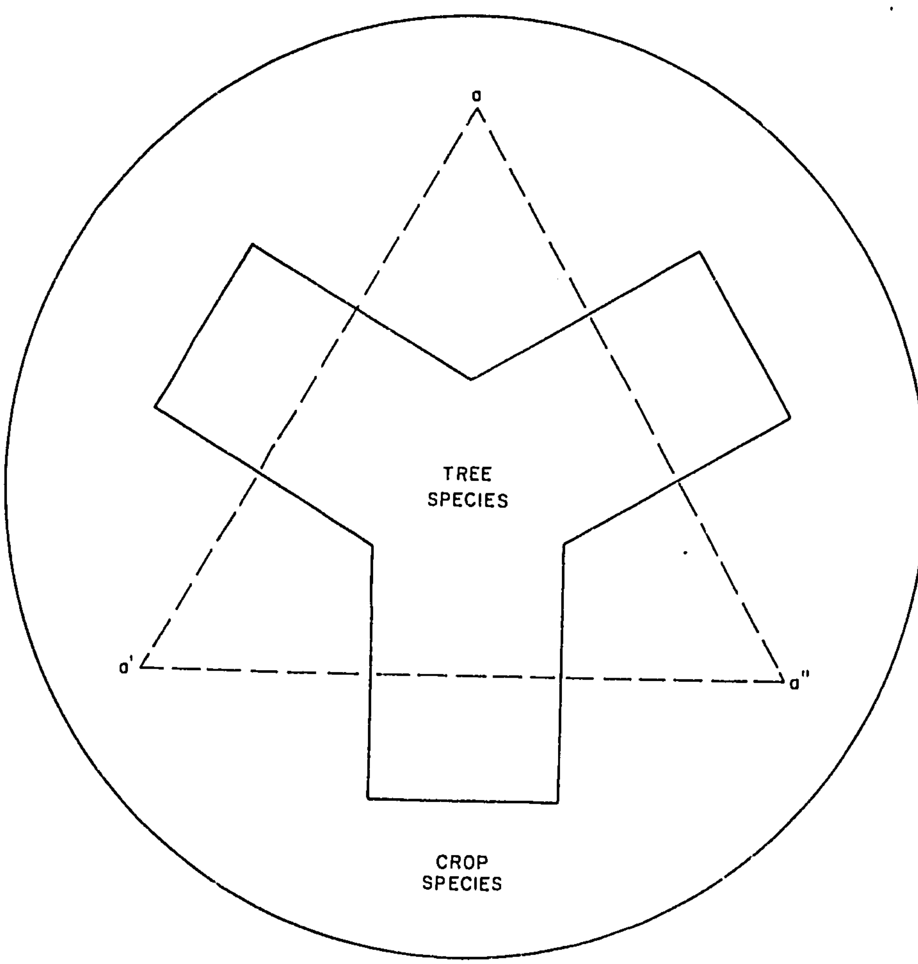

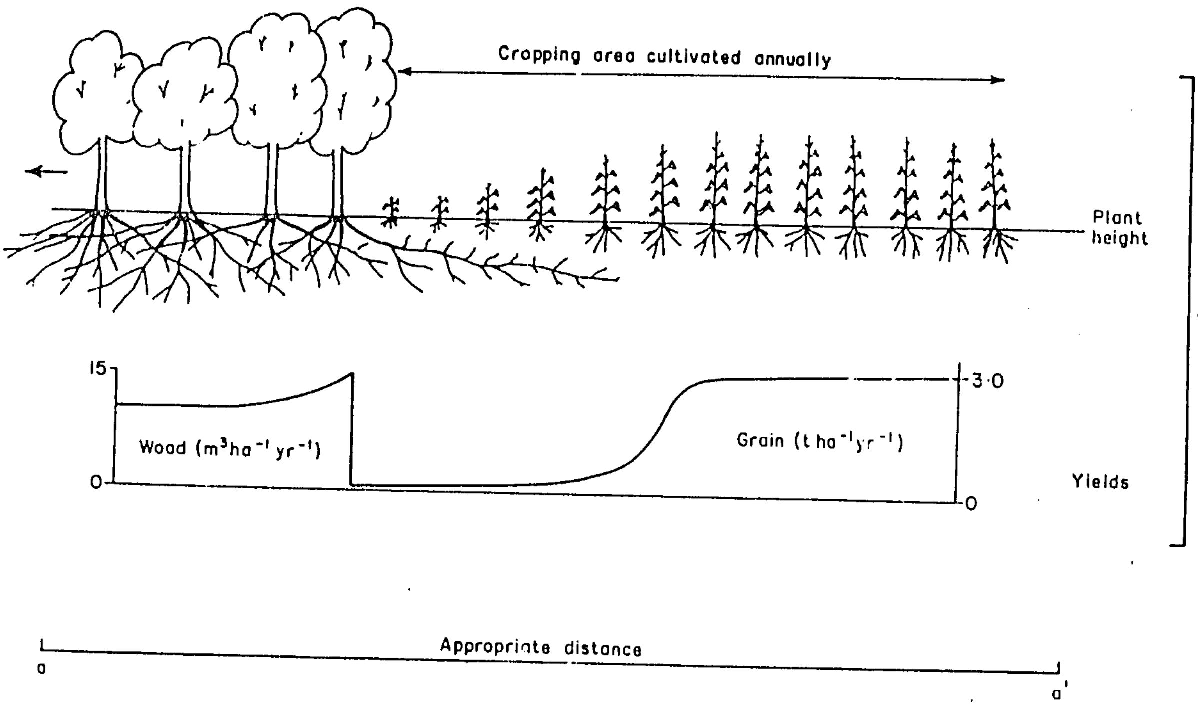

Figure 6. Section through an extended tree/crop interface in which the tree species dominates the crop.

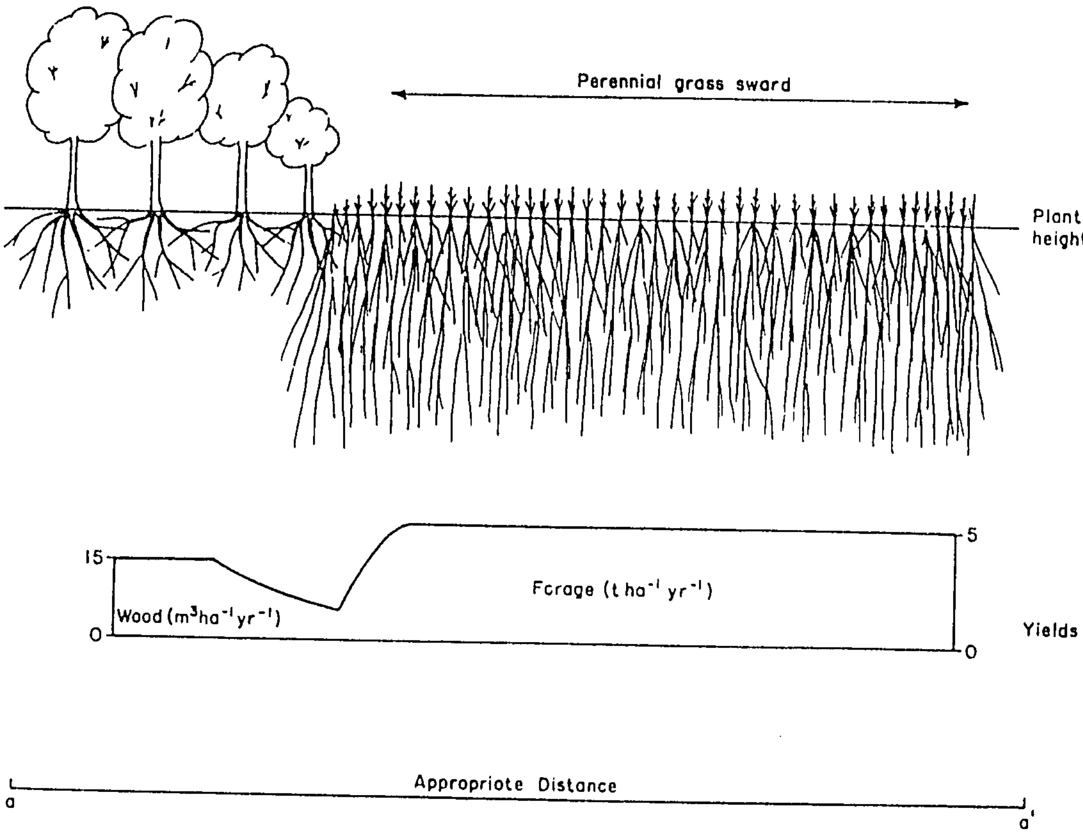

Figure 7. As for Fig. 6 but the growth of the tree species is inhibited by a deep-rooted perennial grass in this case.

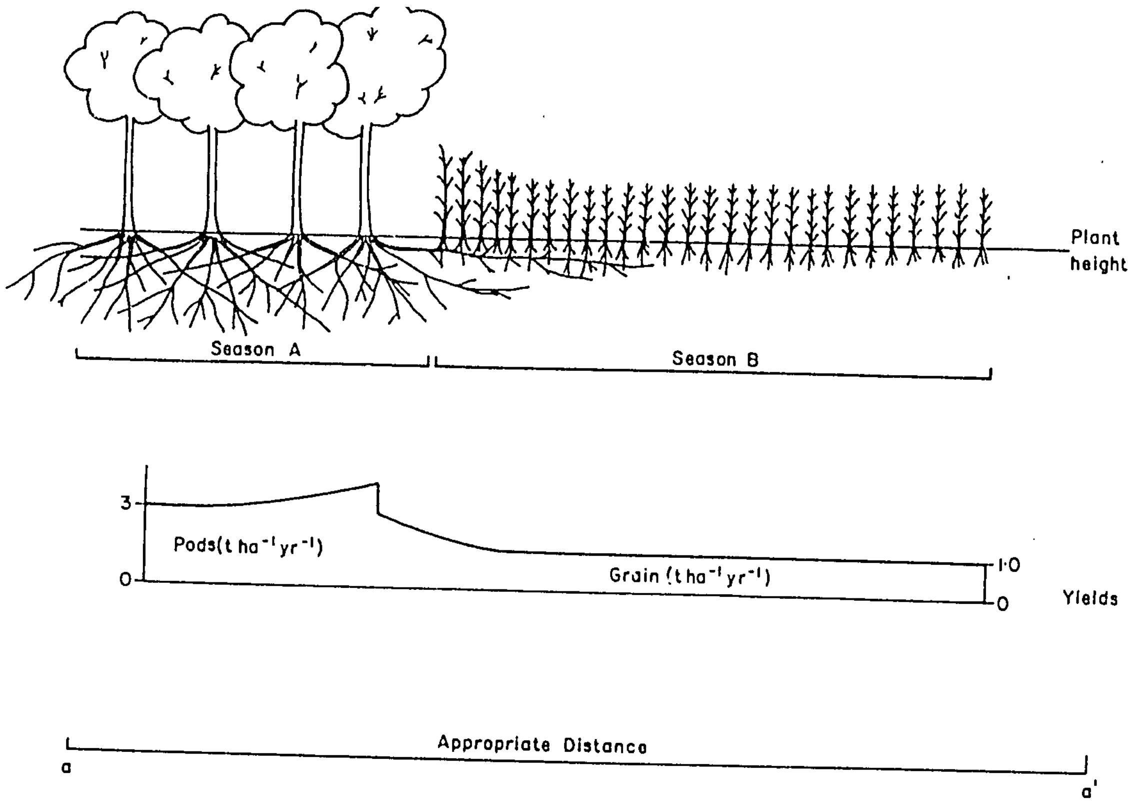

Figure 8. As for Fig. 6, but because the growth of the tree species and the crop are separated in time, both components benefit by the more timely availability of environmental resources which otherwise, would be limited in their own species association (an example would be *Acacia albida* and sorghum or millets).

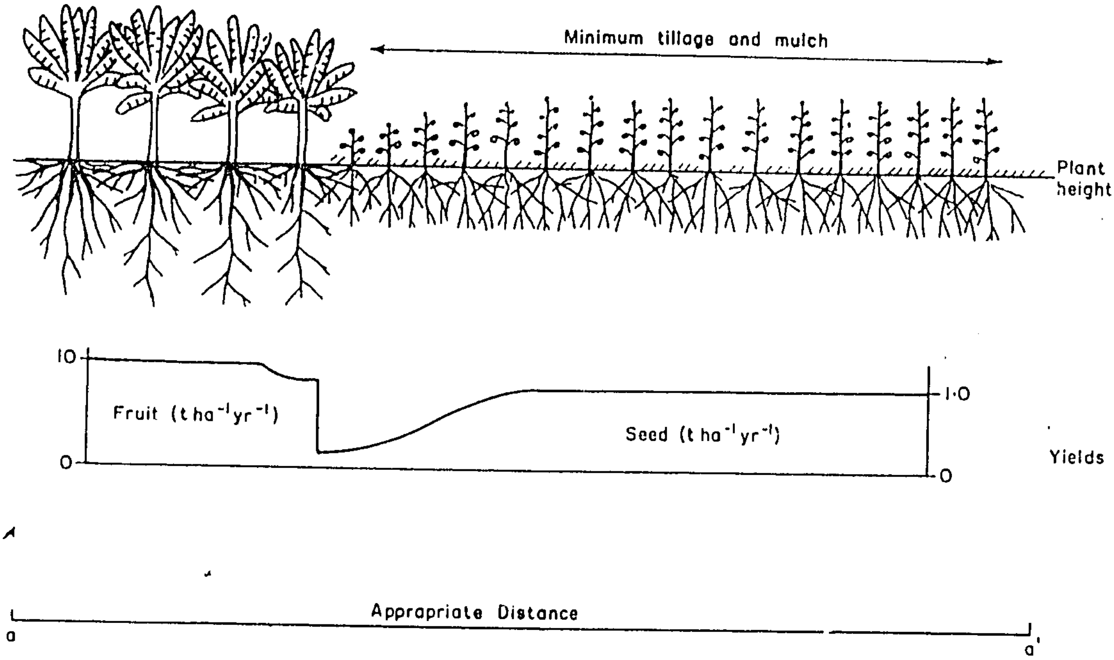

Figure 9. As for Fig. 6, but, here, both plant components are detrimentally affected at the interface, although not severely so.

can be obtained that provides a more conclusive outcome. It is also better to measure over several seasons. This will help replicate in time but it should also be realized that the morphology and development of perennial plant components will themselves be affected with time by the actual sequence of management treatments applied to be experiment (for example, by repeated tillage close to the trees), as well as by the results of continuing interactions between the tree and crop species.

Table 3 shows some suggestions for what may be observed or measured in order to obtain information about the effects of plant interactions in both the short and long term, with some comments on the way the information can be used. Data needs to be collected, at appropriate intervals, along replicated transects across the tree/crop interface, spatially extending beyond the area in which interspecific interactions are taking place; that is including also the "pure" stands of each of the components.

The results of such a set of trials might, for example, indicate that short-season cereals (millets, sorghums) were likely to grow and yield better at close proximity to woody plants (*Leucaena*, *Sesbania*, etc) than grain legumes which, although similarly short-seasoned, suffer from shading stress affecting, particularly, flower initiation and fruit set. Or again, that tree species X has a more extended surface root system than species Y, and so was a less likely choice to associate with long-season agricultural crops because of end-of-rains competition for water. And so on.

The outcome of such investigations are certain to give, at least, valuable clues about the way the plant associations under test "get on" together. And this can further be tested in larger field trials which can then be more critically focussed because many of the possible treatment combinations will have been eliminated. At best, through tree/crop interface studies, it may be possible to reach a sufficient understanding of the situation to be able to enter straight away into design or management procedures with a fair degree of certainty that they will be "on-target". An important decision is the design of plant arrangement in agroforestry systems is whether or not the biological/ environmental interactions between component species encourage or discourage a high degree of proximity. Thus either zonal or a form of mixed cropping can be adapted, respectively.

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TABLE 3 INFORMATION TO BE COLLECTED FROM A TREE/CROP INTERFACE TRANSECT

VR = Visual Records - (see also Appendix for complete list)

Type of information		How obtained	Comments
1. Plant characteristics (less important items in brackets)			
Morphology	- mainstems - branching - habit - vegetative growth flushes - leaf fall	Visual/photographic records and tape measure	Weekly notes and/or measurements are sufficient
Development	- flowering - time(s) of flowering - fruit set - fruit/seed size/ numbers	Visual/photographic records plus simple weighing equipment	Sample branches/ plants can be labelled at the start.
Stress/shelter effects	- water stress - (water conservation) - shading VR - nutrient deficiencies	Soil/plant water potential equipment light meters plant analysis/ fertilizers	Some water measuring equipment is highly desirable - otherwise visual records of plant and soil conditions (by digging) will have to serve.
General	- yield/biomass (of agric. crop) - plant condition VR - pest/diseases - management records	Drying ovens/balances written notes	
2. Environmental changes			
Short-term	- (wind - (humidity/dew) - rain dispersion VR - topsoil water status - (soil temperatures) - light distribution - total intercepted light.	- hand anemometers - dew gauges - small collecting rain gauges - soil water measuring equipment - soil thermometer - light measurement - integrating light measurement	May help clarifying plant responses and visual records will certainly help Will reflect canopy changes This should be attempted if at all possible
Long-term	- soil fertility changes - soil less/compaction - (Soil fauna)	- Litter traps, O.M. analysis Physical/chemical soil analysis percolation rate - levelling pegs/bulk density - samples for identification	Essential to compare tree and agric.crop effects on soil

Figure 10 indicates how the extent of the interface in a 2-component system can be manipulated.

Summary

Tree/crop interface studies will be of particular use to obtain preliminary information quickly about the following factors.

- Choice of species
  - Especially for screening alternatives combinations of woody perennials and agricultural crops.
- The design of agroforestry systems
  - The initial choice of whether a zonal or mixed cropping system is likely to be most productive cannot satisfactorily be made *unless* information about the "interface" is known, however crudely. For example, if the overall biological effect at the tree/crop interface is generally positive then the amount of interface can be maximized (= mixed cropping). If it is negative it can be minimized (= some form of zonal cropping or limited mixed cropping).
- The management of agroforestry systems.
  - Even if "negative" effects are generally detrimental it may be possible, once the environmental resource problems have been identified, to offset or even avoid them through such practice as modifying the time-of-planting of the agricultural crop, changing the ideotypes used, or by choosing cultivars with more appropriate physiological responses. Or, again, by limiting the component(s) by harvesting them at appropriate times, or by some form of pruning or training.

The amount of land needed for tree/crop interface studied will be relatively little compared with that of coventional field trials. Basically, all that is needed are a few trees/bushes (palms, vines, bamboos) and a small area of crop(s). Normally, pairs of plant components would be studied separately before making more complicated arrangements which might be difficult to interpret. For initial plantings some form of "Geometric" design is probably suitable. The kind and extent of observation and data collection made

in replicated transects across the interface can be adjusted to the availability of equipment for measuring various plant and environmental characteristics, and the reliability of the assumptions made will be enhanced (up to a point) by collecting more detailed data if the equipment is available by which to do this.

Tree/crop interface trials can only be considered to provide *preliminary* information. Recent literature on how to express "competitiveness" in plant mixtures with different relative yield potential and occupying different proportions of the available land (see one example in the selected references) indicates how important both plant density and plant rectangularity are in determining the outcome. These aspects are dealt with in a subseqent Working Paper but it is clear that initial tree/crop interface needs to be further considered in more fucussed tirals in which the spacing and arrangement of the component species of the mixture are properly investigated. Such field experiments require considerable resources and it is essential that as much initial information is obtained (e.g. through simple tree/crop interface trials) before they are undertaken.

<u>Selected References</u>

Huxley, P.A. 1980. The need for agroforestry and special considerations regarding field research, pp.117-142 in "Nuclear Techniques in the Development of Management Practices for Multiple Cropping Systems" Proc. of Advis. Group Meeting. Ankara 8-12 Oct. 1979. IAEA, Vienna (also supplementary mimeod appendices from ICRAF).

- discusses some of the greater complications to be found in agroforestry experimentation and (in the appendices) introduces the tree/crop interface concept and geometric designs.

McCulloch, J.S.G., Pereira, H.C., Kerfoot, O. and Goodchild, N.A. 1965. Effect of shade trees in tea yields. Agric. Meteorol. <u>2</u>, 385-399.

- referred to in the text as an example of how to break down the research problem and study the plant responses to environmental factors in detail.

Oranga, H.M. 1981. Multivariate statistical analysis in agroforestry research, pp. 93-105 in L. Buck (Ed) "Proceedings of the Kenya National Seminar in Agroforestry". ICRAF, Nairobi.

- briefly describes principle components analysis, discriminant analysis and canonical correlations analysis and suggests ways in which they are relevant to help analysize the data obtainable in agroforestry investigations.

Willey, R.W. and Rao, M.R. 1980. A competition ratio for quantifying competition between intercrops. Expl. Agric. <u>16</u>, 117-125.

- one of a number of more recent papers that consider intercropping and the ways in which to handle experimental data from detailed field experiments providing yield comparisons. More particularly, it indicates how "competitiveness" needs to be considered in relation to intercrop competition (rather than sole crop yield) and the general yield advantage (or otherwise) of intercropping. Such considerations highlight the *preliminary* nature of tree/crop interface information.

Williams, W.T. (Ed) 1976. Pattern analysis in agricultural science. pp.331. CSIRO, Melborne and Elsevier, Amsterdam.

- an excellent account of both the elements and the techniques and principles concerned with handling sets of attributes. This approach has considerable relevance to the needs becoming apparent in agroforestry field research.

ANNEXURE

Appendix 1.

Characteristics of plant and the environment to be noted and/or examined.

Characteristics of the plant and the environment to be noted and/or examined

A. Specific information about the plants

Growth:

Main stems

- number
- height (cm)
- girth at ground level (mm)
- diameter at breast height (mm at 1.3m)

Branching - notes and/or photos

- numbers
- positions
- lengths (cm) of main ones

General habit - notes / photos

- canopy dimensions (height, depth, and extent, maximum dimension at right angles/2)

Phenology - notes/photos

- Growth flushes
  - dates of
  - number of leaves produced (on marked branches
- Leaf senescence
  - dates of
  - leaf duration (on marked leaves)
- Leaf fall
  - dates of, or if continuous.

Development:

Morphology:

- Positions of flowers/inflorescences
- Number of flowers (on sample branches)

Phenology

- Time/s of flowering (anthesis)
- Fruit set data (at marked fruiting sites)
  - early counts, final counts
- Time of fruit maturation (and hence duration of fruit development)
- Means/ranges of fruit size
- Seed size/numbers (if appropriate)

B. Obvious effects of stress or shelter on plants (if not measured in "A" above)

Water:

- Indications of wilting (notes)
  - times of onset/recovery
  - plant water potentials/stomatal apertures (on samples)
  - soil water potentials (soil water profiles in the rooting zone)
- Indications of water conservation
  - soil surface indications
  - soil water profiles

Light:

- Shading effects -(on dominated species)
  - effects on morphology (internode length, leaf area)
  - effects on flower initiation/fruit set

Nutrients

- Indirectly
  - deficiency symptoms (description)
  - response to fertilizers
- Directly
  - plant tissue samples
  - soil samples

C. General notes

Condition of plants (notes)
(chlorotic, etiolated etc)

Incidence of pests/diseases (record and identification)

Management records

- times of weeding, cultivations, pest control etc.

D. <u>Short-term environmental modifications</u>

<u>Windspeeds over canopy surface</u>

- times, speeds, orientation

<u>Water</u>

- dew formation/air humidity in canopies
- rainfall dispersion / topsoil water status, waterlogging

<u>Temperature</u>

- soil surface (day and night)

<u>Light</u>

- light profiles, light distribution and total shortwave intercepted radiation (at soil surface).

E. <u>Long-term environmental modifications</u>

Soil fertility

- litter formation and organic matter status
- soil chemistry (total base saturation/ CEC/NPK etc)
- soil physical status (bulk densities/ percolation rates).

Soil loss /soil compaction

Soil fauna

- presence of termites, worms, beetle larve etc.

SECTION FOUR

PART 4E

Considerations when experimenting with changes in plant spacing.

PART 4E

CONTENTS

Considerations when experimenting with changes in plant spacing - by P.A. Huxley

General considerations

Crop yields are highly dependent on plant density (plant population per unit area of land) but there are many factors to consider when attempting to assess an "optimum" spacing. The three underlying variables to manipulate are:-

- Plant population per unit area of land (plant "density" = number of plants hectare^{-1}).
- Rectangularity (the ratio of between- to within-row spacing), and
- Plant arrangement. That is whether, within any stated rectangularity, the plants of adjacent rows are opposite one another (i.e. a "square" plant) or are offset ("staggered") in some way.

Rectangularity applies only to row-cropping systems, but the concepts of plant arrangement extend to clumping and other forms of heterogeneous spacing arrangements between species in mixed cropping patterns. Figures 1 to 4 give some row cropping examples.

The highest yields are obtained when a sufficient number of plants occupy an area so as to utilize the environmental resources (light, water, nutrients) maximally, but without plant stature, the distribution of dry matter, or the flowering/fruiting processes being adversely affected. Or to a point where pest organisms are encouraged.

Because available environmental resources usually vary between-seasons there is no set "optimum" plant density for seasonal species, although it is usually feasible to establish a mean plant density at which yields are maximal for the "average" season. In places where there are large seasonal differences in rainfall and/or in cloudiness, therefore, a larger number of years of experimental work are required to establish a recommendation than in more constant environments.

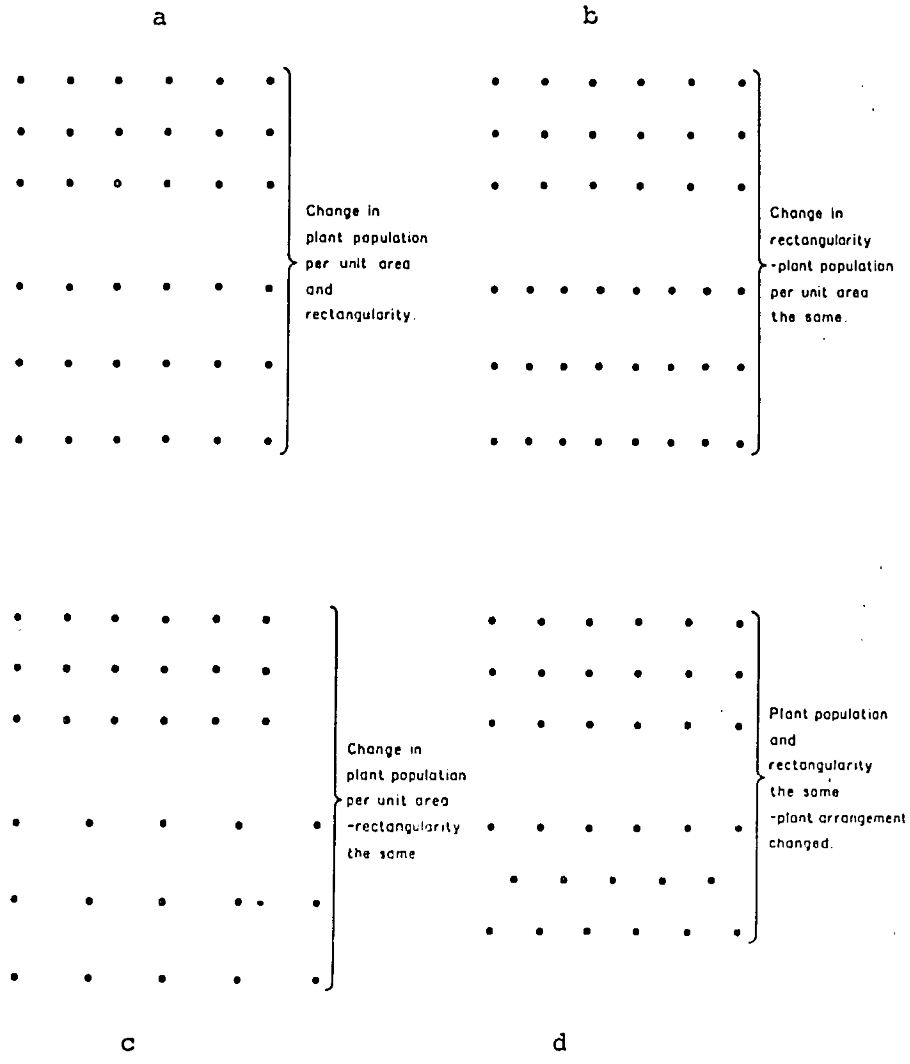


Figure 1. Illustrations of some changes in plant population per unit area (plant density) rectangularity and plant arrangement - see text for explanations.

The resource-sharing capacity of perennials can change markedly within age, and this factor has to be considered in determining original planting distances and subsequent thinning and/ or pruning regimes. With woody perennials we also need to consider not only whether we require total biomass or just a plant part but whether, in the latter case, we are to regularly harvest a renewable part, (e.g. fruits, or vegetative parts such as leafy shoots), or a non-renewable part intermittently (e.g. woody main stem).

Environmental resources, both in spatial and temporal terms, and both above and below ground, can usually be better shared between a mixture of species than by sole cropping, and this is one of the cases for mixed cropping. In sole cropping evenly-spaced plants will be more likely to be sharing environmental resources maximally (but not fully) compared with irregularly-spaced plants, and this is one of the cases for row-cropping. Maximum yields will then, apart from the effects of other management factors, be obtained with a rectangularity of 0.866 (sin 60°) with the plants staggered between rows (that is with all plants spaced equi-distant from one another as in a series of equilateral triangles).Fig. 2

In plant mixtures exact species ratios and distances between plants will depend on the growth habits and physiological responses of the species concerned. The manipulation of rectangularity, where this can be easily managed through row-cropping, can be a powerful tool to obtain effective species combinations. Especially if it is combined with manipulation of sowing or harvesting times (with seasonal crops), or with pruning/lopping regimes(with woody perennials). Then individual species can have better access to, particularly, water and light at critical periods of their growth and development. "Alley-cropping" for example, is one form of mixed planting that utilises the benefits of high rectangularity ratios and lends itself to a range of other management manipulations.

Apart from its major influences on yield per unit area, plant density greatly affects the size of individual plant parts. This factor is commonly used tc manipulate crops so as to provide suitable-sized products so as to satisfy the particular requirements of the farmer, the fresh market, the sawmill, or the cannery or other processing plant. For example with

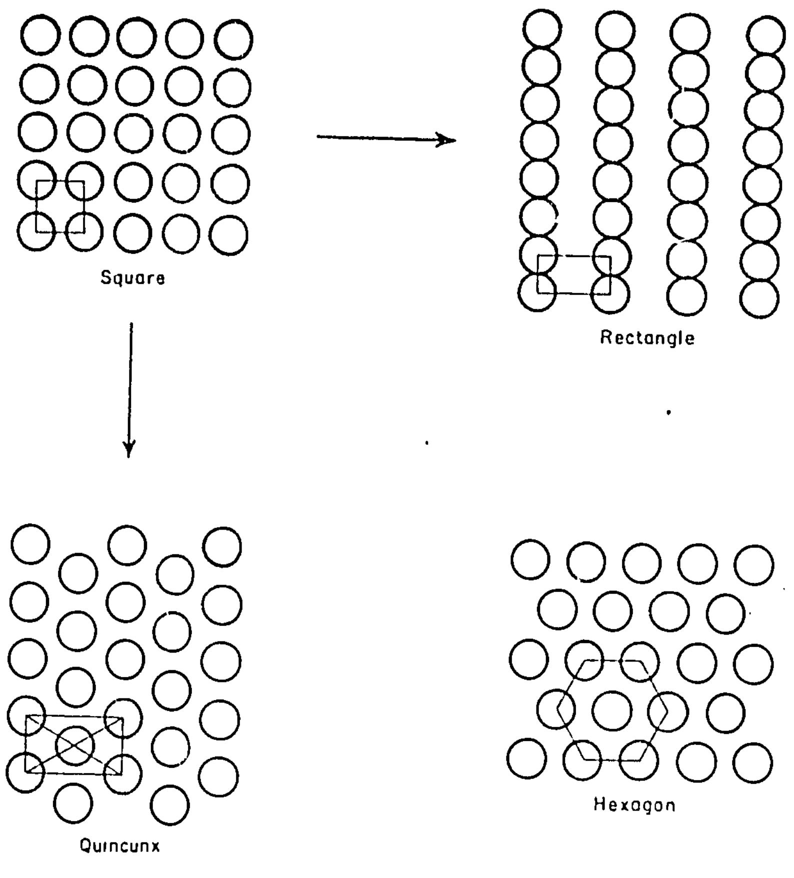


Figure 2. Some alternative planting arrangements. Plants in the hexagonal arrangement are all equidistant from one another (see page 3). The quincunx planting permits successive alternative row thinnings (either diagonally or vertically/horizonally) to leave various regularly-spaced arrangements.

timber or poles; tubers or roots (e.g. carrots); fruits (maize cobs), or even an edible stem and inflorescence such as the pineapple.

Even when plants of the same species are assembled together (sole cropping) plant-to-plant interference effects result in a range of plant sizes. A relatively few specimens become dominant and a greater number suppressed to some degree or another. This results in a positively skewed population distribution for plant size which is more emphasized as plant density is increased and which is accentuated with the age of the crop (Figure 3).

The choice of plant density and arrangement is, of course, only one set of factors to consider in manipulating yield, plant size, or the size of plant parts. The need for access (for example for weeding, crop spraying and harvesting) can impose spacing restraints, particularly on rectangularity, which may not be remedied by concomitant increases in within-row spacing to correct for overall plant population per unit area.

The influence of plant population per unit area of land on yield for a seasonal crop is illustrated in Figure 4a. When the output is measured as total biomass the yield/plant density relationship is asymptotic. On a per plant basis this relationship is described by the commonly-used "reciprocal yield" equation

1. $$\frac{1}{w} = a + bx$$

where: w = the mean weight of an individual plant, and

x = plant population per unit area

– and a and b are a constant and a coefficient respectively.

When the output is a plant part, such as the fruits, seeds, stems or tubers, the relationship is found to be fitted by a parabolic curve of the type:

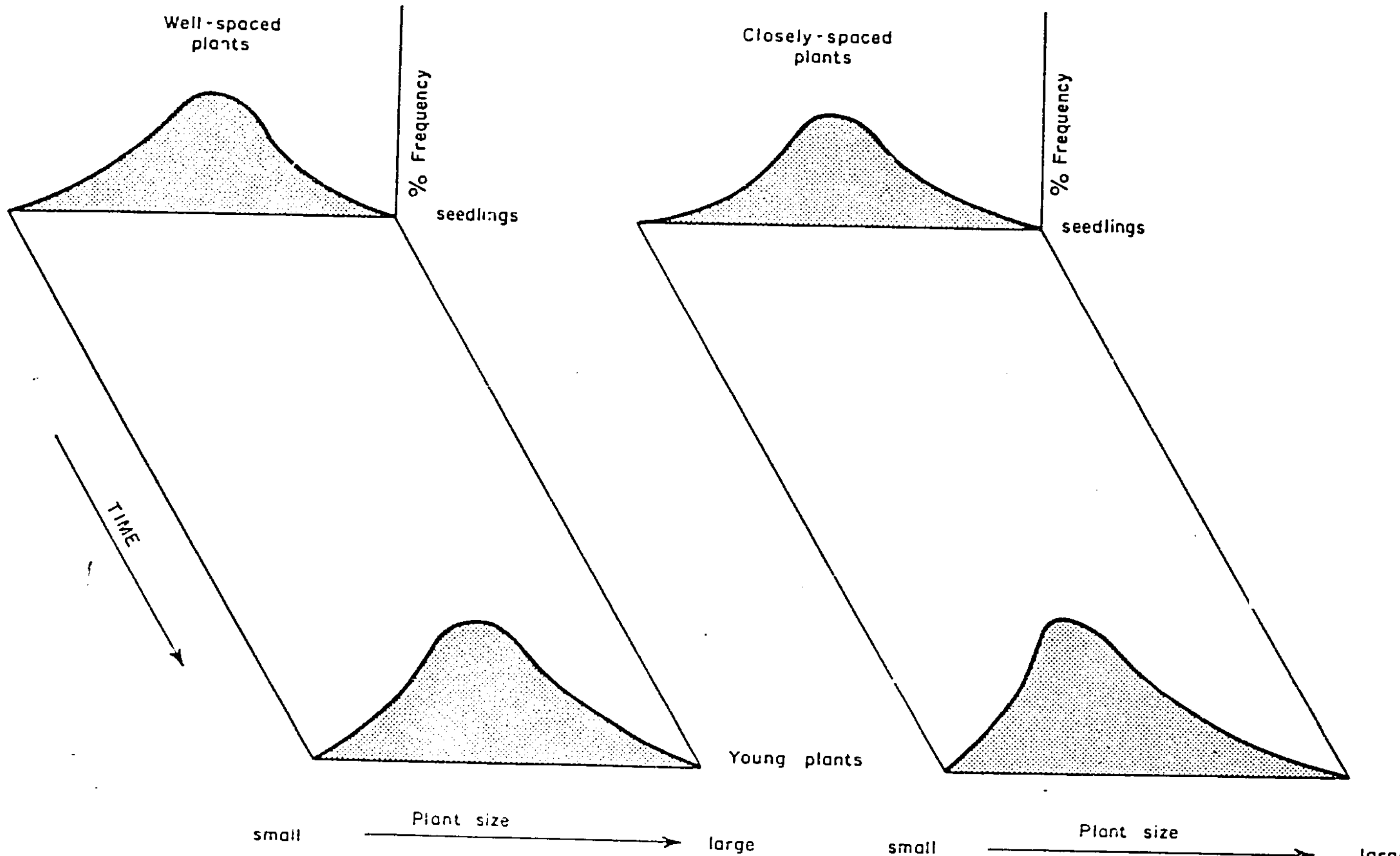


Figure 3. Changes of the frequency distribution of individual plant size with time in a sole cropping situation starting with (a) relatively well-spaced plants and (b) closely-spaced plants. In both cases a few plants become dominant and the frequency distribution for plant size becomes positively skened - but more so with (b) than (a).

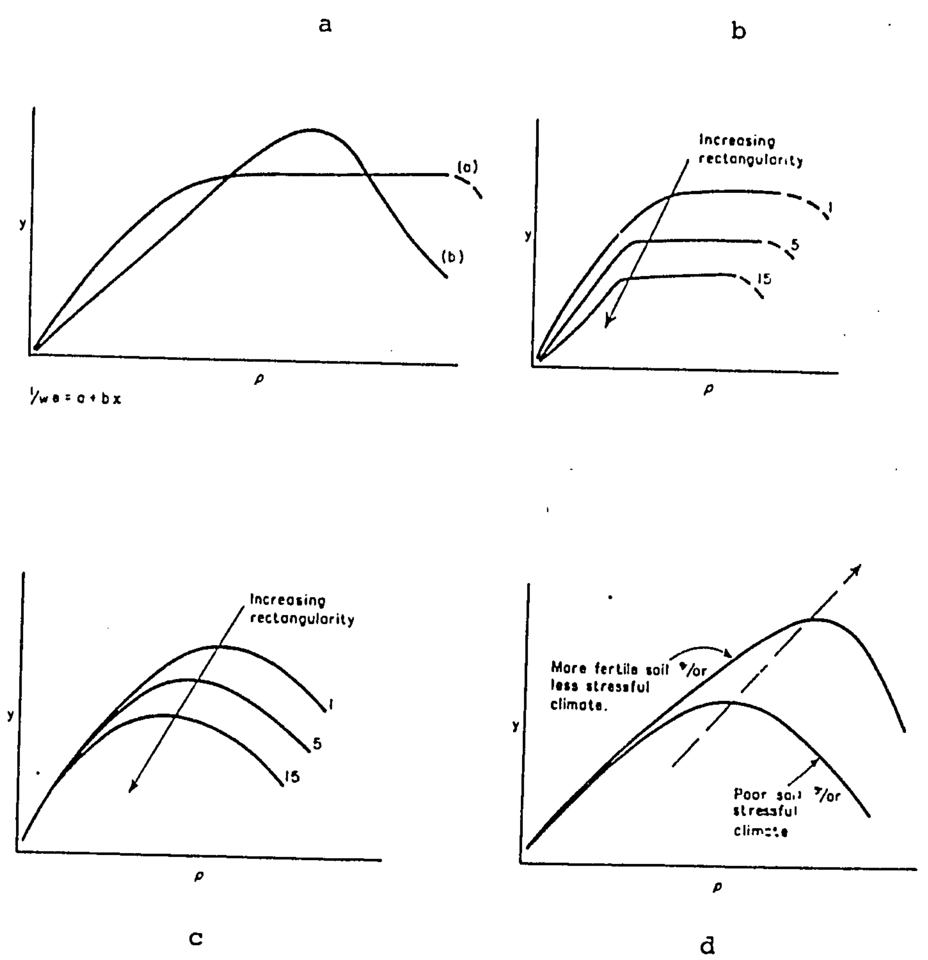


Figure 4. (a) Basic yield per unit area (y) plant density (P) relationships
(b)(c) The effects of increasing rectangularity on an asymptotic and parabolic relationship, respectively.
(d) The general trend in a parabolic yield/density relationship brought about by changing soil fertility and climatic stress.

2. $$\frac{1}{w} = a + bx + cx^2$$

The two relationships can both be expressed by the simple equation:

3. $$\frac{1}{w\theta} = a+bx$$

and when the yield response is asymptotic $\theta = 1$, and when parabolic $\theta<1$. Also the constant "a" represents an influence of plant genotype and "b", the coefficient, is related to environmental potential (see Willey and Heath, 1969, for the arguements).

Figures 4b and 4c indicate the changes in these basic relationships when rectangularity is increased. Although the general principles are well established individual species will, of course, respond to changes in rectangularity in somewhat different ways. For example, the yields per unit are of some indeterminate species with wide ranging shoot systems (such as Solanum potatoes or spreading forms of cowpea) are less affected by higher rectangularities than plants of more rigid form (such as most trees and shrubs) which cannot exploit wide between- to within-spacing so readily.

The overall effects of environmental improvement (more fertile soils, less water stress, improved light conditions) is not only to raise yield levels per unit area of land but to increase the plant population at which this is acheived (Figure 4d. Thus, although the exact extent of any particular environmental improvement has to be measured experimentally for any species (or species mixture), a knowledge of this trend permits at least some degree of conjectural extrapolation based on known principles and responses.

Appropriate orientation of crop rows, even in tropical latitudes, can contribute to better light interception and distribution over the canopy.

Thus North-South oriented rows may be potentially higher yielding than those aligned East-West. However, this aspect may not be considered as important a contributor to sole crop yield as others discussed above, at least in the early phases of investigation, although its effects on light distribution between upper storey (trees) and lower storey (agricultural crops) associations in agroforestry systems can be considerable.

Dealing with woody perennials

The effects of changes in plant density etc described above for seasonal plants will be modified in species with a woody perennial structure by the various ways that a persistent canopy can influence plant form and development, with consequent effects in the distribution of dry matter within the individual plant. Also by ageing effects. As discussed by Cannell (1983) close-spaced trees forming a dense canopy will be taller (and so possess a higher proportion of stemwood), have fewer lower branches (due to self-pruning) and set less fruit (due to shading of potential fruiting sites). Such factors will influence the shape of the parabolic yield/density relationships but not obviate them. Ageing of individuals will diminish, annual dry matter increment in part because of an overall increase in the respiratory load within the population, and also because of an eventual loss of efficiency in canopy photosynthesis through a number of causes. This too will alter the progressive changes o asymptotic and parabolic relationships alike.

Because multipurpose trees species may be grown so as to optimize provision of a range of products: total biomass (for soil restoration/ soil conservation), total woody biomass (for fuelwood), leafy biomass (for fodder), fruits and/or seeds, other plant products (bark, gums, waxes etc), or a combination of these, an understanding of the relevant plant responses to density stress are certainly necessary. Furthermore, harvests may be as a single terminal harvest (but rarely), as irregular harvests during the productive lifespan (e.g. timber or fuelwood thinnings), as regular annual or seasonal harvests once the trees are mature (fruits, seeds) or as intermittent within-season harvests (leafy fodder or browse, sap, gums etc). Sequential or intermittent, harvesting of vegetative materials, or thinning of whole trees will change the level of density stress

so as to set back the trends in plant modification being established, either in so far as these may be reversible on existing parts (e.g. re-establishment of a higher rate of stemwood increment) or, more likely, for the plant parts that are formed anew thereafter (e.g. re-establishment of fruiting points on new branches that can then emerge.

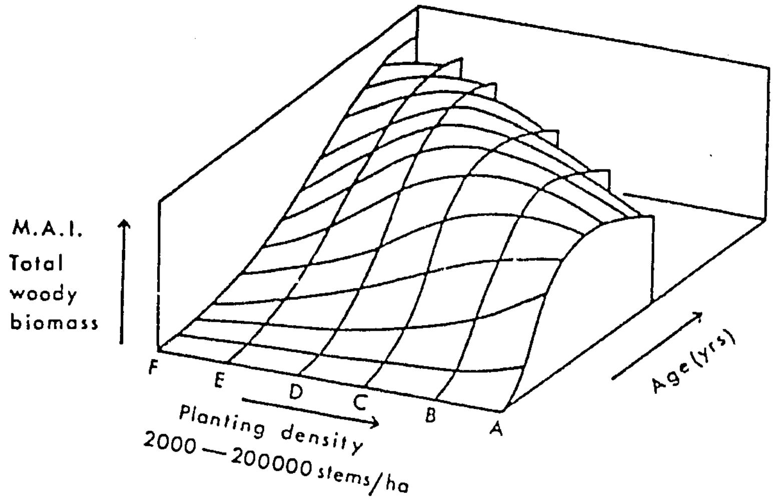
For woody stems and branches foresters consider changes in both the "Current Annual Increment" (CAI) and the average of this with time, the "Mean Annual Increment" (MAI). Figure 5 shows the effects of planting density on MAI for total woody biomass and for merchantable timber, respectively Figures 6 and 7 show hypothetical time-trends for changes in total biomass and a renewable plant part harvested annually, respectively.

Experimental approaches

The establishment of yield/plant density relationships for sole crops can be achieved either by using conventional (e.g. randomized block) or systematic field layouts (for the latter see separate W. Paper). The former are more robust but, if adequate internal guard rows are to be provided (at least double), which is essential for spacing experiments (see Figure 8), then the effective experimental area can be quite restricted Systematic designs enable a wide range of spacing levels to be tested in a small amount of space without the use of internal guard rows. But a rigorous statistical analysis of the results is usually difficult.

Several authors have suggested that only a limited number of spacing treatments (3 or 4) are needed to establish a mathematical yield/plant density curve as long as certain assumptions are satisfied e.g. that the reciprocal yield relationship (or plant weight plotted against plant population per unit land area) is linear. This relationship can hold good with all types of plants, including trees and shrubs, but until any particular species has been studied under a range of environmental and management conditions some departure from a strictly linear relationship cannot just be assumed. It seems prudent, therefore, especially at the start of an experimental programme with a new species, to accept the need to encompass a reasonable range of plant density and rectangularity treatments in any experimental programme e.g. at least 5 plant densities and 3 rectangularities).

(a)



(b)

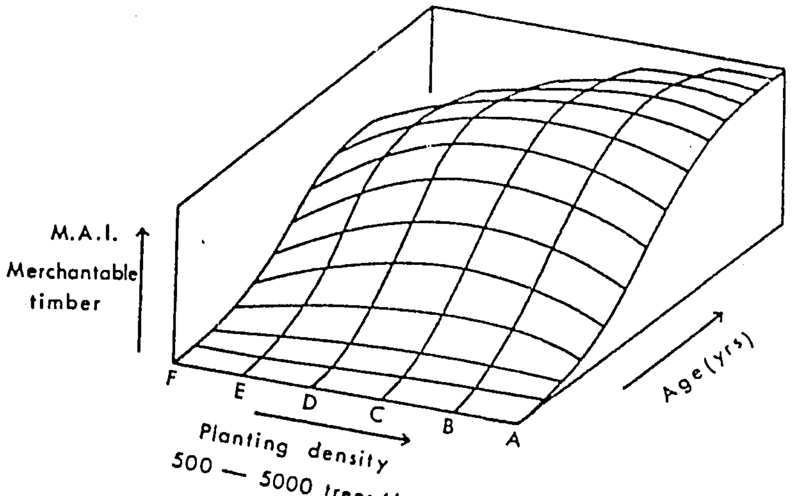


Figure 5. Effects of planting density on the mean annual increment (MAI) of trees grown for woody biomass (a) (branches and stems of any diameter) and merchantable timber (b) stems above a given diameter). Note that there is an optimum density for woody biomass as well as timber production, and that thinning will move the population in the direction A to F. Remember that closely spaced trees will be small in diameter, but not necessarily height, and that, in unthinned stands, the number of trees at harvest will be less than at planting owing to self-thinning. From Cannell, M.G.R. 1983. Plant population and yield of trees and herbaceous crops, pp. 489-502 in P.A. Huxley (Ed) "Plant Research and Agroforestry", ICRAF. Nairobi.

Figure 6. Changes with time of total biomass accumulation per unit area of land for different plant densities of a woody perennial species. Eventually the net annual increment due to carbon fixation and mineral uptake will be exceeded by losses (parts shed, total respiration and this will happen sooner at high plant densities.

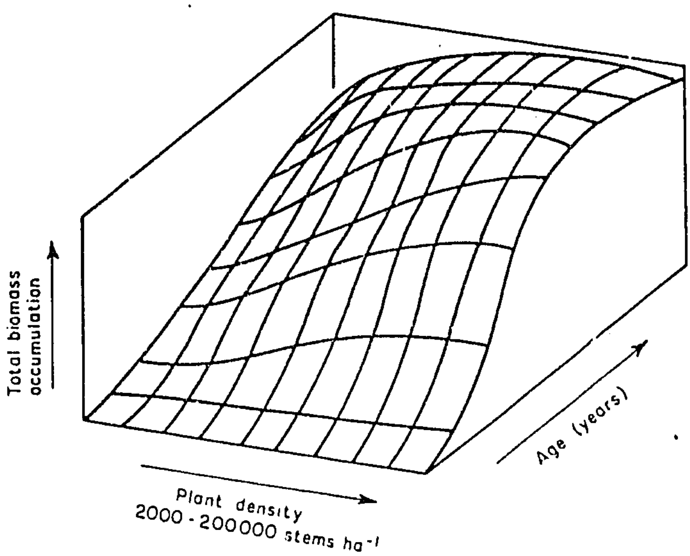
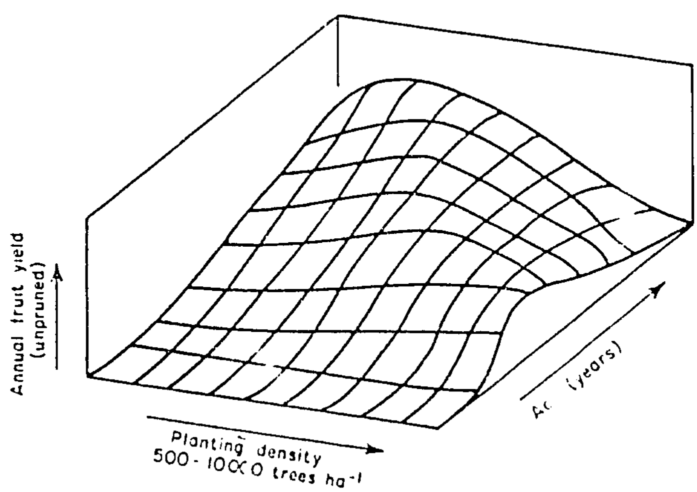


Figure 7. Changes in annual fruit yield with time for a woody perennial species planted at different densities. Small amounts of fruit per plant can give substantial yields per unit area at very high plant populations early on, but increasing densities (and the development of pests and diseases) can make such unpruned stands rapidly unproductive. Mid-level



populations will attain maximum yields per unit area later but possibly become unproductive less quickly. Low levels of plant population will give longer individual tree yields but too wide a spacing will limit yield per unit area (although it may make management easier). Pruning at any time will shift the response to the left.

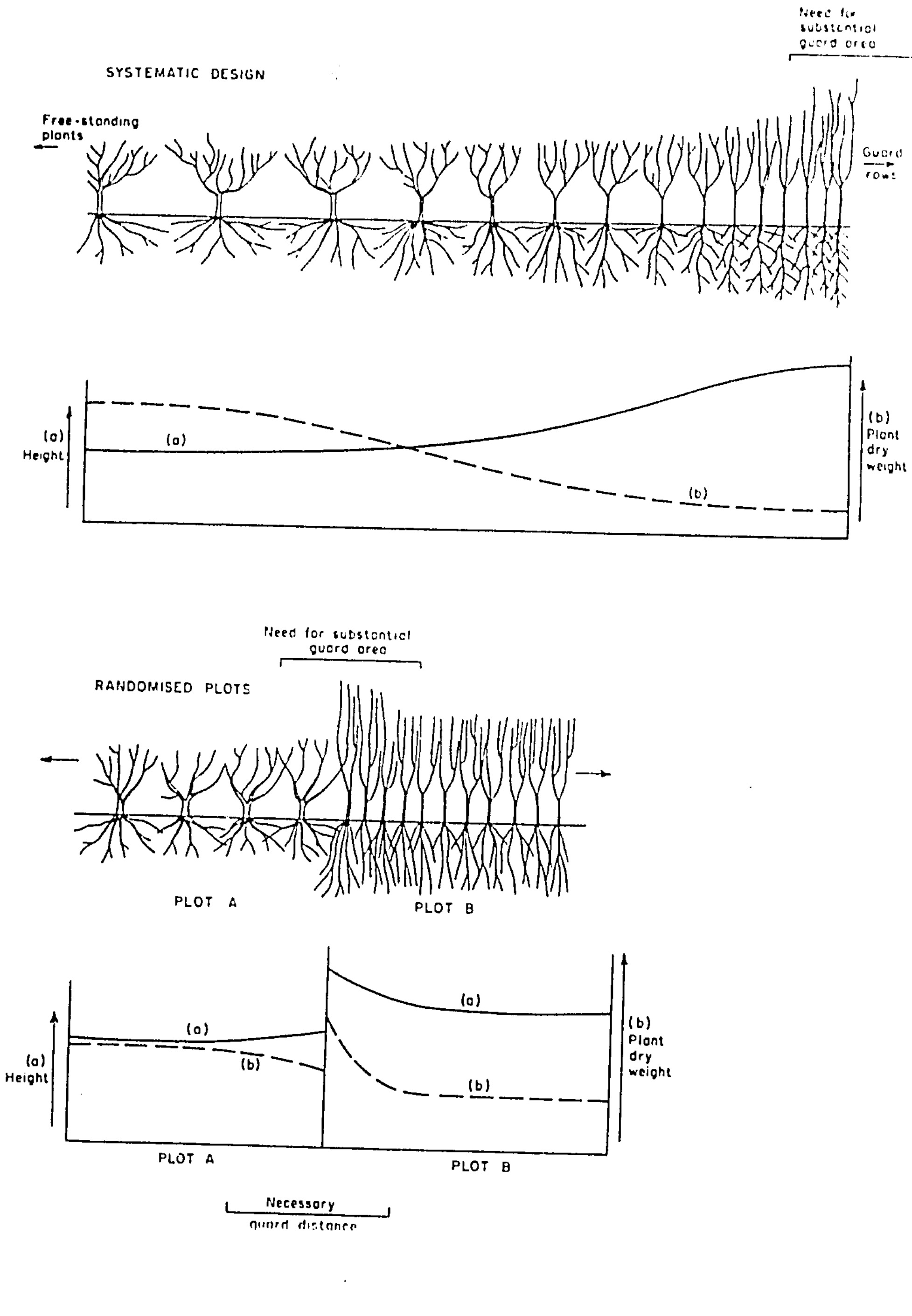


Figure 8 Systematic designs require adequate external guard rows (especially at the close-spaced part) but no internal guard rows. Conventional randomized block layouts involving spacing treatments also require internal (between-plot) guard areas which can often take up a considerable area.

In many mixed cropping situations it is seldom easy to predict the full effects of changes in plant density and arrangement on either the composite or individual yields of the components, or on the size-regulating effects on plant parts. It is, therefore, often necessary to arrange for this to be tested experimentally. This particularly applies to agroforestry plant associations where the species combinations may not have been investigated in this way previously. As the possible combinations of variables and levels of the spacing variables are numerous, and other management factors have also to be included, the space and time taken to obtain reliable results can be considerable. Furthermore, experiments need to be repeated over several seasons and to cover the transformations with age of the woody component(s). We have, therefore, to break the problem down and find quick, cost-effective approaches. This may best be done by formulating a programme in the following manner.

- Evaluate any existing information about the known responses of the individual plant components to changes in plant density and rectangularity.

- Formulate a selected set of treatments that investigates the effects of plant density and rectangularity in an unconfounded way, and also of different levels of intimacy of the components.
  - So that the results can be made much more extrapolatable to further changes in these variables and, to some extent to the effect of changes in environmental conditions as far as these can be predicted from the general body of knowledge.

- Select a basic minimum of other critical management variables (pruning/lopping of woody component(s), time-of-sowing of the seasonal component(s), from what is known or can be postulated as likely to minimize detrimental between-species interface effects.

- Split the investigation into several small, easily-managed experiments if the number of variables and levels that must be studied is still unavoidably large.

Working in the above way is likely to provide a much better understanding of what is happening than by setting up experiments that merely

test "packages" of treatments (for example, a set of "practical" hedge-row comparisons). Such treatments almost invariably confound the effects of plant density and rectangularity and so give results that cannot be extrapolated, or provide any fundamental understanding of plant responses to these overriding variables. The main excuse for undertaking such "package" experiments is when either the problems of species selection and/or management options are so little understood that the main purpose of the experiment is to help define these, or when they are so well known for a particular site or area that simple on-farm trials are all that are needed to test the best of a small set of establishment options.

There is now a large body of literature concerning the evaluation of species mixtures in field trials (see selected references). Comparatively little refers to mixtures of woody perennials and herbaceous species, however.

Rectangularity as an important spacing tool in mixed cropping situations.

Manipulating the rectangularity of the tree/bush species in a mixed tree/crop association can be a convenient way to obviate adverse effects of interspecific interference and this is the basis of "alley-cropping". But Figure 9 illustrates some simple points to remember. First, that changes in rectangularity above 5 or 6 have a greatly diminishing effect. Second, that at low rectangularities even a small change will greatly reduced the plant population per unit area and, as Figure 4 shows this is the more influential of the two variables on yield i many situations. Figure 10 illustrates the advantage often to be gained by revising the in-row spacing of the trees when increasing the rectangularity, giving several examples.

In experimental field layouts it may be desirable to keep rectangularity and plant density confounded and this can be achieved only if between-row spacing changes (rectangularity changes) are simultaneously accompanied by the necessary in-row spacing changes (see legend Figure 9).

If plants in a 2-component mixture were of approximately the same stature, and each is assumed to occupy an approximately equivalent area of alloted space, then row-cropping with

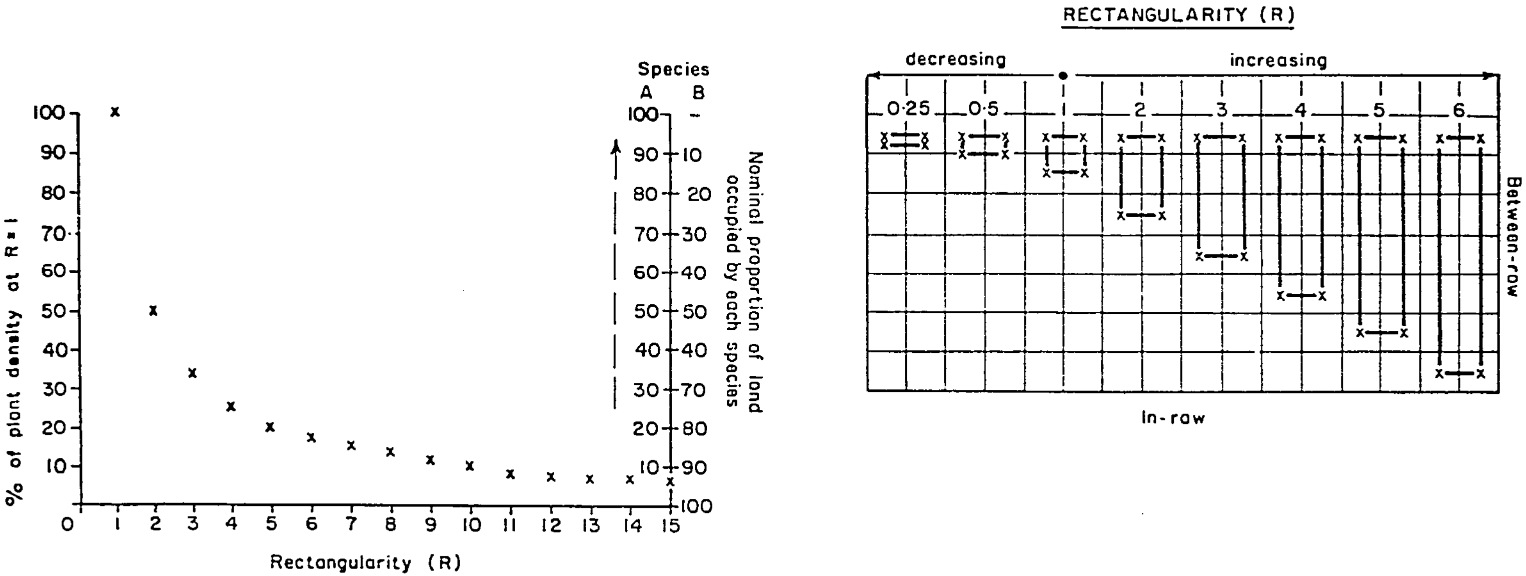


Figure 9. Different rectangularities (right) and the way in which plant population per unit area changes with a change in rectangularity if the in-row spacing remains the same (left). Changes in the nominal allocated area (assuming the species A is a tree and it occupies all the land at its optimum plant density at rectangularity 1) are shown on the right-hand axis, but the actual area utilized by each species will be more in the direction of the dotted arrow as the tree matures and its canopy and roots spread to the between-row space.

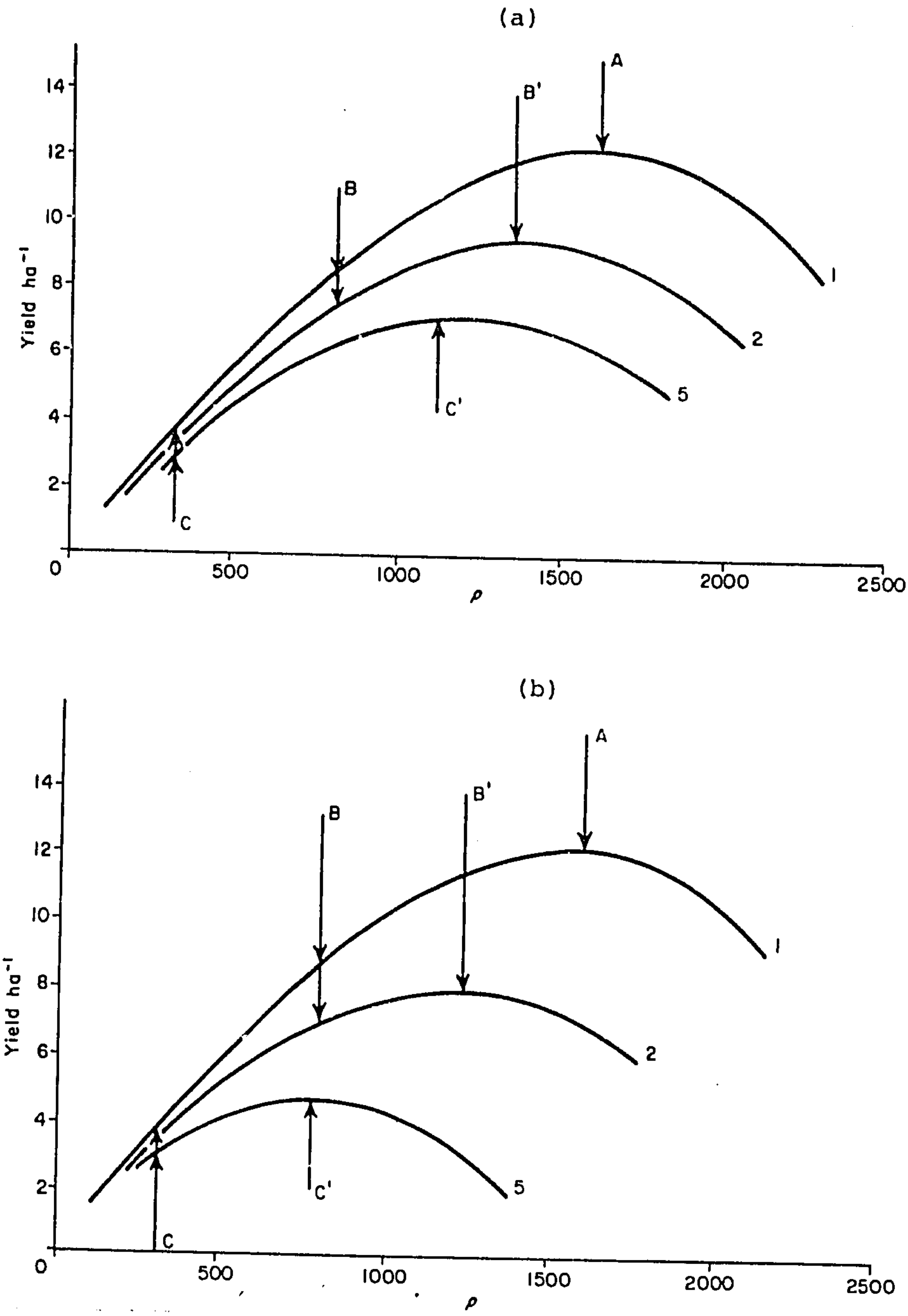
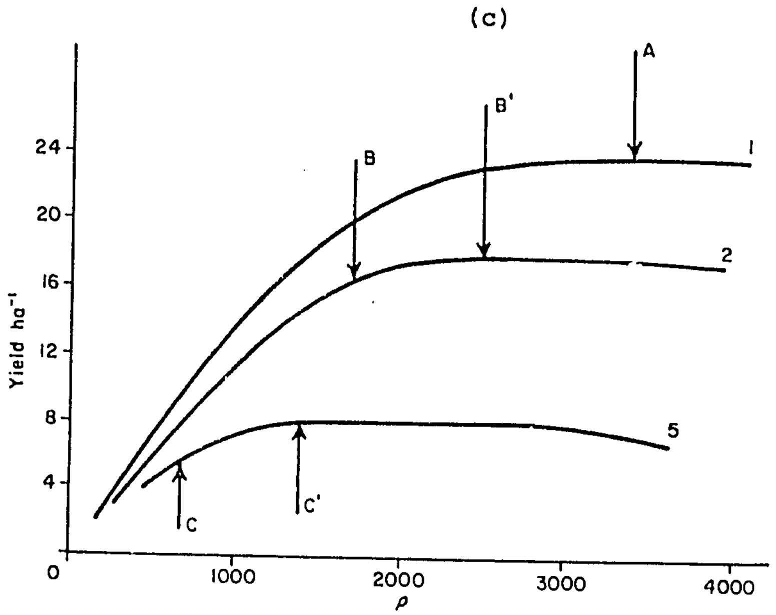


Figure 10. The sets of curves show some postulated yield responses to changes in plant density at different rectangularities (1,2 and 5). In (a) the effects of increasing rectangularity are less than in (b) but, in both cases B and C indicate the yields obtainable when the plant population is reduced to a half or a fifth, respectively when the in-row spacing is *not* changed to compensate for the increase in rectangularity (continue over).



		Plant density	Rectangularity	Nominal area (%)	Revised optimum plant density	Estimated yield(t ha⁻¹)
						Plant part
①	A.	1600 (optimum)	1	100	-	12·2
	B.	800	2	50	(B') 1350	9·6
	C.	320	5	20	(C') 1100	7·1
②	A.	1600 (optimum)	1	100	-	12·2
	B.	800	2	50	(B') 1250	8·0
	C.	320	5	20	(C') 875	4·75
						Biomass
③	A.	3400 (optimum)	1	100	-	24·0
	B.	1700	2	50	(B') 2500	17·5
	C.	680	5	20	(C') 1400	8·0

Figure 10. (continued)

B' and C' indicate on the appropriate curves what scope there is, in this hypothetical situation, for such compensation.

In (c) the same situation is demonstrated for an asymptotic (total biomass) response curve, with less opportunity for compensation in this case. Unless the relationships such as these shown here are known, the effects of manipulation of rectangularity and plant density can only be conjectured.

the two species (as in situations shown later in Figure 12) between-row space as shown on the right-hand axis in Figure 9. If species A is a tree or bush it will clearly soon occupy a greater proportion of the available space at the expense of a smaller-statured agricultural crop species and continue to increase its share as the canopy develops, unless this is restricted by management. In practice, therefore the space allocation will always be less than shown (i.e. in the direction of the right-hand arrow). It may be useful to consider the "extra" space needed, if this can be approximated, in terms of the number of rectangularity units (in-row spacing) it represents, and this should then be added to the initial rectangularity choice (remembering that after R5 or 6 there is little effect or either plant density or allocated space). This may make a useful "rule-of-the-thumb" approach to alley-cropping dimensions, especially if a further correction is also made for any "interface" effects on the yield of the two components (i.e. any likely successful "encroachment on tree space by the agricultural crop, a positive effect; or conversely, any extended interference by the tree beyond its canopy spread). However, to discover what these effects actually are in practice it is really necessary to examine specific tree/crop interfaces in the field. This can be done either by selecting part of a spacing experiment to work on, or by a prior (and relatively simple) separate field experiment using just a simple geometric design (see Section on "The Tree/Crop Interface".

In an "alley-cropping" situation the rectangularity will usually be such that the tree/bush species exerts virtually no intraspecific interference from row to row other than, perhaps, from a small amount of mutual shelter. Thus the three factors to consider in influencing yield are the within-row effects of the tree/bush species on its own growth and development, the interface effects between the tree and the agricultural crop and the within-crop conditions of the latter. The comments made previously highlight the need to consider carefully the within-row spacings of the tree so as to maintain an effective plant population per unit area. This is particularly important in the early years of establishing hedegrows when within-row tree/bush spacing will have an effect on its growth, form and productivity. Later within-row spacing of the hedgerow species will become less influential (Figure 11). It is also important to have a clear understanding of the interface effects, both for chosing compatible species and in order to

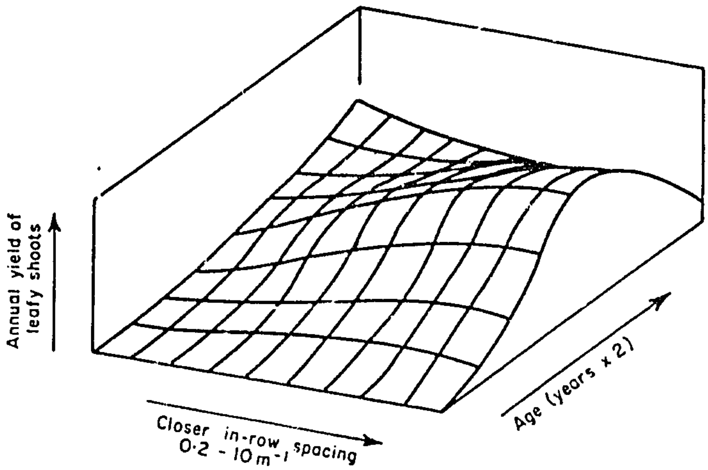


Figure 11. Changes with age in the yield of leafy shoots in hedgerows with different within-row spacing. Assuming no over-browsing or excessive lopping and that hedge height is restricted to that achieved after 4-5 years. A decline in the numbers of active vegetative buds available may sometimes occur with some species (e.g. tea) after continued pruning of leafy shoots.

manipulate the rectangularity to the best effect*. The crop growing in the "alley" will, unless the tree/bush rectangularity is unusually small, be partly growing under "sole crop" conditions and its yield in this central region of the strip can, therefore, be estimated from local knowledge, or from previous sole crop spacing experiments. Effective alley cropping design and management will be brought about by using existing information to estimate the overall outcome of selected species/spacing combinations, and by designing field experiments that provide actual data relating to the underlying issues discussed here.

Design choices

In both mixed and zonal cropping situations the proportions of plant components needed in order to satisfy the particular levels of product required may need to be the modified depending on both the biological requirements to optimize the effect of interactions between components, as well as environmental demands to maintain land sustainability (and thus to keep a high proportion of trees/shrubs in the cropping system). Not only will the individual plant densities for each component require looking into but also the rectangularity options both within and between component species. Figure 12 shows that there are a number of alternative ways of arranging the spacing of the tree component in a mixed tree/crop system depending on what outputs we required and whether the nature of the tree/crop interface indicates better possibilities for either an intimate or separate arrangement. A reduction in adverse interface effects can be achieved by decreasing the size of the individual zonal areas (towards sole cropping) and/or by altering the rectangularity (and in effect, increasing the actual plant density but not the plant population per unit allocated area) of both components so as to leave a bigger gap between them at the interfaces. An example is shown in Figure 13. The effect on within-species yields of increasing the actual plant density has to be compared with any improvement shown by the mixture.

Where we are dealing with seasonal plants of somewhat similar stature (i.e. herbaceous crop plants in general), and if we are concerned only with maximizing the overall yield per unit area of land, then the choice of total plant population of a two-component mixture will depend on the shape of the individual yield/density response curves and the extent to which these are

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* or the 'intimacy' of other mixed cropping arrangements.

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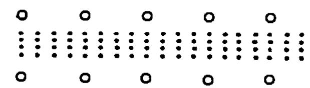
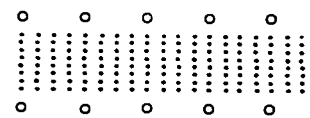
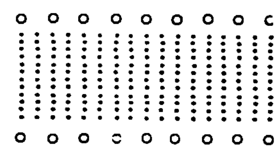
	Species A (O) Plant density (plants ha^{-1}) (a) actual	Species A (O) Plant density (plants ha^{-1}) (b) nominal	Species A (O) Rectangularity	Area ratio	Example	Species B (•) Plant density (plants ha^{-1}) (a) actual	Species B (•) Plant density (plants ha^{-1}) (b) nominal	Species B (•) Rectangularity
(a)	2500	2500	1	1:1		40000	80000	0·5
(b)	1666	1666	1·5	1:2		53333	80000	0·5
(c)	2500	2500	4	1:3		60000	80000	0·5

Figure 12. Various ways of intercropping a tree species (o) and a herbaceous agricultural crop (⁚⁚): (a) interpolating between the tree rows (shown planted on the square); (b) removal of alternate tree rows to allow more space; (c) increasing the tree rectangularity but re-establishing the original plant density by a closer in-row spacing; (continued).

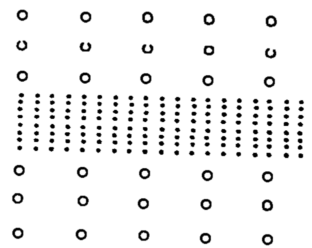
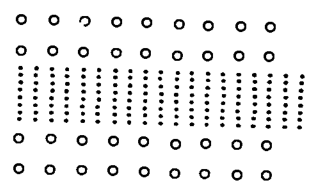
	Species A (o) Plant density (plants ha^{-1}) (a) actual	(b) nominal	Rectangularity	Area ratio	Example	Species B (•) Plant density (plants ha^{-1}) (a) actual	(b) nominal	Rectangularity	Area ratio
(d)	3000	5000	0·5	3:2		32000	80000	0·5	2:3
(e)	5000	10000	1	1:1		40000	80000	0·5	1:1

Figure 12 (cont') (d) and (e) show zonal arrangements (using strips). Biologically the option arrangement to maximize yields will depend on the individual yield/ plant density relationships and the interface effects.

modified in the actual spatial/temporal arrangement in the mixture by between-species interactions.

Figure 14 illustrates some examples of making this choice for 2-component pairs of species that represent a range of different yield/density responses, but without taking any interactions within the mixtures into account (ways of doing this are discussed by Willey and Rao, 1980).

Where one of the components is a tree or shrub then both plant size and the numbers per unit area will be markedly different from those of any herbaceous components (Figure 15). In this case the selection of any appropriate plant density in mixtures may better be made along somewhat different lines (see Huxley, P.A. 1983 The role of trees in agroforestry - some comments), or the space - exploiting possibilities of row-cropping trees at relatively high rectangularities can be utilized. (Figure 10a-c showed the possible advantages that are often still to be gained in compensating the in-row spacing when increasing that between-rows).

In planning spacing experiments it can be useful to know the way in-row and between-row spacings must change in order to maintain a particular plant population per unit area, or some stated fraction of this, and *vice versa*. This is shown in Table 1* as a matrix of factors by which to multiply the plant density chosen as the maximum under consideration (and at a rectangularity of 1.0, initially).

Finally, Figure 16 is an implementation flowchart that indicates the successive stages to be taken when deciding on plant densities and rectangularities. At the same time it indicates some of the more practical questions that need to be answered related to the characteristics of the land use system, as well as showing what type of experimental approach is useful if data still needed for decision-making are not yet available. Appendix 1 displays some suggestions for field layouts involving changes of spacing.

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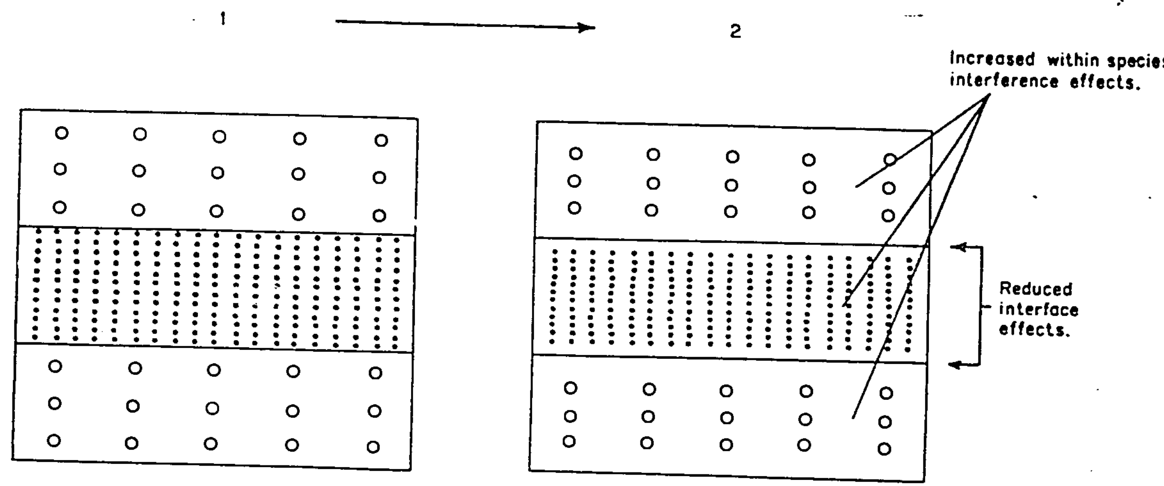
* A micro-computer programme is available to expand this table and to scan the information contained therein for common (or closely similar) between-row or in-row distances.



	Species A (O)				Species B (•)			
	Plant density (plants ha^{-1}) (a) actual	(b) nominal	Rectangularity	Area ratio	Plant density (plants ha^{-1}) (a) actual	(b) nominal	Rectangularity	Area ratio
1.	2500	5000	0·5	1:1	40000	80000	0·5	1:1
2.	2500	6250	0·4	1:1	40000	100000	0·4	1:1

Figure 13. If interface effects are particularly detrimental it may pay to separate the zones as far as possible, and this can be done by increasing the nominal plant density of each. The degree to which this effects yield will depend on the actual yield/plant density relationships for each crop (see Figure 4a).

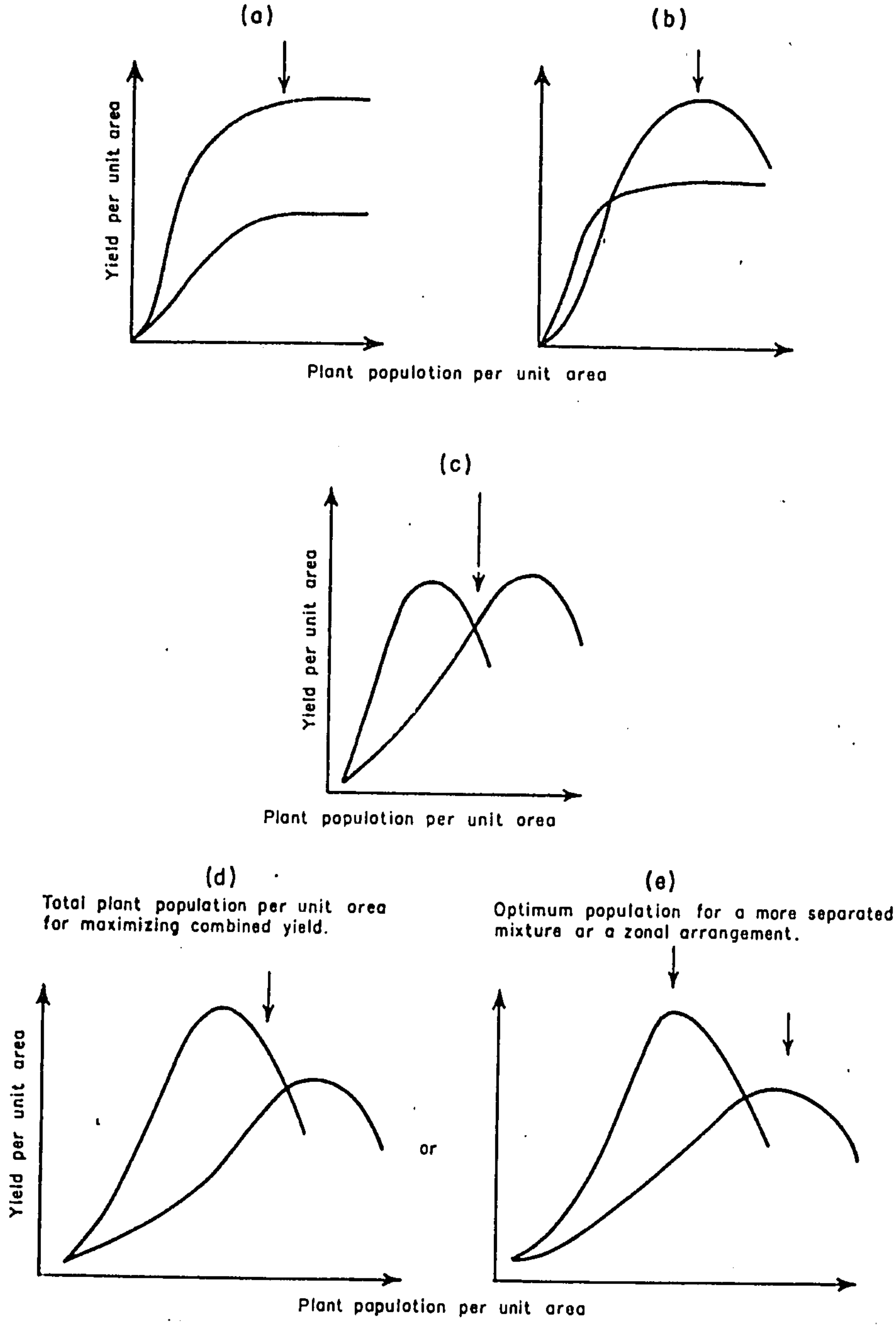


Figure 14. Various yield/plant density relationships of seasonal plant mixtures. The curves show the suggested optimum population of the mixture (a,b & c from Cannell, 1983). (a) two crop species grown for biomass (b) one species grown for biomass and the other for a plant part (c) two species grown for plant parts (and of similar yield potentials)(d) as for (c) but of different yield potentials, (e) as for (d) but to be grown in a zonal system.

Such simplifications do not take into account the farmers requirement to select appropriate yield proportions to suit his needs (see Mead, R. and Willey, R.W. 1980).

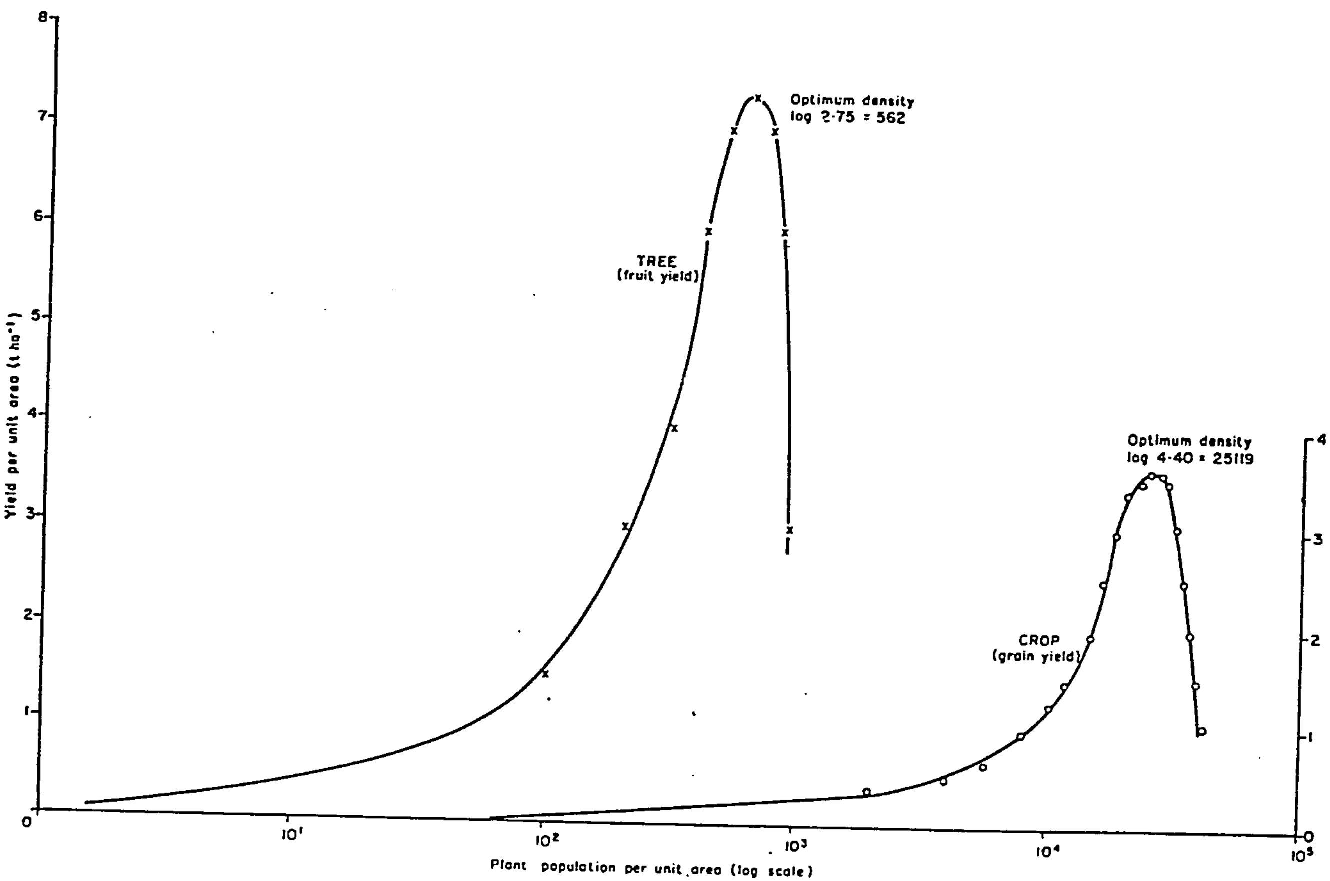


Figure 15. Parabolic yield/density relationships for fresh fruit from a tree species and grain from a cereal. Even when plant density is plotted on a logarithmic scale these two curves barely overlap. Hence "percentage ground cover" is a more practical unit to use with tree/herbaceous crop mixtures.

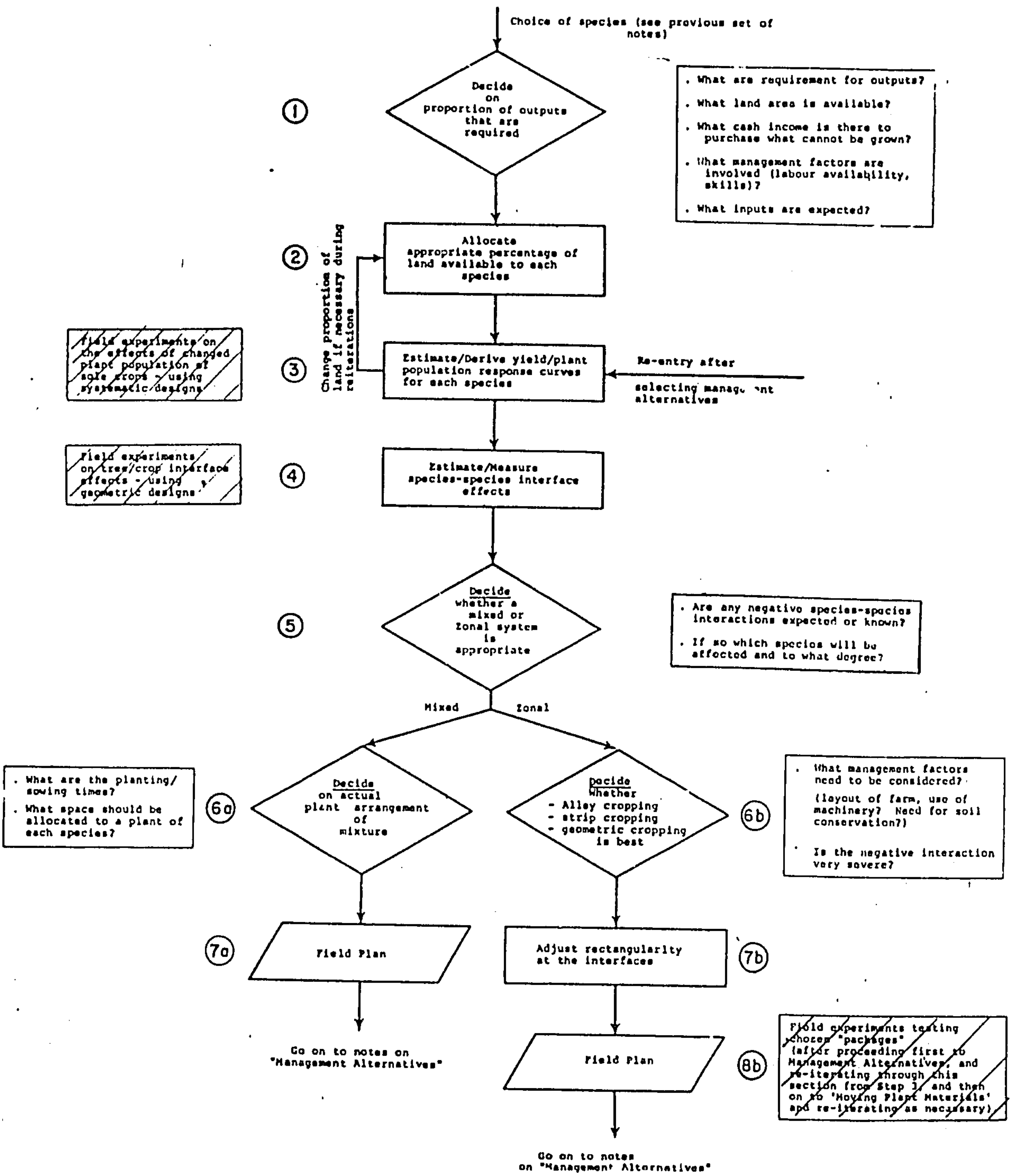
MAXIMUM NO. OF PLANTS PER HECTARE = 1
MAXIMUM RECTANGULARITY 12
MINIMUM RECTANGULARITY 1

FRACTIONS OF DENSITY USED 1/ 10
STEPS OF RECTANGULARITY USED .5

RHO	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00
1.000	1.000	0.816	0.707	0.632	0.577	0.535	0.500	0.471	0.447	0.426	0.408	0.392	0.378	0.365	0.354	0.343	0.333	0.324	0.316	0.309	0.302	0.295	0.289
1.000	1.000	1.225	1.414	1.581	1.732	1.871	2.000	2.121	2.236	2.345	2.449	2.550	2.646	2.739	2.828	2.915	3.000	3.082	3.162	3.240	3.317	3.391	3.464
0.900	1.054	0.861	0.745	0.667	0.609	0.563	0.527	0.497	0.471	0.449	0.430	0.413	0.398	0.385	0.373	0.362	0.351	0.342	0.333	0.325	0.318	0.311	0.304
0.900	1.054	1.291	1.491	1.667	1.826	1.972	2.108	2.236	2.357	2.472	2.582	2.687	2.789	2.887	2.981	3.073	3.162	3.249	3.333	3.416	3.496	3.575	3.651
0.800	1.118	0.913	0.791	0.707	0.645	0.598	0.559	0.527	0.500	0.477	0.456	0.439	0.423	0.408	0.395	0.383	0.373	0.363	0.354	0.345	0.337	0.330	0.323
0.800	1.118	1.369	1.581	1.768	1.936	2.092	2.236	2.372	2.500	2.622	2.739	2.850	2.958	3.062	3.162	3.260	3.354	3.446	3.536	3.623	3.708	3.791	3.873
0.700	1.195	0.976	0.845	0.756	0.690	0.639	0.598	0.563	0.535	0.510	0.488	0.469	0.452	0.436	0.423	0.410	0.398	0.388	0.378	0.369	0.360	0.352	0.345
0.700	1.195	1.464	1.690	1.890	2.070	2.236	2.390	2.535	2.673	2.803	2.928	3.047	3.162	3.273	3.381	3.485	3.586	3.684	3.780	3.873	3.964	4.053	4.140
0.600	1.291	1.054	0.913	0.816	0.745	0.690	0.645	0.609	0.577	0.550	0.527	0.506	0.488	0.471	0.456	0.443	0.430	0.419	0.408	0.398	0.389	0.381	0.373
0.600	1.291	1.581	1.826	2.041	2.236	2.415	2.582	2.739	2.887	3.028	3.162	3.291	3.416	3.536	3.651	3.764	3.873	3.979	4.082	4.183	4.282	4.378	4.472
0.500	1.414	1.155	1.000	0.894	0.816	0.756	0.707	0.667	0.632	0.603	0.577	0.555	0.535	0.516	0.500	0.485	0.471	0.459	0.447	0.436	0.426	0.417	0.408
0.500	1.414	1.732	2.000	2.236	2.449	2.646	2.828	3.000	3.162	3.317	3.464	3.606	3.742	3.873	4.000	4.123	4.243	4.359	4.472	4.583	4.690	4.796	4.899
0.400	1.581	1.291	1.118	1.000	0.913	0.845	0.791	0.745	0.707	0.674	0.645	0.620	0.598	0.577	0.559	0.542	0.527	0.513	0.500	0.488	0.477	0.466	0.456
0.400	1.581	1.936	2.236	2.500	2.739	2.958	3.162	3.354	3.536	3.708	3.873	4.031	4.183	4.330	4.472	4.610	4.743	4.873	5.000	5.123	5.244	5.362	5.477
0.300	1.826	1.491	1.291	1.155	1.054	0.976	0.913	0.861	0.816	0.778	0.745	0.716	0.690	0.667	0.645	0.626	0.609	0.592	0.577	0.563	0.550	0.538	0.527
0.300	1.826	2.236	2.582	2.887	3.162	3.416	3.651	3.873	4.082	4.282	4.472	4.655	4.830	5.000	5.164	5.323	5.477	5.627	5.774	5.916	6.055	6.191	6.325
0.200	2.236	1.826	1.581	1.414	1.291	1.195	1.118	1.054	1.000	0.953	0.913	0.877	0.845	0.816	0.791	0.767	0.745	0.725	0.707	0.690	0.674	0.659	0.645
0.200	2.236	2.739	3.162	3.536	3.873	4.183	4.472	4.743	5.000	5.244	5.477	5.701	5.916	6.124	6.325	6.519	6.708	6.892	7.071	7.246	7.416	7.583	7.746
0.100	3.162	2.582	2.236	2.000	1.826	1.690	1.581	1.491	1.414	1.348	1.291	1.240	1.195	1.155	1.118	1.085	1.054	1.026	1.000	0.976	0.953	0.933	0.913
0.100	3.162	3.873	4.472	5.000	5.477	5.916	6.325	6.708	7.071	7.416	7.746	8.062	8.367	8.660	8.944	9.220	9.487	9.747	10.000	10.247	10.488	10.724	10.954

Table: 1 Factors for multiplying (a) in-row distance and (b) between-row distance of plants in order to achieve selected plant densities and rectangularities. Procede by chosing the maximum plant population required per unit area then calculate the in-row/between-row spacing (x) in metres, for a square plant for that plant density (i.e. R = 1, ρ = 1). For other arrangements multiply x by the appropriate factors given in the table.

FIGURE 16. IMPLEMENTATION FLOWCHART FOR DECIDING ON PLANT POPULATION, RECTANGULARITY AND ARRANGEMENT (Follows "Choice of species flowchart" and continues on to "Management Alternatives"



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- useful field design and also discusses concepts.

ICRAF can supply a 5¼ inch floppy disc (double density) for CP/M microcomputers with a programme for generating Table 1 - apply to ICRAF, P.O. Box 30677, Nairobi, Keny

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PART 4E ANNEX

Appendix 1: Some examples of experimental designs for spacing experiments - by P.A. Huxley

Appendix 2: Plant Population and Yield of Tree and Herbaceous Crops - by M.G.R. Cannell*

* Reprinted from "Plant Research and Agroforestry" (Ed. P.A. Huxley), 1983 ICRAF Nairobi.

Appendix 1.

Some examples of experimental designs for spacing experiments

SEE ALSO

Wright, H.L. and Andrew, I.A. Principles of Experimental Design. (pp 67-82) and Andrew, I.A. and Wright, H.L. Evaluation (pp 108-130). Burley, J. and Wood, P.J. 1976. A manual on species and provenance research with particular reference to the tropics. Commonwealth Forestry Institute, Tropical Forestry Papers No. 10. Oxford.

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- From Mead, R. and Stern, R.D. 1980. Designing experiments for intercropping research. Expl. Agric. 16, 329-342.

A relatively small scale example of the use of factorial treatment structure is provided by an ICRISAT experiment. This involved two sorghum population densities ($S_1 = 180{,}000$ and $S_2 = 120{,}000$ plants/ha), three pigeonpea population densities ($P_1 = 40{,}000$, $P_2 = 80{,}000$ and $P_3 = 120{,}000$ plants/ha) and two row proportions ($A_1 = 2$ sorghum to 1 pigeonpea and $A_2 = 1$ sorghum to 1 pigeon-

$S_1P_2A_1$	$S_2P_1A_2$
$S_2P_3A_2$	S
P	$S_1P_1A_1$
$S_2P_2A_2$	$S_1P_3A_1$

$S_2P_1A_1$	$S_1P_3A_2$
P	$S_1P_1A_2$
$S_1P_2A_2$	$S_2P_2A_1$
$S_2P_3A_1$	S

Fig. 2. One replicate of a 3 X 2 X 2 factorial experiment with 2 sole crop treatments, arranged in two blocks of 8 plots.

pea). Large plots were needed for the collection of both growth and yield data, and hence the A X S interaction was confounded with blocks, giving six treatment combinations plus two sole crop plots (S = 180,000 plants/ha, and P = 40,000 plants/ha) in each block of 8 plots. Four blocks were used, comprising two complete replicates of the twelve factorial combinations, and the arrangements of one replicate (two blocks) is shown in Fig. 2. The original plan for this experiment included three complete replicates of a subset of the treatments shown in Fig. 2, which would have reduced the efficiency for many of the major treatment comparisons by factors of 3/2 or even 2.

Consider again the two principal advantages of factorial experiments with at least three factors. One is that the experimenter is able to examine the extent to which the response to one factor is affected by different levels of a second factor (interaction). In the sorghum/pigeonpea experiment the yield response for the three pigeonpea densities can be assessed (and compared) for the two sorghum densities, and also for the two row arrangements, whereas neither of these interactions could have been assessed from the original non-factorial experiment. The second advantage is the greater economy of the factorial experiment because of its hidden replication. In the sorghum/pigeonpea experiment the average comparison of two pigeonpea densities is based on a total of 8 plots per density whereas, with the original non-factorial design, a comparison between two pigeonpea densities would have been based on only 6 plots (two from each replicate). The advantages of hidden replication apply not only to tables of mean yields, but also to graphs of growth against time.

To illustrate these advantages, consider a theoretical intercropping experiment with 6 replicates of all twelve combinations of three densities of crop A

with four densities of crop B. A comparison of the average yields for two different densities of crop A is based on 24 experimental plots per density; and the comparison of any two particular combinations of densities of the two crops is based on 6 plots per combination. Suppose we now introduce three levels of nitrogen application and two genotypes of crop A, and instead of 6 replicates have no explicit replication, giving 72 plots (3 X 4 X 3 X 2) as before. We now have the same precision as before for the original comparisons, but also have comparisons of approximately the same precision between the nitrogen levels, between varieties and between combinations of any two of the four factors. To argue that the comparison between average yields for different densities of crop A may give different estimates from those for the original experiment only emphasizes the need to consider interactions between factors. The requirement to have the experiment arranged in relatively small blocks may reduce some of the advantages of the four factor experiments, but most can be retained through the device of confounding, which was used very simply in the sorghum/pigeonpea example.

Cochran and Cox (1957) is still the best reference book to help choose an appropriate design if no statistician is available for advice, though the designs have to be adapted slightly if sole crop treatments are to be included. If there are only a few sole crop treatments it may be sensible to include them in each block, as in the sorghum/pigeonpea experiment. It is important to realize that in a factorial experiment with a large number of combinations of different factor levels it is not necessary to have any replication in the sense of plots treated identically. Indeed for a large number of factors it is perfectly possible to draw sensible conclusions from an experiment having only a proportion of all the possible combinations of factor levels. These ideas (all of which appear in Cochran and Cox) are very well-established and are in no sense new or radical. The crucial point, which seems not to have been widely appreciated by researchers, is that the usual practice of having 3, 4 or even more replicates is only sensible if the number of treatment combinations is small. To use 3 or 4 replicates as a reason for avoiding large factorials is to misunderstand the purpose of replication.

A question which is related to the idea of factorial structure is the number of levels of a quantitative factor that should be used. There is a substantial body of statistical theory which points to the advantages of using a small number of levels with large replication rather than many levels with less replication (the replication may be hidden). Statistical results show specifically that the number of levels required should be the same as the number of parameters needed to describe the form of response. Thus only three levels are needed if a quadratic polynomial is used to summarize the yield response. If it is required to detect departures from a quadratic polynomial then a fourth level is needed, but it seems unlikely that more than four levels should be used for any one factor in a randomized experiment, and three will frequently be adequate, particularly if they are well spaced.

Augmented Block Design

The leucaena-spacing experiments on which the model is being based are in the augmented block design of Federer and Raghavarao (1975). The design allows one to ask questions of both a fairly advanced nature, with replications, and a preliminary nature for which replication is unnecessary. For example, one planting utilizing the augmented block design consists of four replications of six plots each (Fig. 1). Each replication has four replicated treatments and two unreplicated, or augmented, treatments. The replicated treatments are 5000, 10 000, 20 000, and 40 000 plants/ha. Augmented treatments range from 2500 plants/ha (preferred by foresters) to 80 000/ha, about the population density of a cornfield.

Analysis of variance is performed only on the replicated treatments, and experimental variations thus derived are used in tests of the augmented treatments. Augmented treatments are adjusted, according to the replication in which they are located, by the formula:

$$T_{adj} = T_{unadj} - X_{i.} + X_{..};$$

where T_{adj} = adjusted treatment mean; T_{unadj}

From Rick H. Van Dan Beldt. 1983. Effect of spacing on growth of leucaena pp.103-108 in "Leucaena research in the Asia-Pacific region. Proceedings of IDRC/NFTA Workshop held in Singapore, 23-26 November, 1982. IDRC, Ottawa.

(see also Annexure to Manual Section 3C for further information on augmented designs).

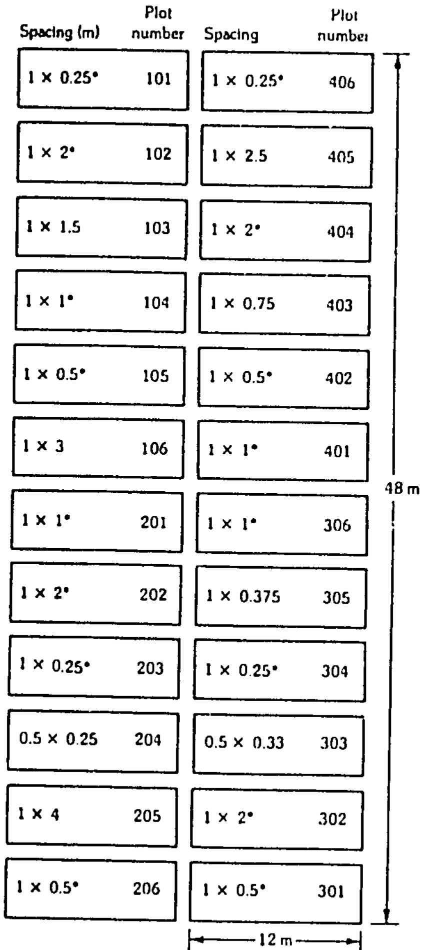


Fig. 1. Augmented block design of University of Hawaii leucaena spacing studies: plots consist of four rows spaced 1 m apart, with variable spacing within rows. Data are taken from centre rows at regular intervals. Means of augmented (nonreplicated) treatments are adjusted according to the replication in which they occur (= replicated treatment).*

= unadjusted treatment mean; $X_{i.}$ = mean of replicated treatments incorporating augmented treatment; and $X_{..}$ = overall mean of replicated treatments.

The augmented block design has the distinct advantage of incorporating far more treatments than the randomized block design used widely in forestry and agriculture. In all, 12 spacings at each site are examined for parameters of growth — height and diameter — over 4 years.

From Willey, R.W. and Rao, M.R. 1980.
A systematic design to examine effects of plant population and spatial arrangement in intercropping, illustrated by an experiment on chickpea/safflower. Expl. Agric. 17, 63-73.

Treatments and design

Four within-row spacings of chickpea were factorially combined with fifteen within-row spacings of safflower at two row arrangements; sole plots of each crop were included at four plant populations, as follows:

Intercrops

Chickpea: 25.0, 12.5, 8.3 and 6.3 cm within-row (C_1-C_4)

Safflower: 75.0 to 19.8 cm within-row in fifteen steps equivalent to 10% increases in population (S_1-S_{15})

Sole crops

Chickpea: 25.0, 12.5, 8.3 and 6.3 cm within-row (C_1-C_4, equal to 13.3, 26.7, 40.0 and 53.3 plants/m^2)

Safflower: 75.0, 38.5, 26.3 and 19.8 cm within-row (S_1, S_8, S_{12}, S_{15}, equal to 4.4, 8.7, 12.7 and 16.7 plants/m^2)

Row arrangements

1 chickpea: 1 safflower in 30 cm rows (1:1)

2 chickpea: 1 safflower in 30 cm rows (2:1)

The basic layout was a strip-plot design with strips of chickpea spacing treatments crossed with the intercrop row arrangement and sole plot treatments (Fig. 1). Safflower spacings were systematically changed, within each row arrangement, with the closest spacing towards the middle of the chickpea strip

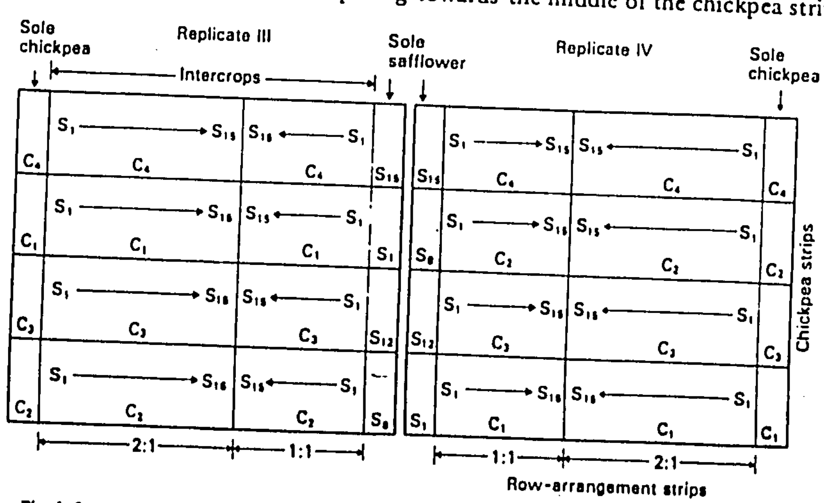


Fig. 1. Lay-out of two replicates showing chickpea and row-arrangement strips, position of sole plots, and direction of systematic change in safflower population.

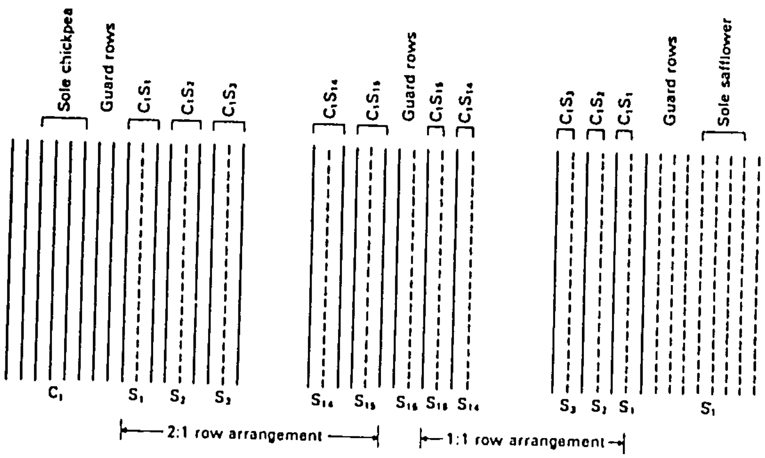
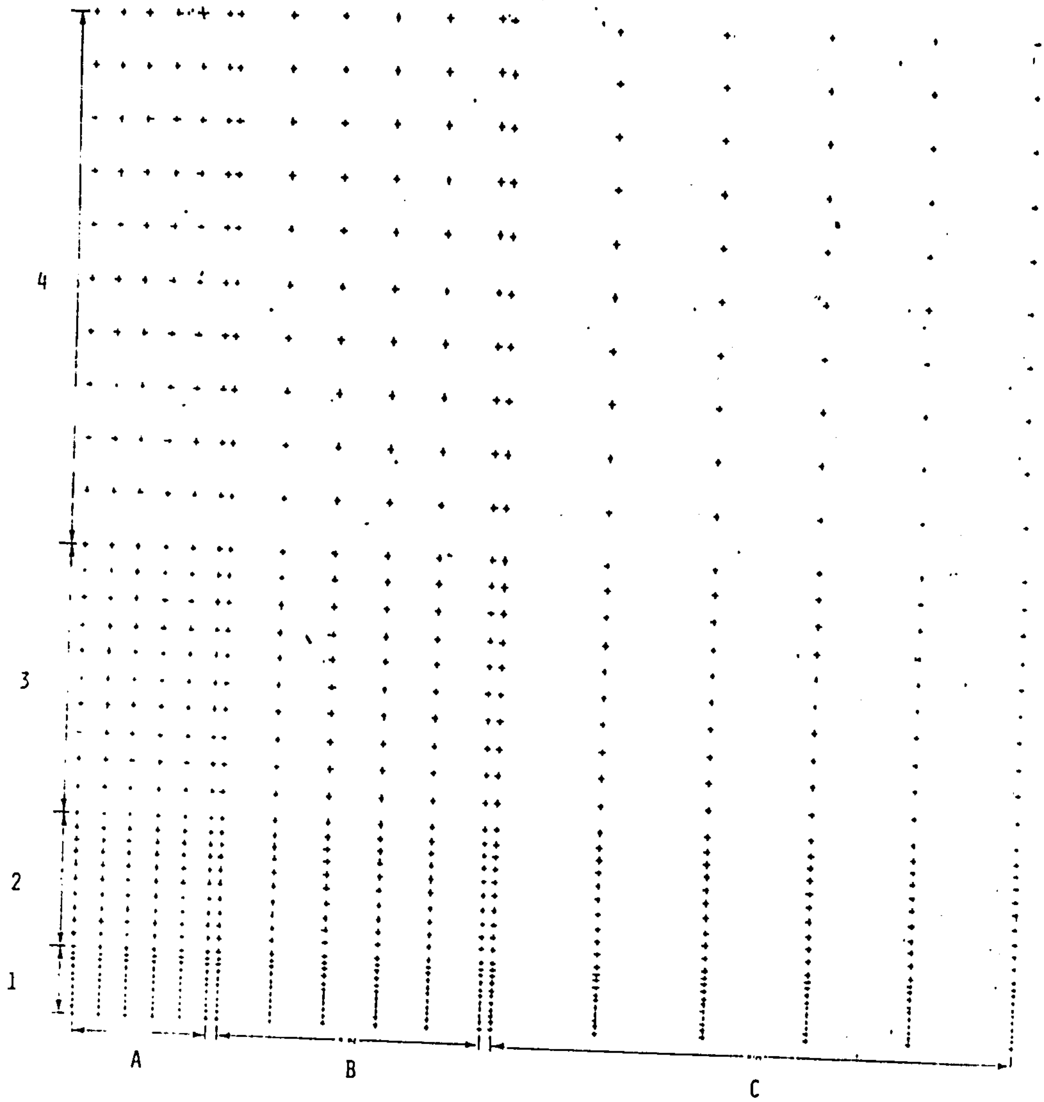


Fig. 2. Lay-out of a chickpea strip (at C_1 population as an example) and sole plots showing number of rows harvested (S_1 to S_{15} = range of systematic safflower populations).

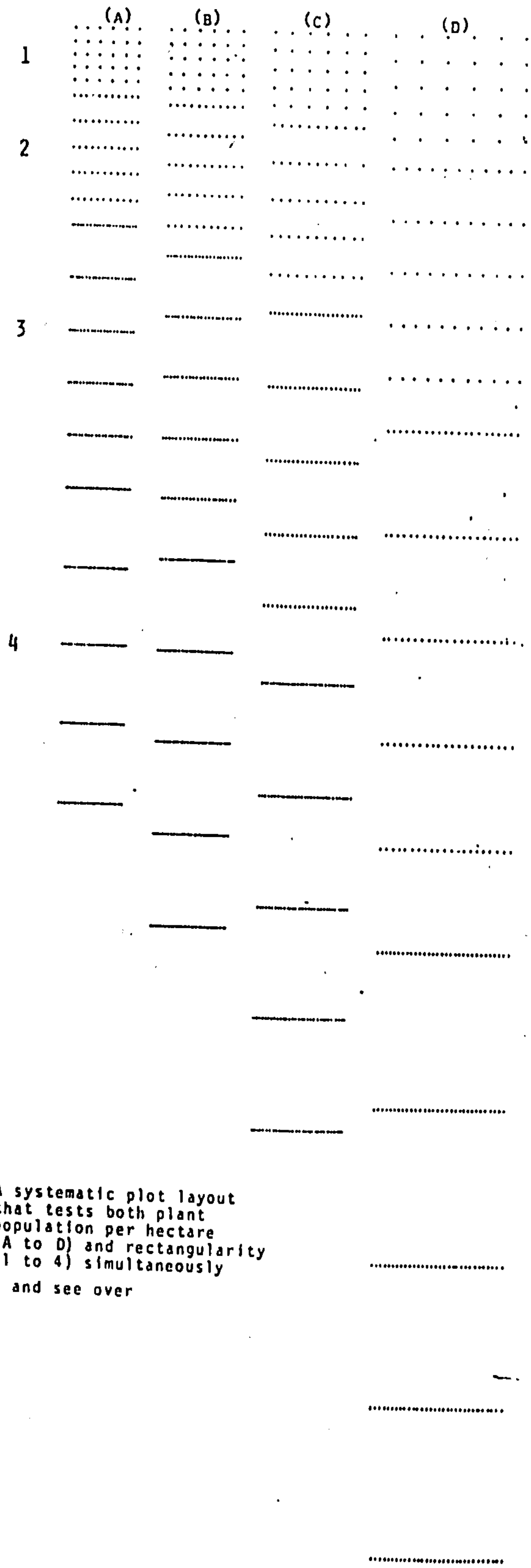
(Fig. 2). For each chickpea strip, a sole chickpea plot was included at the 2:1 row arrangement end and a sole safflower plot at the 1:1 end. Within-row spacings for these sole plots were comparable with the rest of the strip (Fig. 1).

Although the layout was arranged to minimize the need for guard rows within the strips, 2-3 rows were included between the sole plot and intercropping part of the strip and between the two row arrangements (Fig. 2). To minimize the possibility of the systematic changes in safflower plant population coinciding with systematic soil fertility changes, these systematic treatments were arranged N to S in two of the replicates and S to N in the other two (Fig. 1).



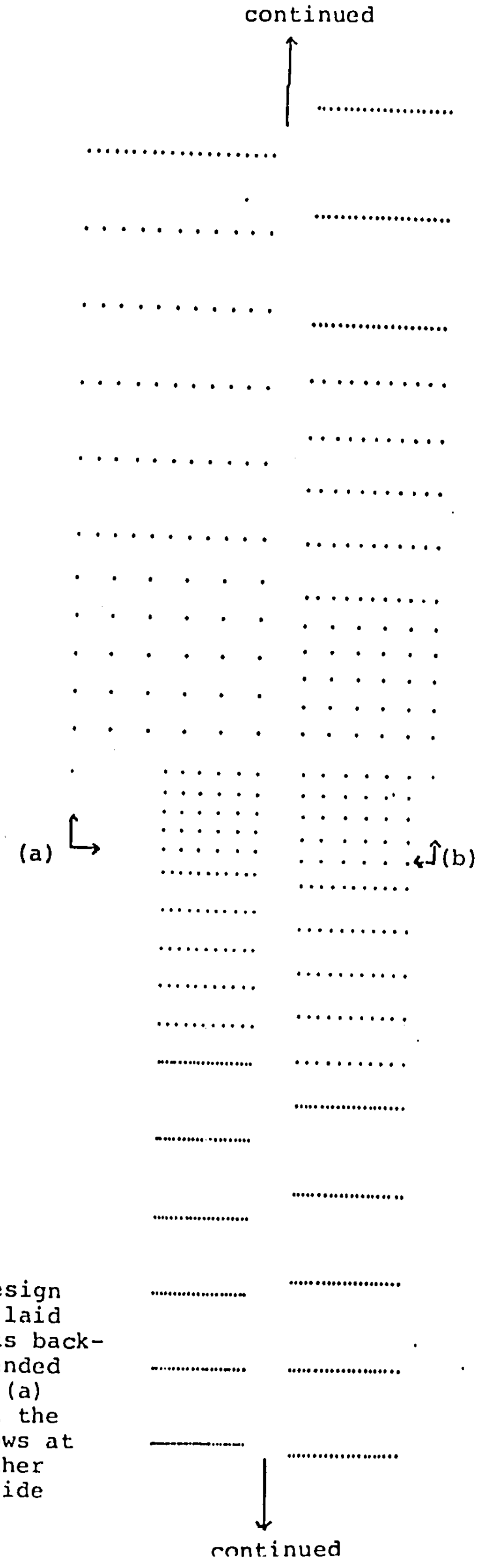
From Getahun, A. and Ndegwa, C.M. 1983. Woodfuel in Kenya: Problems and prospects, pp. 123-146 in Hoekstra, D.A. and Kuguru, F.M. (Eds) "Agroforestry Systems for small-scale farmers". Proc. of an ICRAF/BAT workshop held in Nairobi in September, 1982. ICRAF, Nairobi.

This systematic design tests changes of rectangularity (A-C) at different plant popualtions (1-4), but not both together. It provides a compact field layout and maintains equal sample sizes throughout.



A systematic plot layout that tests both plant population per hectare (A to D) and rectangularity (1 to 4) simultaneously

- and see over



The previous systematic design would be more effectively laid out with the "denser" parts back-to-back (and possibly extended as shown by the arrows at (a) and (b). This would avoid the need for extended guard rows at this part of the design other than at the remaining outside edges.

Appendix 2.

Plant Population and Yield of
Tree and Herbaceous Crops.
- by M.G.R. Cannell

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PLANT POPULATION AND YIELD OF TREE AND HERBACEOUS CROPS

M.G.R. CANNELL
Institute of Terrestrial Ecology, Bush Estate, Penicuik, Midlothian, Scotland.

ABSTRACT. A review is given of the effects of plant population in monoculture on the biomass production, yield, and components of yield in a range of crop types used in tropical agroforestry systems. These include timber trees, fuelwood trees, fruit trees, palms, bananas, various root crops, grain legumes and cereals.

INTRODUCTION

Information on the effects of plant population on the performance of different tree and herbaceous crops is widely scattered in the literature on forestry, horticulture and agriculture. Reviews such as those by Willey and Heath (1969) and Harper (1977) explain the principles concerned, but they do not bring together data on the diverse range of tropical crops that are grown together in agroforestry systems. An attempt has therefore been made to summarize such data for (a) forest trees, (b) fruit trees and palms, (c) storage root crops, (d) grain legumes, and (e) cereals. For each crop, the effects of plant population are described in the figures and/or text on (i) biomass production (or leaf area index) per unit area of land, (ii) yield per hectare and per plant and (iii) the components of yield. The sources of information are quoted mainly in the figure legends.

TREE CROPS

Forest trees (Fig. 1)

Per hectare yields of trees have to be averaged over the years since planting, giving the mean annual increment (MAI), which, like the current annual increment (CAI), increases after planting as the stand leaf area index increases, but *decreases* when the trees age. MAI is greatest at the age when it equals CAI, by which time there is often competition-driven mortality. The plant population ('stocking density') and age giving maximum

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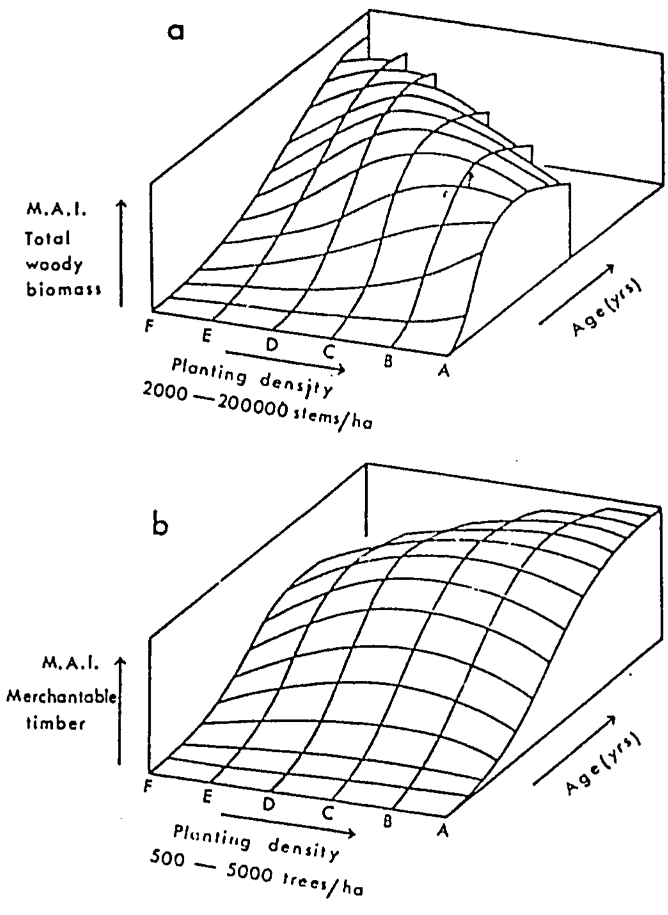

Fig. 1. Effect of planting density on the mean annual increment (MAI) of trees grown for woody biomass (branches and stems of any diameter) and merchantable timber (stems above a given diameter). Note that there is an optimum density for woody biomass as well as timber production, and that thinning will move the population in the direction A to F. Remember that closely spaced trees will be small in diameter, but not necessarily height, and that, in unthinned stands, the number of trees at harvest will be less than at planting owing to self-thinning.

MAI depend on the environmental resources, species and product (Assman, 1970; Hamilton and Christie, 1974; Baskerville, 1965; Cannell and Smith, 1980).

If the product is woody biomass of branches and stems, without regard to individual tree diameter, then MAI maximizes ('culminates') at a younger age with increase in plant population, but the greatest MAI is achieved at a *particular density and age* (density D in Figure 1a). This is because, at very wide spacings the trees age physiologically and so produce less total dry matter per hectare, before they reach maximum MAI, whereas at very close spacings maximum MAI occurs before the stand has developed its full height, cambial surface and canopy depth, and the stand 'stagnates'. Thus in pulpwood plantations the asymptotic yield - density relationship does not hold over a *wide* range of densities, although it does hold approximately over the range of densities included in most studies (Cannell, 1979).

If the product is boles above a given diameter, that is merchantable timber, or fuelwood with a certain minimum volume/surface ratio, then stands at *wide* spacings become productive soonest because they produce large individuals quickly. Stands at close spacings will have small diameter stems to begin with, but after considerable thinning or self-thinning these closely-spaced stands may eventually reach maximum MAI values (including only large diametered stems) similar to those of stands initially planted at wider spacings. In Figure 1b thinning the trees moves the population from lines B to C to D to E and is desirable because it *brings forward* the time of maximum MAI and also salvages the smaller individuals that would otherwise die and rot. Foresters normally prefer this policy - close initial planting and successive thinning (even 'precommercial' thinnings) - because density stress suppresses branching (and weeds) and encourages self-pruning, which in turn increases the proportion of above-ground dry matter going to the boles, decreases knot number and size, and decreases stem taper. Because of these effects, the small tree crowns of density-stressed trees (at desirable spacings) are efficient producers of merchantable bole wood per unit of foliage and ground area (Assman, 1970).

In short, the forester's aim is to keep the degree of density stress at a desirable level, balancing the benefits of density stress on weed and branch suppression against its undesirable effect on decreasing mean bole diameter (and eventually inducing mortality) and a delay in reaching maximum MAI. And at the same time the forester recovers saleable thinnings as soon as he can.

Fruit trees and palms (Fig. 2)

Tree populations giving maximum fruit yields per hectare are much lower than those producing maximum dry matter per hectare, whether the yield is fleshy fruits, seeds, or palm fruits. This is because there is a precipitate decrease in numbers of fruits per tree with increase in mutual shading resulting, at a critical plant population, in decreased yield per hectare above, for instance, leaf area indices of 1 to 2 in shade intolerant apple in England, and above leaf area indices of 3 to 4 in shade tolerant coffee in Kenya. Also, shaded fruits may not ripen

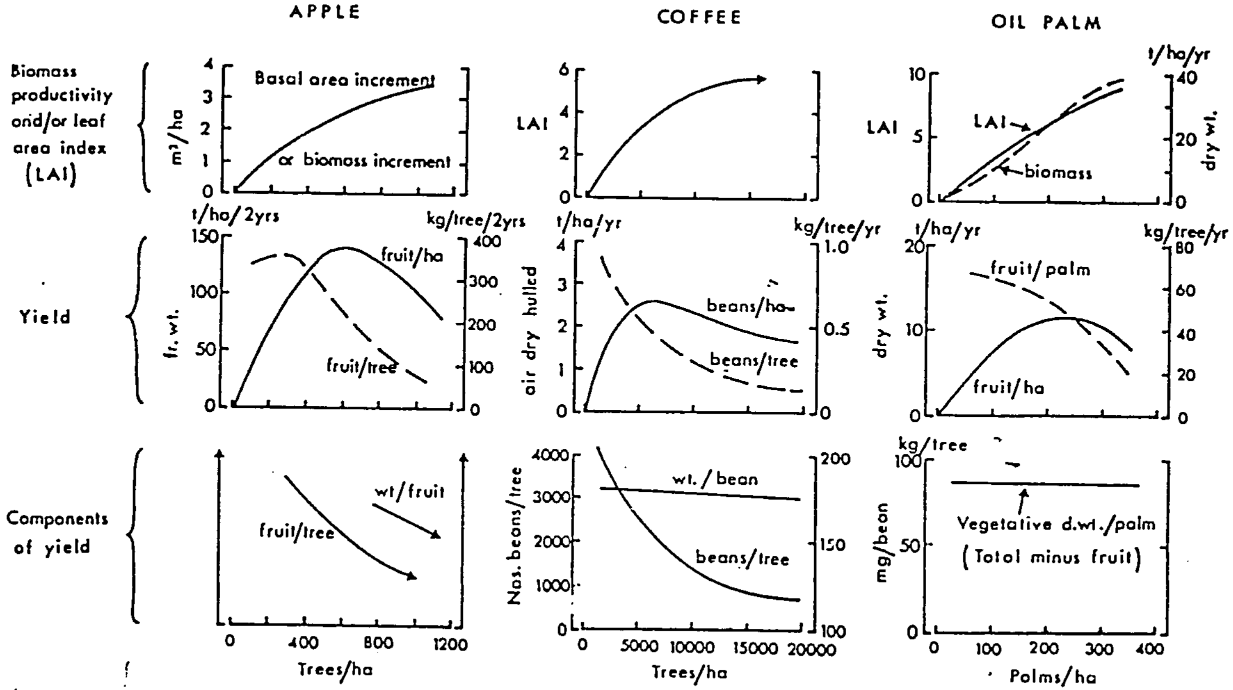
APPLE
COFFEE
OIL PALM
Biomass productivity and/or leaf area index (LAI)
Yield
Components of yield
m²/ha
Basal area increment
∝ biomass increment
LAI
LAI
t/ha/yr
dry wt.
LAI
biomass
t/ha/2yrs
kg/tree/2yrs
fr. wt.
fruit/ha
fruit/tree
t/ha/yr
kg/tree/yr
air dry hulled
beans/ha
beans/tree
t/ha/yr
kg/tree/yr
dry wt.
fruit/palm
fruit/ha
wt/fruit
fruit/tree
Nos. beans/tree
wt. / bean
beans/tree
kg/tree
mg/bean
Vegetative d.wt./palm
(Total minus fruit)
Trees/ha
Trees/ha
Palms/ha

Figure 2.

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properly and may be small, but there may not be much decrease in the mean weights of individual seeds or shelled nuts.

The effects of plant population on dry matter distribution in fruit trees depend on the species. In apple, very widely spaced trees may produce few fruit because cross-pollination is hampered. The optimum proportion of the total dry matter is devoted to apple fruits at an intermediate plant population which decreases as the trees get bigger (Cripps *et al.*, 1975). In self-pollinated Arabica coffee a very large proportion of the total dry matter is apportioned to seeds when the trees are widely spaced and well-illuminated, indeed so much so on young trees that they can 'overbear' (for reasons given by Cannell, 1975). So, for coffee too, the optimum lies at some intermediate population, depending on how the trees are pruned.

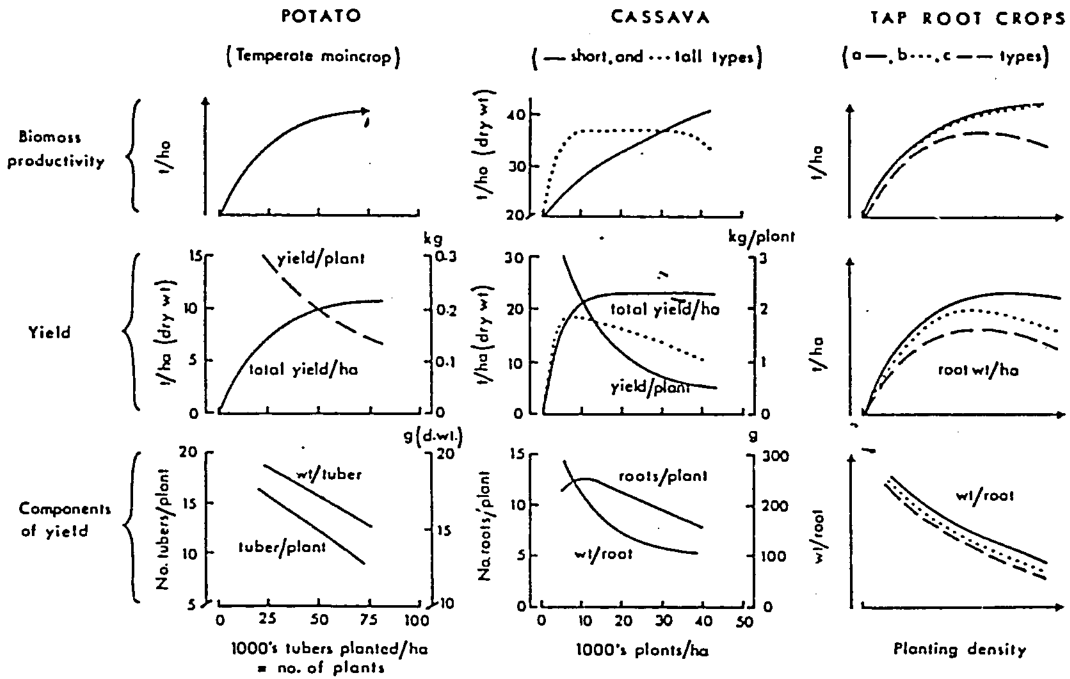
Oil palm is quite different; the proportion of dry matter devoted to fruits increases as the palms get bigger, will decrease if some leaves are pruned off, and will diminish with an increase in plant population because the amount of dry matter produced per palm will be smaller. However, the absolute dry weight of the vegetative parts per palm is surprisingly constant over a wide range of densities, showing that the size of individual palms and their individual dry matter productivities have to exceed a certain minimum before they will produce large amounts of fruits (Corley, 1973). Consequently palms need to be grown at relatively wide spacings and plantations often have only about 200 plants per hectare, as compared with over 400 for apple and well over 1000 for coffee.

HERBACEOUS CROPS

Bananas

Bananas seem to be quite tolerant of increases in density stress, largely because they produce suckers. Unreported 'fan' trials in Jamaica have shown that tetraploid clones will yield similar amounts per hectare over the range 1077 to 2389 plants per hectare. At close spacings the individuals produced fewer suckers, fewer branches, fewer fruits per branch, but similarly sized bananas, and only marginally greater yields per hectare (pers. comm. K. Shepherd, Banana Company of Jamaica). However, at very close spacings ratoon yields could decline.

Fig. 2 (*Opposite*) Effects of planting density on the biomass* and yield of tree crops. *Apple*: from Verheij (1968, quoted by Harper, 1977, his Fig. 7/17); values for 11th to 13th year after planting in Hungary. Stem base cross-sectional areas are linearly related to above-ground biomass (Westwood and Roberts, 1970). The trees were pruned to bush and spindle shapes. *Coffee*: from Browning and Fisher (1976), Kuguru *et al.* (1977) and Cannell (1972); values for 4-year-old *Coffea arabica* L. in Kenya. Bean (=seed) yields differed greatly between sites, but the trends with planting density were similar. *Oil palm*: from Corley (1973); values for 7-year-old *Elaeis guineensis* Jacq. in southern Malaya.
*Biomass values refer to the dry weight above ground, omitting roots and fallen leaves.



POTATO
(Temperate maincrop)
CASSAVA
(— short, and ··· tall types)
TAP ROOT CROPS
(a —, b ···, c — — types)
Biomass productivity
Yield
Components of yield
t/ha
t/ha (dry wt)
kg
kg/plant
yield/plant
total yield/ha
total yield/ha
yield/plant
root wt/ha
g (d.wt.)
g
wt/tuber
tuber/plant
No. tubers/plant
roots/plant
wt/root
No. roots/plant
wt/root
1000's tubers planted/ha = no. of plants
1000's plants/ha
Planting density

Figure 3.

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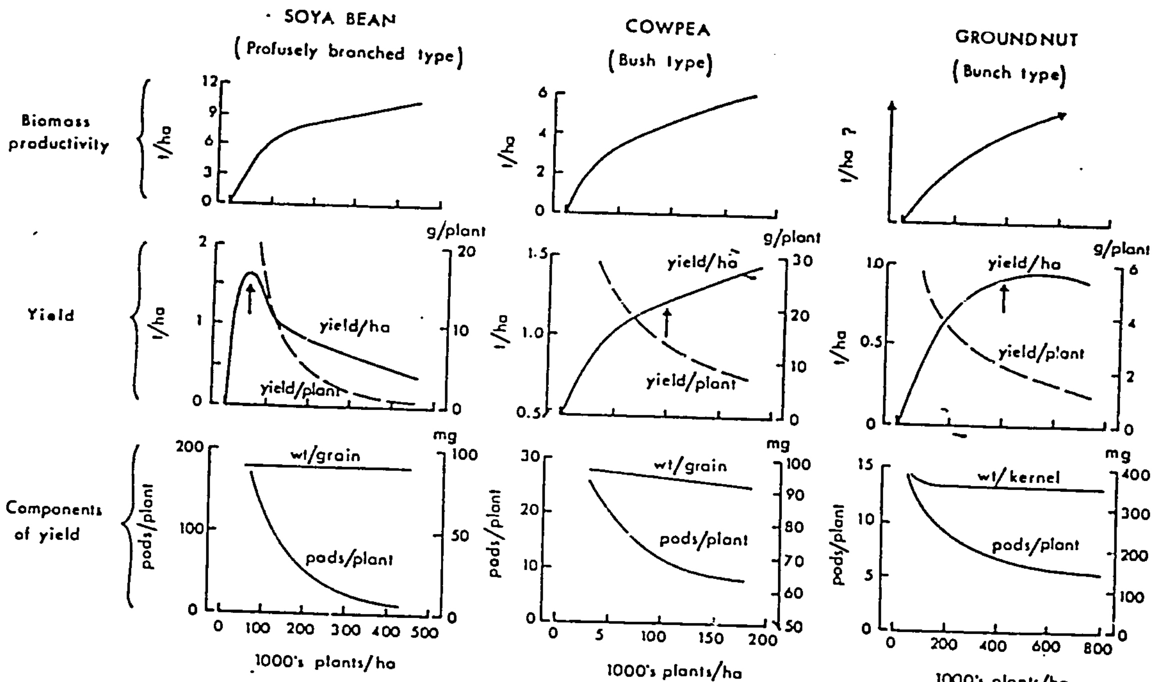
Storage root crops (Fig. 3)

The per hectare yields of storage root crops usually increase to a plateau with increase in plant, or rather *stem*, population (cassava, Enyi, 1973b; potato, Ifenkwe and Allan, 1978a, b), following a similar trend to the increase in total dry matter per hectare. Although there are instances, such as in some tall cassavas, where total dry matter and harvest indices decline at high plant populations, this is not the rule. Increasing cassava plant populations only slightly decreased the harvest index, from 58 to 56 per cent in Tanzania (Enyi, 1973b), had no effect in Malaya (harvest index 55 per cent; Williams, 1972), and increased it from 44 to 58 per cent in Sierra Leone (Godfrey Sam-Aggrey, 1978). In tap root crops (beets, turnips, etc.) there is only a small decrease in storage root/top ratio, or no change at all (Bleasdale, 1966; Currah and Barnes, 1979). The most important factors affecting harvest indices in root crops are: (a) genotype: those varieties which divert a large proportion of their dry matter to storage roots tend, unfortunately, to increase their foliage canopies, and hence total dry weights, rather slowly (for example, cassava, Cock, 1976; Cock *et al.*, 1977); and (b) size-grading, because in all root crops increasing population density decreases the size of individual roots (or tubers, etc.). Thus relatively high plant populations will be desired for single-stemmed root crops, for an early harvest, or small roots; whereas lower populations would be better for multistemmed branching or trailing types, a delayed harvest, or large roots.

Grain legumes (Fig. 4)

The examples given in Figure 4 are *not* necessarily typical of the three species represented; they show only a part of the variation in response to plant population within this diverse group of crops. Note that the greatest yields per hectare typically occur at populations much below those giving greatest total dry matter, but not always (see bush type cowpea). Also the economic optimum populations are typically less than those giving greatest yield (because the seed is expensive), but not invariably. Plant habit is all important. The optimum population

Fig. 3 (*Opposite*) Effect of planting density on the growth and yield* of storage root crops. Potato (*Solanum tuberosum*) from Ifenkwe and Allen (1978 a, b) taking means for cvs Désirée and Maris Piper main crops grown in west Wales at varying within-row spacings, averaged for rows 66 cm and 132 cm apart. Cassava (*Manihot esculenta* Crantz) from Cock *et al.* (1977) for cvs M Col 1080 (tall) and M Col 22 (short) growing in Colombia. Tap root crops: (a) *carrot* (Bleasdale, 1967; Currah and Barnes, 1979; Salter *et al.*, 1979); *parsnip* (Bleasdale and Thompson, 1966); *radish* (Bleasdale, 1967); *turnip* (Hozumi and Ueno, 1954); and *onion* (Frappel, 1973). (b) Size-graded yield of most root crops (including potatoes and cassava). (c) *Red beet* (Bleasdale, 1966); *globe beet* (see Willey and Heath, 1969). *Similar scales are used in the graphs of total biomass (total above ground plus storage root) and storage root weights so that trends in the harvest indices can be judged.



SOYA BEAN
(Profusely branched type)
COWPEA
(Bush type)
GROUNDNUT
(Bunch type)
Biomass productivity
Yield
Components of yield
t/ha
t/ha ?
g/plant
yield/ha
yield/plant
pods/plant
wt/grain
wt/kernel
mg
1000's plants/ha

Figure 4.

for soya bean, by far the most studied species, varies from 70,000 per hectare for profusely branched types in Tanzania (Enyi, 1973a) to almost a million per hectare from determinate, poorly branched types in the USA (Wiggans, 1939). Similarly, the optimum population for groundnuts in East Africa varies from about 90,000 for prostrate, alternately branched types, to over 150,000 for erect, sequentially-branched types (Laurence, 1974; Enyi, 1977).

The main reason for this variation in response lies in the fact that legumes which are indeterminate and spreading, yield by the continued production of branches and flowers over a long time period, whereas determinate types do not. The indeterminate types suffer a profligate loss of flowers if there is substantial mutual shading. Density stress does not necessarily hasten or synchronize flowering (cowpea, Erskine and Khan, 1976; groundnuts, Gopalaswamy *et al.*, 1979); so if indeterminate types are planted at high densities they develop few fruiting nodes (because they develop few branches) and, because self-shading occurs early in their development, they develop few flowers per node. Relatively few of these may survive, or develop filled pods, because mutual self-shading increases as the crop grows. Determinate, erect types suffer less of these adverse effects. In both cases mean grain weights remain relatively unaffected.

Cereals and maize (Fig. 5)

Cereals such as wheat, barley, and especially rice (Yoshida, 1972) give similar yields over 2- to 10-fold ranges in planting density, mainly because they can produce variable numbers of tillers to fill the space available. The plant population at which total dry matter production begins to plateau is usually also the population giving within 5 per cent of the greatest grain yield (Donald, 1963; Fischer *et al.*, 1976). For wheat, this plant population is lower for profusely tillering, or dwarf Norin 10 derivatives, grown with large fertilizer inputs in the tropics, than for poorly tillering or tall varieties grown with small application of fertilizer in temperate regions (see Figure 5). The greatest yield seems to occur when the crop growth rate peaks just before spike dry matter accumulation (Fischer *et al.*, 1976). At higher plant populations yields decrease, at least slightly, because mutual shading leads to (i) wasteful tiller self-thinning; (ii) fewer ears being produced per tiller; (iii) leaf senescence; and (iv) a smaller number of grains being produced per ear and per hectare (Puckridge and Donald, 1967; Willey and Holliday, 1971). The harvest index decreases gradually as plant population increases (Donald and Hamblin, 1976)

Fig. 4 (*Opposite*) Effect of planting density on the growth and yield of grain legumes. Soya bean (*Glycine max* L.) from Enyi (1973a) for a cultivar which produced most of its pods on side branches, grown in Tanzania. Cowpea (*Vigna unguiculata* L.) from Erskine and Khan (1976); the means of two bush type cultivars grown in Papua New Guinea. Groundnut (*Arachis hypogaea* L.) from Gopalaswamy *et al.* (1979); a bunch Spanish type cultivar grown on rainfed lands at Tamil Nadu, India. Arrows mark the economic optimum planting density in each case

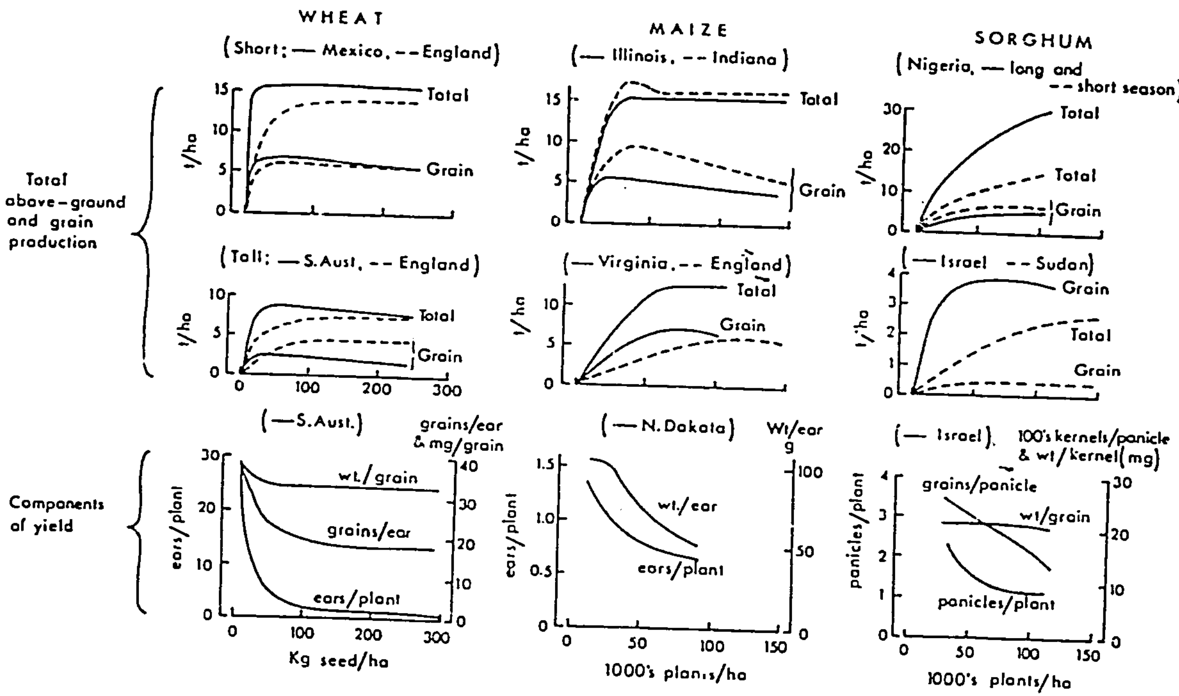

WHEAT
(Short: — Mexico, -- England)
MAIZE
(— Illinois, -- Indiana)
SORGHUM
(Nigeria, — long and -- short season)
Total above-ground and grain production
t/ha
Total
Grain
(Tall: — S.Aust, -- England)
(— Virginia, -- England)
(— Israel -- Sudan)
Components of yield
(—S.Aust.)
grains/ear & mg/grain
wt./grain
grains/ear
ears/plant
Kg seed/ha
(— N.Dakota)
Wt/ear g
wt./ear
ears/plant
1000's plants/ha
(— Israel).
100's kernels/panicle & wt/kernel(mg)
grains/panicle
wt/grain
panicles/plant
1000's plants/ha

Figura 5.

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and at high plant populations net total dry matter production may decrease (Willey and Holliday, 1971).

Sorghum behaves similarly, except that in long-season types the greatest grain yield is obtained at much lower populations than those giving maximum dry matter per hectare.

Maize is somewhat different, because it produces few tillers, and because its inflorescences are held low down on the plant where they are easily shaded. Consequently, maize generally exhibits a more distinct optimum population for yield than other cereals. Mutual shading decreases both the number and size of ears, and the optimum population is lower in countries with high solar radiation receipts than in northwestern Europe (compare USA and England, Figure 5). The search for high yielding hybrid maize varieties has largely been for types which maintain a high harvest index at high plant populations (Bonaparte and Brown, 1975; Donald and Hamblin, 1976).

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Fig. 5 (Opposite) Effects of planting density on the growth and yield of cereal crops. *Wheat*: short (that is, dwarf and semi-dwarf cultivars derived from Norin 10) spring cultivars growing in Mexico, from Fisher *et al.* (1976, their experiment 8), and a winter cultivar ('Gaines') growing in England, from Thorne and Blacklock (1971, their Table 4); tall cultivars growing in South Australia from Puckridge and Donald (1967) and England from Holliday (1960). 1 kg seed ha^{-1} ≡ 2 plants m^{-2}. Yield component data from Puckridge and Donald (1967). *Maize*: data from Illinois for an old cultivar from Morrow and Hunt (1891, quoted by Donald and Hamblin, 1976); Indiana cv. PAGSX29 (Fery and Janick, 1971); Virginia early maturing cv. Va4 (Bryant and Blazer, 1968); England mean of three early maturing hybrids (Milbourn *et al.*, 1978). The yield component data are from North Dakota for early maturing hybrids (Alessi and Power, 1974). *Sorghum*: Nigeria data are for a local long-season cv. Farfara and for the American short-season hybrid NK300 (Goldsworthy and Taylor, 1970). The Israeli data are averages for 2 years and 2 row spacings, for cv. RS610 grown on soil water reserves (Karachi and Rudich, 1966). The Sudanese data refer to unirrigated dwarf cvs 'Wad Akr 51/3' and 'Plainsman' (Gerakis and Tsangarakis, 1969).

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See previous paper for DISCUSSION.

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SECTION FOUR

PART 4F

Systematic designs for field experimentation with MPTs

PART 4F

CONTENTS

(Also circulated as ICRAF Working Paper No. 12).

SYSTEMATIC DESIGNS FOR FIELD EXPERIMENTATION WITH MPTs

The use and misuse of systematic designs

Systematic designs have been suggested in the MPT manual for consideration in the "management trial" stages of MPT's where plant spacing is a prime variable to be investigated (Table 2, Section 3c). Also as a particularly valuable and space-saving design for the *preliminary investigation* of suitable MPT/crop mixtures. There are both advantages and disadvantages in using systematic field layouts, a major concern to many being the difficulties of applying as vigorous a statistical evaluation as they would wish to the data obtained due to the non-randomness of the design.

Advantages as compared with conventional designs

- Systematic designs occupy a much smaller space than randomised block or other conventional layouts.
- Relatively fewer plants will be needed (but this saving may not be as great as expected due to the higher population densities usually being tested).
- The effective experimental area is proportionally much greater than in conventional layouts that include spacing as a variable, and so incorporate multiple internal guard rows.
- The range of levels of the experimental variable under test (for example, spacing) can be greater than in a conventional layout, and it can easily incorporate extremes so as to obtain a better appreciation of plant responses to "density stress", or any other imposed management factor.
- They can provide an easily observable response to a treatment so that they are useful as demonstrations.

Disadvantages as compared with conventional designs

- Systematic designs require a greater level of skill to lay-out in the field.
- Each plot must be sited on an area that is environmentally very uniform (not so difficult as they each can take up only a limited space).
- They are susceptible to damage and need consistent care and attention so as to maintain a high level of management (e.g. weed control) throughout the plot.

- Although they can and should be adequately replicated (preferably using different compass orientations) the data is basically evaluated only by regression analysis (for example yield on plant population).

- Unwanted variability will occur if either:

  - the genetic material used is itself variable, or
  - extreme care is not taken at planting, together with early and proficient gapping-up.

  In addition, particular rows or parts of rows in a systematic spacing layout may sometimes show a degree of unexpectedly dominant or suppressed growth. Any such effects can be obviated by displaying the data in the form of running means.

- All the outer rows of plants in a systematic design are usually discarded as "guards" but, especially in spacing trials, the area of high plant density will require several additional guard rows in order to eliminate any "edge effects". Or the design should incorporate a number (5 or 6) of additional 'dense' steps which are not required.

Systematic field layouts have been used now by agriculturists, horticulturalists, foresters, forage specialists, and so on, for a good many years. Even so they are not often enough included in the field experimenter's choice of field layouts. Especially at the early stages of e perimenting when it may not be quite clear what is likely to be "on-target" or not with regard to a treatment variable which is susceptible to a very wide range of levels (such as plant spacing, fertilizer or herbicide applications). And particularly when these are being tried in a "new" situation.

Overall, systematic designs can be most useful in the early stages of experimentation where a survey of *plant responses* to a variable is required (i.e. effects on growth, flowering etc). They will usually be followed by further field experimentation using more robust designs, especially where reliable *yield data* are to be compared. They should readily lend themselves to investigations with MPT trees/bushes which involve studying the effects of a wide range of plant spacings - either as the primary variable or as a background treatment against which some other management variable is to be tested (lopping or pruning treatments, for example).

Some General Comments on and Examples of Systematic Designs

The "systematic" approach as such can be applied to very straightforward field situations. For example, where plant material is scarce simple "line-out" trials may be all that is possible but even here each line of plants can start with wide spacings (free-standing) and then decrease the distance between plants down the row in order to get at least a first approximation of plant-to-plant interactions in what, in these circumstances, will amount to a hedgerow.

In fact such a layout is not systematically complete because it consists only of a single row of plants and the between-row changes in interferance effects are missing. Systematic designs dealing with plant spacing have to accommodate not only a selected percentage-wise change in plant population, but to do so at a standard rectangularity and plant arrangement. Although some more complicated designs can accommodate both changes in population and rectangularity at the same time (for example, log/log designs).

Two kinds of systematic design have commonly been used to investigate sole crop spacing problems with a wide variety of plant material from vegetables to tree species. These are the "fan" designs (Nelder) and "parallel row" layouts (Bleasdale). Suitable numerical examples are given in Appendix 1. Methods for calculating spacings for either layout are fully described by Bleasdale 1967, and ICRAF can provide a computer programme for making these calculations*

A fan design is shown in Appendix 1 Figure 1. Depending on the number of radii set down, fans suffer from having a limited number of plants to sample at harvest, i.e. just those harvested from any one arc (or group of arcs). The extension of the fan to fit a rectangle (as in Appendix 1 Figure 1b) can usefully increase the sample size for the middle range of plant densities under investigation.

Parallel-row designs (Appendix 1 Figure 2) are easier to lay out in the field. They can be made as long as necessary to achieve a suitable sample size at the wide spacing, but then there is an unnecessarily large sample for close-spaced rows.

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* Written for the Osborne microcomputer or other CP/M based micros and provide on a double-density, single-sided 5¼ inch floppy disc. See Appendix 2.

This can be remedied by using the same number of plants in every row which shortens the more densely planted rows. The design then resembles a "fan", but without true arcs, (Appendix 1 Figure 2).

All systematic designs which incoporate spacing as a variable need some additional guard areas surrounding the close-spaced treatment rows. Otherwise edge-effects (especially extraneous light) will completely distort the growth and/or yield in this part of the layout. The number of such additional guard-rows (which can merely repeat the closest level of spacing) is difficult to predict as it will depend on (a) what the closest spacing actually is; (b) the habit of the plant; and (c) the duration of the experiment. Some 5 or 6 extra rows (extending partially up the side radii in a fan design) are likely to be adequate.

Systematic designs and intercropping trials

For agroforestry mixed cropping experiments, including "tree/crop" interface studies, spacing of both components is an important variable and systematic designs can be used to explore the effects of this.

For intial "compatibility" experiments to decide on the selection of suitable tree/bush species and agricultural crop associates, a simple parallel row design for the trees with replicated strips of the various agricultural crops sown across this at right angles could be suitable (Appendix 1 Figure 3). Such a layout could also involve different management treatments on some or all of the agricultural crops (time-of-planting, fertilizing etc). This would be considered as a preliminary resource-saving investigation and more detailed field experiments would be carried out on the resulting selection of species and/or management treatments The dimensions for a parallel row design with MPT's, as given in Appendix 1, might be suitable for many medium-sized trees.

When there are two known species of trees and agricultural crop, about whose association a considerable amount more information is required, then a more complicated double superimposed parallel row design could be used (see Appendix 1 Figure 4). This is really only suitable for setting down on a research station where it can be carefully supervised and additional instrumentation and data sampling undertaken in order to get the most useful information from it. The additional

dimensions for the agricultural crop parallel row layout are given in Appendix 1.

A rather simpler type of "on-farm" systematic layout - in this example to test the value of a chosen MPT species as a provider of woody mulch - is shown in Appendix 1 Figure 5. The main variables being examined are the size of the area of tree species needed in relation to agricultural crop area and the response of the trees to a standard lopping regime. A subsidiary question is how does the mulch effect the production of the agricultural crop if the soil is tilled or left un-tilled.

Clearly, any other simple combinations of management variables can be dealt with by a systematic layout of such a kind as this. They lack any possibility of statistical analysis unless the same design is replicated many-fold for example, on numerous sites. Even then there may be a degree of bias in between-treatment comparisons as a consequence of not randomizing treatment positions. Nevertheless, such simplistic designs can provide, at low cost, some valuable "first approximation" results and provide a visually easily comprehended outcome for the farmer. They are the least demanding in terms of establishment and maintenance and therefore may have some merit in helping to offset the cost of management experiments with trees on farmer's lands using conventional, randomized field layouts.

Selected References

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- describes how to lay out fan and parallel row designs (and refers to the original work by Nelder, Mead etc).

Huxley, P.A, 1980. Agroforestry Research: the value of existing data appraisal, pp.279-315 in "International Cooperation in Agroforestry" (Ed. Trevor Chandler and David Spurgeon), ICRAF, Nairobi.

- Gives suggestion for a double parallel row and an 'on-farm' systematic designs.

Huxley, P.A. and Maingu, Z, 1978. Use of a systematic spacing design as an aid to the study of intercropping: some general considerations. Expl. Agric. 14, 49-46.

- Introduces the idea of using systematic designs (in this case a "fan") for intercropping research, and considers how to interpret the results.

Willey R.W. and Rao, M.R. 1981. A systematic design to examine effects of plant population and spatial arrangment in intercropping, illustrated by an experiment on chickpea/saflower. Expl. Agric. 17, 63-73.

- describes a strip-plot design with one crop within a main plot arrangement of different populations of another.

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ANNEXURE

APPENDIX 1. Some systematic field layouts for agroforestry research

by P.A. Huxley

APPENDIX 2. Documentation for the systematic spacings design programme

by L. Fidaali

(Enclosure - 5¼ inch floppy disc single-sided, double-density, formatted for the Osborne I).

SOME SYSTEMATIC FIELD LAYOUTS FOR AGROFORESTRY RESEARCH

1. *A fan design suitable for testing the effects of spacing on a multipurpose tree species* - Figure 1.

   (for on-station trials)

This can be laid down as a fan *per se* or as a fan enlarged so as to fit a rectangular plot. The advantage of the latter is that it extends the area for testing the middle range of plant densities, and so improves the accuracy of results in this range, which is usually of most interest. Each fan should be replicated and the replicates sited with a different orientation (N.S.E.W). If only two replicates are possible then they should be at right angles i.e. in line with and at right angles to the prevailing wind, say.

As with all systematic designs the plots chosen should be extremely uniform and flat, and site preparation, weeding and pest control, should be meticulous. Seedlings for planting out should be selected twice in the nursery and it is as well to prepare two or more times the number that will finally be required. Sufficient spaced seedlings should be kept aside unshaded and watered in the nursery for gapping up. This must be done at the earliest opportunity, and more than once if necessary.

In this design the rate of change of spacing (α) has been set at 1.1112 (i.e. an 11 percent rate of change) which is the maximum allowable. The angle between the radii is $6^0 03$ (0.1055 radians). The change in area per plant is from 1.0 to $36.0m^2$ in 18 steps. Taking a suitable point of origin the distance to the baseline is 7.37m. The number of radii establishes the size of the sample to be removed or harvested (less 2 for outside guard rows). If the layout is to fit a rectangle then this will be 55.80m wide and 63.55m long and there will be 25 radii in all.

Plant spacings are as follows:-

Distance (from the point of origin) to r_0 the first single guard row is 8.53m - (but see below for the necessity to add additional guard rows at

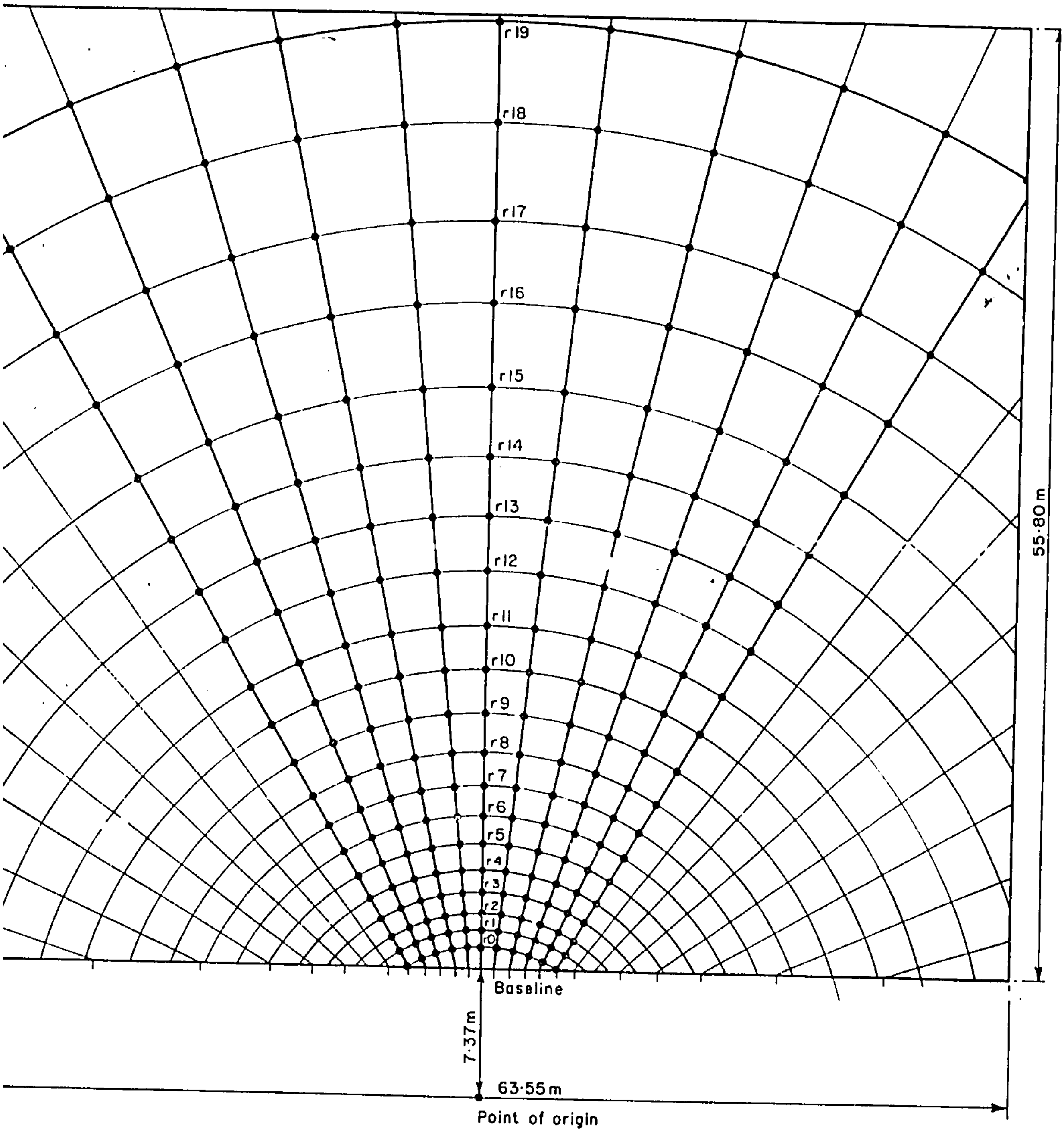

Figure 1. A fan design using 11 radii which can also be extended to fit a rectangle thus increasing the number of plants per arc for the middle range of spacings.

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the "dense" end, these can be at the same initial between-arc interval (i.e. $r_1 - r_0$ = 0.95m).

A "point of origin" is selected and Table 1 then shows the distances of successive arcs from this.

Table 1* Distance of rows (arcs) from point of origin (m)

r_0	8.53m (guard)			
r_1	9.48 = 1m² per plant	r_{11}	27.2	
r_2	10.5	r_{12}	30.2	
r_3	11.7	r_{13}	33.6	
r_4	13.0	r_{14}	37.3	
r_5	14.4	r_{15}	41.4	
r_6	16.0	r_{16}	46.0	
r_7	17.8	r_{17}	51.2	
r_8	19.8	r_{18}	56.9	= 36m²/plant
r_9	22.0	r_{19}	63.2	(guard, or additional rows)
r_{10}	24.5	r_{20}	70.2	

The central radius should intercept the baseline at right angles and the position of the other radii can then be found by marking out the base line (to the right and then to the left) at the intervals given in Table 2.

Table 2 Radii intercept distances to left and right of central radius along baseline

1.	0.78m	7.	6.71m
2.	1.58	8.	8.29
3.	2.41	9.	10.3
4.	3.31	10.	13.0
5.	4.29	11.	16.9
6.	5.40	12.	23.4 (i.e. 12+1+12) = 25 radii in all

Plants in alternate arcs can be staggered without

---

* These and subsequent calculations have been made according to the formulae given in Bleasdale J.K.A. (1967).

changing the allocation of space per unit plant or the rectangularity of the design.

The fan design can also be used to test mixed cropping situations by allocating appropriate radii to different species. As Huxley and Maingu showed it can thus help determine the yield responses to a wide range of plant density changes in terms of 'expected' and 'actual' values, and can be used also with different crop ratios by allocating appropriate numbers of adjacent radii to the species under test (1:1, 2:1, 1:2 etc). Because of the need to maintain a complete plant stand this type of design is really only suitable for on-station work.

A parallel row design suitable for testing the effect of spacing with multipurpose trees, or for the effects of tree or crop management practices against a background of change of spacing of the MPT's - Figure 2

(for on-station or on-farm trials)

As well as being useful for spacing experiments with MPT's grown alone this design is also suitable for preliminary intercropping trials with trees and agricultural crops (or grasses) in which tree spacing is considered an essential variable.

The area per plant and rate of spacing change are as for the fan (above) and the rectangularity is 1.0 (i.e. a 'square' plant). The whole layout can be replicated and also replicate treatments can be arranged at random across the design if management or intercropping are incorporated. This design can be laid out on the contour if a slope is unavoidable.

Distance from the point of origin to the first row is also 8.53m and the same distances for between rows can be used as was for 'between arcs' shown in the first table, above, and repeated below. The length of the rows (plot) will be decided by the number of replicate plants required for each harvested sample, and it can be increased, at will, to fit the available space (as long as the plot is uniform). Other measurements are given in Table 3 below.

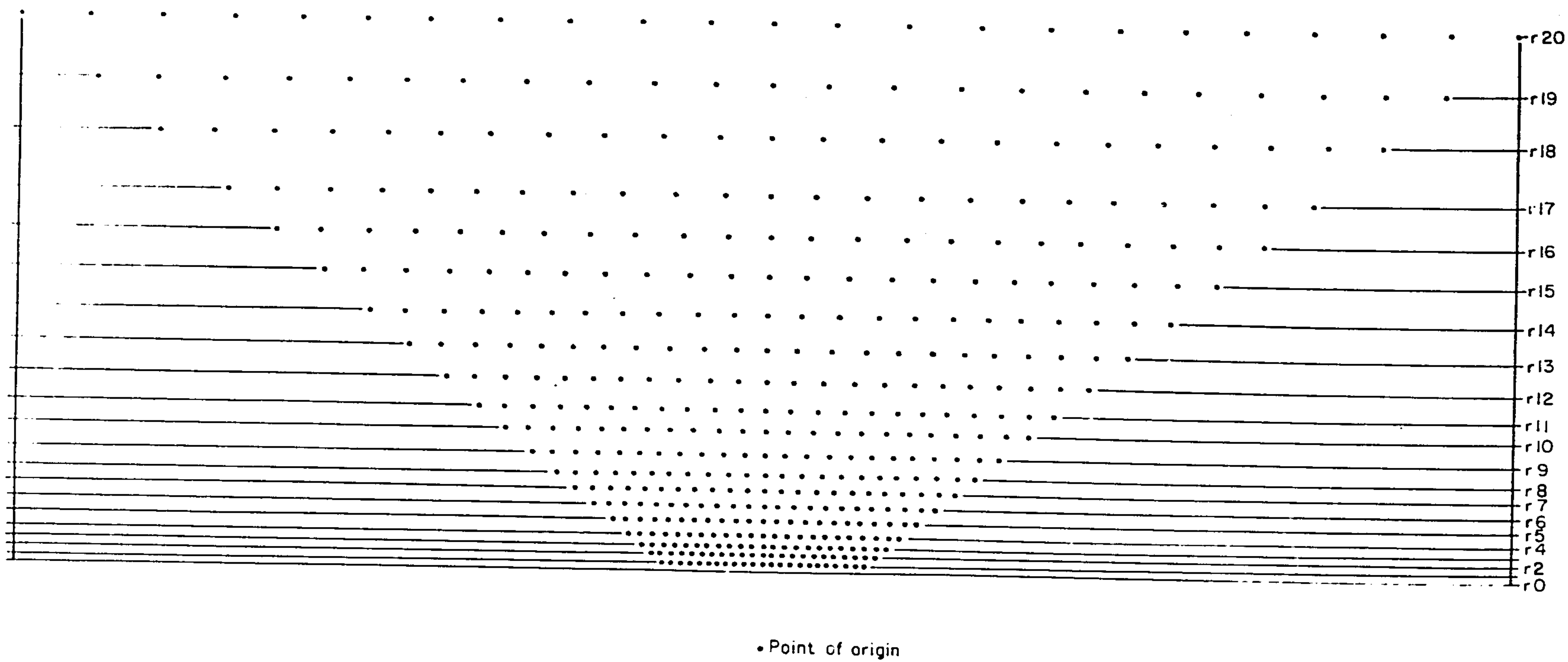

Figure 2. A parallel row design a) with equal numbers of plants per row (centre) and b) extended on either side as necessary.

Table 3 The distance between rows from the point of origin and the between-plant spacing in each row

Distance of row from point of origin		Between-plant spacing in the row	Effective area per tree m^2
r_0	8.53	0.9	-
r_1	9.48	1.0	1.00
r_2	10.5	1.11	1.24
r_3	11.7	1.23	1.53
r_4	13.0	1.37	1.88
r_5	14.5	1.52	2.33
r_6	16.0	1.69	2.87
r_7	17.8	1.88	3.54
r_8	19.8	2.09	4.38
r_9	22.0	2.32	5.40
r_{10}	23.5	2.58	6.67
r_{11}	27.2	2.87	8.24
r_{12}	30.2	3.19	10.2
r_{13}	33.6	3.54	12.6
r_{14}	37.3	3.93	15.5
r_{15}	41.4	4.38	19.2
r_{16}	46.0	4.86	23.6
r_{17}	51.2	5.40	29.2
r_{18}	56.9	6.00	36.1
r_{19}	63.2	6.67	44.5
r_{20}	70.2	7.41	55.0
r_{21}	78.0	8.23	67.9

As before, additional guard rows at the dense end desirable (at the r_0 spacing), and there can be a staggered arrangement of plants in alternate rows, if so wished.

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If this design is required for a preliminary study of tree management practices (for example, in a lopping trial), or for intercropping studies, then the width of each of these treatments will necessarily, be some multiple of 6 metres (the widest tree spacing). In addition, untreated 'guard' areas are needed between the treatments, especially if these differentially effect plant height (as is the case with lopping. (See Fig. 3).

<u>A more complicated parallel-row design for testing intercropping of a multipurpose tree species and an agricultural crop</u> (On-station) Fig.4

This layout involves using overlapping parallel row designs, one for the tree species and one (or more for the agricultural crop. It will probably make little sense to try to intercrop the two species at the densest tree planting distances, even in the first year. Furthermore, as the trees grow older and their canopies spread the degree of overlap of the two designs should be reduced in successive years by intercropping only between tree rows in which this can feasibly be done.

Because of the rather different overall dimensions of the two parallel row layouts space may be more effectively used if several rows of the agricultural crop are planted at each of the succeeding populations in the design instead of just one. Alternatively (or as well) two or more sets of parallel row layouts of the agricultural crop can be used simultaneously within the tree species layout.

The distance apart of rows, and the in-row spacing for the species, can be as given in the parallel row design outlined above. Those suitable for an agricultural crop (such as maize) are shown in Table 4.

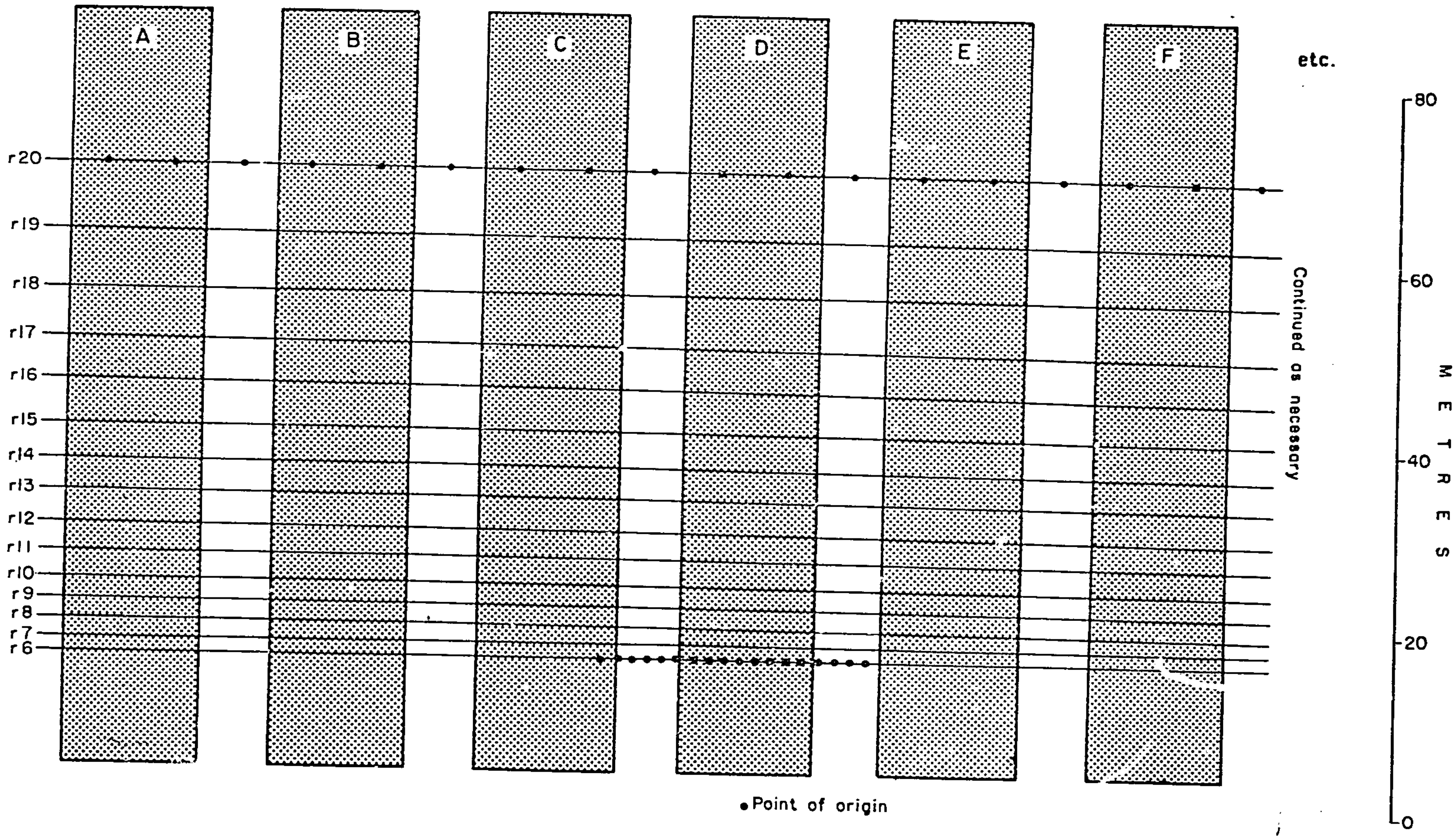

Fig. 3. Experimental treatments (e.g. lopping, pruning etc) superimposed on a parallel row design. The treatments could also be different crop species (at standard spacings) for investigating mixed cropping combinations.

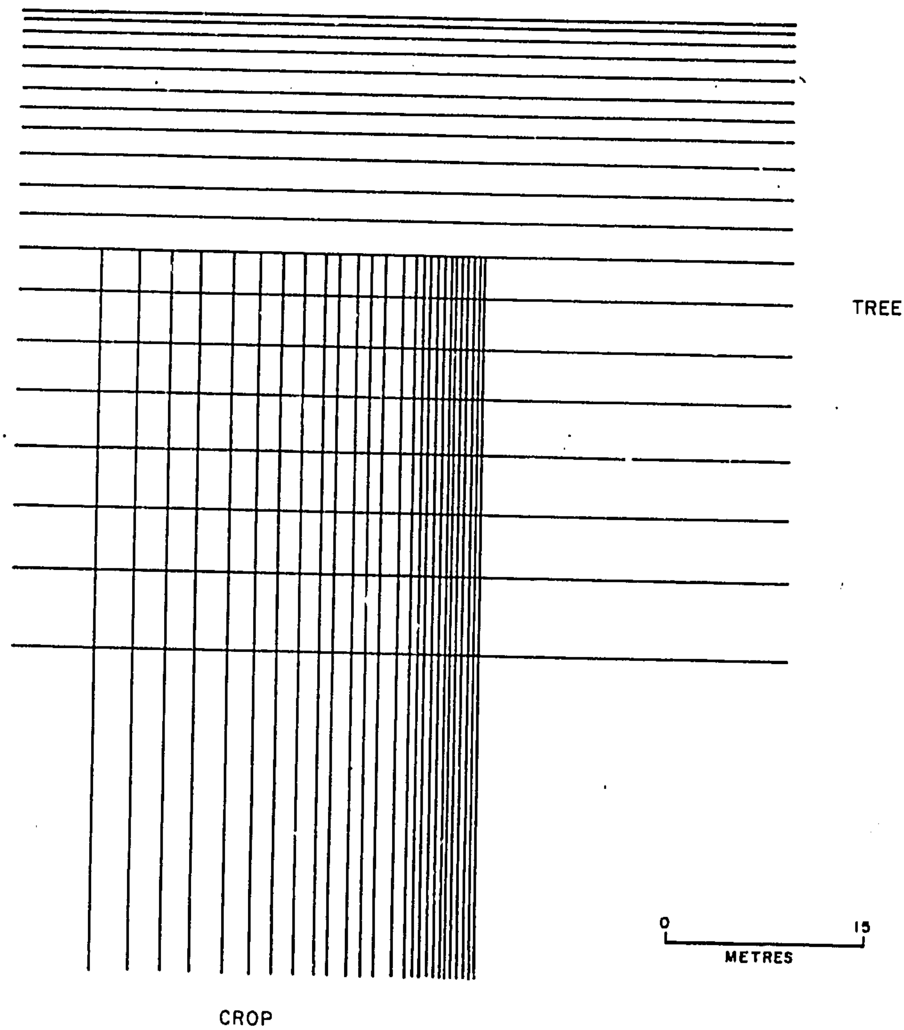

Figure 4. Two superimposed parallel row designs for testing the effects of simultaneously changing plant density in both a tree and a crop species. If the tree parallel row is extended a second crop layout could be fitted in.

Table 4 Measurement for setting out a parallel-row layout suitable for an agricultural crop such as maize

Row Number	Distance from point of origin (m)	No. of plants per metre of row	Distance apart of viable seed (cm)*	Effective area per plant (m^2)
r_0	2.32	12.8	7.8	-
r_1	2.57	11.5	8.7	0.023
r_2	2.84	10.4	9.6	0.028
r_3	3.14	9.4	10.6	0.034
r_4	3.48	8.5	11.7	0.041
r_5	3.85	7.7	13.0	0.051
r_6	4.26	7.0	14.4	0.062
r_7	4.71	6.3	15.9	0.076
r_8	5.21	5.69	17.6	0.093
r_9	5.77	5.14	19.5	0.114
r_{10}	6.38	4.64	21.5	0.139
r_{11}	7.06	4.20	23.8	0.170
r_{12}	7.81	3.79	26.4	0.208
r_{13}	8.65	3.43	29.2	0.255
r_{14}	9.57	3.10	32.3	0.313
r_{15}	10.6	2.80	35.7	0.383
r_{16}	11.7	2.53	39.5	0.469
r_{17}	12.9	2.29	43.7	0.554
r_{18}	14.3	2.07	48.4	0.703
r_{19}	15.9	1.87	53.6	0.860
r_{20}	17.6	1.69	59.3	1.05
r_{21}	19.4	1.53	65.6	1.29
r_{22}	21.5	1.38	72.6	1.58
r_{23}	23.8	1.25	80.3	1.93
r_{24}	26.3	1.13	88.8	2.37
r_{25}	29.1	1.02	98.3	2.90
r_{26}	32.2	0.92	109.0	4.34

* In order to acheive a precise spacing several seeds can be hand-sown in each hole and then singled to one vigorous seedling.

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A systematic arrangement of treatments can sometimes lend itself to trials on farms where space is often very limited and an element of demonstration is also involved. The farmers choice of "best treatment" can also be visually facilitated.

Figure 5 (taken from Huxley 1980) illustrates a simple systematic layout to test the feasibility of using woody mulch on tilled (hoed) or zero tilled land for whatever crop species is chosen (this could change year-by-year if desired, or be a crop mixture). Different proportions of bush to cropped land are provided for, as well as an area solely of bush or crop for comparison of productivity. For simplification no 'guard row' discard areas are shown, clearly, but an appropriate area where the crop grows adjacent to the bushes would be excluded from yield assessments (or, better, recorded in order to examine the effects of the tree/crop interface). Replication in such an investigation would be through chosing an appropriate number of farm sites.

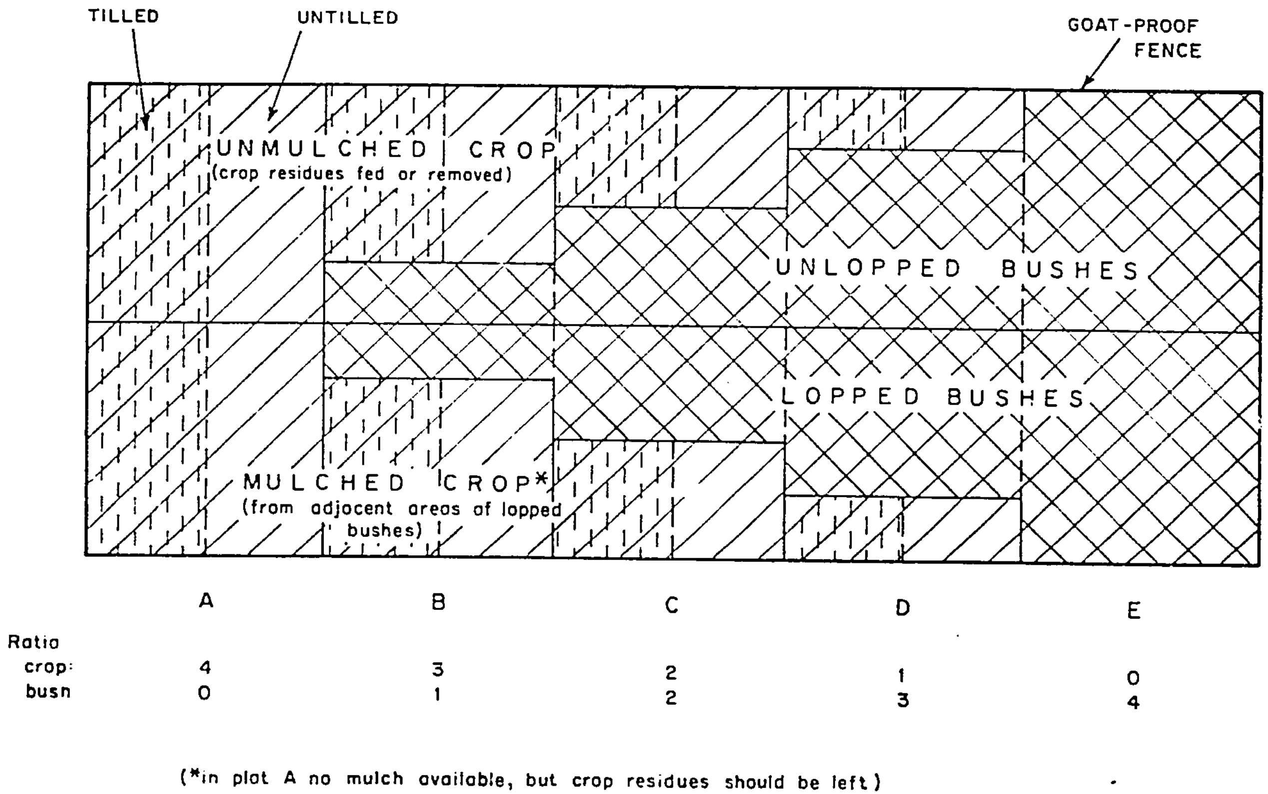

Figure 5. A systematic design for an on-farm trial to investigate the effects of woody model on tilled (hoed) and untilled land. The different areas of bush provide varying amounts of mulch material to their adjacent cropped plots (from Huxley, 1980).

See also Section on

"Considerations when experimenting with changes in plant spacing"

DOCUMENTATION FOR THE SYSTEMATIC SPACINGS DESIGN PROGRAM

(By L.Fidaali, ICRAF Nairobi)

SYSTEM SPECIFICATION

The Program has been written in MBASIC for the Osborne computer under the CP/M operating system.

USER INSTRUCTIONS

1. Starting the system

a) Switch on the Osborne (the switch is located at the back on the right.
b) Insert the PROGRAM disk in the LEFT ('A') drive.
c) Press the Return key
d) A message appears on the screen displaying the Microsoft BASIC logo followed by the word 'ok'.
e) Type in the following command exactly:

    LOAD"SPACING

f) The left drive is momentarily engaged
g) When the word 'ok' appears on the screen again, type in the command:

    RUN

NOW THE PROGRAM HAS BEEN INITIATED

2. Using The Program

You will now see the screen display an introductory message about the SYSTEMATIC SPACINGS DESIGN PROGRAM
At the bottom it says:

    PRESS RETURN TO CONTINUE

The RETURN key is located on the right hand side of the keyboard.
On pressing RETURN the screen clears and you are given a choice for which type of SPACINGS DESIGN you want PARALLEL ROW or FAN. Answer either P or F, in capitals only!!

PARALLEL ROW DESIGN

1. Initial inputs

You will be prompted for:

a) minimum area per plant in metres squared.
(make this smaller than you would want in practice)

b) maximum area per plant in metres squared.
(depends on size of plant, length of experiment and if you want free-standing plants to be included)

c) the number of steps by which you require the spacings to be changed.
(this has to be a reasonable number ie too few will alter the spacing too rapidly - it should not exceed 11% - and too many will mean laying down a large number of rows)

1.1 Validation on initial inputs:

If minimum area exceeds maximum area then you will be prompted to re-input these values
The number of steps must be a number greater than 1 and less than 50

1.2 Initial output:

Using the above inputs the rate of change of spacing will be calculated and displayed on the screen both as a number and as a percentage. If the rate is unsatisfactory (ie less than 1.11 (=11%) then you will be asked to change the initial parameters. You will have a choice either to change ALL three parameters or only the number of steps of spacing change.
If the rate is greater than 1.11 but you are not satisfied you may still change the original conditions at this point to get a more satisfacory rate of change.

2. Second Input

You will next be prompted to key in the RECTANGULARITY. This must be a number in the range .05 to 50 (ie .051 to 49.99). After a small interval a table of results will appear on the screen showing for each row:

1. Distance from point of or...
2. Within row spacing
3. Effective area per plant

Thirteen rows will be presented at a time. Press RETURN to display the next set.

3. Third Input

Next you will be asked whether you require to know the number of plants for your design, Type in either Y or N
If you reply Y then you have a choice of:

-same number of plants in each row
or

-variable number of plants

If the same number is required, at the prompt, type in the number required in each row.

If not then, again at the prompt, type in the total length of the design in metres.

The screen will display the number of plants required to set out the design in the field

NOTE: This number does not include the 5 extra rows you may have asked to see earlier.

4. Printing results

If you want a printout of results then type Y to the next prompt, Otherwise type N

5. Running the program again

You may now run the program again if you wish by replying Y to the next prompt.

6. Exiting the session.

If you reply N to the prompt :

DO YOU WANT TO RUN THE PROGRAM AGAIN

the program will finish its run and you will return to MBASIC. The sign ok will appear on the screen.

To exit from MBASIC, type in the command:

SYSTEM

CP/M will now regain control, this is indicated by the prompt:

A)

When the red light on the disk drive goes off, turn up the lid and remove the diskette.

It is now safe to switch the computer off at the back

FAN DESIGN.

1.Initial inputs

You will be prompted for
a) number of radii required
b) minimum area per plant in metres squared.
c) maximum area per plant in metres squared.
d) the number of steps by which you require the spacings to be changed.
(see PARALLEL ROW design,Initial Inputs,for comments)

1.1 Validation on initial inputs:
The number of radii must be an odd number
If minimum area exceeds maximum area then you will be prompted to reinput these values
The number of steps must be a number greater than 1 and less than 50

1.2 Initial output:
Using the above inputs, the rate of change of spacing will be calculated and displayed on the screen both as a number and as a percentage.If the rate is unsatisfactory (ie less than 1.11 (=11%) then you will be asked to change the initial parameters.You will have a choice either to change ALL three parameters or only the number of steps of spacing change.
If the rate is greater than 1.11 but you are not satisfied you may still change the original conditions at this point to get a more desirable rate of change.

2. Second Input

You will next be prompted to key in the RECTANGULARITY.This must be a number in the range .05 to 50 (ie .051 to 49.9).

3.Third Input:

The next calculation that is carried out is for the angle between radii.
At this point if the arc for the specified number of radii turns out to be greater than 180 degrees,a warning message will appear and you will be asked to change one or more of the parameters input so far.

4.Second output:

A table of values will be displayed,showing for each arc the spacing of plants along a radius,12 arcs at a time.
You can go 5 more steps beyond those displayed,by replying Y at the prompt.

5.Fan in a rectangle

Next you will be given the choice of extending the middle arcs of the fan into a rectangle.Answer Y if this is required.
The dimensions of a suitable rectangle will be calculated and the length,breadth and distance to rectangular base will be displayed.
If these dimensions are not satisfactory then you may change one or more of the original parameters to alter them.If you choose to do this,some helpful hints, as to how the rectangle can be modified, will follow.

6.Display of M1....Mn

A table of values displaying distances along baseline from the central radius at which to mark where other radii cross will appear next on the screen.

7.Number of plants needed

If you want to know the number of plants needed for your design,type Y to the next prompt.
Also give the number of extra arcs required.
The number of plants will be displayed.
NOTE-a) For fan in a rectangle this is only an approximate value.
b) This number does not include the 5 extra arcs you may have asked to see earlier.

8. Printing results

If you want a printout of results then type Y to the next prompt,otherwise type N

9. Running the program again

You may now run the program again if you wish by replying Y to the next prompt.

10. Ending the session.

If you reply N to the prompt :
DO YOU WANT TO RUN THE PROGRAM AGAIN
the program will finish its run and you will return to MBASIC.The sign ok will appear on the screen.
To exit from MBASIC,type in the command:
SYSTEM
CP/M will now regain control,this is indicated by the prompt:
A)
When the red light on the disk drive goes off,turn up the lids and remove the diskette.
It is now safe to switch the computer off at the back

SECTION FOUR

PART 4G

Statistical tools for agroforestry research: Multivariate analysis.

PART 4G

CONTENTS

MULTIVARIATE STATISTICAL ANALYSIS IN AGROFORESTRY RESEARCH

BY

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INTRODUCTION

Multivariate statistical analysis is the analysis of a set of several correlated characteristics simultaneously, observed on each individual in the population under study. Suppose that $\underline{X} = (X_1, X_2, .. X_p)$ is a column vector of p characteristics to be studied in a population. Then multivariate analysis should enable us to study these correlated variables in totality. In this way, the information on intercorrelations between different characteristics is not suppressed as is the case when univariate methods like t-tests are applied. The univariate techniques are less efficient since they normally assume that the variables are independent.

In agroforestry research, the scientist is involved in studying multiple land use practices where the ultimate goal is increased and sustainable production of herbaceous crops together with woody species, perhaps as well as livestock farming, either simultaneously or sequentially in time and space. The objective is high yields per unit of farming land without undermining the maximum carrying capacity of the soil. A good agroforestry system therefore must be able to increase production of food and at the same time be able to improve the conservation and rehabilitation of the soil resources needed for future food production. As such, and in order to understand the mechanism underlying an agroforestry system, many variables such as, water, light and soil must be studied in totality, both in time and space, and the possible interactions among the monocultural subsystems in the whole system must be taken into account. Figure 1 below is a typical representation of an agroforestry system in its simplest form.

For example, it might be decided to introduce a new woody fruit species in a particular existing agroforestry system. The authority concerned with implementation of agroforestry policies will have carefully to conduct soundly designed experimental screening trials to determine whether the given species is able to adapt and also to evaluate its performance in comparison to any species already existing in the system. This would

involve conducting investigations on the trees' adaptability, and an appraisal of environmental factors such as water consumption, humidity, ambient temperature, transpiration (water loss) rates, and soil salinity, for example, which can affect the rates of growth and the ultimate yield. Therefore, in order to understand and evaluate the performance of the fruit tree an agroforester may wish, for various reasons, to study numerous correlated variables on each plant based on biological factors, such as the following:

X_1 - fruit yield per tree

X_2 - biomass weight (kg)

X_3 - leaf area (m^2)

X_4 - leaf length (cm)

X_5 - leaf width (cm)

X_6 - height (m)

X_7 - stem width (m)

X_8 - root depth (m)

X_9 - number of branches

X_{10} - days to first flowering

X_{11} - frequency of flowering per year

X_{12} - fruits/flowers ratio (%)

X_{13} - dry matter weight of fruits (kg)

X_{14} - water consumption (ml/day)

X_{15} - transpiration rate (ml/sec)

X_{16} - calcium of soil around roots (%)

X_{17} - weight of shrubs under its shade (kg)

X_{18} - amount of ammonium fertilizer used (kg)

X_{19} - amount of green foliage feed available for livestock (kg)

X_{20} - protein content of beef of livestock fed on the tree foliage (%)

X_{21} - mineral content of the beef (%)

X_{22} - mean count of number of insects pests per tree

X_{23} - mean angle of inclination of leaves to the incoming sunlight rays

X_{24} - distance to the nearest tree of a different species

X_{25} - distance to the nearest tree of a different species

The list could be made longer. The point is that the research scientist will have to accommodate a huge set of interacting soil, climatic, topographic and socio-economic characteristics making it almost impossible to handle the raw data directly. He needs methods by which he can condense the amount of data to be handled without foresaking too much information. Multivariate methods of analysis can achieve this.

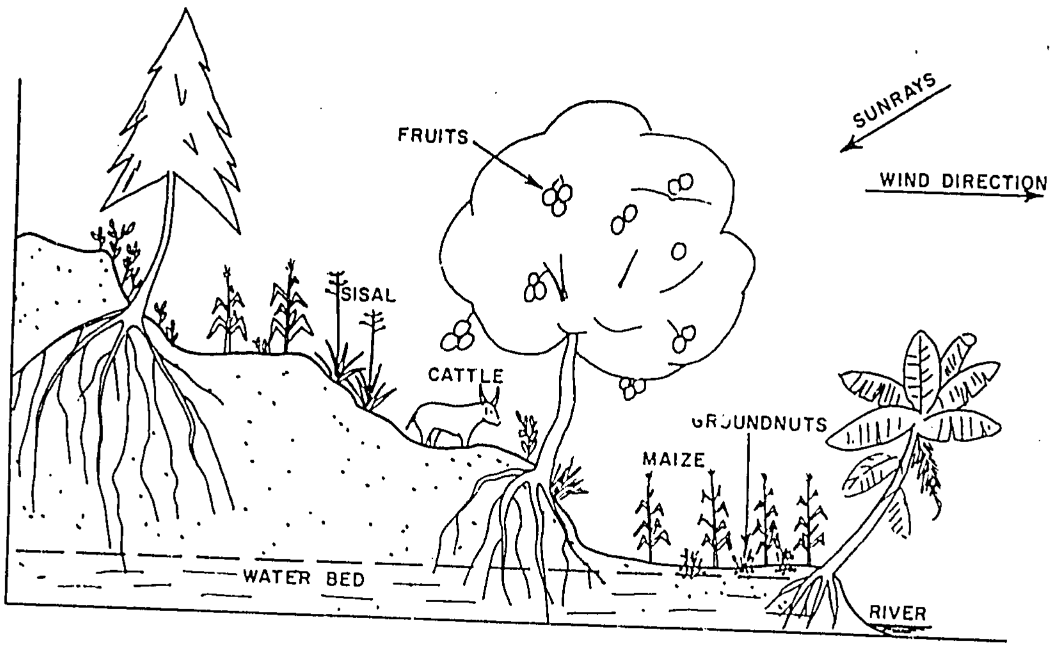

FIGURE 1: AN AGROFORESTRY PRACTICE

By relying upon univariate methods only the possible number of computations and comparisons needed completely to summarise the structure, interrelationships and dependencies of multiple characteristics in agroforestry system simultaneously or sequentially will be beyond comprehension. In many cases, scientists have attempted to analyse too many characteristics through univariate methods and have ended up studying each characteristic or subsystem individually. With univariate analysis, the implicit assumption is that the characteristics being studied are independent and hence no interactions exist. In agroforestry, however, interactions between various production subsystems and management practices, and thus dependence between the variables, is a fundamental feature to be expected. By ignoring such interrelationships, vital information on interdependence mechanisms is suppressed. The loss of such information could prove disastrous to strategies of management and decision-making aimed at optimum operation of the system as a whole.

In this respect, multivariate statistical methods can play a very important role in the science of agroforestry. Such methods enable the research scientist to concentrate his effort and time. He can study a lesser number of variables while still retaining a maximum amount of information about the system under study. Information relating to the inter-correlations between various original variables is carried in these few *derived* variables. This is achieved by transforming the original variables X_1, $X_2 \ldots$, X_p (p= no. of characteristics under study) to a new set of mutually orthogonal variables, say $Y_1, Y_2, \ldots Y_p$ such that each new variable can be represented as

$$Y_i = \alpha_{i1} X_1 + \alpha_{i2} + \ldots + \alpha_{ip} X_p \qquad (1)$$

$$i = 1, 2, 3, \ldots p$$

where $\underline{\alpha}_i = (\alpha_{i1}, \alpha_{i2}, . \alpha_{ip})'$ is a vector on unknown weights. Since these Yi's are mutually orthogonal, we can now apply simple univariate analyses and tests. Normally a maximum of the first four to five of these new variables will be able to explain about 70 to 90 percent of the information contained in the system. Hence the research scientist can often accommodate the consequence of ignoring the 10 percent information lost in the process to analyse only these few new variables q, say, instead of working on the original p variables (where $q << p$). This would appear to be a worthwhile saving both in time and effort.

The sign and magnitude of the coefficient weights, α_{ij} $(i, j = 1, 2, \ldots, p)$ provides an indication of the direction and relative contribution of a corresponding variable in extracting the required information from the original sample space (Lindgren, 1976).

In this paper three powerful multivariate methods which an agroforester should find useful are briefly described. These are, namely, principal components analysis, discriminant analysis, and canonical correlations analysis. For a rigorous discussion of these topics, the reader is referred to the referenced texts on mathematical statistics listed at the end of this paper.

PRINCIPAL COMPONENTS ANALYSIS

In many instances an experimenter may not know, even after building his data matrix (P x N) which characteristics are most significant in explaining variability in his investigations. The tendency is likely to be for him to include all variables which are likely to have *some connection* with the problem under investigation. His next task would be to reduce this massive multi-dimension matrix to a few manageable new variables such that most of the variance in the data is retained. Fewer variables can then be studied without losing vital information on the interdependence structure of the variables. He would concentrate on these for advanced study. It is in this respect that the method of principal components could be an indispensable tool in agroforestry research.

The objective of principal components analysis is to construct a new set of orthogonal variables Y_1, Y_2 --, Y_p as linear functions of the original variables X_1, X_2 --, X_p such that $Y_1 = \underline{\alpha}_1' \underline{X}^p$ ...... (called the first principal component whose variance is λ_1, say) explains the greatest proportion of the total variance in the data. Similarly

$$Y_i = \alpha_{i1} X_1 + \alpha_{i2} X_2 + \ldots + \alpha_{ip} X_p, \quad i = 1, 2, \ldots p \qquad (2)$$

is called the ith principal component whose variance is λ_i the ith most important new variable in terms of accountability to variation in the system. The variables Y_1, Y_2, --, Y_p are mutually orthogonal such that

$$\lambda_1 \geq \lambda_2 \geq \ldots, \geq \lambda_i \geq \ldots, \geq \lambda_p \qquad (3)$$

Normally the first few components, say Y_1 and Y_2 would be most important in explaining a significant proportion of the total variance. If the

scientist can accommodate inferences based on this smaller data matrix, deficient of about 10 percent of the original information on variability, then he should proceed to concentrate his future studies on only these two components, Y_1 and Y_2. Then, by comparing the elements of the co-efficient vector $\underline{\alpha}_i = (\alpha_{i1}, \alpha_{i2}, \ldots, \alpha_{ip})'$ he could identify those original variables X_1, X_2 -- X_p which significantly contribute to the variance of Yi, that is λ_i

For example, suppose we are interested in studying five variables X_1, X_2 X_3, X_3, and X_5. Further, let the first principal component be, say Y_1, $= 0.621X_1 + 0.006X_2 - 0.004X_3 + 0.967X_4 + 0.035X_5$. (4)

Then from Eq (4), we can safely infer that X_1 and X_4 are the most variable characteristics in the system since their coefficient weights of 0.621 and 0.967 respectively are bigger than the other characteristics in Y_1. Therefore the research scientist could as well eliminate X_2, X_3, and X_5 from his future investigations. He should, if money and time are limited, concentrate only on X_1 and X_4 in future surveys when evaluating and comparing different agroforestry stystems. This is logically valid since it is the characteristics with the greater variability that are most useful in appraising the relative performance of different systems or subsystems.

Principal components have been successfully used in clustering analysis. In this, the objective is to determine groupings of data points which are due to some heterogeneity in the system. Suppose in an investigation, only Y_1 and Y_2 result in being statistically and practically significant (Oranga, 1979), then Y_1 can be plotted against Y_2, on the horizontal, and vertical axes, respectively, of a scatter diagram. Such a scatter plot can reveal any systematic or natural grouping of the observations. It can reveal, also, clustering attributable to underlying structural factors such as low soil fertility and management practices which affect the performance and output of individual farm units. Normally, the biometrician would identify the groups. It would then remain the responsibility of the research scientist to characterise the clusters. For example, in Figure 2, four clusters can be clearly identified along with two possible outlier data points in the second and fourth quadrants.

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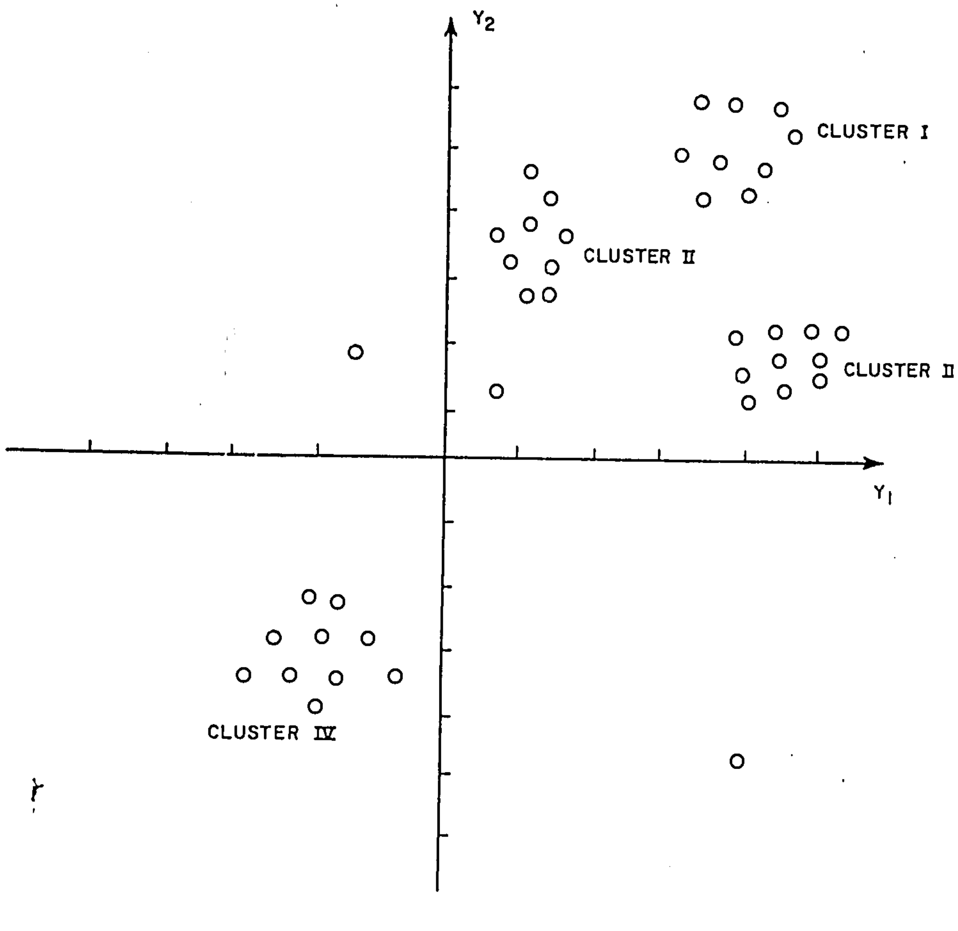
FIGURE 2: A scatter plot of first two principal components Y_1, Y_2.



Principal components analysis has been extensively applied in psychological and educational research. However, biological scientists are also finding this method a useful analytical tool (Seal, 1964; Oranga, 1979) and its potential for agroforestry research has been noted Huxley,(1979).

DISCRIMINANT ANALYSIS

Discriminant analysis is a classification technique. Basically, the method involves classifying an individual or a group of individuals from an unknown origin into one of several distinct and mutually exclusive populations or known groups, while minimizing the probability of misclassifying the individual or group into incorrect populations. This method assumes initial data that can be classified correctly. This technique has been very useful in cases where the aim is to classify an individual unit in its appropriate population, but due to limitations, it is not possible to base the procedure directly on the fundamental characteristic(s) of interest. This might be because the process is expensive in terms of effort and time per unit classification. Or it might involve complete dismantling of the supporting skeleton of the unit and hence be detrimental. In the latter case, it would be necessary to resort to indirectly related characteristics.

In agroforestry research, these types of problems occur. Suppose it is decided to introduce a new known woody plant to Kenya. The problem would be to identify an agro-ecological zone where this species would thrive and still enhance the level of output of the existing systems. The input and environmental requirements of this species are known, say

- soil pH value
- humidity
- soil moisture content (%)
- calcium content (%)
- mean iron requirement (gm)
- mean soil depth (m)

Given that the parameter values or estimates of these characteristics in all the agro-ecological zones across the country are known, the discriminant analysis method permits identification of that zone where the introduced species might best be suited. Further, it would be possible to estimate the probability of wrongly classifying the plant in an unfavourable agro-ecological zone.

Another example of the applicability of discriminant analysis is in silvo-pastoral production systems. Suppose in long term research into the selection of various forms of adaptable silvo-pastoral systems there is interest in comparing performances of selected systems to those already considered as "successful". Assume that all the relevant characteristics have been considered and that the parameter values or estimates of these characteristics are known about the "successful" systems. Then given the corresponding data collected from the silvo-pastoral systems under investigation the method of discriminant analysis could enable, class-ification of these investigated systems according to whether they are successful or "unsuccessful."

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The above are a few examples of potential applications of this powerful multivariate technique in agroforestry research.

The method assumes that we are able to initially divide the whole sample space of data points into k mutually exclusive sets, say R_1, R_2 -- Rk, corresponding to the different populations. In the silvo-pastoral example above, k = 2, i.e.

π_1 - population of successful silvo-pastoral systems
π_2 - population of unsuccessful silvo-pastoral systems

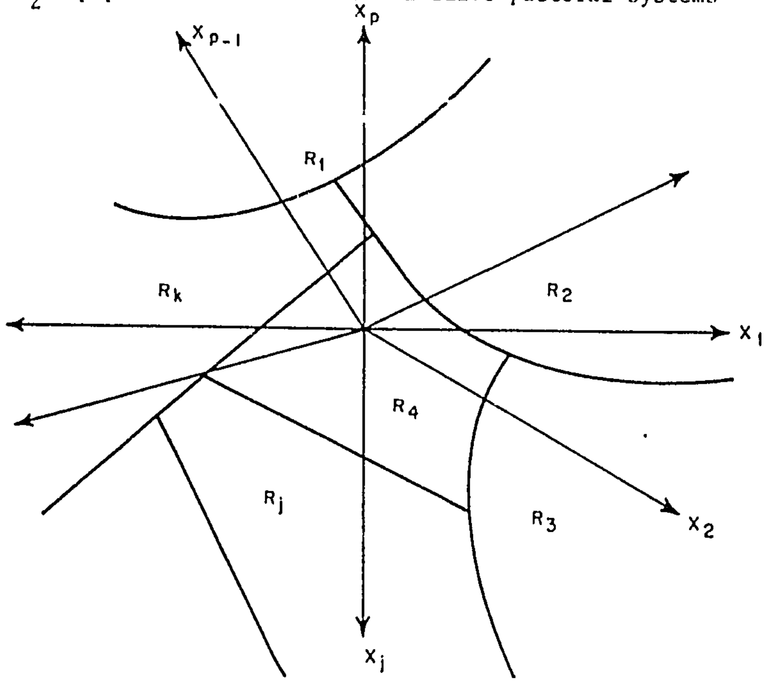


Fig. 3. Partition of sample space.

The decision procedure is then to: classify data point $\underset{\sim}{X}$ to population πj if $\underset{\sim}{X}$ falls in Rj (j=1,2, --k). Under normal situations this is very intricate and virtually impossible when it involves many characteristics X_1, X_2 -- X_p (when p is large). The method of discriminant analysis consists of deriving a new set of orthogonal variables say Y_1, Y_2, -- Y_{p^*} which are linear functions of the original characteristics. That is

$$Y_j = \beta_{j1}X_1 + \beta_{j2}X_2 + \dots + \beta_{jp}X_p, \quad j = 1,2,\dots,p^* \quad (6)$$

the jth linear discriminant function possesses the jth greatest discriminating power δj, say. Hence

$$\delta_1 \geq \delta_2 \geq \dots \geq \delta_j \geq \dots \geq \delta_{p^*}$$

Not all the p^* linear discriminant functions would be significant in the discrimination process. For tests of discrimination power of discriminant functions, see Cooley and Lohnes (1971). Suppose only the first two discriminant functions are significant, then the decision procedure become:

Classify data point $\underset{\sim}{X}$ to population π_j if and only if

$$Y_1 \geq k_1, Y_2 \geq k_2 \quad (7)$$

where k_1 and k_2 are some suitable constants. Such a simple procedure could then be easily programmed and any number of classifications can be done automatically.

For optimal estimation of the coefficient weights $\beta_{j1}, \beta_{j2}, \ldots \beta_{jp}$ the reader is referred to Anderson (1958), listed at the end of the paper.

In scientific literature, discriminant analysis has many synonyms such as classification, pattern recognition, character recognition, identification, prediction and selection to mention a few, depending on the scientific discipline in which it is used.

CANONICAL CORRELATIONS ANALYSIS

In any agroforestry system, the farmer's decision as to what monocultural production subsystems are to be adopted would obviously be influenced by both the agro-climatic and socio-economic factors around him. His decisions would determine the types of agricultural crops or woody plants to include, whether or not to incorporate pig or dairy cattle farming, types of technology to introduce, and what farm management practices to adopt($p_1 + p_2$). Therefore agroforestry research aimed at studying the nature and degree of such interdependent factors should emphasize among-factors inter-relationships.

Suppose we have p_1 agro-climatic factors on one hand, and p_2 socio-economic factors on the other hand, all influencing the decision-making process of the individual farmer's household. Suppose we collect the $p_1 + p_2$ factors from each of N farming units in a region, where both p_1, p_2 are large (say > 20). One research priority would be to investigate the correlation structure between the two subsets of both agro-climatic and socio-economic factors in totality. If $p_1 = p_2 = 1$, then the usually univariate analysis of the simple correlation coefficient would suffice. For the case where $p_1 \geq 2$, $p_2 \geq 2$, the appropriate analysis is the canonical correlations analysis. The method of canonical correlations would enable the research scientist to study the intercorrelations between factors in the two subsets simultaneously. Moreover, the method would enable us to concentrate investigations on a new set of mutually orthogonal variables, say $W_1, W_2 \text{ --} W_q$ and $Z_1, Z_2 \text{ ---} Z_q$ where $q = \min(p_1, p_2)$ respectively.

Let $\underline{X}_1 = (X_{11}, X_{12}, \text{--}, X_{1p1})$ $\underline{X}_2 = (X_{21}, X_{2p2})$ be the variables in the two subsets respectively. Then the new transformed variables are

$$W_i = U_{i1}X_{11} + U_{i2}X_{12} + \ldots + U_{ip1}X_{ip1}$$

$$Z_i = V_1X_{21} + V_{i2}X_{22} + \ldots + V_{ip2}X_{2p2}$$

$$i = 1, 2, \ \ldots, q$$

where Uij's and Vij's are unknown coefficient weights.

Moreover, not all the q new variate pairs Wi, Zi (i=1,2, -- ,q) normally called canonical variables, and the correlation between them ρ_i, say, which is called the canonical correlation ($\rho_1 \geq \ldots \geq \rho_i \geq \rho_q$), will be important in the investigation. Only a few of these might be important in capturing significantly the maximal correlation between $\underline{X}_1$ and $\underline{X}_2$.

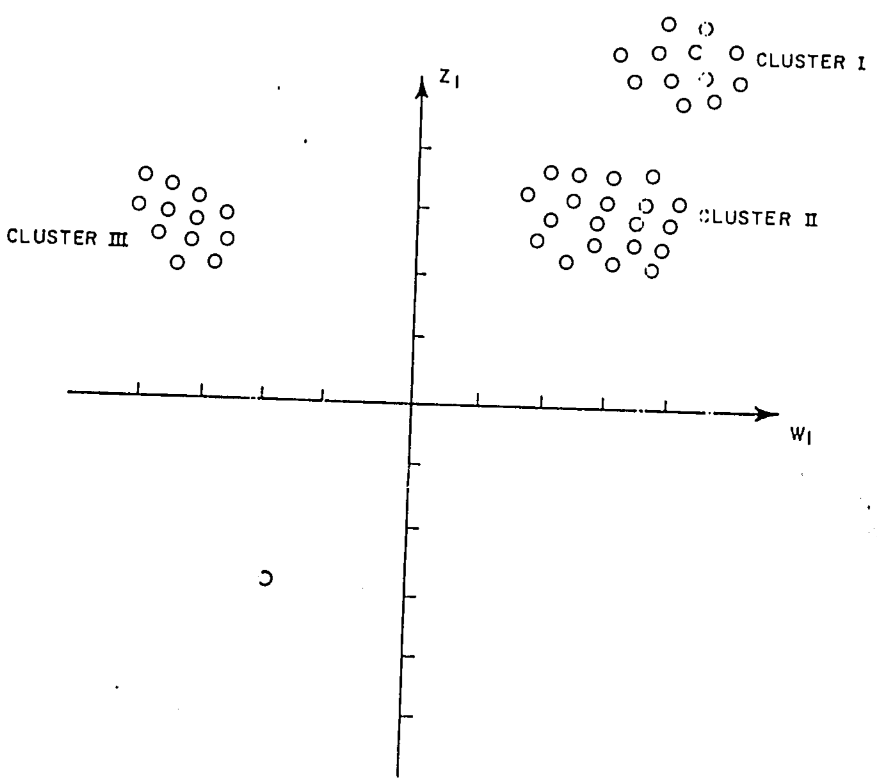
Canonical analysis will yield the canonical variables in order of importance as W_1 and Z_1, W_2 and Z_2, ---, W_q and Z_q) consecutively.

such that correlation (Zi, Zj)=Correlation (Z_k, W_l) = Correlation $(W_{k'}, W_{l'})$
$= 0,\ i \neq j,\ k \neq l,\ k' \neq l'$

Further, the sign and magnitude of the coefficients in Wi and Zi will give an indication of direction and relative importance of the corresponding factors in the correlation coefficient between Wi and Zi and hence the interdependent relations inherent in the total agroforestry system.

Scatter plots of the first pair of canonical variables, W_1, Z_1 (if they contribute a significant proportion of the correlation in the system) of the sample data points has also been successfully used in detecting any clustering which might exist in the system (Fig. 4).

Fig. 4 Clustering by Canonical Variables



CONCLUSIONS

This paper provides just a brief sketch of some of the multivariate "tools" which are available together with some examples of how they could be useful in agroforestry research. There is no doubt that they provide a powerful approach to signify the analysis of the complex systems involved and a useful statistical procedure for facilitating the kinds of comparisons which are need for evaluation.

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SECTION FIVE

SPECIALIZED TECHNIQUES

PART 5A

CONTENTS

(reprinted from "Plant Research and Agroforestry" (Ed. P.A. Huxley ICRAF, Nairobi).

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THE ROLE OF CONTROLLED ENVIRONMENTS IN AGROFORESTRY RESEARCH

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ABSTRACT. Types of elaborate to relatively simple controlled environment facilities are described and some general considerations in using controlled environments are discussed, including some special difficulties with woody perennial plants. Controlled environment studies should be linked to field work and a range of specific areas of research on multipurpose tree species is outlined. Controlled environments can be used to good advantage to grow uniform plants and to explore genetic variation at the seedling stage; to investigate responses of seedlings and young plants to environmental stresses; to investigate adaptability where seedling - mature stage correlations can be established; to explore allelopathic relationships; to help optimize seed germination and plant propagation techniques; for root growth studies, especially those relating to nursery management and planting out; and in the study of plant pests and diseases.

Controlled environment facilities of one kind or another can provide a cost-effective way of obtaining needed information about multipurpose tree species, especially if used in conjunction with field experiments, and by linking these with a network of appropriate facilities according to the specific problems under investigation.

INTRODUCTION

Agroforestry is the term given to sustainable land use systems that involve more or less intimate and interacting associations of agricultural/horticultural crops and woody perennials (trees, shrubs, palms, vines, bamboos), all on the same unit of land. The present scope of interest in such land use systems has

exposed our serious lack of knowledge about them. We have not yet adequately described existing systems, or learned enough about their potential transferability to other similar ecozones. Agroforestry must develop as more than just a descriptive exercise and many of the problems now emerging will be solved only by a combination of appropriate experimental approaches adapted to studying the range of plant component species, as well as the temporal and spatial complexities found in agroforestry systems.

One such approach which has more than proved itself in supporting agricultural research, is the use of controlled environments to examine plant growth and development. This can be done under conditions of environmental stability, of specifically defined environmental differences or, sometimes, sequential types of controlled 'environments' can be applied to a wide range of experimental climatic manipulations which possess varying degrees of control precision.

Phytotron or biotron

Usually this is a complex of similar, controlled units, or batches of units, in which statistically replicated experiments can be conducted under controlled conditions. Environmental control covers radiation (light intensity, light quality and daylength); temperature (day and night, but often without separate control for soil temperature as opposed to air temperature); humidity (often less precisely regulated than the other climatic variables); carbon dioxide concentration of the aerial environment; mineral nutrition (through choice of planting media and/or solid or nutrient solution application); wind; physical rooting conditions (through choice of planting media, watering regime and, sometimes, temperature and control of CO_2 and oxygen concentrations in the root zone); and the facility for applying growth regulating compounds, if required.

Growth chambers or growth rooms

These are the equivalent of single units of controlled environment, with similar control facilities to those mentioned above. In some cases growth chambers are available that use available incoming short-wave solar radiation, thus providing natural light quality, and also natural light flux densities which most artificially lighted growth chamber facilities cannot do. For work on seed germination, or conventional or micropropagation, rather small, controlled environment structures are quite suitable.

Rhizotrons

These are units specifically constructed to enable plant roots and root systems to be examined, usually under some limited form of environmental control or manipulation (that is control of the soil or rooting media used, watering, mineral nutrition and some control of soil temperature). They have been used to study both root form and function and usually consist of one or more sets of subterranean multicomponent facilities (see Huck, this volume). A simpler arrangement may be useful such as a glass-lined pit, or box with glass walls.

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Growing rooms

These are enclosed spaces provided with supplementary lighting and watering facilities in which container-grown plants can usually be grown faster in the seedling stage than would otherwise be the case. In temperate regions several sectors of the horticultural industry use growing rooms to produce vigorous seedlings out of season, under low light conditions, in readiness for planting out at the start of more favourable periods. Supplementary CO_2 is sometimes used to further stimulate growth.

Controlled environment glasshouses or plastic houses are cheap and simple structures, with much less precisely regulated control of temperature and humidity. Light, particularly daylength, can be manipulated if plants are on trolleys which are wheeled into adjacent light-tight, temperature controlled dark rooms. This can be done automatically. Even relatively simple, automated glasshouses in which cooling/heating facilities are provided can be useful to provide 'standard' environments for some kinds of experiments. In the tropics, shade houses often fulfil a similar function, but temperature control is more difficult because of the relatively much greater heat load that must be dissipated.

Field operated cuvettes

Plant or crop physiologists use these to study particular plant processes, for example, carbon fixation and respiration, under otherwise field climates. They consist of relatively small, transparent, gas-tight structures, with ancillary temperature control and monitoring equipment, which can enclose leaves, leafy branches, whole plants or, sometimes, small communities of plants.

Modification of the field environment

This is the crudest form of control, but it can be a useful and cost-effective method. This approach is especially valuable for initial studies of relatively unexplored species. It can take many forms, depending on the objectives of the experiments: shading; control of available water (both by irrigating and by diverting rain with movable covers); shelter; and soil covers to modify topsoil temperatures, are some of the more common techniques.

INVESTIGATING RESPONSES TO ENVIRONMENT

Controlled environment facilities have been developed because there are many problems in evaluating, in the field, the effects on plant growth and development of individual environment factors, or the interactions among them. Light, temperature, humidity, and other factors are so interdependent that a change in one alters the others. It is also virtually impossible in the field to reproduce very closely the environment of any one day on subsequent days (Rook, 1968; Kramer *et al.*, 1972; Kramer, 1978). For such reasons use of sophisticated environment controlled research facilities, such as phytotrons, has accelerated greatly in recent years. The many environmental combinations that are available in such facilities make it possible to study accurately and rapidly

the action and interaction of environmental factors. Phytotrons can be used to dissect or construct a given environment. Growth responses of plants over a wide range of environments can be studied concurrently. Interactions of two or more factors can be evaluated while other factors are kept relatively constant. A major advantage of environment controlled research facilities is that they decrease variability and increase reproducibility of data. Furthermore, such facilities can simulate both diurnal and seasonal changes in climates for widely separated locations.

Phytotrons have sometimes been criticized because of the costs of building and maintaining them. However, they should be judged on the basis of the much better information they provide than can possibly be obtained in the field, glasshouse, or even from small groups of controlled environment chambers (Hellmers, 1969). Controlled environment research often costs less than field research because the smaller number of plants necessary for samples reduces the cost of laboratory analysis. Comparisons of costs of phytotrons and field research often have been woefully misleading because they did not mention the high costs of maintaining and managing experimental areas, costs of field travel, cost of damage to field experiments by weather, insects, and disease (thereby requiring repeating experiments), and the cost of delays in waiting for specific weather conditions (Rook, 1968; Kramer *et al.*, 1972). In any event there is no need to build expensive controlled environment facilities in tropical areas. Such facilities are already established in many countries (Table 1) and arrangements can readily be made to conduct research on tropical plants in such facilities.

GENERAL CONSIDERATIONS IN USE OF CONTROLLED ENVIRONMENTS

Where a high level of control is possible a choice exists as to whether experimental plants are subjected to 'standard' or 'simulated' climatic conditions. 'Standard' climates can be any combination of levels of climatic variables that the experiment requires and the equipment can provide. 'Simulated' light intensity and quality are not easily reproduced artificially. In addition humidity is a somewhat difficult and expensive variable to control precisely. Furthermore diurnal changes in climate, and occurrence of climatic 'noise' (intermittent cloudiness, wind, and temperature and CO_2 fluctuations) are difficult to reproduce exactly under artificial conditions. If the experiment is designed to help relate plant growth or development to field situations then a 'near-simulated' environment is likely to provide the most useful information.

Most plants grown in any form of controlled environment are relatively much more stress-free than those grown outdoors. However, by applying particular environmental stress factors (heat, drought, waterlogging, chilling), either alone or in combination, the effects of these can be critically studied in controlled environment facilities in a way that is not possible outdoors.

In controlled environment facilities using artificial light the daily photosynthetically active radiation (PAR-400-700 nm) can, with modern equipment, equate to that received in many tropical locations, although not to the maximum received in semi-arid regions (for example, usually up to 8 to 12 MJ $m^{-2}day^{-1}$

Table 1. Locations of some major controlled environment facilities available for research on plant growth. There are numerous other smaller controlled environment facilities throughout the world, well capable of carrying out the kind of research work, relevant to agroforestry, that is discussed in this paper.

Name of facility	Location
Phytotron	Division of Plant Industry, CSIRO, PO Box 1600, Canberra, AUSTRALIA
Phytotron	Research Station, Agriculture Canada, Lethbridge, Alverta T1J 4B1, CANADA
Phytotron	91190 Gif-sur-Yvette, FRANCE
Phytotron	Agricultural Research Institute, Martonvasar, 2462 HUNGARY
Phytotron	Government Forest Experiment Station, Tsukuba, Ibaraki, 305 JAPAN
Biotron Institute	Kyushu University, Fukuoka, JAPAN
Controlled Environment Laboratory	DSIR, Palmerston North, NEW ZEALAND
Phytotron	Duke University, Durham, North Carolina, USA
Phytotron	North Caroline State University, Raleigh, North Carolina, USA
Biotron	2115 Observatory Drive, University of Wisconsin, Madison, Wisconsin, USA

compared with around 10 to 18 MJ $m^{-2}day^{-1}$ in semiarid regions. However, 8 to 12 MJ $m^{-2}day^{-1}$ is usually achieved in growth cabinets or rooms, only by using a 'square' climate — that is by providing the full, available energy flux during the entire day.

Pest control is sometimes a problem, inasmuch as the level of phytotoxicity of some normal pesticide formulations is unacceptable when applied to stress-free (unhardened) plants. Biological control offers a useful alternative, particularly for pests such as red spiders, mealy bugs, and aphids which can be extremely troublesome under controlled environment conditions using high humidity levels.

Generally speaking the costs of working at temperatures below ambient are greater than where applied temperature standards or differentials are above it. This can be especially a problem in hot climates where experiments requiring lower temperatures may have to be postponed to the cool season, if there is one. Otherwise the resources of another laboratory in a temperate region must be sought.

SOME DISADVANTAGES WITH WOODY PERENNIAL PLANTS

Agroforestry systems can include a wide range of plant components, one of which, by definition, is a woody perennial plant. No special problems will arise where the plant component to be studied is a herbaceous species. However, controlled environment facilities have several disadvantageous features where experiments with large woody perennials are concerned.

Space is usually limited, even in walk-in growth rooms, and this limits both the number of experimental plants and the length of time they can be maintained in the facility. Plants can be respaced after sequential harvests, but the cost of building very large facilities to carry out experiments with adult trees may well be prohibitive. Hence with woody plants, only relatively young seedlings or small saplings can be investigated.

All controlled environment facilities have climatic gradients of one kind or another. With smaller, easily handled plant species the easiest way to overcome these is to periodically move all the experimental plants within a growth room or chamber. With larger seedlings or small trees this is less easily done without damaging the plants.

The cost of an experiment using a controlled environment facility is increased in proportion to the length of time it continues. Experiments with woody perennials are, therefore, relatively more costly than those with annual plants. Breakdowns in equipment are also more likely the longer an experiment continues.

Some of the information required about multipurpose tree species concerns the effect of environmental factors on phenology and, more particularly, on the reproductive stages. These are difficult to study in controlled environment facilities because of the size and cost restrictions mentioned above.

The behaviour of a woody perennial in any one season is often highly dependent on what occurred in a previous one. Most controlled environment facilities cannot maintain woody plants under controlled conditions for such a long period of time.

Despite these disadvantages a number of types of experiments can be of immediate value to support studies of multipurpose tree species.

LINKING CONTROLLED ENVIRONMENT STUDIES WITH FIELD WORK

The kind and degree of control of particular climatic factors that is necessary, as well as the degree of control over nutrition and the rooting environment, very much depend on the kind of experiment being undertaken. For example, a study of daylength responses is of little value unless both day temperatures and night temperatures are also controlled, because the interactions between these are often of considerable importance. Then again, with nitrogen fixation tests, it may well serve just to standardize the environment using relatively crude environmental control. At the same time, facilities for sterilized conditions are essential to prevent crossinfection of *Rhizobium* strains.

The need for separate environmental controls over plant roots and tops may well be important (for example, see Cooper, 1973), as for instance in studying early growth patterns of multipurpose tree species in support of nursery techniques and

planting-out practices. Many other examples could be given.

There are relatively few sophisticated phytotron facilities available (see Table 1), but growth room/growth cabinets are more widespread, and the simpler forms of controlled environment equipment to modify and monitor changes in field environments are now commonplace. With the co-operation of the more advanced facilities there exists the possibility of establishing networks of research activity which are mutually supportive, and range from field tests to highly specific problem solving studies of more detailed plant - environment responses.

At this stage in the study of woody species which have promise for agroforestry systems, controlled environment facilities will be used primarily in conjunction with field experiments to solve problems, or provide information about essentially practical issues. These will be related to questions about biosystematics and seed source identification, juvenile - mature stage correlations, environmental adaptability of species and provenances, appropriate propagation methods, responses of juvenile plants to environmental stress factors (particularly in relation to planting-out techniques), allelopathic relationships in agroforestry plant mixtures, root studies, and *Rhizobium* and mycorrhizal investigations (in relation to field programmes on nitrogen fixation and plant nutrition, and inasmuch as these concern establishment and growth on particular sites). All such investigations can be made more fruitful by using controlled environment studies of an appropriate kind to support the necessary field experiments, as a considerable amount of work with agricultural crop species has already shown.

EXAMPLES OF USE OF CONTROLLED ENVIRONMENTS

The following are some specific examples of the types of experiments that have already established controlled environments as valuable research tools.

Growth of uniform plants

Controlled environments are now considered indispensable for producing uniform plants for biochemical studies such as those of Alofe *et al.*, (1973), Jeffs and Scharver (1976) and Sun *et al.*, (1978), something that cannot be satisfactorily accomplished in the field or even the glasshouse. With controlled environments experiments can be repeated under identical conditions, regardless of season or weather, and the work of various investigators can be reliably compared.

With the exception of a few genera (for example, *Leucaena*, *Prosopis*, *Casuarina*, and the Australian *Acacia* spp.) the genetic variation available for many multipurpose tree species has, as yet, been only sparsely explored. Much remains to be done in identifying both clinal and non-clinal within-species genetic variation. Because of the magnitude of the task, most of this work is being done by simple field tests, but inevitably there will be a case for using controlled environment facilities to explore the biosystematic relationships of the less tractable groups (for example, within-species variation in the *Prosopis alba / chilensis / flexuosa* complex).

In cases that warrant it the current confusion arising

through international exchange of multipurpose tree germplasm of dubious origin may also need attention; specifically to establish accurate seed source identification under completely uniform growing conditions.

Apart from selecting species and genotypes able to withstand particular site-imposed environmental stresses (see below) there is an urgent need to investigate the general adaptability range of multipurpose tree species to particular ecozones. There is also need to gain some knowledge of the genotype × environment (G × E) interactions involved, in order to be able to predict the performance of any species or provenance more precisely when it is moved into a similar, but altered, environmental situation. Again, a good deal of this work will be done through normal field elimination trials sited throughout the environmental range considered suitable. However, to the extent to which early seedling or juvenile stage growth is related to later performance, it will be possible to ascertain general climatic adaptability in terms of temperature ranges and daylength responses much more rapidly if controlled environment facilities are available. This may be particularly important for multipurpose tree species whose normal range covers a wide variation in latitude and/or altitude (for example, *Acacia tortilis*, *Azadirachta indica*, *Parkinsonia aculeata*, *Pithecellobium dulce*, and so on).

Exposure of plants to stress at different stages of development

An important advantage of using controlled environments is that plants can be subjected to stress at any stage of growth. This usually is not possible in the field where the desired stress only rarely coincides with the plant growth stage under study. Controlled environments have been found indispensable in studying the physiological role of cotyledons of woody plants in seedling development. For example, exposure of *Pinus resinosa* seedlings in the cotyledon stage to low temperature, low light intensity, or air pollution inhibited initiation and growth of primary needles as well as dry weight increment of seedlings (Kozlowski and Borger, 1971; Constantinidou *et al.*, 1976). Marked variations among species in the physiological role of cotyledons of woody angiosperms to seedling development were demonstrated under controlled environmental conditions (Marshall and Kozlowski, 1974a, b, 1976, 1977).

Many of the multipurpose tree species now being considered for use in agroforestry systems, or in some form of social or community forestry, will be needed for sites that are less than completely favourable; that is they may be subjected to soils which are saline/alkaline, or acid, which have impeded drainage, or are extremely sandy or unstable. There may be permanent or intermittent exposure to high winds, salt spray, high advective energy loads, prolonged drought periods, chilling or frosts. All environmental variables that can be very precisely simulated in appropriate, controlled environment facilities which are well suited for cost-effective germplasm screening programmes. Even crude environmental modification can be a useful technique to investigate the effects of plant stresses (Summerfield *et al.*, 1976).

Juvenile - mature stage correlations may have to be established using seedlings, or juvenile stages, to develop tests for

the appropriate plant characters which are found to be correlated with the capacity to overcome such particular environmental disadvantages. Large numbers of seedlings can be screened in controlled environments, using an appropriate test method to select suitable stress-resistant germplasm. For such work a relatively low level of environmental control is suitable for the actual screening processes, although the initial experimental work to establish the technique may require more elaborate controls.

The agricultural crop plant components in agroforestry systems, which have usually been selected for sole cropping, may need further attention from plant breeders. Similarly they too will need screening for such factors as shade tolerance, drought tolerance, and so on. Much of this work can be hastened by the use of controlled environment facilities.

Effects of environmental factors on physiological processes and growth

Controlled environments can provide insight into the influence of radiation, temperature, humidity, wind, and the composition of the atmosphere, as well as such edaphic factors as soil temperature, water supply, aeration, mineral supply and pH, on physiological processes and the growth of plants (Tibbitts and Kozlowski, 1979). Research in controlled environments can also produce excellent data on effects of interactions of environmental factors. Examples are the interactions of light intensity and temperature, light intensity and CO_2, and air humidity and mineral supply on stomatal aperture (Meidner and Mansfield, 1968; Davies and Kozlowski, 1974; Pereira and Kozlowski, 1976; Pallardy and Kozlowski, 1979), and photoperiod and temperature on physiological mechanisms of development which lead to flowering (Blondon *et al.*, 1977). Whole programmes of experiments have been carried out to explore the responses of a crop, in this case cowpea (*Vigna unguiculata*), to climatic variables and changes in nitrogen nutrition in relation to field practices (see Huxley and Summerfield, 1976a and many subsequent papers by various authors).

Controlled environment facilities can be used to select climatic regions in which to field test new species and varieties or to assist in the selection of plants for use in specific climatic regimes. Went (1957) wanted to find plants capable of growing rapidly on the mountains of Southern California, so that they could provide quick cover for watershed protection following large forest fires. A series of temperature conditions in a phytotron included field averages and extremes. Two species, from over 30 species suggested and tested, were selected. The entire study was completed and the results successfully applied in the field within a year.

Allelopathy

Seed germination and plant growth are inhibited by a variety of naturally occurring compounds that are released to the soil from roots and aerial tissues of neighbouring plants (Kramer and Kozlowski, 1979; Norby and Kozlowski, 1980). Allelopathic compounds may be released by volatilization, leaching from living

or dead tissues, exudation from roots, and decay of plant tissues. Allelopathic compounds are important because they influence plant succession, dominance, vegetation dynamics, structure of plant communities, and crop yield (Rice 1974, 1979; and see Brunig and Sander, this volume).

A large body of evidence shows that allelopathic compounds are produced by many tropical plants. For example, Abdul-Wahab and El-Naib (1972) found that water extracts of the leaves and culms of *Imperata cylindrica* contained scopolin, scopoletin, chlorogenic acid, and isochlorogenic acid, all known phytotoxins. Eussen and Soerjani (1970) also demonstrated an allelopathic effect of *Imperata* because leaves placed on the surface of the soil were incorporated into soil that inhibited growth of a test species. Chou and Young (1975) showed that aqueous extracts of 12 species of subtropical grasses inhibited seed germination and radicle growth of test plants.

Parpiev (1971) investigated the relationships between shrubs and small trees in the middle Asia deserts and the herbaceous vegetation under the shrubs and trees. Extracts of genetically and ecologically similar species of shrubs and small trees were favourable to germination of the seeds, but extracts of genetically and ecologically distinct species inhibited germination. Thus patterning was strongly influenced by allelopathy. Parpiev's results emphasized a very important point, namely that toxic interactions are generally much more likely to occur, and to be more striking, if species have only relatively recently been brought in contact with each other. This is probably the chief reason why introduced weeds and trees exhibit such striking allelopathic effects at times (for example, *Eucalyptus* spp. in California are pioneer weeds in old-field successions). Species that have evolved together for thousands of years in natural climax ecosystems are unlikely to retain strong allelopathic interactions.

Agroforestry research must be particularly concerned with allelopathy because allelochems have been shown to block nitrogen fixation by inhibiting nodule production and reducing haemoglobin content of nodules (Rice, 1979).

Plants of Faboideae and Mimosoideae generally nodulate under proper conditions, as do the majority of the legumes which do not belong to the Caesalpinioideae. Rao *et al.*, (1973) tested extracts of non-nodulating *Cassia fistula* and *C. occidentalis* (Caesalpinioideae) and non-nodulating *Leucaena leucocephala* (Mimosoideae) against *Rhizobium* strains from six genera and species of legumes. All strains of *Rhizobium* were inhibited by extracts of the non-nodulating species. Pieces of roots of the non-nodulating species also inhibited *Rhizobium*.

The evidence from many geographical areas and vegetation types indicat that inhibition of nitrification by vegetation is a widespre nenomenon. In South Africa soils taken from the *Trachypogon plumosus* grassland climax community showed a consistent lag in production of nitrate (Stiven, 1952). Meiklejohn (1962) reported that the lack of available nitrogen in Ghana grassland soils was due mainly to absence of bacteria able to oxidize nitrite to nitrate. Meiklejohn (1968) also found that soils under native grass in Rhodesia contained very few nitrifiers, but that the same soils, when cleared and planted with

crops, contained many more nitrifiers. Soils under improved grass pasture and under two legumes contained about 100 times as many nitrifiers as soils under native grass.

The mechanisms of action of allelochems are diverse and include:

- inhibition of cell division and elongation;
- inhibition of gibberellin - or indoleacetic acid induced growth;
- reduction of mineral uptake;
- retardation of photosynthesis;
- inhibition or stimulation of respiration;
- inhibition or stimulation of stomatal opening;
- inhibition of protein synthesis and changes in lipid and organic acid metabolism; and
- inhibition of haemoglobin synthesis (Rice, 1974).

It is quite clear that controlled environment facilities will be very useful in quantifying allelopathic effects on growth, mechanisms of action of allelochems, and isolation and identification of allelopathic chemicals.

Environmental effects on plant propagation

A very wide range of multipurpose tree species is currently being introduced, but relatively few of these species have been critically investigated with regard to their optimum requirements for seed germination. Furthermore, because many of them are outbreeding species, germplasm is highly heterozygous and the possibility for immediate distribution of superior genotypes exists only if vegetative or micropropagation techniques are used. So far little work has been done on this for the species concerned. Although some genera such as *Albizia*, *Erythrina*, *Glyricidia* are propagated vegetatively with ease, others (*Acacia*, *Leucaena*, and some *Prosopis* spp.) are not.

Seed germination and vegetative and micropropagation techniques all require, to a greater or lesser extent, some form of environmental control. Experiments to determine the optimum conditions under which practical field or laboratory production should be carried out are best done using an appropriate, controlled environment research facility. In some cases there is opportunity to manipulate the plant in order to obtain suitable material for propagation, and this can be done for tropical species even in temperate regions.

During the last decade there has been a surge of interest in producing 'containerized' forest nursery stock in semicontrolled greenhouses rather than in conventional forest nurseries (Owston and Kozlowski, 1981). In some regions containerized seedlings, using control of temperature, photoperiod, water and mineral supply, can be produced in ten weeks to a year. In arid or semiarid regions, planting of containerized seedlings is usually more reliable than direct sowing (Weber *et al.*, 1977). However, little is known about the specific environmental regimes needed to produce the best planting stock for many sites. Much more work is needed to establish optimum economic conditions for raising containerized seedlings of multipurpose tree species. Although much of this work can be done in the field, the use of fairly simple controlled environment facilities can provide more

precise, extrapolated results.

Studies of Rhizobium and mycorrhizas

Many of the trees showing promise for agroforestry are not only multipurpose but fast growing and nitrogen fixing (refer to Nitrogen Fixing Tree Association, PO Box 680, Waimanalo, Hawaii, 96795, USA). They include not only those in the Papilionaceae and Mimosoideae, but also such genera as *Casuarina* and *Alnus*. Furthermore, we now appreciate that endotrophic mycorrhizal associations are both commonplace and important in improving the nutrient extracting capacity of many plant species. The positive interactions which occur when plants are simultaneously hosting both rhizobial and mycorrhizal associations are relatively new and exciting areas to explore (Daft and El-Giahmi, 1976).

A great deal of preliminary work is still needed with multipurpose tree species to record the occurrence of nodules in the field, to test them for their nitrogen fixing capacity, and to examine roots for the occurrence of mycorrhizas (Keya, 1979; Redhead, 1979). Such work must be closely followed by planned programmes of research to evaluate nitrogen fixation quantitatively, using young plants in containers, and to examine strain host relationships. Rather precise environmental control is required and programmes have already been initiated in various laboratories in support of field trials and investigations. There is scope for considerable expansion of such research if benefits from field inoculation are to be achieved similar to those which have been made with leguminous agricultural crop species and, for mycorrhizas, with certain species of forest and fruit trees.

Root studies

One of the most neglected areas of research still remains the study of plant roots and root systems. Largely because of the difficulties involved in studying living materials in soil, especially *in situ*. However, there has been considerable progress in methodology in recent years. Once again a combination of approaches using both field investigations and more detailed studies under controlled conditions (rhizotrons) has been very effective in obtaining results (Head, 1973; Huck and Taylor, 1981; and see Huck, this volume). One of the most urgent and more practical areas for research concerns the examination of rooting in nursery and planting-out situations for so far unexamined species of multipurpose trees. This could quickly result in guidelines for their more efficient field management.

Studies of plant pests and diseases

In the field or glass- or plastic house it is often impossible to separate the effects of fungal pathogens and environmental factors on plants. Each pathogen, and often each stage of pathogen with a complex life cycle, has specific environmental requirements. Plant pathogens are particularly sensitive to soil water supply (Griffin, 1978), air humidity (Yarwood, 1978), temperature (Helgeson *et al.*, 1972), and light intensity and quality (Yarwood, 1959). Wind commonly prevents formation of dew, which plays a vital role in the infection process, and it causes

raindrops or dew to dry off faster than in quiet air. For such reasons controlled environment facilities are now considered essential in conducting research on plant diseases. Controlled environments provide optimum conditions for studies of effects of disease on physiological processes and the growth of higher plants, as well as for virus assays, insect vector multiplication, root infection studies, and successive completion of disease cycles. Controlled environments also are essential for detailed studies of effects of climatic factors on host - parasite relations (Dimock, 1967).

Comparatively little is known about the diseases and pests of many multipurpose tree species, except where they have been specifically studied because of a pest-associated character (for example, *Azadirachta indica*, because of the insecticidal properties of its sap (Schmutterer *et al.*, 1981)). Although studies must begin in the field to inventory the occurrence of pests and diseases, and to establish their aetiology and epidemiology, there is considerable scope for establishing, early on, screening programmes for resistance using all the advantages that controlled environmental research can offer.

CONCLUSIONS

Information about growth and development of a wide range of multipurpose tree species is urgently needed. It would be foolish not to utilize controlled environment facilities, of one kind or another, to help provide this information as rapidly as possible. In many cases, and as long as the experimental work is closely related to problem-oriented field programmes, to do so can be cost-saving. Controlled environment facilities can then be used to investigate relevant plant responses to environment or to eliminate, or at least greatly reduce, the normal range of environmental variation which can obscure responses to other factors which are the specific objective of the investigation.

There is a whole range of agroforestry investigations, with multipurpose tree species in particular, for which one form or another of controlled environment facility will be helpful. At the lower end, crude forms of control or modification are easily and relatively cheaply established, and this should be encouraged at a national level. The more elaborate facilities, such as phytotrons and rhizotrons, are limited in number but, for more detailed work, some form of international support for research networks which include these powerful facilities, could be of considerable value.

In all cases, controlling the environment whether at a simple or sophisticated level, provides just such a facility. If the experimental objectives are clear and the experiments well-designed and planned to take advantage of the environmental control available, the costs involved will be low relative to the information that can be obtained. Otherwise investment in such research may well be misplaced.

Controlled environments should be used judiciously to answer critical questions that cannot be readily answered in the field alone. However, experienced investigators use controlled environments with due regard to some of their limitations. For example, responses of field grown and chamber grown plants to

environmental stresses are not always identical. Van Volkenburg and Davies (1977) found that cotton and soya bean leaves of field grown plants were thicker than leaves of plants grown in growth chambers at 30°C and 26°C, day and night temperatures, respectively. Davies (1977) also found that stomata of chamber grown cotton and soya bean plants were more sensitive to low light intensity than were field grown plants. The morphological differences brought about by changing light quality through the use of different kinds of lamps, may not even be the same for different cultivars of the same species (Huxley and Summerfield, 1976b) and, overall, plant morphology may well differ from that of field grown plants.

Another problem is that the responses of a species to stress in the competitive situation of a plant community may differ from results predicted on the basis of responses determined without plant competition. For example, growth of some species in a plant community in the field may be increased, despite allelopathy stress, because they may gain a competitive advantage as a result of greater impacts on other species with which they interact in the successional process. Growth of certain other species may be reduced by allelopathy stress more than expected because of reduced competitive potential.

For a discussion of guidelines for use of controlled environments the reader is referred to the book by Tibbitts and Kozlowski (1979). Despite some limitations of controlled environments they can be a valuable research tool in agroforestry, especially when field experiments are used in conjunction with research conducted in controlled environments.

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SECTION FIVE

PART 5B

Methods for Assessing Rhizobia and VA mycorrhizae for Multipurpose trees

CONTENTS

Methods for Assessing Rhizobia and VA Mycorrhizae for Multipurpose trees

by Jake Halliday

Introduction

Nitrogen-fixing trees potentially benefit from at least two symbiotic relationships with microorganisms. Association with rhizobia confers nitrogen fixing ability. Infection with vescicular arbuscular (VA) mycorrhizae enhances phosphorus uptake. A vigorous tree at a particular location is frequently a manifestation of an especially effective match between the tree genotype, its symbiotic partner(s), and its environment. In fact such a tree could be heavily dependent on its microsymbioses for its nutrition. Germplasm explores needs to be aware that later performance of a collected accession introduced to a new location may be below expectation unless a specific effort is made to reconstitute equally effective associations.

Introduced tree species can fail to encounter fully effective microsymbionts spontaneously in the native microflora, and/or nodulate effectively with available inoculants. Even when the trees are inoculated, the strains provided may not match the tree's specific requirements. Thus an integrated approach to germplasm exploration, selection and introduction in which seeds, rhizobia and mycorrhizae are viewed as inseparable components of the germplasm unit is warranted.

An earlier section of this manual dealt with collection methods. This section describes established methods for selecting superior strains of *Rhizobium* and for using them as inoculants for trees. Methods for selection and evaluation of mycorrhizae for leguminous trees are much less developed at this time. This chapter outlines methods for determining the degree to which a leguminous tree is infected with VA mycorrhizae. For those interested specifically in selection and inoculation methods, several references to research papers in this area are provided.

Principles of Rhizobium strain selection

> "Strain selection is performed to ensure that a legume seed inoculant contains a strain, or strains, of *Rhizobium* capable of forming fully effective, nitrogen-fixing nodules on the legume species for which it is recommended and in the soil and climate in which the legume is grown".

Previous publications by the author (1,2) have defined step-wise screening approaches to strain selection. Most selection procedures for crop legumes stress the matching of specific rhizobial strains with the host genotype, sometimes even at the varietal level. This approach is valid for a MPT like leucaena, but is inappropriate for most other MPTs because the seed lines are not genetically pure. Genetic diversity of planting material is just one of the features of multipurpose trees that makes it necessary to rethink some of the conventional approaches to selection of *Rhizobium* strains for use in inoculants.

A second complication for inoculation of MPTs is that vegetative propagation may be necessary for some species. Conventional inoculant methods involve application of rhizobia directly to the propagule or indirectly to the soil. Modifications have not been validated for use with vegetative propagation. Such validation is necessary because delay time between planting and root emergence can be much longer with vegetative propagules than in the case of seed germination. The period during which rhizobia are vulnerable to adverse factors is prolonged. There may not be survival of adequate numbers of effectively nodulate the root when it finally emerges.

Procedures which follow were used successfully to select rhizobia for forage legume introductions in acid, infertile soils of tropical Latin America (1). The principles underlying the approach apply equally well to strain selection for MPTs and some alternative methodologies are mentioned in the text. Individual investigators can modify the techniques and improvise with equipment to suit their purposes and the facilities available to them, provided they adhere to the principles of *Rhizobium* strain selection stressed here.

Selection criteria

Some characteristics of strain or *Rhizobium* to be used as legume inoculants can be regarded as "essential" whereas others are "desirable" depending on the specific selection objective. Essential traits are:

- Ability to nodulate the MPT in the field conditions under which it is grown. such strains are referred to as "infective". Strains of *Rhizobium* which are infective in the field will usually have exhibited "competitive ability" if they displaced nodulation by native strains present at the site. They will also have been "stress tolerant" if they successfully nodulated legumes in soils with excesses or deficiencies in their physical/chemical composition.

- Capacity to fix sufficient nitrogen to sustain production close to, or surpassing, the level possible if the legume were supplied with nitrogenous fertilizers. Such strains are referred to as "effective". Strains which are fully effective are usually carbon efficient and hydrogen efficient as well. The "efficiency" of *Rhizobium* strain is seldom measured during strain selection and use of the term in this context should be avoided. Effectiveness is usually what is meant.

- Ability to perform satisfactorily when subjected to the component processes of commercial-scale inoculant production systems. Inoculant strains must multiply well in bulk culture and be able to mature to high populations in the carrier material.

- Able to survive well during distribution to, and use by, farmers. Strains should be tolerant to the anticipated maximum temperature that they will encounter. They must also survive well during the seed/soil inoculation procedures. Additionally they must survive on seed in soil from the time of their application until the emerging legume radicle is susceptible to infection (usually at least seven days). Strains for MPTs will need to survive for even longer periods if they are used with vegetative propagules, and/or to cope with delayed germination.

Traits that are held to desirable are:

- Long-term persistence is expected of strains of *Rhizobium* used to inoculate perennial species. Implicit in the concept of persistence is saprophytic competence, a summary term for all those traits that permit a *Rhizobium* strain to live as a stable member of the soil microflora, even in the absence of its legume host. This trait is particularly desirable in strains of *Rhizobium* used to inoculate MPTs. Persistence of strains for annual crop legumes from season-to-season may be considered a desirable trait in some circumstances, as it obviates the need for inoculation in subsequent years. Lut there may be cropping systems in which carry-over strains from a previous crop may nodulate a following crop relatively ineffectively and even out-compete effective introduced strains. This can occur in rotations of soybean with peanut and cowpea that nodulate with the cowpea miscellany.

- Fungicide or insecticide resistance may be desirable traits when normal practice is to sow legume seeds pre-treated with these substances, some of which are toxic to certain strains of *Rhizobium*.

Basis for strain selection

Rhizobium strains do vary widely in the characteristics listed above. Some strains nodulate some genera, or species, or varieties of legumes and not others. Among strains capable of infecting and nodulating a particular legume, there is great variation in the amount of nitrogen they fix, i.e. variation in effectiveness. There is considerable strain variation in the other listed traits as well and thus an opportunity exists to select superior strains. Unlike higher plants which can be improved through breeding and hybridization, *Rhizobium* improvement is currently practical only by selection from natural populations.

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Need for strain selection

As will be appreciated from the following procedures, the selection of superior *Rhizobium* strains is a lengthy undertaking Several years of study may be necessary to complete characterization and testing. Given that strains of *Rhizobium* for many legumes, including some MPTs, have already been developed at research labs around the world, it makes sense to obtain and use these rather than initiate an extensive selection program.

Selection of rhizobia is only really justified when the specific selection objective cannot be satisfied by strains held in existing collections. Examples of circumstances which justify a strain selection program are:

- When the legume of interest is an uncommon species for which there is no recommended inoculant strain. This is the "state-of-the-art" for the majority of MPTs.

- when inoculation of the particular legume with recommended strains of *Rhizobium* under field conditions fails to give adequate nodulation and nitrogen fixation. This can occur if the legume variety is different from that with which the inoculant strain was developed, or if the soil and climatic condition vary from those under which the inoculant was developed.

Matching rhizobia to soil type

The step-wise selection procedure given here derives a *Rhizobium* strain recommendation for legumes planted under a particular soil condition. This approach is innovative in the sense that strains of *Rhizobium* in current use as legume seed inoculants are developed for the species of legume with which they will be used, rather than the soil type in which the legume will be grown.

The need to inoculate

In the technologically advanced countries, it is normal farm practice to modify soil conditions to be suitable for a particular crop. It is not

unreasonable therefore to expect a rhizobial inoculant for a legume species to perform well wherever that legume is grown. In the developing nations, however, soil amendment is minimal or not practical at all, and crop plants are often grown under stresses of adverse soil factors that cannot be economically alleviated. For most utilizations, e.g. reforestation, MPTs will be introduced to unamended soils. It may be unreasonable to expect that a single strain of *Rhizobium* will perform equally well as an inoculant in the wide array of soil types under which its MPT host will be grown in the tropics. One reason that legume inoculation is not widely successful in developing countries is that available inoculants obtained from the U.S., Australia, or elsewhere do not have strains selected for, and adapted to, the extremes of soil stress encountered in the tropicss (2).

There is a widely held view that strain selection and legume inoculation have little potential for improving yields of tropical legumes (including MPTs), since tropical legumes are not specific in their *Rhizobium* strain requirements, and because suitable rhizobia occur universally in tropical soils. Spontaneous nodulation, which is often observed in leguminous MPTs in their natural environment, creates an impression that specific inoculation is not required.

There are notable exceptions, such as soybeans and leucaena, and thus two categories of tropical legumes were recognized. The Promiscuous (P) group can be nodulated by a wide array of strains of tropical rhizobia. The specific (S) group requires specific rhizobial strains for nodulation. The majority of tropical legume species were judged to belong to the P group and it has been generalized that it is unnecessary to inoculate these legumes with rhizobia, as no benefit would be expected.

The grouping of tropical legumes simply as S or P types is no longer tenable nor useful (3). Many tropical legumes previously placed in the P group are now known to form fully effective (i.e. high nitrogen-fixing) symbioses with only a few strains out of the diverse array of rhizobia that can nodulate them. Thus a distinction is drawn between this promiscuous-ineffective (PI) group of legumes and the promiscuous-effective (PE) group (2). Studies of the *Rhizobium* affinities of the tropical forage legumes, for example, reveal that a majority of them are in the PI group, suggesting

a potential for increasing their production by providing appropriate strains of rhizobia.

The important role played by stress factors of tropical soils as modifiers of symbiotic performance is now well recognized (4). Thus tropical legumes can and do benefit from inoculation when strains are selected specifically for the particular variety of legume being planted and for tolerance of the soil conditions in which that legume is to be grown.

Strain selection objective

No strain selection program should be undertaken without clear definition of the specific selection objective(s). The methods of selection employed may need to be modified to suit the objective. As an example the specific selection objective for which the procedures that follow were developed was "to select strains of *Rhizobium* able to nodulate and fix nitrogen in association with acid tolerant legume accessions being introduced to the acid, infertile soils of Latin America".

Step-wise screening strategy

Successful selection of superior rhizobia is favored if the number of strains from which the selection is made is large and diverse. The most meaningful test of *Rhizobium* performance is field evaluation, since this is an integrated appraisal of the various traits that make up a successful inoculant strain. However, the management of field trials to select rhizobia is difficult and costly, even when the number of strains under test is small. Multi-stage screening procedures progressively eliminate undesirable strains from an initially high number of contenders to yield a relatively small number of promising strains for testing at the field level. This is one way to reconcile the requirements that selection be from a diverse genetic base, and that strains also be assessed under field conditions.

It is advisable to include in the screening procedure strains of *Rhizobium* that originated from a diverse array of host plant germplasm and that are representative of diverse geographic regions. But some reduction of the number of strains can be made based on what is known from other selection programs. In general, rhizobia isolated originally from the same genus, and sometimes species, as the legume for which a superior strain is being sought, emerge

from selection programs as the best strains for use in legume inoculants. Also, when the specific selection objective includes tolerance to a particular soil stress or climatic condition, rhizobia isolated from legumes growing under those conditions are the most likely to be rated highly in the selection process (5). Hopefully, there is a *Rhizobium* collection or collections or authenticated strains of known origin available to the investigator. Otherwise, a suite of strains has to be assembled. Only after checking whether likely strains are available from existing *Rhizobium* collections, such as the *Rhizobium* Germplasm Resource at NifTAL, should collection and isolation of new strains be contemplated. Pre-selection of strains with suitable background should aim to generate a cluster of 50-100 rhizobia that will feed into the first stage of the strain procedure.

Stage 1. Screening for genetic compatibility

In this stage, strains of *Rhizobium* are screened for ability to nodulate the legume of interest The test used involves a high degree of bacteriological control and is suited to handling large numbers of strains. The systems most commonly used is based on growth tubes in which seedlings are raised in a solid, nutrient medium under artificial illumination. Seeds must be surface sterlized, usually with concentrated sulphuric acid, hypochlorite, or acidified mercuric chloride. Germination of MPT seeds may be problematic and some guidelines are give in Appendix I.

Seeds are pre-germinated in inverted, sterile petri dishes of water agar. When the radicles are 3-5cm long, uniform seedlings are transferred aseptically to tubes containing agar deeps (or slants). Tubes are routinely 2.5 x 25cm, capped with a plug of muslin-wrapped cotton wool. Aliquots of 1.0 ml of suspension of the test strains are added to each tube either at transplanting or 3-5 days later. At least three replications of each strain treatment are essential and five are preferred. Roots of seedlings should be shielded from light. Alternatively, tubes may be wrapped in aluminum foil. Two control treatments are required. In one case the plants are "inoculated" with sterile water only (uninoculated control) and in the other case they are provided with 70 ppm nitrogen as ammonium nitrate (or potassium nitrate) solution (referred to as the plus nitrogen control). Tubes are scored at intervals for the presence or absence of nodules. With many tropical legumes tumor - or callus-like outgrowths can occur in

roots of seedlings raised in growth tubes. Those outgrowths occur in the presence or absence of rhizobia and are not nodules. They cannot be distinguished from nodules by eye. Plants should be harvested from tubes and checked under a binocular microscope for real nodules. "Apparent" nodules lack structural organisation and leghemoglobin. Timing of the harvest varies depending on legume species but will usually be about 21-35 days after sowing.

Some investigators place significance on other data taken on plants grown in growth tubes. "Earliness to nodulation" may be of some value. It is inappropriate, however, to attribute relative nitrogen fixation effectiveness to strains based on nitrogen accumulation in plants raised under such artificial conditions. The root medium and atmospheric composition within plugged test-tubes differ from those which the plants require for optimum performance and may constrain expression of nitrogen-fixing potential.

Alternate methodologies are required for MPTs that are large-seeded and which become cramped in growth tubes. These include the use of growth pouches or "Gibson" tubes. Growth pouches are made of autoclavable plastic and have an absorbent towel insert. Seedlings germinate in a fold (or are pre-germinated and transplanted into the fold) at the upper rim of the pouch. Roots develop within the pouch nourished by a nutrient medium, and plant tops grow in the open air. The method offers the advantage that effective nodulation can be reliably determined, but caution in attributing relative effectiveness of strains on a pouch test basis is necessary. Modifications of the method include subdividing the pouches with heat bonding to permit a single pouch to be used for several strain treatments, or replications of the same treatment.

In the case of "Gibson" tubes, the tube contains a long agar slant that reaches to the upper rim of the tube, and are filled to the rim with liquid medium or sterile water. They are capped with aluminum foil. Radicles of pre-germinated seedlings are entered through a small orifice in the aluminum. The roots develop inside the tube and the plant tops grow outside the tube. The method offers similar advantage to those of pouches, namely that effective nodulation shows up readily. Modifications of "Gibson" tubes include omission of the liquid phase or half filling the tubes.

Obviously, if nodulation occurs in the uninoculated control treatments in Stage I, the bacteriological control has been inadequate and the experiment is invalidated.

Some texts advocate dedication of entire light rooms for the culture of plants in growth tubes. Most workers will find a low cost system of racks and portable fluorescent tubes more than adequate for their needs. Such a system is highly flexible and can be readily modified to provide lateral illumination for growth tubes or overhead illumination for pouches. The issue of light quality has been overplayed. Regular domestic flourescent lamps have served satisfactorily in the screening procedure described here.

Stage II. Screening for nitrogen fixation effectiveness

In this stage the objective is to rank infective strains from Stage I in order of *potential* nitrogen fixation effectiness with the legume species/cultivar of interest. Theoretically, in this test there should not be any factors limiting growth of the legume except nitrogen, so that full expression of each strain's nitrogen fixation effectiveness is possible. In practice it is assumed that the nutrient regime and other aspects of growth conditions are not limiting, even though there are known examples of legumes for which standard conditions are not non-limiting. Sand jar assemblies are used in this test because they permit more realistic growth conditions than tubes, pouches, etc., but retain the high degree of the bacteriological control which is still essential if valid results are to be expected.

The Leonard jar is one example of such a sand jar assembly. Watering is the most common source of contamination in *Rhizobium* strain testing in pots and in the field. Leonard-type sand jars greatly reduce the frequency of watering and are, therefore, less prone to contamination. Sand jars are easily constructed from locally available materials, but have the disadvantage that sterilizing them required a very large autoclave.

As with growth tubes, surface sterilized pre-germinated seeds are sown in the sand jars.

Four seedling are allowed to establish and thinned later to two by snipping off the tops. Drops (standardized rate) of suspensions of strains of *Rhizobium* are added to seedlings in the jars five days after sowing (one strain per jar). Plants are harvested destructively at a time after sowing that depends on the legume under test. Usually 60 days after sowing is appropriate.

Data taken on sand jar experiments vary from investigation to investigation and include the following:

- nodule number
- nodule dry weight and/or fresh weight
- nodule color
- nodule distribution
- total plant fresh/dry weight
- top weight (fresh/dry)
- root weight (fresh/dry)
- acetylene reduction rate
- percentage N in tissues
- total N produced

Of these, total N produced is the most meaningful integration of nitrogen fixation effectiveness over time and, as this is highly correlated with total plant dry weight, a reliable measure of relative effectiveness of strain of *Rhizobium* is possible with nothing more sophisticated nor costly than a common balance.

The main problem encountered with this test relates to overheating in greenhouses or growth rooms where the experiments are performed. Most of the sand jar trials observed by this author in the tropics are, in fact, selecting high temperature tolerant rhizobia at the same time! Other problems relate to the occasional failure of the irrigation from beneath which depends on capillary rise, and breakage of glass components in autoclaving and handling.

Strains are ranked on the basis of their performance in Stage II. The demarcation of effectiveness categories is somewhat subjective, but nevertheless useful. Strains are assessed relative to the uninoculated control and the plus

nitrogen control and described as (in ascending order of merit) parasitic, ineffective, partially effective, moderately effective, or fully effective.

Ordinarily about 30-50 strains would be evaluated at Stage II in Leonard jars. Three replications are essential and five are preferred. The top ten strains are chosen for further screening at Stage III.

The principal merit of Leonard jar trials is that data on the potential effectiveness of strains of *Rhizobium* with a particular legume tend to be upheld in independent screening trials by other investigators. Thus, researchers can exchange information that is stable and demonstrable on the nitrogen-fixing potential of strains. Pot and field trials, on the other hand, given information of the plant/*Rhizobium* soil interaction that may or may not be repeatable at other locations (5).

Stage III. Screening for symbiotic effectiveness under physical, chemical and biological stresses of site soils

The fully effective nitrogen fixation effectiveness expressed under Stage II conditions will not necessarily be upheld under real field conditions. Thus, before selecting a final cluster of three strains of *Rhizobium* for field evaluation, it is advisable to subject a larger group (ten) of potentially effective strains to some of the physical, chemical and biological stresses of soils for the inoculant is being developed. This stage is particularly useful if the specific selection objective includes adaptation to a particular stress, such as soil acidity. Stage III also has a value in selection programs for "non-stress" soils. In Stage II sand jar evaluation, test strains did not have to compete against native rhizobia.

This third stage involves a pot experiment in which strains are tested with the host plant and production related to that of uninoculated control plants and nitrogen fertilized plants. Soil is collected from the plough layer and mixed to uniformity to produce a homogeneous experimental material. Unsterilized soil is used. Soil may be amended at fertilizer rates equivalent to field practice (for methods, see ref. 6) but only the nitrogen control plants

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receive nitrogen (equivalent to 100 kg N/ha). Not all soils behave satisfactorily in pot experiments and other amendments may be necessary, particularly with heavier soils. The following should be considered:

- sieving to remove large soil aggregates and stones;
- addition of high carbon ratio residues, such as bagasse, at 1-2% (dry weight basis) to counterbalance excessive mineralization of nitrogen resulting from soil handling;
- addition of volcanic cinder, vermiculite, or other materials to improve soil aeration and drainage.

The sowing procedure and inoculation is the same as for sand jars in Stage II. About 6-8 seedlings are planted and thinned to 2-4 plants pot, depending on the species. Thinning is by snipping off the plant tops, rather than pulling entire plants from the soil. Pot size is optional, but 20-25 cm in diameter is usual. Six replications of each treatment are required.

Precautions against cross-contamination in this stage are essential. Watering, which in greenhouses in the tropics is needed daily, is the primary source of contamination. It can be minimized by:

- filling pots so that the soil level is 3 cm below the pot rim;
- watering gently to avoid splashing;
- using grid or mesh benches instead of solid benches, so that pots can drip through onto the floor;
- raising pots on supports (such as petri dish lids) so that there can be no water flow on the bench surface from the emergent roots from one pot to those of another;
- assigning watering to a single, well trained individual.

Other precauations include avoidance of overheating of the roots and nodules in pots and minimizing non-treatment effects. Pots should

be set up in a randomized, complete block design but not re-randomized thereafter because of the overriding problem of contamination through handling.

As with sand jars, plant dry matter production is the most meaningful parameter to be determined and is the basis for ranking strains. The top three strains are promoted to Stage IV.

Stage IV. Single location evaluation of strains of *Rhizobium* and inoculation methodology under field conditions

Strains emerging from Stage III are evaluated for nodulation and nitrogen fixation under field conditions. Although the preferred measure of the response by a leguminous MPT to inoculation with the test strains of *Rhizobium* is total biomass production, there are many factors which, under field conditions, can prevent differences in nitrogen fixed by the strains being translated into long-term differences in yield. Therefore, field trials should include an interim harvest after only three or four months growth, i.e. before treatment differences become masked by other influences.

The trial has three basic treatments: plants inoculated with *Rhizobium*; plants not inoculated; and plants not inoculated but fertilized with nitrogen.

The comparison between *Rhizobium* strain treatments is most valid, in a scientific sense, when there are no other factors limiting plant growth. But the comparison is most realistic when the level of agronomic inputs is economically feasible and similar to that to be used in the region where the MPT is to be grown. It is therefore best to field test rhizobia at two fertility levels, in one case aiming to eliminate all limiting factors, and in the other case adhering to the level of imputs that are "normal practice" for the region.

Experience has indicated that four replications are desirable. With three treatments at two fertility levels replicated four times, a 24 plot, randomized, complete block design results. The treatments in the first replication can be deliberately arranged to serve as a demonstration in which the treatments that are most frequently compared are located side-by-side to facilitate visual observation of treatment differences. A suitable layout is that used for the International Network of Legume Inoculation Trials (6). Row spacing, planting distance, and seed rate depend on the legume in question.

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Plot size will necessarily be bigger for NFT inoculation trials, but be smaller than would be required for long-term production trials. Thestandard plot size and layout used in the International Network of Legume Inoculation Trials is recommended.

It is best to sow the "uninoculated" and "nitrogen fertilized" plot first. Only after the seeds in these plots have been covered are the inoculated seeds prepared for sowing in the remaining plots. This minimizes the risk of contamination of the plots that are not to receive rhizobia.

When the specific selection objective includes overcoming soil stress, the field trial at Stage IV can amalgamate the strain selection approach and other strategies for overcoming the stress. For example, several inoculation methods could be appraised for their ability to overcome the effect of acid soil stress on nodulation.

Precautions against cross contamination are of paramount importance. Common pathways of contamination are:

- Careless handling of inoculated seed at planting time.
- Use of field implements without sterilizing them between plots.
- Tramping from plot to plot (by laborers, animals, visitors, etc.)
- Run-off and other drainage problems caused by poor site selection.

The best *Rhizobium*/inoculation method combination is then selected and subjected to further testing in Stage V. It could be justified to produce and use legume inoculant based on Stage IV evidence, but there remains the risk that the selected strain will be a successful inoculant only in the specific soil and climatic conditions under which it was selected. A further stage is essential to determine the range of suitability of inoculant developed for a single location in Stage IV.

Stage V. Multi-location testing of the response to inoculation with selected *Rhizobium* strains

A standard design developed for the International Network of Legume Inoculation Trials (INLIT) is available for those comtemplating multi-location trials on the response of legumes to inoculation with selected strains of *Rhizobium* (6).

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One of the major constraints to fuller utilization of legume inoculation in the tropics is that there has not been convincing demonstration on a wide scale that production will result with local legume varieties under local soil and climatic conditions (2). Stage V trials can assist in deriving the data necessary for predicting more reliably whether a legume will respond to inoculation or not.

Stage V trials can be used to characterize selected strains for competition and persistence if the inoculant strain is "marked" serologically or with antibiotic resistance. Such strains of *Rhizobium* can be detected in the nodule population and their ability to compete against strains natice to the site determined. These strains can also be detected, if present, in the soil in following seasons, or in the nodule populations of subsequent legume crops sown uninoculated. The International Network of Legume Inoculation Trials (INLIT) coordinated by the University of Hawaii NifTAL Project are available for 17 agriculturally important tropical legumes including the MPT *Leucaena leucocephala*. Inoculants developed for INLIT each contain three serologically distint, effective strains of *Rhizobium* from diverse geographic and host germplasm backgrounds (6). Each INLIT is potentially an ecological study of the relative performance of the three exotic strains between themselves and in competition with indigenous soil strains. The INLIT is also a long-term persistence trial. A mixed inoculant of 6 marked strains suitable for use with most leguminous MPTs (7) is also offered to researchers in the tropics through NifTAL's INLIT program.

Pre-screening tests for special cases

For some specific selection objectives, the development of rapid screening procedures may reduce the time taken to develop a reliable inoculant strain, or may greatly increase the likelihood of successful inoculant strains emerging from the step-wise screening previously described. For example, in the case of selection of rhizobia for acid, infertile soils, a laboratory pre-screening that preceded the Stage I test greatly increased the range and numbers of strains that could be addressed (8). It eliminated effective strains pre-destined to fail in the field but which would have passed through Stages I, II and possibly III consuming time and resources. The pre-screening test was based on the reasonable assumption that for a strain of *Rhizobium* to be a

successful inoculant for legumes grown in acid soils, ability to multiply well at low pH is essential trait. Synthetic media were developed that tested ability to multiply at low pH, and only those strains passing the test were fed into the step-wise screening program. Investigators may find it useful to adopt rapid pre-screening steps for their own objective(s).

A cautionary note about screening

As with any screening program, there is always the risk that discarded materials that could not be accommodated in the later stages would have performed well in the field. In the procedure described, the stage-to-stage transition that is most problematic is that from Stage II to Stage III. Ranking of strains in sand jars do not necessarily hold up when subjected to the stresses of site soils. Although 10 fully effective strains are passed across from II to III, examples have occurred in which as few as three of the strains could nodulate at Stage III and only one of these was effective (1).

When dealing with uncommon legume species (most MPTs fall in this category) an investigator should be concerned about whether the routine media used in Stage I and Stage II are, in fact, non-limiting on growth of the legume plant so that *Rhizobium* characters can be expressed. As an example of this, it was found that *Stylosanthes capitata* a legume with high tolerance to soil acidity factors and native only to acid soil regions of South America, could not be nodulated by any one of more than 100 *Stylosanthes* isolates (including many specifically from *S. capitata*) tested at Stage I. Nor would *S. capitata* grow in Stage I. Only when the growth medium was acidified to a pH lower than 5.0 and the Ca and P levels ten-fold would the plant nodulate and grow.

Even through the screening procedure is lengthy, attempts to short-cut the sequence are ill-advised. Recommendation of strain of *Rhizobium* for MPT inoculation without first performing field trials similar to those described in Stage IV and Stage V is risky in the face of accumulation data that show that site variation in performance of selection strains is common (5).

Inoculation technology

The underlying objective of inoculation technology is to place sufficiently high numbers of preselected strains or rhizobia in the vicinity of the emerging root that they have a competitive advantage over any indigenous soil strains with lesser nitrogen fixing ability in the formation of root-nodules.

This involves:

- selection of strains of rhizobia that are compatible and effective nitrogen fixers with particular legumes;
- multiplying selected strains to high population densities in bulk cultures;
- incorporating the liquid rhizobial cultures into a carrier material (usually finely milled peat) for packaging and distribution; and
- coating the seeds of legumes with the carrier or implanting the soil with the inoculant directly into the seed drill.

Production methods for legume inoculants will not be described here, as this is generally left to specialists. Recently however, several simplified, low cost techniques for producing inoculants have become available, making local small scale production feasible (2,9). Assistance in this area is available through NifTAL.

Differing opinions on strain composition of inoculants

There are at least three opinions about the best approach on inoculant strain composition:

- an inoculant should have a single, highly effective strain appropriate for individual species (this results in numerous inoculants);
- inoculants should have a single "wide-spectrum" strain that varies from good to excellent in nitrogen fixation with a range of legumes;
- or that inoculants have several strains, each being the best strain for each host species for which the inoculant is recommended.

There may be a conflict between the option that would be chosen for commercial expendiency and that which is scientifically excellent. In Australia "wide-spectrum" strains are used when these are available, but there is increasing use of specialized inoculants with specific strains for individual hosts. Despite research findings of possible antagonistic and competitive effects in culture and the likelihood of competition in nodule formation from the less effective strains, this is the approach used successfully by the U.S. inoculant industry.

Given the number of leguminous MPT species being addressed (an expert group was unable to reduce a priority list to less than 44 species), and given also that inoculant for these is needed even before development of specialized inoculants can be completed, NifTAL advocates routine use of a multi-strain inoculant incorporating wide-spectrum, fast- and slow-growing rhizobia. Results to date with this inoculant vindicate this approach (9).

Inoculation methods

The first attempts at inoculation involved the transfer of soil from one field to the next but with the isolation of the organisms responsible for nodule formation, artificial cultures soon replaced the laborious soil transfer technique.

The most commonly used inoculation technique is to treat seed just before sowing either with a dust or with a slurry in water or adhesive solution. Adhesives such as gum arabic and substituted celluloses not only ensure that all the inoculum adheres to the seed surface but also provides a more favorable environment for survival of the inoculant. Pelleting of inoculated seed with finely ground coating materials such as lime, bentonite, rock phosphate and even bauxite have been used to protect rhizobia during their time on the seed coat.

An alternative to pelleting and pre-inoculation in recent years has been the use of concentrated liquid or solid granular peat culture. These are sprayed or drilled directly into the soil with the seed during planting. Suspensions of rhizobia either as reconstituted frozen concentrates or suspensions of peat inoculant can be applied with conventional equipment. Similarly, granulated peat inoculants can be drilled in from separate hoppers on the drilling equipment. These methods have been especially successful for introducing inoculant strains into situations where there are large populations of competing, naturally occurring soil rhizobia or in cases of adverse conditions such as hot-dry soils and where insecticide or fungicide seed treatment precludes direct seed inoculation. Solid inoculant, also known as granular or "soil implant" inoculant, is appropriate for use at the time of transplanting MPT seedlings to their final sites. Liquid inoculants are the best form for seedlings being

raised under nursery conditions.

Measuring the nitrogen fixed by MPTs

"How much nitrogen/ha/year does the species fix?" is a question asked frequently by researchers involved with legumes. This author believes firmly that it is so difficult to measure nitrogen fixation by a perennial species under field conditions, and that the answer obtained is of so little real value to those concerned with tree production, that there is little need to be preoccupied with quantifying nitrogen fixation by MPTs.

It is very important for a MPT researcher to know that he has optimized the opportunity for nitrogen fixation by providing seedlings, if necessary, with the correct *Rhizobium*. It is much less important to know how much nitrogen is ultimately fixed. Thus, total nitrogen fixed is primarily a datum of academic interest.

It is sometimes misunderstood that a nitrogen fixation value is needed for choosing whether to plant nitrogen-fixing or non-fixing trees. This choice is better supported by determining the nitrogen application rate required for the non-nitrogen fixer to attain productivity equivalent to the nitrogen fixing species. This does not involve measuring nitrogen fixation at all.

Methods such as acetylene reduction and the use of isotopic nitrogen are not readily applicable to field studies with perennial species and are unacceptably imprecise for studies with deep rooting trees (10). Approaches such as are used by ecologists to determine nitrogen balances in overall soil, plant, atmosphere systems are perhaps the only valid way to measure nitrogen fixation in MPTs. Few production-oriented tree researchers are in a position to accomplish the major undertaking which this involves.

Vescicular arbuscular mycorrhizal technology

Although there are parallels between rhizobial and mycorrhizal technologies, neither strain selection methods nor inoculation practices for VA mycorrhizae are well established at this time. It is known that;

- there is variation in the symbiotic value of different VA mycorrhizae;

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- there is a degree of host: mycorrhiza specificity;

- VA mycorrhizae are absent from some soils;

But these observations tend to be exception, rather than the rule, and are not a strong basis for a VA mycorrhizal inoculation technology.

MPT researchers should be on the look out for instances when their trees do not have VA mycorrhiza and only then contemplate remedial inoculation. This section provides a method used at NifTAL for determining the extent of spontaneous mycorrhizal infection of MPTs.

Sampling and staining roots for mycorrhizal observations

Fine, non-lignified roots are rinsed of soil debris and cut into 1.0 cm segments. These are immersed in potassium hydroxide (10%) at 90°C in a water bath for 2-2.5 hours. Further bleaching is accomplished with a 20 minute immersion in alkaline hydrogen peroxide solution (30ml of 30% peroxide + 5ml household ammonia + 165ml water). The root segments are then rinsed three times in tapwater. After acidifying for 3 minutes in 1% hydrochloric acid, the roots are stained for 10 minutes in lactophenol with trypan blue at 90°C. Excess stain is drained off and the roots are rinsed twice in tapwater. If additional destaining appears necessary, the roots are rinsed in lactophenol. The roots are ready for mounting at this stage.

It is customary to squash the root portion under a cover slip and to observe at about x 20 maginification. Hyphae appear blue and vescicules may be seen in cells. Arbuscules may also be observed in some cells but are not always present.

Determining the percentage infection is only a semi-quantitative estimate, but does serve to distinguish between those species that are heavily mycorrhizal and those which are only sparsely infected. By convention, the "percentage infection" is the proportion of examined root samples that are found to be mycorrhizal. Obviously, much depends on the adequacy of the sample on which the observations are made.

Some observations on VA mycorrhizal infection of MPTs in Hawaii

Mycorrhizal infection of many MPTs occurs spontaneously in field soils in Hawaii. Thirty species of NFT were sown in Hamakuapoko soil (Typic Haplustoll, ph 6.9) on the Island of Maui.

Naturalized vegetation at the site includes spiny amaranth (*Amaranthus spinsosa*), some wild Cruciferae, and the legumes *Indigofera fructicosa* and *Leucaena leucocephala*. All but one of the introduced species were observed to be heavily infested with VA mycorrhizae by 12-16 weeks after planting (Table 1). This suggests that specific inoculation of NFT seeds with VA mycorrhizae may be unnecessary.

Further research is necessary to determine whether other species are readily infected with native VA mycorrhizae and whether VA mycorrhizae are ubiquitous in tropical soils.

Research to compare VA mycorrhizal infection of four MPTs (*Parkia roxburghii, Acacia farnesiana, A. nilotica,* and *A. senegal*) grown in soil of widely differing pH revealed that infection was greatest in high pH (8.5) soils and was absent from all species in soil from a low pH(4.5) site.

None of the above considerations precludes the possibility that at some point in the future, mycorrhizal inoculant technology might emerge based on displacement of relatively infective native strains by selected strains that are more highly effective phosphorus absorbers. But for the present, inoculation of NFTs with mycorrhizae seems unnecessary. This is perhaps just as well because inability to raise VA mycorrhizae in the absence of a host plant remains a serious obstacle to large-scale production of VA mycorrhizal inoculants.

It has been shown that leucaena seedlings raised under nursery conditions did not become infected spontaneously in a peat moss/vermiculite rooting medium. The medium had not been sterilized, but it is presumed that the source materials were largely free of mycorrhizal spores. Following transplanting to Hamakuapoko field soil, seedlings become progressively infected with VA mycorrhizae and after 8 weeks attained a level of infection (90%) typical of field grown leucaena (Table 2).

Table 1. Observations on presence or absence of nodules and the degree of VA mycorrhizal infection on roots of leguminous trees introduced to Hamakuapoko soil.

NFT No.	Species	Nodulation	VA Mycorrhizal infection
101	Acacia albida	yes	90 %
106	Acacia holoserica	yes	42 %
171	Acacia mangium	yes	80 %
152	Acacia mellifera	yes	76 %
103	Acacia nilotica	yes	91 %
154	Acacia nubica	yes	88 %
157	Acacia seyal var. seyal	yes	99 %
338	Albizia chinensis	yes	96 %
181	Albizia falcataria	yes	94 %
185	Albizia julibrissin	yes	91 %
182	Albizia moluccanna	yes	97 %
161	Calliandra calothyrsus	yes	96 %
321	Cassia siamea	no	100 %
320	Enterolobium cyclocarpum	yes	98 %
127	Julbernardia globiflora	no	28 %
569	Leucaena leucocephala	yes	95 %
114	Prosopis africana	yes	90 %
116	Prosopis juliflora	yes	94 %
323	Samanea saman	yes	100 %
303	Sesbania grandiflora	yes	86 %
120	Tamarindus indica	no	98 %

(from Halliday and Nakao, 1982)

Table 2. VA Mycorrhizal infection of Leucaena leucocephala established by direct seeding or by transplanting.
(Data of P. Nakao, unpublished)

Plant age (days)	VA Mycorrhizal infection (as percentage)			
	direct seeded		transplanted	
21	51	in field	0	nursery
49	74		0	
56	82		0	
63	95	in field	2	in field
70	>95		43	
84	>95		61	
112	>95		95	

-- nursery plants raised in dibbling tubes in a non-sterile peat moss-vermiculite mixture (3:5 ratio by volume) and transplanted to the field on day 60.

-- Typic Haplustoll, pH 6.9, Hamakuapoko, Maui, Hawaii.

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TECHNICAL NOTE ON THE GERMINATION OF LEGUMINOUS TREE SEEDS

Summary

Seeds of 33 leguminous tree species were tested for germination following mechanical or chemical scarification. The treatments gave germination of over 50% for 28 of the species. Mechanical or chemical scarification of about three times the number of seeds needed for an experiment with leguminous tree species is recommended as a rule of thumb when the germination rate of the seeds is in doubt.

Introduction

An ability to germinate seeds of leguminous trees reliably is an essential prerequisite for systematic research with this class of plants. For researchers more accustomed to dealing with crop legumes, poor germination of the seeds of leguminous trees can be especially frustrating While there may be particular techniques known to some researchers for certain species, it is difficult to obtain sound guidelines for germinating seeds of leguminous tree species dependably.

The legume family has arboreal species that are numbered in the thousands. Many of the species have physically and/or physiological dormancy. Commonly the degree of dormancy is dependent on the age of the seeds. Dormancy is often confounded by loss of viability, a factor heavily dependent on the conditions of seed storage. Perhaps most seriously, the genetic heterogeneity in the majority of leguminous tree species makes it difficult to conceive of a germination procedure that will work consistently at the species level.

Tables 1 and 2 are offered as a record of the experiences in one laboratory with certain seed batches of an array of leguminous tree species. There is little guarantee that these procedures will give the same results in the hands of other researchers using different batches of seeds of the same species. It is even unlikely that the same procedures applied to the same seed batches will give the same results at a later date. These considerations not withstanding, there is value in sharing and accumulating such data from which more reliable guidelines might be derived at

some point in the future.

Materials and methods

Seeds were obtained from the Nitrogen Fixing Tree Germplasm Resource housed at the University of Hawaii NifTAL Project. Background information on the source of the seeds is presented in Table 1.

Treatments used to improve germination were: (a) snipping; (b) immersion in acid for varying periods of time; (c) immersion in hot (80 degrees C) water; or (d) no treatment. Snipping involved cutting off a small portion of the seed coat at the end of the seed opposite the embryo with nail clippers. Concentrated sulphuric acid was used in the acid immersion treatment. At the end of the immersion period, seeds plus acid were tipped into a large excess volume of sterile, distilled water at ambient temperature. Seeds were then imbibed in sterile water and germinated on water-agar in a 28°C incubator.

Results and discussion

The percentage germination of the various species is given in Table 2. Mechanical scarification by snipping or chemical scarification with concentrated sulphuric acid gave germination of more than 50% with 28 out of the 33 species listed. Only two of the accessions had germination of less than 30% and these were not scarified. Determination of the duration of immersion was largely subjective and based on seed size, shape and apparent hardness. These results suggest that if scarification, whether mechanical or chemical, is employed then satisfactory germination can be expected with many leguminous tree species. The results also suggest that at least three times the number of seeds actually needed for an experiment should be treated.

Table 1. Source of seed batches used in germination studies.

Species	Accession No.	Source	Seed Age (months)
Acacia albida	(NFT 101)	Ethiopia via Kew Gdns	>10
Acacia auriculiformis	(NFT 136)	By NifTAL from Malaysia	7
Acacia cyanophylla	(NFT 111)	Kiryat Hayim, Israel	> 9
Acacia holoserica	(NFT 106)	Brisbane, Australia	3
Acacia mangium	(NFT 171)	Brumas, Sabah, Malaysia	8
Acacia mellifera	(NFT 152)	Khartoum, Sudan	>12
Acacia nilotica	(NFT 103)	Ludhiana, Punjab, India	> 8
Acacia nubica	(NFT 154)	Khartoum, Sudan	>12
Acacia pennatula	(JR 1)	Xalapa, Mexico	17
Acacia senegal	(NFT 151)	Shambat, Sudan	>12
Acacia seyal v. seyal	(NFT 157)	Khartoum, Sudan	>12
Albizia chinensis	(NFT 338)	Manoa, Oahu, Hawaii	> 3
Albizia falcataria	(NFT 181)	Bislig, Philippines	> 7
Albizia lebbek	(NFT 328)	Paia, Maui, Hawaii	3
Albizia lebbek	(JR 2)	Cardel, Mexico	5
Albizia julibrissin	(NFT 185)	Longwood Gdns, USA	> 7
Albizia moluccana	(NFT 182)	Manoa, Oahu, Hawaii	> 7
Albizia polyphylla	(NFT 339)	Los Angeles, USA	> 3
Brachystegia spiciformis	(NFT 135)	Zimbabwe	12
Calliandra calothyrsus	(NFT 161)	Java, Indonesia	21
Cassia siamea	(NFT 321)	Puunene, Maui, Hawaii	4
Enterolobium cyclocarpum	(NFT 320)	Puunene, Maui, Hawaii	1
Enterolobium cyclocarpum	(JR 3)	Cempoala, Mexico	5
Gliricidia sepium	(JR 4)	Cempoala, Mexico	4
Julbernardia globiflora	(NFT 127)	Salisbury, Zimbabwe	12
Leucaena leucocephala	(JR 5)	Buena Vista, Mexico	4
Leucaena leucocephala	(NFT 569)	Pukalani, Maui, Hawaii	1
Pithecellobium dulce	(NFT 327)	H'poko, Maui, Hawaii	4
Pithecellobium lanceolatum	(JR 6)	Cempoala, Mexico	1
Prosopis africana	(NFT 114)	Senegal	>10
Prosopis juliflora	(NFT 116)	California, USA	>10
Prosopis tamarugo	(NFT 169)	Chile	> 9
Pscidia communis	(JR 7)	Cempoala, Mexico	4
Samanea saman	(NFT 323)	H'poko, Maui, Hawaii	4
Sesbania grandiflora	(NFT 303)	Kohala, Hawaii	5
Tamarindus indica	(NFT 120)	Townsville, Australia	> 8

> The collection date was not known. Seeds are at least as old as stated based on the known date of receipt at NifTAL

Table 2. Percentage germination of seeds of leguminous trees following treatment as specified.

Species	Accession No.	a	b	c	d
Acacia albida	(NFT 101)	79	77 (10 min)	-	-
Acacia auriculiformis	(NFT 136)	-	58 (30 min)	21	-
Acacia auriculiformis	(NFT 136)	-	70 (40 min)	-	-
Acacia cyanophylla	(NFT 111)	-	1 (10 min)	-	-
Acacia holoserica	(NFT 106)	-	45 (15 min)	-	-
Acacia mangium	(NFT 171)	-	74 (15 min)	-	-
Acacia mellifera	(NFT 152)	100	-	-	-
Acacia nilotica	(NFT 103)	31	13 (15 min)	-	-
Acacia nubica	(NFT 154)	-	100 (25 min)	-	-
Acacia pennatula	(JR 1)	-	13 (20 min)	-	-
Acacia pennatula	(JR 1)	-	73 (30 min)	-	-
Acacia pennatula	(JR 1)	-	7 (60 min)	-	-
Acacia senegal	(NFT 151)	-	-	-	7
Acacia seyal v. seyal	(NFT 157)	67	30 (10 min)	-	-
Albizia chinensis	(NFT 338)	100	-	-	-
Albizia falcataria	(NFT 181)	-	57 (30 min)	-	-
Albizia lebbek	(NFT 328)	90	-	-	-
Albizia lebbek	(JR 2)	100	-	-	-
Albizia julibrissin	(NFT 185)	90	-	-	-
Albizia moluccana	(NFT 182)	68	-	-	-
Albizia polyphylla	(NFT 339)	100	-	-	-
Brachystegia spiciformis	(NFT 135)	93	-	-	-
Calliandra calothyrsus	(NFT 161)	64	52 (15 min)	-	-
Cassia siamea	(NFT 321)	68	51	-	-
Enterolobium cyclocarpum	(NFT 320)	-	78 (30 min)	-	-
Enterolobium cyclocarpum	(JR 3)	-	58 (30 min)	-	-
Enterolobium cyclocarpum	(JR 3)	-	95 (40 min)	-	-
Gliricidia sepium	(JR 4)	30	-	-	-
Julbernardia globiflora	(NFT 127)	-	-	-	71
Leucaena leucocephala	(JR 5)	-	100 (25 min)	-	-
Leucaena leucocephala	(NFT 569)	100	-	100	-
Pithecellobium dulce	(NFT 327)	94	-	-	-
Pithecellobium lanceolatum	(JR 6)	45	-	-	-
Prosopis africana	(NFT 114)	100	-	-	-
Prosopis juliflora	(NFT 116)	33	-	-	-
Prosopis tamarugo	(NFT 169)	-	100 (20 min)	-	-
Psidia communis	(JR 7)	-	-	-	16
Samanea saman	(NFT 323)	58	-	-	-
Sesbania grandiflora	(NFT 303)	94	36 (10 min)	-	-
Tamarindus indica	(NFT 120)	93	97 (15 min)	-	-

Treatments: (a) snipping opposite end of seed from embryo;
(b) immersion in acid for stated periods of time;
(c) immersion in hot water (80 degrees C);
(d) no treatment.

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METHODS FOR ASSESSING RHIZOBIA AND VA MYCORRHIZAE FOR MULTIPURPOSE TREES.

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Introduction

Nitrogen-fixing trees potentially benefit from at least two symbiotic relationships with microorganisms. Association with rhizobia confers nitrogen fixing ability. Infection with vescicular arbuscular (VA) mycorrhizae enhances phosphorus uptake. A vigorous tree at a particular location is frequently a manifestation of an especially effective match between the tree genotype, its symbiotic partner(s), and its environment. In fact such a tree could be heavily dependent on its microsymbioses for its nutrition. Germplasm explorers need to be aware that later performance of a collected accession introduced to a new location may be below expectation unless a specific effort is made to reconstitute equally effective associations.

Introduced tree species can fail to encounter fully effective microsymbionts spontaneously in the native microflora, and/or nodulate effectively with available inoculants. Even when the trees are inoculated, the strains provided may not match the tree's specific requirements. Thus an integrated approach to germplasm exploration, selection and introduction, in which seeds, rhizobia and mycorrhizae are viewed as inseparable components of the germplasm unit is warranted.

An earlier section of this manual dealt with collection methods. This section describes established methods for selecting superior strains of Rhizobium and for using them as inoculants for trees. Methods for selection and evaluation of mycorrhizae for leguminous trees are much less developed at this time. This chapter outlines methods for determining the degree to which a leguminous tree is infected with VA mycorrhizae. For those interested

specifically in selection and inoculation methods, several references to research papers in this area are provided.

Principles of Rhizobium strain selection

> "Strain selection is performed to ensure that a legume seed inoculant contains a strain, or strains, of Rhizobium capable of forming fully effective, nitrogen-fixing nodules on the legume species for which it is recommended and in the soil and climate in which the legume is grown."

Previous publications by the author (1,2) have defined step-wise screening approaches to strain selection. Most selection procedures for crop legumes stress the matching of specific rhizobial strains with the host genotype, sometimes even at the varietal level. This approach is valid for a MPT like leucaena, but is inappropriate for most other MPTs because the seed lines are not genetically pure. Genetic diversity of planting material is just one of the features of multipurpose trees that makes it necessary to rethink some of the conventional approaches to selection of Rhizobium strains for use in inoculants.

A second complication for inoculation of MPTs is that vegetative propagation may be necessary for some species. Conventional inoculant methods involve application of rhizobia directly to the propagule or indirectly to the soil. Modifications have not been validated for use with vegetative propagation. Such validation is necessary because delay time between planting and root emergence can be much longer with vegetative propagules than in the case of seed germination. The period during which rhizobia are vulnerable to adverse factors is prolonged. There may not be survival of adequate numbers to effectively nodulate the root when it finally emerges.

Procedures which follow were used successfully to select rhizobia for forage legume introductions in acid, infertile soils of tropical Latin America (1). The principles underlying the approach apply equally well to strain selection for MPTs, and some alternative methodologies are mentioned in the text. Individual investigators can modify the techniques and improvise with equipment to suit their purposes and the facilities available to them, provided they adhere to the principles of Rhizobium strain selection stressed here.

Selection criteria

Some characteristics of strains of Rhizobium to be used as legume inoculants can be regarded as "essential" whereas others are "desirable" depending on the specific selection objective. Essential traits are:

-- ability to nodulate the MPT in the field conditions under which it is grown. Such strains are referred to as "infective." Strains of Rhizobium which are infective in the field will usually have exhibited "competitive ability" if they displaced nodulation by native strains present at the site. They will also have been "stress tolerant" if they successfully nodulated legumes in soils with excesses or deficiencies in their physical/chemical composition.

-- capacity to fix sufficient nitrogen to sustain production close to, or surpassing, the level possible if the legume were supplied with nitrogenous fertilizers. Such strains are referred to as "effective." Strains which are fully effective are usually carbon efficient and hydrogen efficient as well. The "efficiency" of a Rhizobium strain is seldom measured during strain selection and use of the term in this context should be avoided. Effectiveness is usually what is meant.

-- ability to perform satisfactorily when subjected to the component processes of commercial-scale inoculant production systems. Inoculant strains must multiply well in bulk culture and be able to mature to high populations in the carrier material.

-- able to survive well during distribution to, and use by, farmers. Strains should be tolerant to the anticipated maximum temperature that they will encounter. They must also survive well during the seed/soil inoculation procedures. Additionally, they must survive on seed in soil from the time of their application until the emerging legume radicle is susceptible to infection (usually at least seven days). Strains for MPTs will need to survive for even longer periods if they are used with vegetative propagules, and/or to cope with delayed germination.

Traits that are held to be desirable are:

-- long-term persistence is expected of strains of Rhizobium used to inoculate perennial species. Implicit in the concept of persistence is saprophytic competence, a summary term for all those traits that permit a Rhizobium strain to live as a stable member of the soil microflora, even in the absence of its legume host. This trait is particularly desirable in strains of Rhizobium used to inoculate MPTs. Persistence of strains for annual crop legumes from season to season may be considered a desirable trait in some circumstances, as it obviates the need for inoculation in subsequent years. But there may be cropping systems in which carry-over strains from a previous crop may nodulate a following crop relatively ineffectively and even out-compete effective introduced strains. This can occur in rotations of soybean with peanut and cowpea that nodulate with the cowpea miscellany.

-- fungicide or insecticide resistance may be desirable traits when normal practice is to sow legume seeds pre-treated with these substances, some of which are toxic to certain strains of Rhizobium.

Basis for strain selection

Rhizobium strains do vary widely in the characteristics listed above. Some strains nodulate some genera, or species, or varieties of legumes and not others. Among strains capable of infecting and nodulating a particular legume, there is great variation in the amount of nitrogen they fix, i.e. variation in effectiveness. There is considerable strain variation in the other listed traits as well and thus an opportunity exists to select superior strains. Unlike higher plants which can be improved through breeding and hybridization, Rhizobium improvement is currently practical only by selection from natural populations.

Need for strain selection

As will be appreciated from the following procedures, the selection of superior Rhizobium strains is a lengthy undertaking. Several years of study may be necessary to complete characterization and testing. Given that strains of Rhizobium for many legumes, including some MPTs, have already been developed at research labs around the world, it makes sense to obtain and use these, rather than initiate an extensive selection program.

Selection of rhizobia is only really justified when the specific selection objective cannot be satisfied by strains held in existing collections. Examples of circumstances which justify a strain selection program are:

-- when the legume of interest is an uncommon species for which there is no recommended inoculant strain. This is the "state-of-the-art" for the

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majority of MPTs.

-- when inoculation of the particular legume with recommended strains of *Rhizobium* under field conditions fails to give adequate nodulation and nitrogen fixation. This can occur if the legume variety is different from that with which the inoculant strain was developed, or if the soil and climatic conditions vary from those under which the inoculant was developed.

Matching rhizobia to soil type

The step-wise selection procedure given here derives a *Rhizobium* strain recommendation for legumes planted under a particular soil condition. This approach is innovative in the sense that strains of *Rhizobium* in current use as legume seed inoculants are developed for the species of legume with which they will be used, rather than the soil type in which the legume will be grown.

The need to inoculate

In the technologically advanced countries, it is normal farm practice to modify soil conditions to be suitable for a particular crop. It is not unreasonable therefore to expect a rhizobial inoculant for a legume species to perform well wherever that legume is grown. In the developing nations, however, soil amendment is minimal or not practiced at all, and crop plants are often grown under stresses of adverse soil factors that cannot be economically alleviated. For most utilizations, e.g. reforestation, MPTs will be introduced to unamended soils. It may be unreasonable to expect that a single strain of *Rhizobium* will perform equally well as an inoculant in the wide array of soil types under which its MPT host will be grown in the tropics. One reason that legume inoculation is not widely successful in developing countries is that

available inocuiants obtained from the U.S., Australia, or elsewhere do not have strains selected for, and adpated to, the extremes of soil stress encountered in the tropics (2).

There is a widely held view that strain selection and legume inoculation have little potential for improving yields of tropical legumes (including MPTs), since tropical legumes are not specific in their Rhizobium strain requirements, and because suitable rhizobia occur universally in tropical soils. Spontaneous nodulation, which is often observed in leguminous MPTs in their natural environment, creates an impression that specific inoculation is not required.

There are notable exceptions, such as soybeans and leucaena, and thus two categories of tropical legumes were recognized. The promiscuous (P) group can be nodulated by a wide array of strains of tropical rhizobia. The specific (S) group requires specific rhizobial strains for nodulation. The majority of tropical legume species were judged to belong to the P group and it has been generalized that it is unnecessary to inoculate these legumes with rhizobia, as no benefit would be expected.

The grouping of tropical legumes simply as S or P types is no longer tenable nor useful (3). Many tropical legumes previously placed in the P group are now known to form fully effective (i.e. high nitrogen-fixing) symbioses with only a few strains out of the diverse array of rhizobia that can nodulate them. Thus a distinction is drawn between this promiscuous-ineffective (PI) group of legumes and the promiscuous-effective (PE) group (2). Studies of the Rhizobium affinities of the tropical forage legumes, for example, reveal that a majority of them are in the PI group, suggesting a potential for increasing their production by providing appropriate strains of rhizobia.

The important role played by stress factors of tropical soils as modifiers of symbiotic performance is now well recognized (4). Thus tropical legumes can

and do benefit from inoculation when strains are selected specifically for the particular variety of legume being planted and for tolerance of the soil conditions in which that legume is to be grown.

Strain selection objective

No strain selection program should be undertaken without clear definition of the specific selection objective(s). The methods of selection employed may need to be modified to suit the objective. As an example the specific selection objective for which the procedures that follow were developed was "to select strains of Rhizobium able to nodulate and fix nitrogen in association with acid tolerant legume accessions being introduced to the acid, infertile soils of Latin America."

Step-wise screening strategy

Successful selection of superior rhizobia is favored if the number of strains from which the selection is made is large and diverse. The most meaningful test of Rhizobium performance is field evaluation since this is an integrated appraisal of the various traits that make up a successful inoculant strain. However, the management of field trials to select rhizobia is difficult and costly, even when the number of strains under test is small. Multi-stage screening procedures progressively eliminate undesirable strains from an initially high number of contenders to yield a relatively small number of promising strains for testing at the field level. This one way to reconcile the requirements that selection be from a diverse genetic base, and that strains also be assessed under field conditions.

It is advisable to include in the screening procedure strains of Rhizobium that originated from a diverse array of host plant germplasm and that are representative of diverse geographic regions. But some reduction

of the number of strains can be made based on what is known from other selection programs. In general, rhizobia isolated originally from the same genus, and sometimes species, as the legume for which a superior strain is being sought emerge from selection programs as the best strains for use in legume inoculants. Also, when the specific selection objective includes tolerance to a particular soil stress or climatic condition, rhizobia isolated from legumes growing under those conditions are the most likely to be rated highly in the selection process (5). Hopefully, there is a Rhizobium collection or collections of authenticated strains of known origin available to the investigator. Otherwise, a suite of strains has to be assembled. Only after checking whether likely strains are available from existing Rhizobium collections, such as the Rhizobium Germplasm Resource at NifTAL, should collection and isolation of new strains be contemplated. Pre-selection of strains with suitable background should aim to generate a cluster of 50-100 rhizobia that will feed into the first stage of the strain selection procedure.

Stage I. Screening for genetic compatibility

In this stage, strains of Rhizobium are screened for ability to nodulate the legume of interest. The test used involves a high degree of bacteriological control and is suited to handling large numbers of strains. The system most commonly used is based on growth tubes in which seedlings are raised in a solid, nutrient medium under artificial illumination. Seeds must be surface sterilized, usually with concentrated sulphuric acid, hypochlorite, or acidified mercuric chloride. Germination of MPT seeds may be problematic and some guidelines are given in Appendix I.

Seeds are pre-germinated in inverted, sterile petri dishes of water agar. When the radicles are 3-5 mm long, uniform seedlings are transferred aseptically to tubes containing agar deeps (or slants). Tubes are routinely

2.5 x 25 cm, capped with a plug of muslin-wrapped cotton wool. Aliquots of 1.0 ml of suspension of the test strains are added to each tube either at transplanting or 3-5 days later. At least three replications of each strain treatment are essential and five are preferred. Roots of seedlings should be shielded from light. Alternatively, tubes may be wrapped in aluminum foil. Two control treatments are required. In one case the plants are "inoculated" with sterile water only (uninoculated control) and in the other case they are provided with 70 ppm nitrogen as ammonium nitrate (or potassium nitrate) solution (referred to as the plus nitrogen control). Tubes are scored at intervals for the presence or absence of nodules. With many tropical legumes, tumor- or callus-like outgrowths can occur on roots of seedlings raised in growth tubes. These outgrowths occur in the presence or absence of rhizobia and are not nodules. They cannot be distinguished from nodules by eye. Plants should be harvested from tubes and checked under a binocular microscope for real nodules. "Apparent" nodules lack structural organization and leghemoglobin. Timing of the harvest varies depending on legume species but will usually be about 21-35 days after sowing.

Some investigators place significance on other data taken on plants grown in growth tubes. "Earliness to nodulation" may be of some value. It is inappropriate, however, to attribute relative nitrogen fixation effectiveness to strains based on nitrogen accumulation in plants raised under such artificial conditions. The root medium and atmospheric composition within plugged test-tubes differ from those which the plants require for optimum performance and may constrain expression of nitrogen-fixing potential.

Alternate methodologies are required for MPTs that are large-seeded and which become cramped in growth tubes. These include the use of growth pouches or "Gibson" tubes. Growth pouches are made of autoclavable plastic and have an absorbent towel insert. Seedlings germinate in a fold (or are pre-germinated

and transplanted into the fold) at the upper rim of the pouch. Roots develop within the pouch nourished by a nutrient medium, and plant tops grow in the open air. The method offers the advantage that effective nodulacion can be reliably determined, but caution in attributing relative effectiveness of strains on a pouch test basis is necessary. Modifications of the method include subdividing the pouches with heat bonding to permit a single pouch to be used for several strain treatments, or replications of the same treatment.

In the case of "Gibson" tubes, the tube contains a long agar slant that reaches to the upper rim of the tube, and are filled to the rim with liquid medium or sterile water. They are capped with aluminum foil. Radicles of pre-germinated seedlings are entered through a small orifice in the aluminum. The roots develop inside the tube and the plant tops grow outside the tube. The method offers similar advantages to those of pouches, namely that effective nodulation shows up readily. Modifications of "Gibson" tubes include omission of the liquid phase or half filling the tubes.

Obviously, if nodulation occurs in the uninoculated control treatments in Stage I, the bacteriological control has been inadequate and the experiment is invalidated.

Some texts advocate dedication of entire light rooms for the culture of plants in growth tubes. Most workers will find a low cost system of racks and portable fluorescent tubes more than adequate for their needs. Such a system is highly flexible and can be readily modified to provide lateral illumination for growth tubes or overhead illumination for pouches. The issue of light quality has been overplayed. Regular domestic fluorescent lamps have served satisfactorily in the screening procedure described here.

Stage II. Screening for nitrogen fixation effectiveness

In this stage the objective is to rank infective strains from Stage I in order of potential nitrogen fixation effectiveness with the legume species/cultivar of interest. Theoretically, in this test there should not be any factors limiting growth of the legume except nitrogen, so that full expression of each strain's nitrogen fixation effectiveness is possible. In practice it is assumed that the nutrient regime and other aspects of growth conditions are not limiting, even though there are known examples of legumes for which standard conditions are not non-limiting. Sand jar assemblies are used in this test because they permit more realistic growth conditions than tubes, pouches, etc., but retain the high degree of the bacteriological control which is still essential if valid results are to be expected.

The Leonard jar is one example of such a sand jar assembly. Watering is the most common source of contamination in *Rhizobium* strain testing in pots and in the field. Leonard-type sand jars greatly reduce the frequency of watering and are, therefore, less prone to contamination. Sand jars are easily constructed from locally available materials, but have the disadvantage that sterilizing them requires a very large autoclave.

As with growth tubes, surface sterilized pre-germinated seeds are sown in the sand jars. Four seedlings are allowed to establish and thinned later to two by snipping off the tops. Drops (standardized rate) of suspensions of strains of *Rhizobium* are added to seedlings in the jars five days after sowing (one strain per jar). Plants are harvested destructively at a time after sowing that depends on the legume species under test. Usually 60 days after sowing is appropriate.

Data taken on sand jar experiments vary from investigation to investigation and include the following:

- nodule number
- nodule dry weight and/or fresh weight
- nodule color
- nodule distribution
- total plant fresh/dry weight
- top weight (fresh/dry)
- root weight (fresh/dry)
- acetylene reduction rate
- percentage N in tissues
- total N produced

Of these, total N produced is the most meaningful integration of nitrogen fixation effectiveness over time and, as this is highly correlated with total plant dry weight, a reliable measure of relative effectiveness of strains of Rhizobium is possible with nothing more sophisticated nor costly than a common balance.

The main problem encountered with this test relates to overheating in greenhouses or growth rooms where the experiments are performed. Most of the sand jar trials observed by this author in the tropics are, in fact, selecting high temperature tolerant rhizobia at the same time! Other problems relate to the occasional failure of the irrigation from beneath which depends on capillary rise, and breakage of glass components in autoclaving and handling.

Strains are ranked on the basis of their performance in Stage II. The demarcation of effectiveness categories is somewhat subjective, but nevertheless useful. Strains are assessed relative to the uninoculated control and the plus nitrogen control and described as (in ascending order of merit)

parasitic, ineffective, partially effective, moderately effective, or fully effective.

Ordinarily about 30-50 strains would be evaluated at Stage II in Leonard jars. Three replications are essential and five are preferred. The top ten strains are chosen for further screening at Stage III.

The principal merit of Leonard jar trials is that data on the potential effectiveness of strains of Rhizobium with a particular legume tend to be upheld in independent screening trials by other investigators. Thus, researchers can exchange information that is stable and demonstrable on the nitrogen-fixing potential of strains. Pot and field trials, on the other hand, give information of the plant/Rhizobium soil interaction that may or may not be repeatable at other locations (5).

Stage III. Screening for symbiotic effectiveness under physical, chemical and biological stresses of site soils

The fully effective nitrogen fixation effectiveness expressed under Stage II conditions will not necessarily be upheld under real field conditions. Thus, before selecting a final cluster of three strains of Rhizobium for field evaluation, it is advisable to subject a larger group (ten) of potentially effective strains to some of the physical chemical and biological stresses of soils for the inoculant is being developed. This stage is particularly useful if the specific selection objective includes adaptation to a particular stress, such as soil acidity. Stage III also has a value in selection programs for "non-stress" soils. In Stage II sand jar evaluation, test strains did not have to compete against native rhizobia.

This third stage involves a pot experiment in which strains are tested with the host plant and production related to that of uninoculated control plants and nitrogen fertilized plants. Soil is collected from the plough layer

and mixed to uniformity to produce a homogeneous experimental material. Unsterilized soil is used. Soil may be amended at fertilizer rates equivalent to field practice (for methods, see ref. 6), but only the nitrogen control plants receive nitrogen (equivalent to 100 kg N/ha). Not all soils behave satisfactorily in pot experiments and other amendments may be necessary, particularly with heavier soils. The following should be considered:

-- sieving to remove large soil aggregates and stones;

-- addition of high carbon ratio residues, such as bagasse, at 1-2% (dry weight basis) to counterbalance excessive mineralization of nitrogen resulting from soil handling;

-- addition of volcanic cinder, vermiculite, or other materials to improve soil aeration and drainage.

The sowing procedure and inoculation is the same as for sand jars in Stage II. About 6-8 seedlings are planted and thinned to 2-4 plants/pot, depending on the species. Thinning is by snipping off the plant tops, rather than pulling entire plants from the soil. Pot size is optional, but 20-25 cm in diameter is usual. Six replications of each treatment are required.

Precautions against cross-contamination in this stage are essential. Watering, which in greenhouses in the tropics is needed daily, is the primary source of contamination. It can be minimized by:

-- filling pots so that the soil level is 3 cm below the pot rim.
-- watering gently to avoid splashing.
-- using grid or mesh benches instead of solid benches, so that pots can drip through onto the floor.
-- raising pots on supports (such as petri dish lids) so that there can be no

water flow on the bench surface from the emergent roots from one pot to those of another.

-- assigning watering to a single, well trained individual.

Other precautions include avoidance of overheating of the roots and nodules in pots and minimizing non-treatment effects. Pots should be set up in a randomized, complete block design but not re-randomized thereafter because of the overriding problem of contamination through handling.

As with sand jars, plant dry matter production is the most meaningful parameter to be determined and is the basis for ranking strains. The top three strains are promoted to Stage IV.

Stage IV. Single location evaluation of strains of Rhizobium and inoculation methodology under field conditions

Strains emerging from Stage III are evaluated for nodulation and nitrogen fixation under field conditions. Although the preferred measure of the response by a leguminous MPT to inoculation with the test strains of Rhizobium is total biomass production, there are many factors which, under field conditions, can prevent differences in nitrogen fixed by the strains being translated into long-term differences in yield. Therefore, field trials should include an interim harvest after only three or four months growth, i.e. before treatment differences become masked by other influences.

The trial has three basic treatments: plants inoculated with Rhizobium; plants not inoculated; and plants not inoculated but fertilized with nitrogen.

The comparison between Rhizobium strain treatments is most valid, in a scientific sense, when there are no other factors limiting plant growth. But the comparison is most realistic when the level of agronomic inputs is economically feasible and similar to that to be used in the region where the

MPT is to be grown. It is therefore best to field test rhizobia at two fertility levels, in one case aiming to eliminate all limiting factors, and in the other case adhering to the level of inputs that are "normal practice" for the region.

Experience has indicated that four replications are desirable. With three treatments at two fertility levels replicated four times, a 24 plot, randomized, complete block design results. The treatments in the first replication can be deliberately arranged to serve as a demonstration in which the treatments that are most frequently compared are located side-by-side to facilitate visual observation of treatment differences. A suitable layout that used for the International Network of Legume Inoculation Trials (6). Row spacing, planting distance, and seed rate depend on the legume in question.

Plot size will necessarily be bigger for NFT inoculation trials, but can be smaller than would be required for long-term production trials. The standard plot size and layout used in the International Network of Legume Inoculation Trials is recommended.

It is best to sow the "uninoculated" and "nitrogen fertilized" plot first. Only after the seeds in these plots have been covered are the inoculated seeds prepared for sowing in the remaining plots. This minimizes the risk of contamination of the plots that are not to receive rhizobia.

When the specific selection objective includes overcoming soil stress, the field trial at Stage IV can amalgamate the strain selection approach and other strategies for overcoming the stress. For example, several inoculation methods could be appraised for their ability to overcome the effect of acid soil stress on nodulation.

Precautions against cross contamination are of paramount importance. Common pathways of contamination are:

-- careless handling of inoculated seed at planting time.

-- use of field implements without sterilizing them between plots.

-- tramping from plot to plot (by laborers, animals, visitors, etc.)

-- run-off and other drainage problems caused by poor site selection.

The best Rhizobium/inoculation method combination is then selected and subjected to further testing in Stage V. It could be justified to produce and use legume inoculant based on Stage IV evidence, but there remains the risk that the selected strain will be a successful inoculant only in the specific soil and climatic conditions under which it is was selected. A further stage is essential to determine the range of suitability of inoculant developed for a single location in Stage IV.

Stage V. Multi-location testing of the response to inoculation with selected Rhizobium strains

A standard design developed for the International Network of Legume Inoculation Trials (INLIT) is available for those contemplating multi-location trials on the response of legumes to inoculation with selected strains of Rhizobium (6). One of the major constrains to fuller utilization of legume inoculation in the tropics is that there has not been convincing demonstration on a wide scale that production increases will result with local legume varieties under local soil and climatic conditions (2). Stage V trials can assist in deriving the data necessary for predicting more reliably whether a legume will respond to inoculation or not.

Stage V trials can be used to characterize selected strains for competition and persistence if the inoculant strain is "marked" serologically or with antibiotic resistance. Such strains of Rhizobium can be detected in the nodule population and their ability to compete against strains native to the site determined. These strains can also be detected, if present, in the soil in following seasons, or in the nodule populations of subsequent legume crops sown uninoculated. The International Network of Legume Inoculation Trials (INLIT) coordinated by the University of Hawaii NifTAL Project are available for 17 agriculturally important tropical legumes including the MPT Leucaena leucocephala. Inoculants developed for INLIT each contain three serologically distinct, effective strains of Rhizobium from diverse geographic and host germplasm backgrounds (6). Each INLIT is potentially an ecological study of the relative performance of the three exotic strains between themselves and in competition with indigenous soil strains. The INLIT is also a long-term persistence trial. A mixed inoculant of 6 marked strains suitable for use with most leguminous MPTs (7) is also offered to researchers in the tropics through NifTAL's INLIT program.

Pre-screening tests for special cases

For some specific selection objectives, the development of rapid screening procedures may reduce the time taken to develop a reliable inoculant strain, or may greatly increase the likelihood of successful inoculant strains emerging from the step-wise screening previously described. For example, in the case of selection of rhizobia for acid, infertile soils, a laboratory prescreening that preceded the Stage I test greatly increased the range and numbers of strains that could be addressed (8). It eliminated effective strains predestined to fail in the field but which would have passed through Stages I, II, and possibly III consuming time and resources. The prescreening test was based on

the reasonable assumption that for a strain of Rhizobium to be a successful inoculant for legumes grown in acid soils, ability to multiply well at low pH is an essential trait. Synthetic media were developed that tested ability to multiply at low pH, and only those strains passing the test were fed into the step-wise screening program. I''estigators may find it useful to adopt rapid pre-screening steps for their o objective(s).

A cautionary note about screening

As with any screening program, there is always the risk that discarded materials that could not be accommodated in the later stages would have performed well in the field. In the procedure described, the stage-to-stage transition that is most problematic is that from Stage II to Stage III. Rankings of strains in sand jars do not necessarily hold up when subjected to the stresses of site soils. Although 10 fully effective strains are passed across from II to III, examples have occurred in which as few as three of the strains could nodulate at Stage III and only one of these was effective (1).

When dealing with uncommon legume species (most MPTs fall in this category) an investigator should be concerned about whether the routine media used in Stage I and Stage II are, in fact, non-limiting on growth of the legume plant so that Rhizobium characters can be expressed. As an example of this, it was found that Stylosanthes capitata, a legume with high tolerance to soil acidity factors and native only to acid soil regions of South America, could not be nodulated by any one of more than 100 Stylosanthes isolates (including many specifically from S. capitata) tested at stage I. Nor would S. capitata grow in Stage I. Only when the growth medium was acidified to a pH lower than 5.0 and the Ca and P levels lowered ten-fold would the plant nodulate and grow.

Even though the screening procedure is lengthy, attempts to short-cut the sequence are ill-advised. Recommendation of strains of Rhizobium for

MPT inoculation without first performing field trials similar to those described in Stage IV and Stage V is risky in the face of accumulating data that show that site variation in performance of selected strains is common (5).

Inoculation technology

The underlying objective of inoculation technology is to place sufficiently high numbers of preselected strains of rhizobia in the vicinity of the emerging root that they have a competitive advantage over any indigenous soil strains with lesser nitrogen fixing ability in the formation of root-nodules. This involves:

-- selection of strains of rhizobia that are compatible and effective nitrogen fixers with particular legumes;

-- multiplying selected strains to high population densities in bulk cultures;

-- incorporating the liquid rhizobial cultures into a carrier material (usually finely milled peat) for packaging and distribution; and

-- coating the seeds of legumes with the carrier or implanting the soil with the inoculant directly into the seed drill.

Production methods for legume inoculants will not be described here, as this is generally left to specialists. Recently however, several simplified, low cost techniques for producing inoculants have become available, making local small scale production feasible (2,9). Assistance in this area is available through NifTAL.

Differing opinions on strain composition of inoculants

There are at least three opinions about the best approach on inoculant

strain composition:

-- an inoculant should have a single, highly effective strain appropriate for individual species (this results in numerous inoculants);

-- inoculants should have a single "wide-spectrum" strain that varies from good to excellent in nitrogen fixation with a range of legumes;

-- or that inoculants have several strains, each being the best strain for each host species for which the inoculant is recommended.

There may be a conflict between the option that would be chosen for commercial expediency and that which is scientifically excellent. In Australia "wide-spectrum" strains are used when these are available, but there is increasing use of specialized inoculants with specific strains for individual hosts. Despite research findings which suggest that multi-strain inoculant should be avoided, because of possible antagonistic and competitive effects in culture and the likelihood of competition in nodule formation from the less effective strains, this is the approach used successfully by the U.S. inoculant industry.

Given the number of leguminous MPT species being addressed (an expert group was unable to reduce a priority list to less than 44 species), and given also that inoculant for these is needed even before development of specialized inoculants can been completed, NifTAL advocates routine use of a multi-strain inoculant incorporating wide-stpectrum, fast- and slow-growing rhizobia. Results to date with this inoculant vindicate this approach (9).

Inoculation methods

The first attempts at inoculation involved the transfer of soil from one

field to the next, but with the isolation of the organisms responsible for nodule formation, artificial cultures soon replaced the laborious soil transfer technique.

The most commonly used inoculation technique is to treat seed just before sowing either with a dust or with a slurry in water or adhesive solution. Adhesives such as gum arabic and substituted celluloses not only ensure that all the inoculum adheres to the seed surface but also provides a more favorable environment for survival of the inoculant. Pelleting of inoculated seed with finely ground coating materials such as lime, bentonite, rock phosphate and even bauxite have been used to protect rhizobia during their time on the seed coat.

An alternative to pelleting and preinoculation in recent years has been the use of concentrated liquid or solid granular peat culture. These are sprayed or drilled directly into the soil with the seed during planting. Suspensions of rhizobia either as reconstituted frozen concentrates or suspensions of peat inoculant can be applied with conventional equipment. Similarly, granulated peat inoculants can be drilled in from separate hoppers on the drilling equipment. These methods have been especially successful for introducing inoculant strains into situations where there are large populations of competing, naturally occurring soil rhizobia or in cases of adverse conditions such as hot-dry soils and where insecticide or fungicide seed treatment precludes direct seed inoculation. Solid inoculant, also known as granular or "soil implant" inoculant, is appropriate for use at the time of transplanting MPT seedlings to their final sites. Liquid inoculants are the best form for seedlings being raised under nursery conditions.

Measuring the nitrogen fixed by MPTs

"How much nitrogen/ha/year does the species fix?" is a question asked frequently by researchers involved with legumes. This author believes firmly that it is so difficult to measure nitrogen fixation by a perennial species under field conditions, and that the answer obtained is of so little real value to those concerned with tree production, that there is little need to be preoccupied with quantifying nitrogen fixation by MPTs.

It is very important for a MPT researcher to know that he has optimized the opportunity for nitrogen fixation by providing seedlings, if necessary, with the correct Rhizobium. It is much less important to know how much nitrogen is ultimately fixed. Thus, total nitrogen fixed is primarily a datum of academic interest.

It is sometimes misunderstood that a nitrogen fixation value is needed for choosing whether to plant nitrogen-fixing or non-fixing trees. This choice is better supported by determining the nitrogen application rate required for the non-nitrogen fixer to attain productivity equivalent to the nitrogen fixing species. This does not involve measuring nitrogen fixation at all.

Methods such as acetylene reduction and the use of isotopic nitrogen are not readily applicable to field studies with perennial species and are unacceptably imprecise for studies with deep rooting trees (10). Approaches such as are used by ecologists to determine nitrogen balances in overall soil, plant, atmosphere systems are perhaps the only valid way to measure nitrogen fixation in MPTs. Few production oriented tree researchers are in a position to accomplish the major undertaking which this involves.

Vesicular arbuscular mycorrhizal technology

Although there are parallels between rhizobial and mycorrhizal technologies, neither strain selection methods nor inoculation practices for

VA mycorrhizae are well established at this time. It is known that:

-- there is variation in the symbiotic value of different VA mycorrhizae;
-- there is a degree of host:mycorrhiza specificity;
-- VA mycorrhizae are absent from some soils;

But these observations tend to be the exception, rather than the rule, and are not a strong basis for a VA mycorrhizal inoculation technology.

MPT researchers should be on the look out for instances when their trees do not have VA mycorrhiza and only then contemplate remedial inoculation. This section provides a method used at NifTAL for determining the extent of spontaneous mycorrhizal infection of MPTs.

<u>Sampling and staining roots for mycorrhizal observations</u>

Fine, non-lignified roots are rinsed of soil debri and cut into 1.0 cm segments. These are immersed in potassium hydroxide (10%) at $90^{o}C$ in a water bath for 2-2.5 hours. Further bleaching is accomplished with a 20 minute immersion in alkaline hydrogen peroxide solution (30 ml of 30% peroxide + 5 ml household ammonia + 165 ml water). The root segments are then rinsed three times in tapwater. After acidifying for 3 minutes in 1% hydrochloric acid, the roots are stained for 10 minutes in lactophenol with trypan blue at $90^{o}C$. Excess stain is drained off and the roots are rinsed twice in tapwater. If additional destaining appears necessary, the roots are rinsed in lactophenol. The roots are ready for mounting at this stage.

It is customary to squash the root portion under a cover slip and to observe at about x20 magnification. Hyphae appear blue and vescicules may be seen in cells. Arbuscules may also be observed in some cells but are not always present.

Determining the percentage infection is only a semi-quantitative estimate, but does serve to distinguish between those species that are heavily mycorrhizal and those which are only sparsely infected. By convention, the "percentage infection" is the proportion of examined root samples that are found to be mycorrhizal. Obviously, much depends on the adequacy of the sample on which the observations are made.

Some observations on VA mycorrhizal infection of MPTs in Hawaii

Mycorrhizal infection of many MPTs occurs spontaneously in field soils in Hawaii. Thirty species of NFT were sown in Hamakuapoko soil (Typic Haplustoll, ph 6.9) on the Island of Maui. Naturalized vegetation at the site includes spiny amaranth (Amaranthus spinosa), some wild Cruciferae, and the legumes Indigofera fructicosa and Leucaena leucocephala. All but one of the introduced species were observed to be heavily infested with VA mycorrhizae by 12-16 weeks after planting (Table 1). This suggests that specific inoculation of NFT seeds with VA mycorrhizae may be unnecessary.

Further research is necessary to determine whether other species are readily infected with native VA mycorrhizae and whether VA mycorrhizae are ubiquitous in tropical soils.

Research to compare VA mycorrhizal infection of four MPTs (Parkia roxburghii, Acacia farnesiana, A. nilotica, and A. senegal) grown in soil of widely differing pH revealed that infection was greatest in high pH (8.5) soils and was absent from all species in soil from a low pH (4.5) site.

None of the above considerations precludes the possibility that at some point in the future, mycorrhizal inoculant technology might emerge based on displacement of relatively ineffective native strains by selected strains that are more highly effective phosphorus absorbers. But for the present, inoculation of NFTs with mycorrhizae seems unnecessary. This is perhaps just

as well because inability to raise VA mycorrhizae in the absence of a host plant remains a serious obstacle to large-scale production of VA mycorrhizal inoculants.

Table 1. Observations on presence or absence of nodules and the degree of VA mycorrhizal infection on roots of leguminous trees introduced to Hamakuapoko soil.

NFT No.	Species	Nodulation	VA Mycorrhizal infection
101	Acacia albida	yes	90 %
106	Acacia holoserica	yes	42 %
171	Acacia mangium	yes	80 %
152	Acacia mellifera	yes	76 %
103	Acacia nilotica	yes	91 %
154	Acacia nubica	yes	88 %
157	Acacia seyal var. seyal	yes	99 %
338	Albizia chinensis	yes	96 %
181	Albizia falcataria	yes	94 %
185	Albizia julibrissin	yes	91 %
182	Albizia moluccanna	yes	97 %
161	Calliandra calothyrsus	yes	96 %
321	Cassia siamea	no	100 %
320	Enterolobium cyclocarpum	yes	98 %
127	Julbernardia globiflora	no	28 %
569	Leucaena leucocephala	yes	95 %
114	Prosopis africana	yes	90 %
116	Prosopis juliflora	yes	94 %
323	Samanea saman	yes	100 %
303	Sesbania grandiflora	yes	86 %
120	Tamarindus indica	no	98 %

(from Halliday and Nakao, 1982)

It has been shown that leucaena seedlings raised under nursery conditions did not become infected spontaneously in a peat moss/vermiculite rooting medium. The medium had not been sterilized, but it is presumed that the source materials were largely free of mycorrhizal spores. Following transplanting to Hamakuapoko field soil, seedlings became progressively infected with VA mycorrhizae and after 8 weeks attained a level of infection (95%) typical of field grown leucaena (Table 2).

Table 2. VA Mycorrhizal infection of *Leucaena leucocephala* established by direct seeding or by transplanting. (Data of P. Nakao, unpublished)

Plant age (days)	VA Mycorrhizal infection (as percentage)			
	direct seeded		transplanted	
21	51	in field	0	nursery
49	74		0	
56	82		0	
63	95	in field	2	in field
70	>95		43	
84	>95		61	
112	>95		95	

-- nursery plants raised in dibbling tubes in a non-sterile peat moss-vermiculite mixture (3:5 ratio by volume) and transplanted to the field on day 60.

-- Typic Haplustoll, pH 6.9, Hamakuapoko, Maui, Hawaii.

Appendix 1.

TECHNICAL NOTE ON THE GERMINATION OF LEGUMINOUS TREE SEEDS

Summary

Seeds of 33 leguminous tree species were tested for germination following mechanical or chemical scarification. The treatments gave germination of over 50% for 28 of the species. Mechanical or chemical scarification of about three times the number of seeds needed for an experiment with leguminous tree species is recommended as a rule of thumb when the germination rate of the seeds is in doubt.

Introduction

An ability to germinate seeds of leguminous trees reliably is an essential prerequisite for systematic research with this class of plants. For researchers more accustomed to dealing with crop legumes, poor germination of the seeds of leguminous trees can be especially frustrating. While there may be particular techniques known to some researchers for certain species, it is difficult to obtain sound guidelines for germinating seeds of leguminous tree species dependably.

The legume family has arboreal species that are numbered in the thousands. Many of the species have physical and/or physiological dormancy. Commonly the degree of dormancy is dependent on the age of the seeds. Dormancy is often confounded by loss of viability, a factor heavily dependent on the conditions of seed storage. Perhaps most seriously, the genetic heterogeneity in the majority of leguminous tree species makes it difficult to conceive of a germination procedure that will work consistently at the species level.

Tables 1 and 2 are offered as a record of the experiences in one laboratory with certain seed batches of an array of leguminous tree species. There is little guarantee that these procedures will give the same results in

the hands of other researchers using different batches of seeds of the same species. It is even unlikely that the same procedures applied to the same seed batches will give the same results at a later date. These considerations not withstanding, there is value in sharing and accumulating such data from which more reliable guidelines might be derived at some point in the future.

Materials and methods

Seeds were obtained from the Nitrogen Fixing Tree Germplasm Resource housed at the University of Hawaii NifTAL Project. Background information on the source of the seeds is presented in Table 1.

Treatments used to improve germination were: (a) snipping; (b) immersion in acid for varying periods of time; (c) immersion in hot (80 degrees C) water; or (d) no treatment. Snipping involved cutting off a small portion of the seed coat at the end of the seed opposite the embryo with nail clippers. Concentrated sulphuric acid was used in the acid immersion treatment. At the end of the immersion period, seeds plus acid were tipped into a large excess volume of sterile, distilled water at ambient temperature. Seeds were then imbibed in sterile water and germinated on water agar in a 28 ^{o}C incubator.

Results and discussion

The percentage germination of the various species is given in Table 2. Mechanical scarification by snipping or chemical scarification with concentrated sulphuric acid gave germination of more than 50% with 28 out of the 33 species listed. Only two of the accessions had germination of less than 30% and these were not scarified. Determination of the duration of immersion was largely subjective and based on seed size, shape and apparent hardness. These results suggest that if scarification, whether mechanical or chemical, is employed then satisfactory germination can be expected with many leguminous

tree species. The results also suggest that at least three times the number of seeds actually needed for an experiment should be treated.

Table 1. Source of seed batches used in germination studies.

Species	Accession No.	Source	Seed Age (months)
Acacia albida	(NFT 101)	Ethiopia via Kew Gdns	>10
Acacia auriculiformis	(NFT 136)	By NifTAL from Malaysia	7
Acacia cyanophylla	(NFT 111)	Kiryat Hayim, Israel	> 9
Acacia holoserica	(NFT 106)	Brisbane, Australia	3
Acacia mangium	(NFT 171)	Brumas, Sabah, Malaysia	8
Acacia mellifera	(NFT 152)	Khartoum, Sudan	>12
Acacia nilotica	(NFT 103)	Ludhiana, Punjab, India	> 8
Acacia nubica	(NFT 154)	Khartoum, Sudan	>12
Acacia pennatula	(JR 1)	Xalapa, Mexico	17
Acacia senegal	(NFT 151)	Shambat, Sudan	>12
Acacia seyal v. seyal	(NFT 157)	Khartoum, Sudan	>12
Albizia chinensis	(NFT 338)	Manoa, Oahu, Hawaii	> 3
Albizia falcataria	(NFT 181)	Bislig, Philippines	> 7
Albizia lebbek	(NFT 328)	Paia, Maui, Hawaii	3
Albizia lebbek	(JR 2)	Cardel, Mexico	5
Albizia julibrissin	(NFT 185)	Longwood Gdns, USA	> 7
Albizia moluccana	(NFT 182)	Manoa, Oahu, Hawaii	> 7
Albizia polyphylla	(NFT 339)	Los Angeles, USA	> 3
Brachystegia spiciformis	(NFT 135)	Zimbabwe	12
Calliandra calothyrsus	(NFT 161)	Java, Indonesia	21
Cassia siamea	(NFT 321)	Puunene, Maui, Hawaii	4
Enterolobium cyclocarpum	(NFT 320)	Puunene, Maui, Hawaii	1
Enterolobium cyclocarpum	(JR 3)	Cempoala, Mexico	5
Gliricidia sepium	(JR 4)	Cempoala, Mexico	4
Julbernardia globiflora	(NFT 127)	Salisbury, Zimbabwe	12
Leucaena leucocephala	(JR 5)	Buena Vista, Mexico	4
Leucaena leucocephala	(NFT 569)	Pukalani, Maui, Hawaii	1
Pithecellobium dulce	(NFT 327)	H'poko, Maui, Hawaii	4
Pithecellobium lanceolatum	(JR 6)	Cempoala, Mexico	1
Prosopis africana	(NFT 114)	Senegal	>10
Prosopis juliflora	(NFT 116)	California, USA	>10
Prosopis tamarugo	(NFT 169)	Chile	> 9
Pscidia communis	(JR 7)	Cempoala, Mexico	4
Samanea saman	(NFT 323)	H'poko, Maui, Hawaii	4
Sesbania grandiflora	(NFT 303)	Kohala, Hawaii	5
Tamarindus indica	(NFT 120)	Townsville, Australia	> 8

> The collection date was not known. Seeds are at least as old as stated based on the known date of receipt at NifTAL

Table 2. Percentage germination of seeds of leguminous trees following treatment as specified.

Species	Accession No.	Treatments a	b	c	d
Acacia albida	(NFT 101)	79	77 (10 min)	-	-
Acacia auriculiformis	(NFT 136)	-	58 (30 min)	21	-
Acacia auriculiformis	(NFT 136)	-	70 (40 min)	-	-
Acacia cyanophylla	(NFT 111)	-	1 (10 min)	-	-
Acacia holoserica	(NFT 106)	-	45 (15 min)	-	-
Acacia mangium	(NFT 171)	-	74 (15 min)	-	-
Acacia mellifera	(NFT 152)	100	-	-	-
Acacia nilotica	(NFT 103)	31	13 (15 min)	-	-
Acacia nubica	(NFT 154)	-	100 (25 min)	-	-
Acacia pennatula	(JR 1)	-	13 (20 min)	-	-
Acacia pennatula	(JR 1)	-	79 (30 min)	-	-
Acacia pennatula	(JR 1)	-	7 (60 min)	-	-
Acacia senegal	(NFT 151)	-	-	-	7
Acacia seyal v. seyal	(NFT 157)	67	30 (10 min)	-	-
Albizia chinensis	(NFT 338)	100	-	-	-
Albizia falcataria	(NFT 181)	-	57 (30 min)	-	-
Albizia lebbek	(NFT 328)	90	-	-	-
Albizia lebbek	(JR 2)	100	-	-	-
Albizia julibrissin	(NFT 185)	90	-	-	-
Albizia moluccana	(NFT 182)	68	-	-	-
Albizia polyphylla	(NFT 339)	100	-	-	-
Brachystegia spiciformis	(NFT 135)	93	-	-	-
Calliandra calothyrsus	(NFT 161)	64	52 (15 min)	-	-
Cassia siamea	(NFT 321)	68	51	-	-
Enterolobium cyclocarpum	(NFT 320)	-	78 (30 min)	-	-
Enterolobium cyclocarpum	(JR 3)	-	58 (30 min)	-	-
Enterolobium cyclocarpum	(JR 3)	-	95 (40 min)	-	-
Gliricidia sepium	(JR 4)	30	-	-	-
Julbernardia globiflora	(NFT 127)	-	-	-	71
Leucaena leucocephala	(JR 5)	-	100 (25 min)	-	-
Leucaena leucocephala	(NFT 569)	100	-	100	-
Pithecellobium dulce	(NFT 327)	94	-	-	-
Pithecellobium lanceolatum	(JR 6)	45	-	-	-
Prosopis africana	(NFT 114)	100	-	-	-
Prosopis juliflora	(NFT 116)	33	-	-	-
Prosopis tamarugo	(NFT 169)	-	100 (20 min)	-	-
Psidia communis	(JR 7)	-	-	-	16
Samanea saman	(NFT 323)	58	-	-	-
Sesbania grandiflora	(NFT 303)	94	36 (10 min)	-	-
Tamarindus indica	(NFT 120)	93	97 (15 min)	-	-

Treatments:
(a) snipping opposite end of seed from embryo;
(b) immersion in acid for stated periods of time;
(c) immersion in hot water (80 degrees C);
(d) no treatment.

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SECTION FIVE

PART 5C

Herbicides for MPT's

PART 5C

CONTENTS

PREFACE

Many agroforestry landuse systems in the tropics involve the use of a low level of inputs and herbicides are unlikely to feature prominently for the time being. On research stations, however, chemical weed control may well offer an efficient and cost-effective alternative to manual and mechanized methods.

At present there is relatively little information about the use of herbicides with many of the wide range of multipurpose tree species that show promise - including the leguminous "fast-growing nitrogen-fixing " trees. Using placed contact herbicides (e.g. paraquat) or contact/translocated ones (e.g. glyphosate) may pose few problems - as long as the herbicide is not sprayed on to young stems that still retain a photosynthesising cortex - but the degree of selectivity of soil acting herbicides needs to be carefully explored.

This Part contains one paper that provides information and we hope that readers will send in the results of their experiences with weed control methods in general for inclusion in future revisions.

Some references and information on where to obtain more advice is included at the end.

P.A. Huxley
Jan. 1984

Evaluation of herbicides for use in transplanting *Leucaena* and *Prosopis* on semi-arid lands without irrigation

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Abstract

The herbicides oxyfluoren (Goal), oryzalin (Surflan) alachlor (Lasso), metolachlor (Dual) and naproamide (Devrinol) were examined at 2 rates for use in transplanting operations with *Prosopis* and *Leucaena*. The herbicides were evaluated in a season in which only 150 mm of rainfall occurred 120 days after transplanting. The greatest biomass production of *Leucaena* and *Prosopis* was obtained with oryzalin at 2.8 kg a.i./ha. Oryzalin increased the biomass production over non-treated controls by 4 to 5 fold for *Prosopis* and *Leucaena*. Oryzalin was second to naproamide in grass control and second to oxyfluoren in forb control. Oxyfluoren at 1.12 kg a.i./ha provided the best forb control (but the 4th best grass control) and the second greatest biomass production. Oryzalin increased the survival of *Leucaena* and *Prosopis* in the control from 70 to 89 and 80 to 94% respectively.

INTRODUCTION

Fast growing nitrogen-fixing trees of the genera *Prosopis* and *Leucaena* show potential for fuelwood and forage production in semi-arid lands (Brewbaker and Hutton, 1979; Felker *et al.*, 1983). Previous reports have identified promising genetic material from *Prosopis* that produced 29 dry T/ha in 2 yrs with 600 mm annual water input when experiencing 42°C daily maximum temperatures (Felker *et al.*, 1983). However these studies were conducted on experimental farms where irrigation was available for use in transplant and where the weed competition was reduced through years of weed control efforts. The 30 million hectares on which *Prosopis* currently occurs in the United States does not have water available for irrigation at transplant. Nearly all the area currently occupied by mesquite is in a mixed grass/brush vegetation type with a large and diverse weed seed reservoir. This paper presents results of an effort to develop practical management techniques for promising genetic strains of *Prosopis* and *Leucaena* on previously uncultivated semi-arid lands.

Due to limited moisture availability, control of weeds during the initial growth stages of newly transplanted seedlings will be important. Both mechanical and chemical weed control will probably be required in plantations

designed to produce biomass at a price competitive with coal on an energy basis. However, this paper only reports on chemical methods for weed control.

Nitrofen (TOK) and alachlor have been recommended for use in Leucaena (Brewbaker and Hutton, 1979). However, EPA has withdrawn nitrofen from the market because of health hazards. Oxyfluoren (Goal) has been recommended by Rohm and Haas as a substitute for nitrofen. Brewbaker (pers. comm.) has found that oryzalin (Surflan) was also a useful pre-emergence herbicide for Leucaena.

Simazine has been safely used on Prosopis 3 months after transplant (Felker et al., 1981). However when used with an irrigation at transplant on a sandy Arizona soil it caused approximately 50% mortality to Prosopis seedlings (Felker unpublish. obs.). Trifluralin (Treflan) was used in Kingsville Texas at 1.38 kg/ha a.i., and gave inadequate weed control in an unusually high rainfall year. The major weeds in that planting were johnsongrass (Sorghum halepense), prickly mallow (Sida spinosa), sunflowers (Helianthus annuus), nutsedge (Cyperus esculentus and C. rotundus), silverleaf nightshade (Solanum elaeagnifolium) and bermuda grass (Cynodon dactylon).

In this study five pre-emergence herbicides were compared to a non-treated unweeded control plot. Percent weed cover was estimated 45, 75, and 105 days after transplant. The dry biomass of the trees in the various herbicide treatments were compared 110 days after

transplant. Previously described regression equations were used to predict dry biomass from stem diameter measurements.

Herbicides were chosen primarily for use during the first 90 days following transplant. Simazine and similar inexpensive long residual herbicides such as diuron (Karmex) and bromacil (Hyvar) can be safely used 90 days after transplant. However as noted earlier simazine caused a high mortality when used at transplant with an irrigation. Due to the long term nature of tree plantings, carry over to the next crop is not a problem as in annual crop rotations. Therefore chemicals with the longest residual possible are desirable. Thus herbicides were selected primarily for low phytoxicity to newly transplanted seedlings and secondarily for wide spectrum weed control.

Alachlor (Lasso) and oryzalin (Surflan) were included at the recommendation of J. L. Brewbaker for weed control in Leucaena. Metolachlor (Dual) was included because the previous unusually high rainfall season had much nutsedge (Cyperus spp.). Naproamide (Devrinol) was included because of its long residual and broad spectrum activity. Oxyfluoren (Goal) was included because of its broad leaf control and usefulness in other tree planting operations (Heilman pers. comm.). Oxadiazon (Ronstar) was excluded because of cost considerations.

Materials and Methods

Mesquite (*Prosopis alba* 0166) and leucaena (*Leucaena leucocephala* K8) were examined with 5 herbicides at two rates, and an unweeded check plot in a randomized complete block design. Three replicates were used. Mesquite and leucaena were planted in alternate rows 1.5 m apart. Trees were planted 1 m apart in the row. Three rows containing 4 trees of leucaena and mesquite were used per replicate. A low and a high rate for each herbicide was used based upon the manufacturers recommendation. THe low and high rates of the herbicides were as follows; naproamide - 1.12 and 2.24 kg a.i./ha, alachlor - 2.24 and 4.48 kg a.i./ha, metolachlor - 1.40 and 2.8 kg a.i./ha, oxyfluoren - 0.56 and 1.12 kg a.i./ha and oryzalin 1.40 and 2.8 kg a.i./ha.

The plot was disked the winter prior to planting as necessary to control weeds and provide good penetration of winter rains. Herbicides were applied with a tractor mounted PTO driven boomsprayer. All the herbicides were incorporated with a disk, except for Goal for which incorporation is not desirable. Three-month-old seedlings were transplanted in 3.8 x 3.8 x 38 cm cardboard plant bands. The cardboard containers were not removed prior to transplant. The seedlings were inoculated with a rhizobial strain specific for mesquite or leucaena. A tree planter, modified from conventional forest or horticultural planters to plant seedlings 40 cm deep, was used to plant the

seedlings on 14 April 1982. The planter was pulled by an 85 hp John Deere 4 wheel drive tractor. The seedlings were side dressed with liquid 10-34-0 fertilizer at the rate of 60 kg P_2O_5 per hectare during transplant. At the time of planting no weeds were present except for disked bermuda grass in replicate one.

Two major soil types occurred in this plot, one was a fine-loamy, mixed, hyperthermic udic argiustalf, and the other a fine-loamy, mixed, hypothermic, typic ochraqualf.

A chickenwire fence 60 cm tall with 5 cm diameter holes was placed around the plots. This fence eliminated rabbit browse to Prosopis which was severe in non-fenced areas.

An analyses of the weed cover was conducted at monthly intervals after planting. Because the tree planter went through the soil (at a depth of 50 cm) after herbicide incorporation, the weed cover was examined in the row and between the rows. In each replicate three 0.5 x 0.5 m quadrats were systematically located; (3) between the rows, (3) in the mesquite rows and (3) in the leucaena rows (a total of 9 quadrats per replicate).

Basal diameters of all the transplanted trees were measured 110 days after transplant on 5 Aug 1982. Previously described regression equations (Felker et al., 1982) were used to convert basal diameters to dry weight. An analyses of variance was conducted on the calculated biomass of the surviving trees and on percentage survival.

Results

One of the most important considerations in screening herbicides is that they produce minimal toxic side effects. Phytotoxicity can result in both stunted growth and increased seedling mortality. Percentage survival was measured in these trials to check for herbicide induced seedling mortality.

As can be seen in Table 1 all the herbicides examined gave increased survival over the non-treated control. Leucaena and Prosopis had seedling survivals in the non-herbicide treated control plot of 70 and 80% respectively despite the fact that the 110 days following transplant had frequent 35°C temperatures and only 150 mm rainfall. Significant differences in survival did not occur among the treatments. However as a whole the treated plots had significantly higher survival than the control. The survival for Leucaena and Prosopis was 87% and 94% respectively in the highest biomass yielding treatment (Oryzalin 2X) indicating very little problem with phytotoxic side effects. The higher survival in the herbicide treated plots probably can be attributed to decreased moisture stress.

Forty-five days after transplanting the grass cover was less than 2% (Table 2) and the forb cover was less than 1% (Table 3). During this period the lowest grass cover occurred in the alachlor treatment and the lowest forb cover occurred in the oxyfluoren and oryzalin treatments. During

this period the significant differences did not occur between individual herbicide treatments for forb or grass cover. However collectively the treatments were significantly different from the control. At the 75 day evaluation the alachlor grass control activity was greatly diminished. Oryzalin, naproamide, and metolachlor had the greatest grass control activity at both 75 and 105 days. The greatest forb control was provided by oxyfluoren, oryzalin, and metolachlor in that order. Naproamide had the greatest grass control but lacked the combination of grass and forb control provided by oryzalin or metolachlor. In almost all cases the 2X rates provided more control than the 1X rate but in only a few cases were these differences significantly different at the 5% level.

An analyses of the herbicide treatments on the percent cover of individual weed species is presented in Table 4. Weed species that had greater than 1% cover are listed. The statistical significance of herbicide effects on the percent cover of individual weed species was examined with Tukey's HSD test. The grass species with the greatest percent cover, Digitaria bicornis (crabgrass) was significantly different from the control in all herbicide treatments. However no herbicides gave significantly better crabgrass control than any other. Most herbicides behaved similarly. Cyperus rotundus (nutsedge) was the only species in which two chemicals were significantly different from each other. Metolachlor 2X gave significantly better control of nutsedge

than either oryzalin or oxyfluoren 2X. We suspect the increased nutsedge cover in the oryzalin and oxyfluoren treatments is the result of less competition from other weed species. Metolachlor and oryzalin were complimentary in their control of weed species and a metolachlor plus oryzalin mixture should provide excellent grass control and good forb control.

In our 12 ha adjacent field plots Solanum elaeagnifolium (silverleaf nightshade) is the forb controlled with most difficulty. In the trial reported here none of the treatments were significantly different from the control although oryzalin 2X had 5 fold lower percent cover than the control. Fortunately directed post-emergence control of silverleaf nightshade is possible with 2, 4 DB.

This pattern of percent weed cover is reflected in the biomass production in Table 5. Oryzalin at the 2X rate provided the best combination of grass and forb cover and the greatest biomass production for both Leucaena and Prosopis. Surprisingly oxyfluoren at the 2X rate provided the second best biomass production even though it provided less grass control than metolachlor, oryzalin, or naproamide. Evidently, the biomass production achieved by oxyfluoren is attributable to its control of forbs.

In 1981 the costs of the 2X herbicide rates in US dollars per hectare were; naproamide $179, oryzalin $77, oxyfluoren $73, alachlor $44 and metolachlor $36. Thus the

combination of the oryzalin 1X rate and either the metolachlor 2X rate or the oxyfluoren 1X rate would have the same approximate cost as the oryzalin 2X rate. These combinations should provide better grass control than oryzalin or oxyfluoren alone while providing reasonably good forb control.

With only 150 mm rainfall during the 120 day period following transplanting, this trial represents an unusually dry season. We would expect similar results in similar dry seasons, but possibly considerably different results in a normal or wet season.

Discussion

This manuscript reports some of the first work for weed control for leguminous tree transplanting operations in semi-arid regions. Chemical weed control methods can be useful as they increase percentage survival by approximately 20% (from 70-89% for *Leucaena* and from 80-94% for *Prosopis*) and as they increase biomass production by four to five fold. The high survivals obtained during this drought period demonstrates that seedlings can be successfully transplanted in semi-arid regions without supplemental irrigation.

This work has implications for those who wish to maintain *Prosopis* free from rangelands. Practices such as nitrogen fertilization which stimulate grass and forb cover should greatly hinder the survival and growth of *Prosopis* and *Leucaena*. In contrast intensive grazing practices which

remove most grasses and forbs would essentially consist of weeding the Prosopis and should increase Prosopis survival and growth.

Of the herbicides examined here alachlor is too short lived, and naproamide is too expensive for the control it provides. Oryzalin, oxyfluoren, and metolachlor in that order offer the greatest promise. Combinations of these herbicides, in addition to mechanical weed control methods, should provide reasonable weed control on semi-arid sites until multi-year evaluations can be carried out.

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Table 1. Effect of herbicide treatment on *Leucaena* and *Prosopis* survival.

Herbicide	Rate	Survival %	
		Leucaena	Mesquite
Naproamide	2X	97	89
Naproamide	1X	96	94
Oryzalin	1X	90	94
Oryzalin	2X	87	94
Alachlor	2X	87	97
Metolachlor	1X	86	97
Alachlor	1X	85	94
Oxyfluoren	1X	82	92
Metolachlor	2X	80	92
Oxyfluoren	2X	80	92
Control	--	71	81

None of the means are significantly different at 5% level as judged by Tukey's HSD range test. However, a planned contrast indicated that the average of all treatments was significantly different from control at 2% level.

Table 2. The effect of herbicides on percent grass cover 45, 75, and 105 days after transplanting *Prosopis* and *Leucaena*.

Grass Cover (%) Time after transplanting								
45 days			75 days			105 days		
Herbicide	Rate	% Cover	Herbicide	Rate	% Cover	Herbicide	Rate	% Cover
Oxyfluoren	2X	2.19a	Control	--	84a	Control	--	108a
Control	--	2.05a	Alachlor	1X	35b	Alachlor	1X	47b
Metolachlor	2X	1.83a	Alachlor	2X	24bc	Alachlor	2X	35bc
Oryzalin	1X	0.94a	Oxyfluoren	2X	20bc	Oxyfluoren	2X	31bc
Naproamide	2X	0.49a	Oxyfluoren	1X	15bc	Oxyfluoren	1X	26bc
Oxyfluoren	1X	0.45a	Metolachlor	1X	15bc	Metolachlor	1X	25bc
Oryzalin	2X	0.41a	Oryzalin	1X	15bc	Oryzalin	1X	22bc
Naproamide	1X	0.38a	Naproamide	1X	12c	Naproamide	1X	20bc
Metolachlor	1X	0.19a	Metolachlor	2X	10c	Metolachlor	2X	17c
Alachlor	1X	0.16a	Oryzalin	2X	10c	Oryzalin	2X	16c
Alachlor	2X	0.13a	Naproamide	2X	8c	Naproamide	2X	15c
In row Leucaena		1.10a			21b			31b
In row mesquite		0.51a			20b			31b
Between rows		0.90a			26a			37a

Within a column percent grass cover followed by same letter is not significantly different at 5% level as judged by Tukey's HSD test. Absolute herbicide rates are given in methods section.

Table 3. The effect of herbicides on percent forb cover 45, 75, and 105 days after transplanting *Prosopis* and *Leucaena*.

Forb Cover time after transplanting: 45 days			75 days			105 days		
Herbicide	Rate	% Cover	Herbicide	Rate	% Cover	Herbicide	Rate	% Cover
Control	--	1.02a	Control	--	33a	Control	--	51a
Oryzalin	1X	0.67ab	Alachlor	1X	22ab	Alachlor	1X	29ab
Naproamide	2X	0.34ab	Alachlor	2X	16abc	Alachlor	2X	27ab
Oxyfluoren	1X	0.33ab	Naproamide	1X	11bc	Oryzalin	1X	20b
Alachlor	2X	0.28ab	Oryzalin	1X	10bc	Naproamide	1X	20b
Naproamide	1X	0.22b	Metolachlor	1X	10bc	Metolachlor	1X	19b
Metolachlor	1X	0.08b	Naproamide	2X	9bc	Naproamide	2X	17b
Metolachlor	2X	0.05b	Oxyfluoren	1X	7bc	Oxyfluoren	1X	16b
Alachlor	1X	0.04b	Metolachlor	2X	5bc	Metolachlor	2X	11b
Oryzalin	2X	0.02b	Oryzalin	2X	3c	Oryzalin	2X	6b
Oxyfluoren	2X	0.01b	Oxyfluoren	2X	2c	Oxyfluoren	2X	6b
In row leucaena		0.19b			9b			18b
In row mesquite		0.15b			10b			18b
Between rows		0.49a			15a			24a

Within a column percent forb cover followed by the same letter is not significantly different at 5% level as judged by Tukey's HSD test. Absolute herbicide rates are given in methods section.

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Table 4. Influence of herbicides on species composition.

Species	control	Metolachlor 1X	Metolachlor 2X	Alachlor 1X	Alachlor 2X	Napropamide 1X	Napropamide 2X	Oryzalin 1X	Oryzalin 2X	Oxyfluoren 1X	Oxyfluoren 2X
	Grasses (% cover)										
Digitaria bicornis	41a	6b	2b	13b	9b	6b	5b	-b	1b	5b	5b
Cenchrus incertus	23a	4b	4b	11ab	15ab	4b	2b	1b	-b	4b	2b
Dichanthelium sp.	17a	2a	-a	11a	-a	-a	-a	6a	-a	-a	-a
Cyperus rotundus	11a	6ab	-b	10ab	8ab	10ab	8ab	14a	14a	10ab	15a
Panicum coloratum	7a	-a	-a	1a	-a	-a	-a	-a	-a	-a	2a
Panicum texanum	6a	6a	2a	-a	2a	-a	-a	-a	-a	2a	-a
Cynodon dactylon	-a	-a	9a	-a	-a	-a	-a	-a	-a	4a	7a

Table 4. (Cont.)

Species						Forbs (% cover)					
	control	Metolachlor 1X	Metolachlor 2X	Alachlor 1X	Alachlor 2X	Napropamide 1X	Napropamide 2X	Oryzalin 1X	Oryzalin 2X	Oxyfluoren 1X	Oxyfluoren 2X
Sida Spinosa	17a	5b	4b	9ab	6b	7b	6b	3b	2b	3b	-b
Solanum elaeagnifolium	10a	7a	3a	8a	14a	6a	5a	12a	2a	7a	3a
Palafoxia texana	7a	1ab	1ab	-b	1ab	-ab	-b	-b	-b	1ab	-b
Croton texensis	4a	3a	3a	6a	4a	4a	4a	4a	2a	2a	1a
Parthenium hysterophorus[a]	3	-	-	-	-	-	-	-	-	-	-
Helianthus annuus[a]	2	-	-	-	-	-	-	-	-	-	-
Euphorbia prostrata[a]	2	-	-	-	-	-	-	-	-	-	-

Table 4. (Cont.)

Species	control	Meto-lachlor 1X	Meto-lachlor 2X	Ala-chlor 1X	Ala-chlor 2X	Napro-amide 1X	Napro-amide 2X	Ory-zalin 1X	Ory-zalin 2X	Oxyfl-uoren 1X	Oxyfl-uoren 2X
	Forbs (% cover)										
Portulaca oleracea[a]	1	-	-	-	-	-	-	-	-	-	-
Cucumis melo[a]	-	-	-	1	-	-	-	-	-	-	-
Amaranthus sp.[a]	-	-	-	1	-	-	-	-	-	-	-
Ipomea sagittata[a]	-	-	-	1	-	-	-	-	3	-	-

The percent cover is the average of 3 samples for each of 3 locations (in-row Leucaena, in-row mesquite, between rows) for each of 3 reps for a total of 27 observations per herbicide rate combination.

All species with 1% or greater percent cover are listed. Dashes represent values less than 1 not zero's. Means with same letter are not significantly different at 5% level.

[a]Not examined in ANOVA.

Table 5. Effect of herbicide treatment on *Leucaena* and *Prosopis* dry biomass per tree.

Herbicide	Rate	Dry biomass per tree (g) Leucaena	Dry biomass per tree (g) Prosopis
Oryzalin	2X	138 a	58 a
Oxyfluoren	2X	132 ab	39 ab
Oryzalin	1X	99 ab	31 ab
Oxyfluoren	1X	74 abc	24 ab
Alachlor	2X	65 abc	28 ab
Metolachlor	1X	63 abc	18 b
Naproamide	2X	63 abc	35 ab
Metolachlor	2X	59 bc	35 ab
Naproamide	1X	54 c	20 b
Alachlor	1X	44 c	14 b
Control	--	27 c	16 b

Within the same column mean biomass per tree values followed by the same letter are not significantly different at 5% level as judged by Tukey's HSD test.

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ADDENDUM

Note on methods being used for weed control in a semi-arid region for leguminous tree transplanting operations at Caesar Kleberg Wildlife Research Institute, Texas A & I University, Kingsville, Texas, U.S.A.

Land preparation prior to planting is essential for both tree establishment and future weed control. It is always much easier and less expensive to control a weed seed crop than it is to control existing weeds in a crop situtation.

Several months prior to planting a chosen site should have existing vegetation mowed off and cleared of any shrubs or undesired trees. Following the initial land clearing, an application of Round-up herbicide; a non-selective post-emergence herbicide, should be applied to kill off all existing vegetation and to prevent root sprouting. Next, the area is disked to bury the dead material and clean up the field for future tillage practices. After an initial disking, the field should be subsoiled at a depth of about one half meter to allow for water infiltration, soil aeration and root penetration. A second disking is then needed to seal the soil up to prevent moisture loss and to prepare it for chemical applications.

Once the field has been properly prepared, a pre-plant herbicide is applied to reduce weeds with newly transplanted seedlings. In two separate field trials with pre-plant herbicides, we have found early grass competition among newly transplanted seedlings of Prosopis and Leucaena, greatly reduces survival and rate of growth. (Table 1 & 5) Currrently, we have found Oryzalin at 2.5 lb.a.i./ac. the safest and most effect herbicide at the time of seedling transplant for prosopis and leucaena than any other. (Table 2) However, we are looking at combinations with Oryzalin, such as oryzalin 1.25 lb. a.i./ac. + metolachlor 2.5 lb a.i./ac. and Oryzalin 1.25 lbs.a.i./ac. + Oxyflouren 0.5 lb. a.i./ac. to help control weeds which oryzalin does not control on its own.

Though herbicides greatly reduce weed competition, none are 100% effective. Therefore, mechanical cultivation becomes an added tool in controlling weeds and aerating the soil, giving the seedlings an added advantage of survival and growth. Here in Kingsville we have had good success using a single row row-crop cultivator on seedlings up to a meter in height. So with the pre-plant herbicide and a row-crop cultivator we are able to maintain a weed free environment for seedlings for 4 to 5 months or a meter in height.

Commercially available pre-plant herbicides are adequate weed suppressents, however they have a short residual and are too expensive for long term applications. Therefore, we are experimenting with less expensive, long residual herbicides for use once the trees are well established and can no longer be mechanicaly cultivated. Chemicals such as bromacil at ½ lb. a.i./ac., diuron at 2 lbs. a.i./ac. and simazine at 2 lbs. a.i./ac. have shown some promise and are currently being compared in field trials With 6-8 months control from these types of herbicide, weeds should be suppressed long enough to achieve canopy closure and no longer be a deterant to tree growth.

So with proper field preparation, the application of herbicides in conjunction with cultivation, superior seedling growth and survival can be achieved.

Dom Smith
Field Manager

SELECTED REFERENCES

Fryer,J.D., R.J.Makepeace and J.H. Fearon, 1977. Weed control Handbook Vol. I. Principles (6th Edition) Blackwell's Scientific Pub. Oxford. - Highly recommended.

Fryer, J.D., R.J. Makepeace and J.H.Fearon, 1978. Weed Control Handbook Vol. II. Recommendations (8th Edition) Blackwell's Scientific Pubs, Oxford. Mainly for temperate situations.

Kasasian, L. 1971. Weed control in the tropics. Leonard Hill, London.

Klingman, G.C. and F.M. Ashton, 1975. Weed Science: principles and practices, John Willey and Sons, New York London Sydney, Toronto.

Koch, W. (Ed). 1977. Weeds in tropical crops in "Diseases, pests and weeds in tropical crops" (Eds Kranz J., Schmutterer H. and W. Koch) pp. 545 - 616. John Wiley and Sons. Chichester, New York, Brisbane, Toronto.

Seth, A.K. 1977. Integrated weed control in tropical plantations. In "Integrated Control of Weeds" (Eds. J.D. Fryer and Schooichin Matsunaka) pp 69-85. University of Tokyo Press.

Specialized Journals

Weed Abstracts (Comm. Agric. Bur.)

Weed Science (Journal Weed Science Soc. of America)

Pesticide Science (Pub. by Soc. for Chem. Ind.)

Weed Research (Journal European Weed Res. Soc., Pub. Blackwells).

- Also Research Stations specializing in tropical tree crops (coffee, cocoa, tea, coconuts, oil palm etc have a considerable amount of information available about weed control in those crops. Individual CGIAR International Agricultural Research Stations all undertake work on weed control.

  and for additional information about weed control with fast-growing nitrogen-fixing trees, contact:

  Professor J.L Brewbaker
  Nitrogen Fixing Tree Association
  P.O. Box 680
  Waimanalo
  Hawaii 96795
  USA.

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Information on tropical weed control can also be obtained from:

- The Weed Research Organisation
  Agricultural Research Council
  Kidlington
  Oxford, UK.

- The International Plant Protection Centre
  Oregon State University
  Corvallis
  Oregon 97331
  U.S.A.

BASIC GUIDELINES FOR SCIENTIFIC AND GENERAL PURPOSE PHOTOGRAPHY

"THE SCOPE OF THIS APPENDIX IS LIMITED TO PROVIDING THE MOST BASIC GUIDELINES AND INFORMATION WHICH THE AUTHOR* FEELS MIGHT BE OF USE FOR SUCCESSFUL GENERAL PURPOSE AND SCIENTIFIC PHOTOGRAPHY"

* ERICK FERNANDES
ICRAF

SECTION FIVE

PART 5D

Basic guidelines for scientific and general purpose photography

PART 5L

CONTENTS

Page

C O N T E N T S

Basically, a camera is a box with a lens on one side and a film container on the other. The camera contains a shutter and the lens an iris. Light enters the camera through the lens and exposes the film when the shutter is opened. Photography is a simple process and modern cameras make it even more simple.

The Camera

There are numerous types and makes of camera available today. From the most humble Instamatic to the 'Rolls-Royce' of cameras "the Hasselblad"; one is limited only by the amount of money one is prepared to spend.

- 35 mm cameras are by far the most commonly used. They are compact and lightweight and the image is of high enough quality for most applications. In recent years the "reflex viewing system" has been incorporated into 35 mm cameras. This system enables the photographer to see the exact image which will be exposed. The term "single lens reflex" (SLR) is synonymous with modern day cameras. Such cameras also offer the benefits of "through the lens" (TTL) metering and control of both shutter and aperture without removing the eye from the view finder.

- The 35 mm SLR user has at his disposal the most comprehensive range of interchangeable lenses and accessories, which allow incredible versatility. The small size and weight of modern systems mean that they are fast and easy to use.

- There are manual and/or automatic types of SLR camera

  - A manual SLR (e.g. Olympus OM 1-N, Nikon F_2 Photomic), allows the photographer complete control over aperture and shutter speed selection. This gives a photographer the flexibility to explore various exposure possibilities in any given photographic situation

  - The new generation of SLR cameras, e.g. Canon T50 is totally automatic, with meter, shutter, aperture and film advance all electronically controlled. Some of the newer automatics (Olympus OM20) even focus for you!!

- It is a fallacy that 35 mm cameras are only for amateurs, while larger format cameras (e.g. Hasselblad) are used exclusively by professionals. Leading magazines and advertising agencies have made nonsense of this belief - obtaining excellent results from the 35 mm format.

- The major manufacturers of 35 mm SLR cameras include

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- Olympus
- Canon
- Nikon
- Leica
- Ashai Pentax
- Minolta

- All the above makes offer excellent equipment with a comprehensive range of cameras and accessories. The author uses the Olympus OM-1N (manual) and the Olympus OM-2N (automatic) systems. These cameras, 6 years old now, have performed faultlessly from the Cairngorms (Scotland) to the Chalbi Desert (Northern Kenya).

Films

There are numerous types of transparency (reversal) and negative films available on the market. A basic understanding of the quality of films available is a valuable tool for selecting the right type of film for particular photographic subjects or situation.

Slow film (25-64 ASA 18-15 DIN)

These films have the ability to capture a wide range of tones. In addition they have extremely fine grain and this enables very high definition to be obtained. These films are good for use in the tropics where the light is invariably good.

Medium film (125 ASA, 22 DIN)

The films within this range offer the photographer a wide latitude in terms of exposure selection. Again these films are best used where the light conditions are good.

Fast film (400 ASA, 27 DIN)

These films are able to cope with a wide range of light conditions but unlike the slow films have a coarse grain. They are favoured by the news photographer.

Colour film

There are two types available in a whole range of speeds (fast, medium or slow):

- colour reversal (slide)
- colour negative

- Below is a list of some of the colour films commonly available. The author has included some comments on each film mentioned based on personal experience and/or published tests carried out by "Amateur Photographer" a weekly magazine published in the U.K.

Colour reversal (slide) film

- Kodachrome 25	a slow film but one of the sharpest and least grainy of available slide films. Colours less saturated than Ektachromes
- Kodachrome 64	one of my favorites as an all round film with almost identical sharpness and grain as K-25
- Ektachrome 64 (64 ASA)	lovely saturated colours. Good grain and sharpness but needs to be developed soon after use
- Ektachrome 400 (400 ASA)	very good in difficult lighting and excellent quality for such a fast film
- Agfacolor CT 18	known as Agfachrome in USA. Good all round film with warm colours. Grainier and less sharp than Ektachromes
- Agfacolor CT 21 (100 ASA)	Agfachrome in USA; faster and more grain than CT 18
- Fujichrome 100 (100 ASA)	Similar to E 64 and a reasonable general purpose film
- Ektachrome Infra Red	special film sensitive to infrared and visible spectrum; very much a specialist film requiring critical exposure and focus
- Kodak photomicrography 2483 (ASA 16)	Another specialist film for microscope slides. Sharper and more contrast than Kodachrome

- To improve colour saturation (i.e. density and strength of colour) in slide films, "overrate the film" i.e. for Kodachrome 25 (25 ASA) set it at 32 ASA or for 64 ASA set it at 80 ASA. This procedure only works for slide film.

Colour negative film

- Kodacolor II (100 ASA)	very good general purpose film with fairly saturated colours. Fine grain and sharp

- Agfa CNS2 (80 ASA)	Not as sharp and fine grained as as Kodacolor II.
- Fujicolor FII (100 ASA)	Similar to Kodacolor II
- Agfacolor CNS 400 (400 ASA)	Good film for high contrast light. Sharper and finer grain than other 400 ASA film
- Kodacolor 400 (400 ASA)	Good for dull days and indoors with flourescent light. Not so good in sunshine. Good grain and sharpness for a fast film

Black and white film

- Ilford FP 4 (125 ASA)	Probably the best medium speed b/w general purpose film
- Ilford PAN F (50 ASA)	A good slow film, with very fine grain, sharpness and high contrast
- Kodak TRI X (400 ASA)	Excellent fast film in terms of sharpness and grain
- Kodak plus X (125 ASA)	o.k.
- Kodak Panatomic X (32 ASA)	Good for scientific photography. Sharp and fine grained

- With black and white film if you can see a subject, you can photograph it!

Some Guidelines for Good Photography

Composition

- Try to fill the frame with the subject matter. This ensures that your picture provides sufficient detail of the subject.

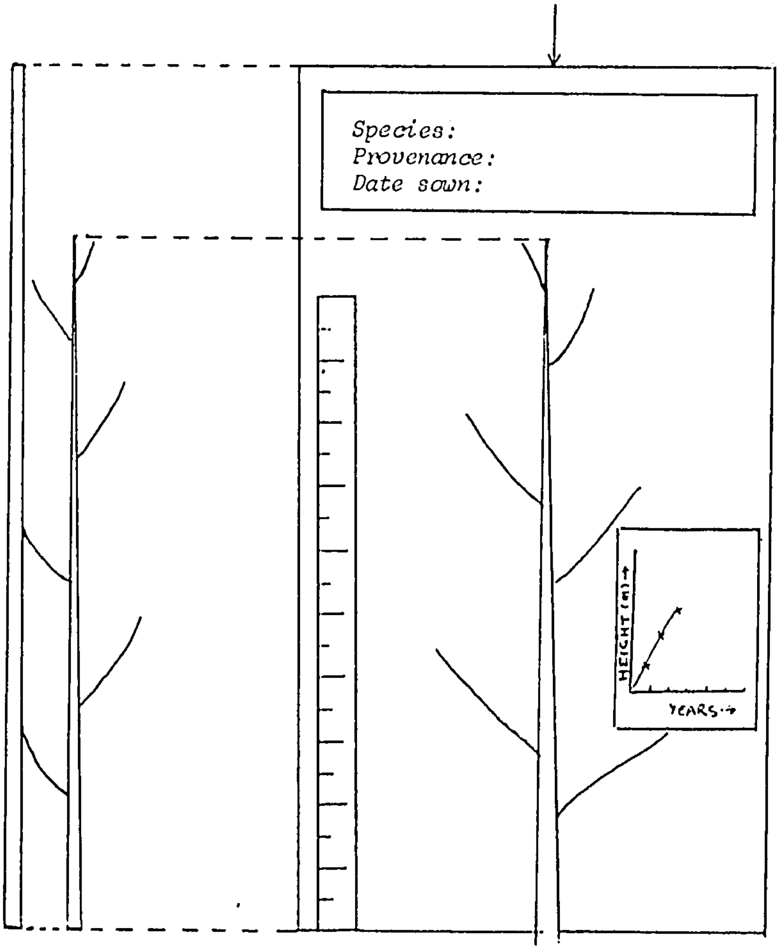
- Always keep in mind the possibility of using a picture for more than one purpose e.g. a shot of an animal alone can only be used to depict the animal. A shot of the same animal browsing a particular species of tree can be used to depict

— the animal

— the vegetation

— the interaction between animal and vegetation.

- When taking pictures for scientific purposes it is often necessary to have additional information about the subject e.g. species, size, growth characteristics, etc. This additional information is most easily incorporated into a picture by using a flat non-glossy light grey board immediately behind the subject. Any information about the subject can now be attached to the board as shown below:



The above technique is also useful for photographing seedlings and other small subjects. It is then necessary to get the camera down to ground level or nearly so. Shoot at f8-f16 (use a tripod if necessary) to ensure adequate 'depth of field' - see page 6.

- An additional advantage of using the above arrangement is that a distracting background of other vegetation etc. is eliminated. This helps to enhance the detail of the subject. A white board should not be used as this can result in underexposure of the subject due to increased reflection from the board. If a black background is used, it will be necessary to use flash to get correct exposure.

Time-lapse photography

It is a commonly used technique for scientific purposes. It enables a visual record of rate/form of growth especially with vegetation. The prerequisite for such photography is that a fixed spot must be located so as to enable the camera to be re-located at the very same spot for subsequent pictures. This is most effectively done with the aid of a tripod. Once the tripod legs have been located for the first picture, their positions may be pegged out enabling the legs to be placed in exactly the same spots for future pictures.

Macro-photography

In scientific photography it is often necessary to obtain close-up photographs of some parts of the subject e.g. flower, fruits, spines. These can then be used in conjunction with a photograph of the whole tree, for example, to give a complete and accurate pictorial description (von Maydell).

- The use of macro lenses is the simplest way to shoot good close-ups. Apart from the camera manufactures who produce macro lenses, Vivitar and Tamron are two companies that produce very high quality and relatively inexpensive macro/accessory lenses. (See interchangeable Accessory camera lenses - manufacturers and distributors).

Aperture - depth of field

When the camera shutter is opened, light enters the camera through the lens and the film is exposed. The iris comprises a system of metal leaves which open and close. The gap in the centre is the *aperture* whose size is measured in f-steps. The larger the f number the smaller the aperture. The aperture governs the volume of light incident on the film and the shutter controls the length of time that light is permitted to fall on the film.

- Aperture determines the "depth of field". Depth of field is the area of acceptable sharpness in front of and behind the subject in focus. This depth is determined by the aperture you have selected and the distance from the subject in focus to the film plane. As you get closer to your subject, or as you 'open' your lens (e.g. from f 22 to f 2.8) the depth of field becomes shallower. By "stopping" your lens down (e.g. from f 3.5 to f 22) or moving away from your subject the depth of field or zone of acceptable sharpness can be increased. However, a shallow depth of field is sometimes useful in eliminating

distracting foregrounds or backgrounds.

Exposure/exposure meters

Correct exposure is obtained when the aperture and shutter speed are coupled in the right relationship, which in turn is governed by the ASA film speed.

- Modern cameras incorporate fairly sophisticated. light meters. Most SLR cameras have through the lens (TTL) metering - whereby the light entering the lens is measured. In most pictures the emphasis is on the centre of the frame, so the light meters in many SLR cameras are biased towards this area. Hence, precautions must be taken with centre - weighted TTL meters when the emphasis is on other parts of the picture.

- Some meters, however, give an average overall reading. These are okay for evenly lit subjects but can give wrong readings where there is a great difference in light levels. Consequently most professionals use a hand held light meter in conjunction with the TTL meter. Most camera manuals state what type of TTL meter the camera has.

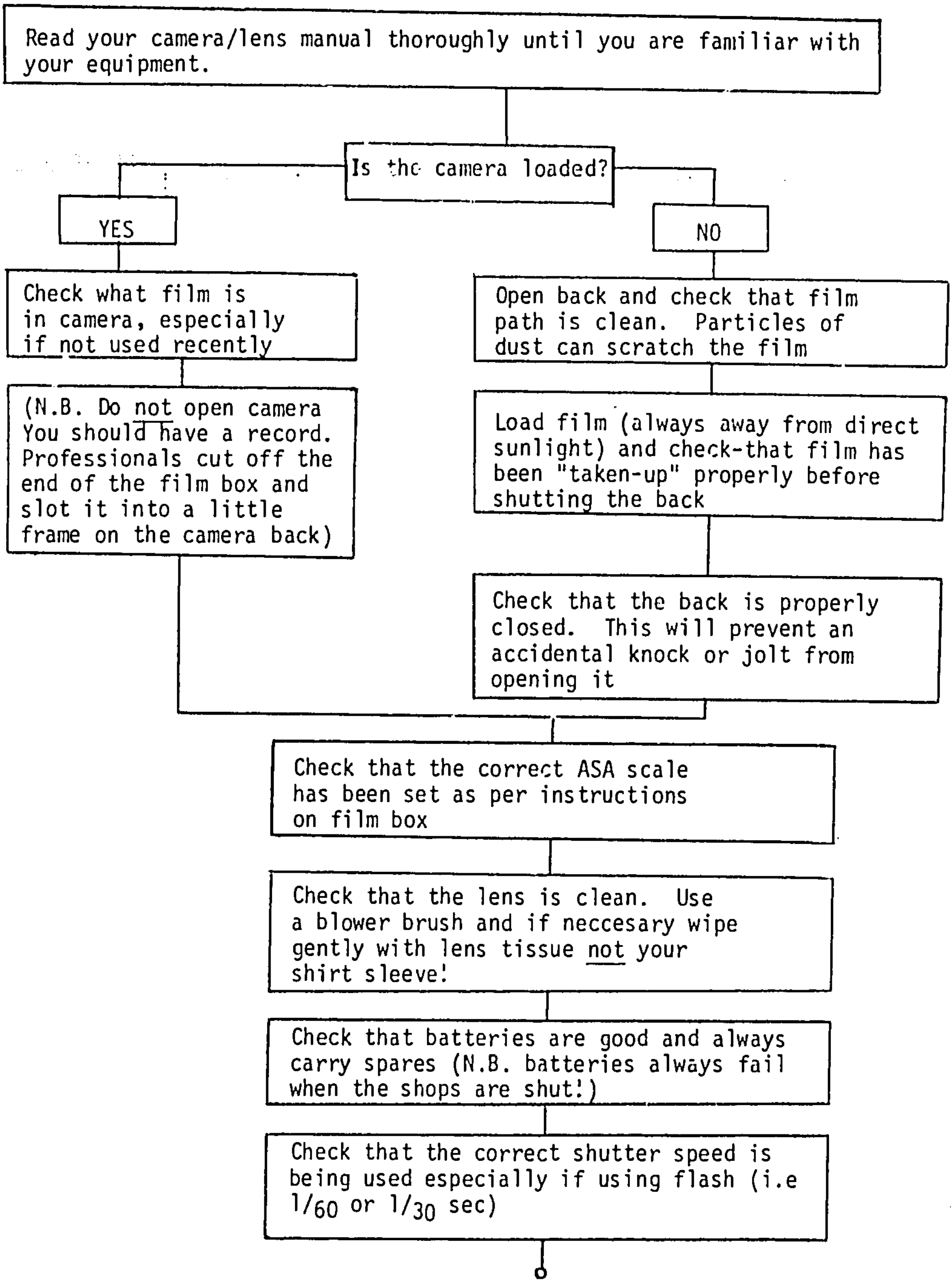
- A trade secret of most professional photographers is "bracketing". This involves exploring various exposure levels when photographing a particular subject. This is a form of insurance whereby the photographer make sure he gets the picture he wants. In some cases, a picture is obtained which even the most experienced photographer could not have expected. There are several ways to bracket:

  - Vary the f-stop from the one indicated by the meter. Thus, a frame is taken at the metered aperture, then one each at a ½ stop over and under the original aperture. When light levels are low, the aperture may be varied by as much as ± 2 f stops.

  - If depth of field is critical, the shutter speed can be varied instead. Thus at a fixed f-stop one frame is taken at the indicated shutter speed e.g. 1/250 sec, then one at 1/125 sec and another at 1/500 sec.

  - With fully automatic cameras, the only way to alter the exposure is to alter the ASA setting. Thus, when using 64 ASA film, one frame should be shot at the correct setting, then the dial set at 80 ASA (½ stop over) and another shot at 50 ASA (½ stop under).

Check List Before Using Camera



Camera Care and Storage

- Dust and moisture are the main agents that can damage a camera. Store the camera in a cool, dry place and make sure that the shutter and timer are free from tension. Do not store the camera near moth balls as these can damage metal surfaces. Protect against excess moisture by using silica gel.

  - One way to protect against both dust and moisture when using a camera is to enclose the camera within a polythene bag with only the front element of the lens sticking out. This is easily done by making a hole in the bag for the lens barrel and securing the bag to the barrel using rubber bands or tape. The bag can then be pulled over the rest of the camera body.

  - The above is a temporary measure and if you are constantly working in very dusty or wet conditions then get yourself a Nikonos III camera made by Nikon. It is dustproof, waterproof and virtually indestructible. Its unique construction features, an inner body which is sealed into the outer casing and this enables it to be taken under water to a depth of 50 metres. It is the only 35 mm camera that can be sterilised!!

- Remove the batteries if storing the camera for a long period of time. (Before re-inserting batteries again, wipe the battery surfaces with a dry cotton cloth).

- Avoid dropping or hitting the camera.

- After use near the sea, wipe the camera surfaces clean with a soft cloth; never leave salt on the camera. (Aerosol effect near the sea can cause salt to be deposited on the camera even though it has not been in direct contact with the water).

- Avoid excessive force when mounting on a tripod.

- Avoid touching the surfaces of the lens. (Clean only with a soft brush or wipe lightly with a lens tissue).

- Always have a filter (UV or polariser) screwed in onto the front of the camera lens. These filters not only improve the picture but also protect the lens. Better to scratch a filter that costs a few $s than to scratch a camera lens that costs $100's.

- Never leave a camera (loaded or unloaded) in the boot of a car or inside a locked car. Temperatures inside cars can get very high and this can damage both the film and camera.

- Use a good case or bag to store and carry your equipment in. Soft foam padded shoulder bags are the most useful for working out of when

on the move. They hold a lot while offering easy access.

Metal cases provide the best protection for transporting equipment in all weathers, although they are slower to work out of, than shoulder bags. A silver finish is essential if working in hot sunny climates as it reflects the sun. Metal cases are also useful to sit or stand on. When in a car always put your equipment where it will not suffer heavy jolts (i.e. not on the floor).

Camera Manufacturers and Distributors

- Hasselblad Great Britain Ltd.
  York House
  Empire Way
  Wembley, U.K.

  Tel: (01) 903 3435

- Olympus Optical Co. (U.K.) Ltd.
  2-8 Honduras Street
  London EC1Y 0TX
  England (U.K.)

  Tel: (01) 253 2772

  or

  Olympus Camera Corporation
  Crossways Park, Woodbury
  New York 11797
  U.S.A.

  Tel: 516-364-3000

- Nikon U.K. Ltd.
  20 Fulham Broadway
  London SW6
  U.K.

  Tel: (01) 381 1551

- Pentax, U.K. Ltd.
  Pentax House
  South He. Avenue
  South Harrow
  U.K.

  Tel: (01) 864 4422

Interchangeable Accessory Camera Lenses (Manufacturers and Distributors)

- Vivitar Corporation
  2700 Pennsylvania Avenue
  Santa Monica, C.A. 90406
  U.S.A.

  Tel: (213) 870 0181 and (213) 829 3672 or

  Vivitar (U.K.) Ltd., Vivitar House
  Ashville Trading Estate, Nuffield Way
  Abingdon, Oxon LX14 1RP, England Tel: (0235) 26600

Recommended Books

The following list is only intended as a guide. They are books that the author has found most stimulating and helpful.

- The Life Library of Photography published by Time-Life Books

- Feininger, Andreas "The Complete Colour Photographer"
  Publishers (UK) Thames and Hudson
  (US) Prentice Hall

- Fusco, P and McBride, W. "The Photo Essay: How to communicate with Pictures"

  Publishers (UK) Thames and Hudson
  (US) Alskog

- Ricciardi, Mirella "Vanishing Africa"
  Publishers (UK) Collins
  (US) Holt, Rinehart and Winston

- Sontag, Susan "On Photography"
  (UK) Penguin Books
  (US) Farrar, Straus and Giroux

- Izzi, G. and Mezzatesta, F. "The Complete Manual of Colour Photography"
  (UK) Victor Gollancz

- von Maydell, H.-J. "Trees and Shrubs of the Sahel with Special Consideration of their Possible Use"
  Publisher - GTZ (Germany)

- Any of John Hedgecoe's Books!

Readers Comments

Is there a need for further sections on:

- Film emulsions - densitometry
- Processing

- etc.?

SECTION SIX

USEFUL TOPICS AND INFORMATION

PART 6A

CONTENTS

SOME ECONOMIC CONSIDERATIONS WHEN DEALING WITH MPT RESEARCH - by Dirk Hoekstra

Economics deals with helping people to make decisions about the allocation of scarce resources in a rational way in order to achieve designated targets.

To formulate and implement multipurpose tree research programmes three consecutive steps have been identified in which economics may play a role.

- The identification of appropriate technologies for research
- The appraisal of such potential technologies
- The use of scarce research resources in order to generate such technologies where necessary.

In the following pages a brief attempt has been made to outline some of the economic issues involved in each of these steps. They are in no way complete and should only be used as a basis for discussion to arrive at a more comprehensive list.

Identification of appropriate technologies for research

The identification of appropriate agroforestry technologies for research can often best be derived through a diagnosis and design process. This is fully outlined in ICRAF's "Guidelines for Agroforestry Diagnosis and Design"(1983).

Diagnosis

In the diagnostic phase of the planning process economics should be used to define the system's "boundaries" in which any new system or technical package has to operate, as well as to analyse existing systems so as to identify the economic "bottlenecks". The boundaries and bottlenecks can then, in turn, become the focal point(s) for designing appropriate agroforestry as well as non-agroforestry solutions for the development of improved forms of landuse.

Boundaries may be subdivided into the following.

- Farm family resources
- Physical resources and environmental potentials
- Government/social environment (policies, infrastructure etc).

For a further sub-division of those broad categories see Hoekstra (1983).

Bottlenecks are commonly exposed with the help of weekly, monthly or seasonal profiles, for example:

- Labour profiles: depict the supply and demand of labour over time.
- Cash flows: show cash inflows and outflows, including loans and debt servicing over time.
- Food profiles: show food production (storage and consumption) over time (for the main products only); a more sophisticated form is the nutrition profile.
- Energy profiles: show the consumption of energy, as well as the supply of energy products over time.

Traditionally such profiles will have been formulated on the basis of studies that provide detailed quantative information. Although the acquisition of such detail is the ideal, in rapid rural appraisal, where little time and/or data are available, only a rough qualitative picture identifying critical periods may be all that is possible, or necessary.

Design

While the diagnostic phase roughly indicates the types of products and services required the design phase looks at how this may be accomplished and derives "specifications" for the technologies required.

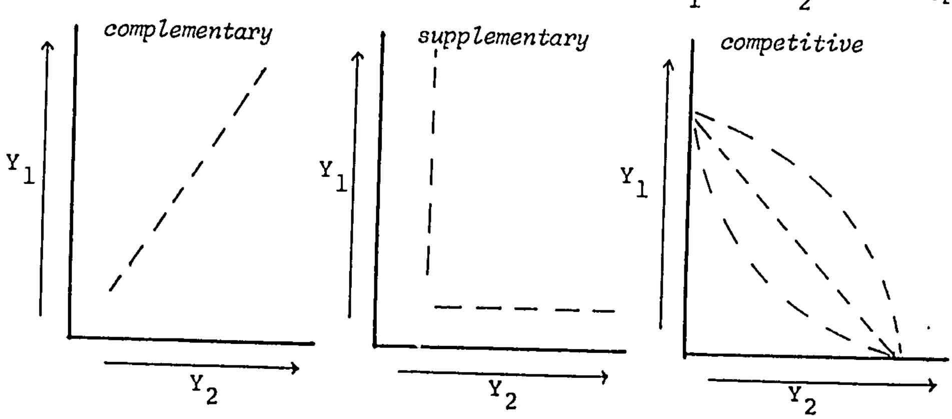
In trying to define the role of multipurpose trees in fulfilling the demands of a system, some basic knowledge is required as to how such trees "behave" if managed for a single as well as for multiple purposes. Such

information may not be available and therefor may have to be the subject of research.

Basically three different relationships can exist when comparing differences between the levels of outputs from a multipurpose tree (see Figure 1).

- Complementary, that is where an increase in one output results in a corresponding increase in another. Such a relationship may exist, for example, where trees have both a service and a productive role but it will, in general, be less frequent in multipurpose trees when comparing any two production roles.
- Supplementary, where an increase in one output does not affect the level of another. Again such a relationship will exist most frequently between a productive and service role, but less frequently between any two productive roles.
- Competitive, where an increase in one output decreases the level of another output. This relationship will be most common between two productive roles of a multipurpose tree.

Figure 1: Complementary, supplementary and competitive output/output relationships. Y_1 and Y_2 are outputs.



The outcome of these relationships can be examined for individual trees, for two or more trees and for tree/crop mixtures. Research may be required to find out more about the technical aspects and quantitative results of complementary, supplementary or competitive relationships on these different levels of scale before any economic evaluation can be carried out.

Appraisal for technical choices

The appraisal of multipurpose trees merits special economic treatment because of the multiple outputs and periods involved.

Multiple output theory

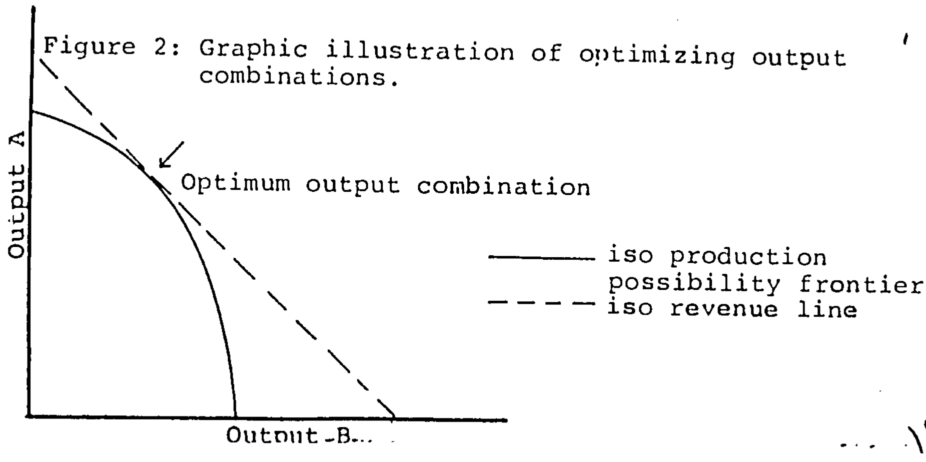
Theory on the appraisal of multiple output systems was originally developed around 1920 by Edgeworth - Bowley using a box diagram.

Recently this theory has been elaborated upon in articles and publications dealing with intercropping and/or multiple cropping.

Amongst the best known ones are Willey, (1979) Hildebrand, (1976) and Flinn, (1979). Reference to this theory has also been made in articles by Filius (1981) and Raintree (1981) dealing with economic aspects of agroforestry.

A graphical approach can be used to portray the optimization of multiple output systems using iso-revenue curves and iso-production possibility frontiers. This is quite useful whenever the problem is limited to two outputs (Figure 2) in a one-period production process (usually less than one year).

Figure 2: Graphic illustration of optimizing output combinations.



Linear programming was developed to deal with optimizing more complex systems, for example, multiple-component, multiple-input production systems. Using linear programming, the underlying optimization principle of "marginal-cost equals marginal-benefits" is similar to that in the simple two-output production system mentioned above.

Multiple periods

Decision-making increases in complexity with the introduction of multiple periods.

The economic theory on the valuation of time has been developed by economists like Hirschleifer, Fisher, Hicks and Ferguson. The principles are explained in a more popular form in many economics textbooks for example, Price Gittenger (1982).

The value of time (usually referred to as discounting) has been combined with linear programming in what is called multi-stage linear programming (also called poly-periodic and dynamic programming). This method has been described by Agrawal *et al* (1973) and Hadley (1964) and an agroforestry application has been made by Burgess (1981).

Due to the complexity of the matrix and the considerable size of computer memory required, this method is not yet popular, and the appraisal of multiperiod production systems is therefore often based on the non-optimization method of discounted budget comparison. A computer programme has been developed by Etherington and Matthews in collaboration with ICRAF to prepare and analyse multi-period agroforestry models (MULBUD) Appendix 1.

Objectives of appraisal

The economic appraisal of multipurpose trees may either be done *ex-ante* or *ex-poste*.

The main aim of the *ex-ante* (or prior) economic analysis of a potential multipurpose tree system at this planning stage of the research programme is to assist the researcher on how to focus his/her attention on a more limited range of research activities than would otherwise be the case. First of all it may examine whether or not it is worthwhile to pursue the use of multipurpose trees, for example, as

compared with combinations of trees each used to provide single outputs. Secondly, if it is worthwhile, then to appraise what product combinations and what arrangements of multipurpose trees and possibly crops may appear to be the most economic.

The main aim of the *ex-poste* (or subsequent) appraisal of potential multipurpose tree systems is to confirm or readjust the lines of research initially adopted. (See Appendix 2).

The economic use of research resources

In planning actual experiments, decisions needs to be taken, among others about:-

- The size and structure of any one experiment.
- The allocation of research resources between different experiments.

Each of these decisions will have its costs in terms of *benefits foregone* in comparison with other experimental designs; or other combinations of experiments that might have been implemented. As well as benefits , in terms of savings, in the use of scarce resources that could have been applied to other experimental programmes and/or conserved or used in some other way for the national benefit.

Such a seemingly endless combination of interrelated possibilities appears to lend itself ideally for problem solving with the help of analytical tools such as linear programming. However, the great difficulty in constructing a linear programme matrix for such a situation would, in many cases, be the lack of concrete data about costs and benefits of experimentation.

Guidelines for experimental decision-making

Some simple guidelines are provided to be used to prepared a linear programming exercise, or to structure a "common sense" approach.

- First of all an inventory should be made of the available research resources over the next (say) five years remembering that most multi-purpose tree experiments will take at least that amount of time to provide results.

- Land, both "on-station" as well as "on-farm" should be inventorised, considering the specific demands certain experiments will make upon it (slope, soil type, etc).

- The available labour resources should be specified according to availability and skill (for example, managerial, operational, etc).

- An inventory of the available supporting captial equipment should be made (laboratory facilities, field operation equipment, etc.).

- Finally, the general operational budget over the next five years should be estimated, so as to be able to ascertain to what extent the inventorized resources can be maintained, or even increased.

- The next step would be to specify for each experiment its possible size and structure ("desirable" and "minimal") in order to reach any set of designated research objectives; also to indicate the requirements in resource use for each.

- Once a range of possible experiments, each with a few design options, has been identified, the relative scarcity of the available research resources should be estimated. The easiest method is to look for the scarcest factor. Sometimes, this is quire obvious, in other cases it can be determined by computing the resource requirements of some research combinations.

- Once the scarcest amongst the research resources is known either a) a tentative selection can be made from amongst the different design options that is those designs which require the least of that resource are chosen assuming that they equally fulfil the primary and secondary objectives of the research programme and/or do not delay the achievement of specified goals within any specified time limits or b) an attempt is made to acquire the additional resources needed (or the

provision of them) *before the programme is initiated.* This rather straightforward and commonsense approach is emphasized here because of the particular nature of experiments with multipurpose trees, which invariably involve a long-term investment in land, labour and skills.

- In deciding on the *combination* of experiments a priority has to be given to each one of them.

  - Since actual "benefits" may be difficult to formulate exactly, it may be best to rank the experiments in terms of their *potential* contribution to fulfilling the needs of the system (in most cases this will be the farm system). Such priority ranking is best decided upon by the system operator (the farmer) in combination with the researcher.

- Once this ranking of experiments has been established a first attempt at combining the experiments may be made by simply adding experiments to a combination in their sequence of priority ranking until a research resource becomes scarce.

- A further refinement may then be made if, for example, a top ranking experiment takes up so much of a resource that hardly any of the other experiments can be carried out. In such cases it may be worth while to examine what the elimination of that one experiment would mean in terms of gains in other experiments.

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SECTION 6A ANNEX

Appendix 1: MULBUD Computer Programme

Appendix 2: Ex-ante economic analysis of candidate AF systems/ technologies

APPENDIX 1

MULBUD

MULBUD, a microcomputer programme for modeling and analysing agroforestry system technologies has been developed by the Australian National University and ICRAF.

MULBUD Version 3 is designed to run on 8-bit microcomputers using the CP/M operating system with at least 53k usable RAM and having dual desk drives with at least 140k bytes per disk. Thus it will run on most Z80 and 8080 microcomputers running the CP/M operating system with a total of 64k bytes of RAM memory. Ideally, MULBUD should be run on a system with an 80 column screen. The compiled package is about 335k in size so MULBUD is resident on two disks which are operated consecutively on "A" drive with data files on "B" drive. The package is always started by using Disk 1. If your computer has less than 172K bytes per disk, you will be provided with a third disk with the HELP message file on it.

Further information on MULBUD will be made available upon request.

EX-ANTE ECONOMIC ANALYSIS OF CANDIDATE AF SYSTEMS/TECHNOLOGIES

To give a detailed account of the why and how of economic analysis of candidate AF systems/ technologies may be rather too ambitious for an appendix. Fortunately it is not necessary because most of what applies to the economic analysis of other land use systems applies equally to AF and has been well documented. Appropriate references in this context are Gittinger's "Economic Analysis of Agricultural Projects" and FAO's "Economic Analysis of Forestry Projects" (See references).

The purpose of this appendix is therefore to give broad guidelines on this subject matter, which would make the aforementioned textbooks better accessible to analysts who want to carry out *ex-ante* economic analysis of candidate AF system/technologies.

Why and How

An *ex-ante* economic analysis of candidate AF system/technologies is carried out to influence the technology design so as to get some sort of assurance that the proposed AF system/ technology is feasible and beneficial.

The methods and procedures are contained in what is usually referred to as *project analysis*, which has *financial* and *economic* aspects.

Financial aspects of project preparation and analysis deal with projecting and evaluating the effects of an intervention on the various project participants i.e. farmers, project agencies, national treasury.

The economic aspects, on the other hand, deal with evaluating the use of scarce resources required for the intervention, from a society's point of view.

Although usually hampered by lack of data, it is still useful to attempt some of these analysis in this early stage of technology development.

However it would be unrealistic to conduct analysis in the same amount of detail as for development project preparation and analysis.

As a rough rule of thumb it is suggested to subject technologies whose main beneficiaries are individuals to the financial type of analysis, while subjecting technologies whose main objective is conservation/ sustainability of whole areas, of which society as a whole will benefit in the future, to the economic type of analysis.

Because ICRAF's D&D exercises have so far mainly resulted in research proposals of AF technologies directly benefiting individuals, emphasis in this appendix has been put on the financial aspects of project analysis in which the farmer's view point is central.

Evaluation of candidate AF Systems/ Technologies from a farmer's point of view

To evaluate whether or not a candidate technology will become feasible and beneficiary to the farmers, it is important to look into the following questions:-

- Is the technology making the best use of the farm's resources?
- Is the technology feasible, given the farm's labour availability (amount, seasonal distribution, management skills)?
- Is the technology feasible, given the farm's available capital resources (own as well as borrowing potential?)
- What are the risks involved with the introduction of the technology?

The following step-wise approach is suggested to find answers to these questions.

Step 1. *Determine the type of inputs and outputs required for the introdution of the technology and plot them on a time scale.*

Step 2. *Quantify these inputs and outputs in physical terms on a per unit area basis.*

Labour inputs should be broken down by activity establishment, maintenance, harvesting), type (adult male or female, children) and likely source (family, hired, community).

Material inputs may be broken down in type (planting material, fertilizers, agricultural chemicals, water, tools veterinary services, fodder, equipment, breeding stock etc) and source (farm produced, purchased or hired, other sources).

Step 3. *Determine the likely scale at which the technology will be introduced into a farming system.*

To find an answer to this question a farm planning exercise has to be conducted, which requires step 4 (labour analysis) and step 5 (cash flow analysis) to be carried out simultaneously.

To get a first approximation of the level at which an AF technology may be introduced it is useful to clearly understand the purpose of the technology. Many *service* oriented ones are site specific and therefore self explanatory in terms of scale (area) e.g. shelterbelts, fencing, grazing area improvement, conservation measures in the cropland etc.

Scaling of technologies which are more *product* oriented, requires information on whether the product will be used to satisfy household requirements and/or will be produced for cash sale.

If the farmer's only objective, is to satisfy the household needs, the analyst has to obtain an estimate of the physical quantity required for example, annual fuelwood reqirements for cooking. The scale of the technology can then be computed by dividing such annual quantities by the per unit area production.

If the farmer intends to sell all or part of the products for cash, a first approximation of scale depends on the analyst's judgement of the marketing potentials and relative profitability of the technology in comparison with other cash generating farm activities.

In practice such a scaling exercise may become more complicated because of the often multi-purpose nature of agroforestry technology i.e. trees combine productive and sustainability (service) functions. Another factor to consider in such a scaling exercise is whether or not other (non) agroforestry technologies are being considered to satisfy the same need.

The end result of this first attempt at scaling the AF technology into the farming system will be referred to as *the plan* in step 4 and 5.

Step 4. *Subject the plan to a labour analysis.*

AF technologies may be grouped into 2 categories for this analysis:-

- Those which intend to replace an existing land use system/farm activity
- Those which are complimentary in terms of land utilized.

The labour analysis of the first group may be started on a *partial basis*, by comparing amount, type and timing of labour between the new AF technology and the existing technologies/ activities. In case little difference is found in labour utilization, no further analysis is required. When there are substantial labour savings, or alternatively, increased labour demands, present/potential use of such labour should be examined. If there is no use for the saved labour (on or off-farm), or if additional labour can be hired relatively easily, the analysis may be completed by indicating either the amount of labour saved or the amount of labour which has to be hired.

If the labour saved by the introduction of the new technology can be utilized (on or off-farm) the analyst should indicate how and when (see also cost benefit analysis). If the extra labour for the introduction of the techonology cannot be hired the analyst has a number of options (not mutually exclusive).

- Check if a gradual phasing of the technology into the system would alleviate the labour constraints (important when establishment labour requirements are high).
- Reduce the scale at which the technology was originally conceived (Step 3). This may be realistic when the technology's produce is mainly for sale. In case most of the produce is for home consumption or the technology performs an essential service function it may be less feasible.

- Indicate the change(s) in composition/ management of existing activities (on or off-farm) in order to provide the necessary labour. Such an exercise would require a whole farm labour budget.

- Ask technicians to redesign the technology.

With the second group of technologies, complimentary in terms of land use, the analyst needs a *whole farm* labour budget of the present farming system, to judge whether or not labour for this activity is available. If not, the four options as spelled out in the previous paragraphs apply.

Step 5. *Subject the plan to a cash flow analysis*

To determine whether or not the plan is feasible from a financial point of view, it is important to check whether or not the hired labour requirements (Step 4) and the material inputs (Step 2) can in fact be financed by the resources available to the farmer.

Such an analysis requires first of all information on the market prices of all cash inputs and the outputs sold.

Once these have been obtained, a cash cost profile of the technology can be computed by multiplying quantities of purchased/hired inputs by their market prices.

This cash cost profile has to be complimented with the cash benefit profile, by multiplying sold outputs by their price.

A similar procedure as in the previously explained labour analysis can then be followed to determine whether sufficient cash is raised within the whole farm system or *credit* facilities are available at the right time so as to be able to purchase the necessary inputs. If this is not the case, the analyst has again the same four options i.e. phasing, scaling, altering existing farm plan or ask for a redesign of the technology.

Step 6. *Cost benefit or farm investment analysis.*

The analysis is carried out to determine whether or not a new or improved technology leads to a better use of farm resources.

The *with* and *without* project comparison is commonly used for such an analysis.

The analysis may be *partial* or *whole farm* in nature. The great advantage of the whole farm approach, is that it does not require the analyst to compute opportunity prices for his own farm resources, because the combined opportunity returns of such resources are the production value minus the cost of all non farm resources in the *without* project situation. If the use of own farm resources in the *with* project situation is in fact larger than in the *without* situation i.e. using previously idle resources, the opportunity cost of such resources is implicitly priced at zero, since no income is forgone. The analyst should insure however that a farmer is prepared to put these previously idle resources to productive use.

The disadvantage of the whole farm approach is that the analyst is required to work out a whole farm plan for the *with* project situation, which is a rather time sonsuming activity, even though computerised like linear programming may be used.

For the benefit of those analysts who prefer to use partial budgeting but realize that the introduction of the technology requires re-allocation of farm resources in the *with* project situation (see step 4 and 5) some guidelines are provided with regard to valuation of those resources and outputs according to the *opportunity cost principle*.

Valuation of inputs

- Because the *with* and *without* comparison aims at determining the incremental net benefits, the analyst needs not to value those inputs which remain the same in the *with* and *without* situation. Because many AF technologies are in fact alternative uses of land, there is no need to incorporate land cost into the comparison since it would be cancelled out. If the *with* technology situation does in fact require more land than the *without* situation the cost of such land is determined by its contribution to production in the *without* situation. In case such additional land was not utilized previously, it would be equal to zero. If it was utilized, its cost

would be the per unit area total production value minus all cost except land cost. In case the additional land has to be rented, the rent paid is used to value the land.

- Valuation of incremental or saved *labour* also depends on its potential other uses. If there is/was no use, including off-farm employment, opportunity cost would be equal to zero. If the saved/incremental labour will be used for/is used at the expense of off-farm employment the opportunity cost of labour will be the net wage received. If the saved/incremental labour will be used/is withdrawn from alternative agricultural activities, the opportunity cost of labour would be the production value of the alternative use minus all costs except labour divided over the total amount of labour units used. To avoid elaborate calculations analysts often use 50-75% of the going market price of labour as opportunity cost of family labour in the off season and 125% of the market price in the peak season. Additional hired labour is valued at the market price.

Valuation of outputs

- Market prices may be used for all ouputs sold, but the opportunity price principle should be used for those outputs which are consumed on the farm.

- For those outputs consumed by the family, for which a local market does exist, the market price may be used as the appropriate opportunity price on condition that the farmers do have cash to buy them. If not, which may frequently be the case, or if the local market in fact does not ensure a proper supply throughout the year, the opportunity price will have to be put substantially above the market price.

- Certain outputs of AF technologies are achieved by saving inputs necessary to obtain a certain quantity of a community e.g. fuelwood planting for home consumption to replace fuelwood collection. Other outputs of AF technologies come indirect through the non tree component in the system for example, sustained yields annual crops through conservation oriented technologies; improved cattle performance by providing shade in grazing land etc.

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the rate is higher than 50% or when comparing matually exclusive alternatives.

Step 7. *Sensitivity analysis*

This analysis deals with risk and uncertainty i.e. what will happen to the attractiveness of the technology (expressed in one of the aforementioned measures) if some of the assumptions with regard to quantities, prices or discount rates change. This analysis is very important at the technology development stage since it test the robustness of the candidate technology.

The techniques for the sensitivity analysis are simply re-calculating the measure of *technology worth* under the revised assumption(s).

A very useful variant of this analysis is the *switching value* or *breaking even point*. Such an analysis answers the questions as to how much an element would have to change before the technology would no longer meet the minimum level of acceptability as indicated by one of the measure of *technology worth*.

Evaluation of candidate AF technologies/ systems from a societies point of view

Looking at AF technologies/systems from the point of view of the use of scarce resources and objectivies of society as a whole requires a second look at the following.

- The type of benefits and costs to be considered.

- The valuation of benefits and costs.

In the financial type of analysis only those benefits and costs are considered which are received/borne by the one from whose point of view the analysis is conducted. Only by doing a financial analysis for different project participants will it be possible to obtain a picture of all direct costs and benefits. For example a financial analysis of a taungya system may be conducted both from the forestry service's point of view as well as from the farmer's point of view. In the forestry analysis, labour provided free of charge by the farmers to establish, maintain and harvest the forest trees, as well as the agricultural produce

belonging to the farmers need not to be considered in the *with* project situation. In the farmer's analysis, on the other hand the labour provided free of charge to the forestry service is part of the cost of producing the agricultural crops, while forest products are not considered. In an economic analysis all direct costs and benefits are considered irrespective as to who will be the beneficiaries or who will be responsible for the costs.

Besides considering all direct costs and benefits, economic analysis also tries to incorporate all *secondary* costs and benefits as well as the *intangible* costs and benefits.

Secondary costs and benefits may be viewed as costs and benefits which arise outside the project, but are a result of the project. Of particular importance with regard to agroforestry are so called *technological spillover* or *technological externalities* in the form of positive or negative environmental impacts. An example of a positive environmental impact are soil and water conservation in the upper parts of a watershed benefiting the lower regions. An example of a potential negative environmental impact is an increase in birds harmful to crops. Most of these secondary costs and benefits can be incorporated in the analysis in a similar way as the direct cost and benefits. Analysts may however find it difficult to make appropriate quantitative estimates.

Intangible costs and benefits are often related to specific government policies other than increasing the *gross national income*, for example creation of employment, income redistribution. Such objectives become usually part of a so called *social cost benefit* analysis.

Quantification and valuation of such costs and benefits is rather difficult and most analysis therefore apply a *least cost* analysis. *Multi-criteria* methods may also be used to analyse candidate technologies.

Valuation of all costs and benefits for an economic evaluation is based on the value of inputs and outputs in alternative uses in the society i.e. *shadow pricing.* Financial prices are the stating point for revaluation of inputs and outputs for the economic analysis. Adjustments should be made for transfer payments (subsidies, taxes), price of foreign exchange, price distortations caused by government policies.

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Note: This Appendix has also been used as an appendix to ICRAF's Working Paper No. 7 ICRAF 1983, Resources for Agroforestry Diagnosis and Design.

SECTION SIX

PART 6B

Understanding Agroforestry Systems

PART 6B

CONTENTS

All these papers are reprinted from "Plant Research and Agroforestry" (Ed P.A. Huxley) 1983. ICRAF, Nairobi.

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COMMENTS ON AGROFORESTRY CLASSIFICATIONS: WITH SPECIAL REFERENCE TO PLANT ASPECTS*

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ABSTRACT. A structural process for designing classifications for particular purposes is suggested. Clearer conceptions of the spatial and temporal patterns involved in various forms of agroforestry land use are needed if they are to be adequately classified. The chronology of plants occupying land is related to the *sequence* of crop species and *succession*, or the occupancy of the land itself. Space utilization must take into account sole, mixed or zonal cropping systems. A standard terminology that will encompass all forms of land use is proposed.

INTRODUCTION

Commentaries on world agricultural systems (for example, Duckham and Masefield, 1970; Grigg, 1974; Ruthenberg, 1980) include detailed accounts of perennial cash crop systems and/or shifting cultivation with planted tree fallows. The role of woody perennials in many other kinds of agroforestry systems is either omitted or scarcely mentioned, however. Existing classifications of agricultural land use systems are, in any case, inadequate for agroforestry because they fail to encompass the greater dimensions of space and time needed. While forestry classifications do not offer sufficient complexity.

If we are to consider agroforestry land use systems analytically there is a need to have a clear conception of the broader spatial and temporal references involved. This becomes particularly important when considering systems analysis procedures. Furthermore, in order to compare *all* types of land use systems a common set of references is required. It must serve for tropical peasant farming where different cropping schemes may be arranged no more than tens f metres apart, as well as for plantation forestry, where the scale may in kilometres.

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* Based on an ICRAF 'in-house' paper of August 1979 which was circulated prior to the meeting.

Similarly, any common scheme has to deal with within season cropping lasting only months, as well as with rotations of woody perennials, the individual steps of which may each take over half a century.

The ideas presented in this paper are put forward as examples of what has to be more fully explored, with some suggestions for consideration.

TOWARDS CLASSIFYING AGROFORESTRY SYSTEMS LOGICALLY AND COMPATIBLY

Classification schemes for agroforestry land use systems must be able to include the necessary wide range of temporal and spatial scales. And they have to accommodate a logical way of grouping key factors on which the primary and secondary production of such systems will depend, as well as indicating how the system is managed.

Types of classification

Sets or subsets of information, in this case descriptions and data concerning agroforestry land use systems, can be assembled in several ways to facilitate data storage, extraction, description and comparison. If data are logically hierarchical it may conveniently be assembled and stored in this form. However, such a scheme is enormously cumbersome to reorganize if a new need, requiring a new access approach to the stored data, is required. Assembling descriptive information and/or numerical data in a network form allows a greater flexibility in deciding, or changing, the ways that data items can be related to one another. A relational arrangement, in the mathematical sense, may be an excellent way of storing and retrieving data about agroforestry land use systems, but it is less likely to be helpful in classifying them for practical purposes. Simple hierarchical schemes have been proposed by Torres (1983) and a more complex combination of categories, based on sets of agroforestry techniques, by Combe and Budowski (1979), later modified by Wiersum (1980).

Generating compatible classifications

Any classification is of value only in as much as it facilitates inductive statements, or conclusions, about particular cases in relation to general laws or taxonomic concepts. To be of practical use a classification must be easily understood and readily handled. In an agroforestry or general land use systems context, the concepts dealt with must cover both biological/environmental/physical *and* social/economic/management elements. These complexities may not be comfortably assembled in just a single classification scheme, any one of which could be constructed in order to serve a different purpose. If a parallel series of classifications is to be made it could be helpful to have them originate from the same structural process (see Figure 1).

Any scheme of classification should start from the concept of the 'proto-agroforestry' land use system: a simple unit consisting of a woody perennial, an agricultural crop species (woody, herbaceous or a grass), and man. Figure 1 indicates a process whereby practical classification schemes can be assembled

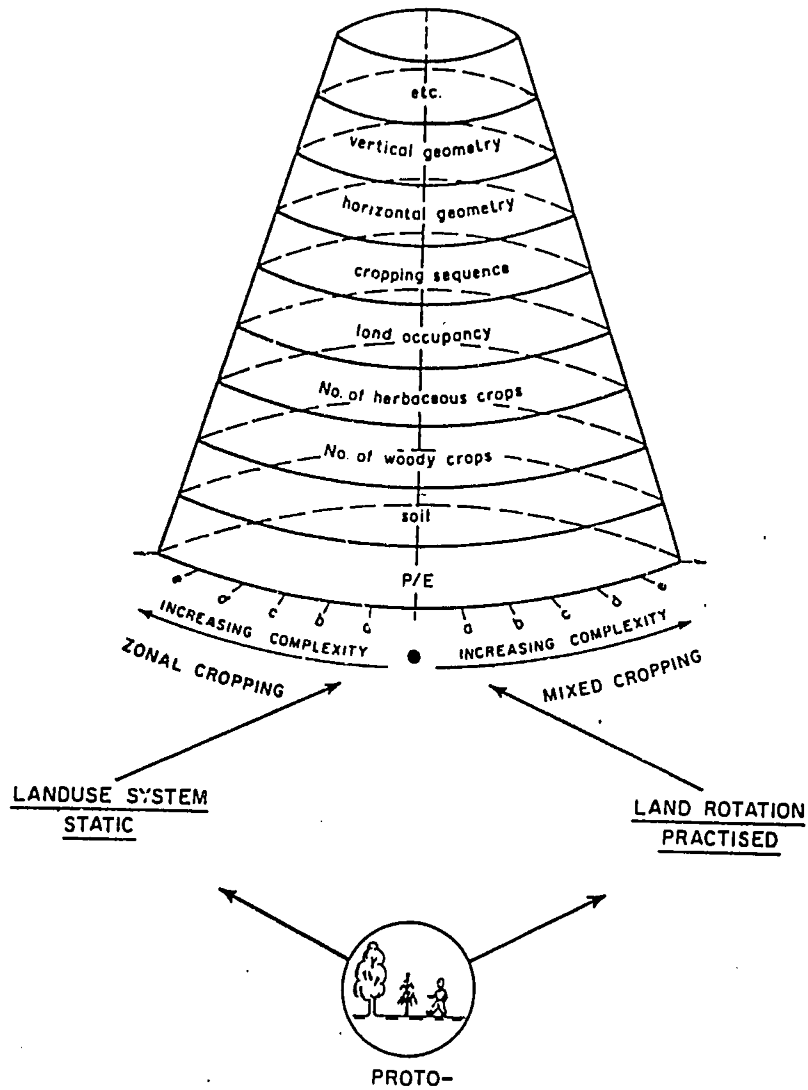

Fig. 1. Steps towards classifying agroforestry systems. From 'proto-agroforestry' (woody perennial, crop plant, man) a first major step is to specify whether land rotation is practised or not. Then, within each of these initial categories, to indicate whether the lands is managed under a mixed or zonal cropping scheme. Subsequently a hierarchy of other characteristics can be assembled (the priority ranking, from the bottom upwards, will depend on the purpose of the classification), indicating for each the level of complexity involved at the particular site, and in appropriate steps (*a*, *b*, *c*, and so on) for each characteristic. In such a way the components for a classification scheme can be grouped and compared, and their relative importance evaluated. (Amended from original 'in-house' paper, 1979.)

to suit particular purposes. For example, with an emphasis on biological components, or on management, and so on. Animals may be included as secondary producers. Two basic categories designating land use / land management have been chosen to form initial (hierarchical) steps. Three-dimensional schemes can be useful, at least to help display the alternatives (Huxley, 1972; Spedding, 1975) — this is done in Figure 1 — taking 'increasing complexity' as the third-dimensional category for each of a prioritized list of characters that need to be considered. Any specific outcome may be directed towards either an hierarchical or a network type of classification system.

In Figure 1 the two initial steps in classification are: first, whether land rotation is practised or not. For example, cropping may be followed by bush fallow, or individual cropping patterns may be rotated. Second, is a management decision one which affects the whole organization of a land unit; that is whether the spatial arrangement of crop components is zonal or mixed. Zonal arrangements can be, for example, alley cropping, strip cropping or some other geometrical arrangement whereby the crop components are separated within the unit of land being cropped, although to some extent they still interact biologically or management-wise. For example, litter or residues can be transferred from one to the other.

Thereafter biological/physical/environmental and social/economic/management characteristics can be categorized in any logical way and, within each, *in order of increasing complexity*. The arrangement of these steps will be the same in any one classification, but they could be rearranged, omitted, or added to in other classifications made for different purposes. For example, systems can be categorized according to a series of factors which relate mainly to their primary production potential. That is according to the following.

- The level (or range) of soil fertility.
- The rainfall/evaporation ratio (periodicity and probability).
- The number of woody components.
- The number of agricultural crop components.
- Land occupancy.
- The cropping sequence.
- The horizontal geometry.
- The vertical geometry.

Or, again, according to management characteristics.

- Inheritance and land tenure.
- Level of inputs in terms of labour, skill, machinery.
- Land unit size (and social/economic factors related to this).
- Access to capital.
- Need to obviate risk/uncertainties.

And so on.

Another agroforestry classification might be based on a mixtures of these. Whatever is chosen as the set of basic variables they need to be ranked, and the structure of actual systems categorized in terms of the increasing complexity involved in each.

Terminology

No set of common terms exists at present that will completely serve for all forms of land use, whether small- or large-scale, or short- or long-term. And there is probably little to be achieved by trying to establish a new set of definitions. The terms in common usage by agriculturalists and by foresters relating to area, for example, 'field', 'plot', 'block', 'zone', and so on, may suffice, although each of these can be used to mean something different under different circumstances. A glossary of terms used in agroforestry is certainly needed, with cross-referencing of all comparable terms at present in use. Many terms used for different types of crop mixtures, such as multiple, inter-, relay, and mixed cropping are, certainly, now well understood (for example, see Beets, 1978).

MAJOR CONSIDERATIONS OF TIME

In agroforestry systems the time dimensions can be particularly complex. They must relate to the life cycle or economic spans of the plant species involved, and hence the phenological events within them; to the management practices carried out from planting to final harvesting in multiple crop systems; also to the sequence of cropping on any unit of land which will involve short-term herbaceous species and long-term woody ones.

Multiple cropping schemes on the same unit of land may involve many crops a year. At the other extreme, shifting cultivators in moist, lowland tropical forest can clear previously cultivated 'forest fallow', so as to replant agricultural crops only after 30 or 40 years or so. And the cropping phase may last about four or five years before the land is allowed to revert to natural secondary forest again. Or it may be planted to a selected woody species or mixtures of species. Where agricultural rotations on whole fields are still practised, this may involve phases of up to several years with the same crop, especially with grass leys.

Cropping period

Agroforestry involves multiple cropping in which at least one woody perennial species is involved. In considering a chronological order of events, planting or sowing, and final harvesting and clearing, form natural limits. Within this will be a juvenile and a mature phase. The whole can be designated as the 'cropping period'. For perennial species this is not necessarily the same as the life span, because they are seldom left, either in agriculture or in plantation forestry, to reach an uneconomic stage. Particularly with perennials, either sequential or partial harvesting is possible. Or a significant harvest can be taken at regular or infrequent intervals, as can happen with some fruit harvesting or the lopping of fuelwood and/or building poles. Terms such as 'ratooning' or 'coppicing' are used to describe the more regular forms of harvesting for agricultural crops or trees.

Sequence and succession

In considering the chronology of plants occupying land there are

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two conceptual comparisons to be made — *sequence* and *succession*. The first refers to the crop species, the second to the occupancy of land itself.

Sequence is the time course of events among crop* components utilizing the same unit of land. That is a designation of the patterns of planting, growing and harvesting with respect to each other. This can be described as 'co-incident', 'concomitant', 'overlapping' (of which the extreme case is 'relay' cropping), and 'interpolated'; as shown diagrammatically in Figure 2. Where more than two species are combined, each will stand time-wise in relation to another in one of these ways.

The other comparison is in relation to the occupancy of any unit of land, and the successive way in which it is planted or sown. A single crop species, or a sequence of different species, whatever the real time of the cropping periods involved, may occupy the same unit of land either 'intermittently' or 'continuously', depending on whether or not the land is left vacant for any reason between planting or sowing successive crops.

Continuous systems assume only that there is a virtually unbroken succession of either the same or different crops. This occurs, for agricultural or horticultural species with a short life cycle, only where there is a continuously favourable environment. For example, in the lowland humid tropics, or in partially controlled environments such as with irrigated crops and in greenhouses. Species with longer life cycles, spanning years, can more readily be planted at an appropriate season, even where there is an unfavourable climate for part of the year. That is they are planted successively, and can occupy the land continuously.

These expressions of succession refer to a characteristic of the way land is used but, because the removal of a crop canopy and exposure of bare soil can, in the tropics and subtropics, lead to extremely rapid soil degradation, it is probably better to define 'continuous' and 'intermittent' in real time, and not relative to the length of, say, the maximum cropping period involved. Figure 3 gives some examples of crop successions with different crop sequences involved.

MAJOR CONSIDERATIONS OF SPACE UTILIZATION

Crop geometry

Land can be planted or sown to a single crop (sole cropping). Or to more than one species, which can then be arranged in some form of mixture; or the species or species mixes can be clustered into zones. These zones might take the form of strips of similar or differing widths; or of some other geometric arrangement, such as a chequerboard or diamond pattern.

There are a number of integrating areas in all classifications relating to plant associations or land use, however, For example, a microzonal agricultural system, such as 'alternate row' cropping, is merely more spatially regularized than a mixed cropping one in which the individuals of different plant species are sited in an irregular fashion (but seldom spaced randomly).

* The term 'crop' is used here in its widest sense to incorporate forbs, grasses and woody perennial species.

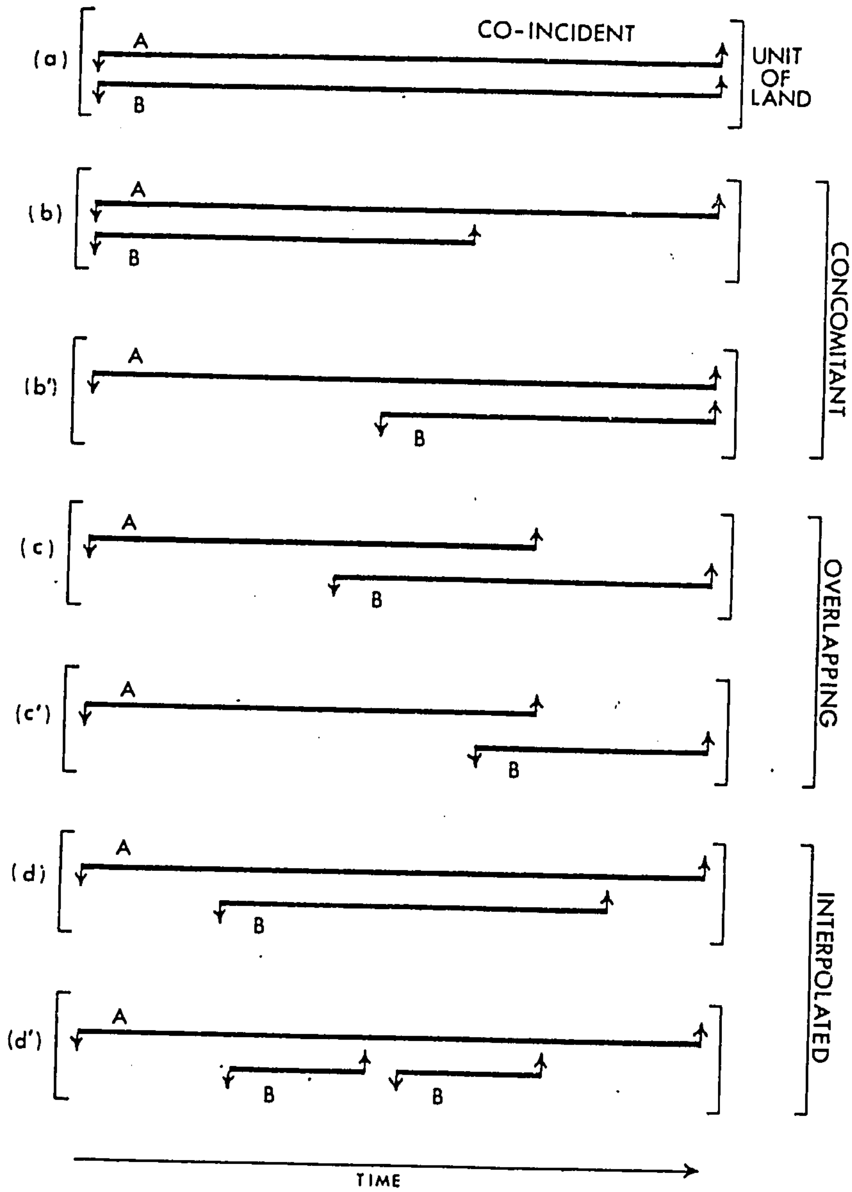

Fig. 2. Cropping sequences: (a) co-incident; (b) and (b'), forms of concomitant sequences; (c) and (c'), forms of overlapping sequences and (d) and (d'), forms of interpolated sequences. For more than two component systems the individual species making up pairs of crops relate to one another in the same way. ↓ = sowing/planting. ↑ = harvesting/clearing.

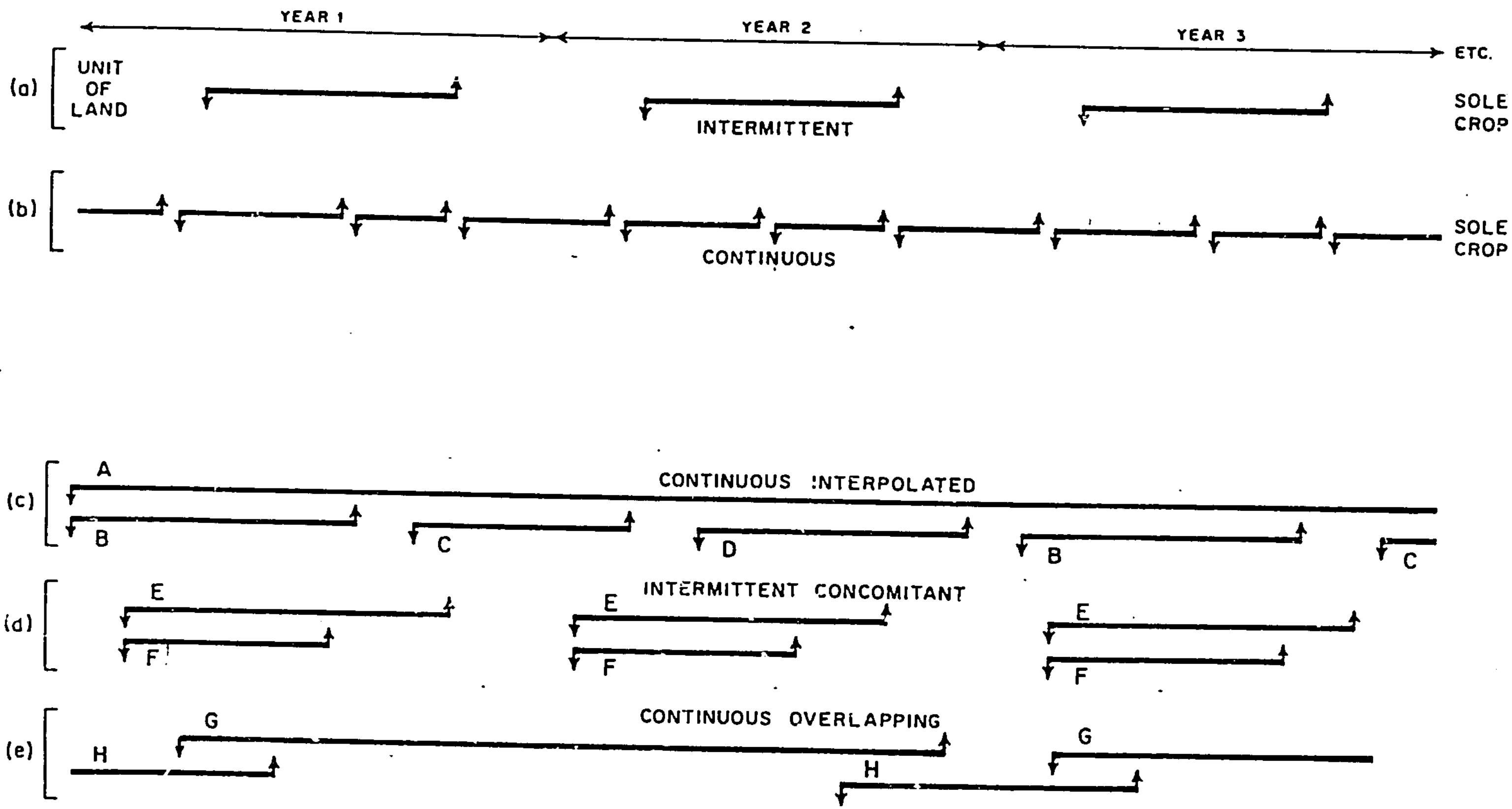
YEAR 1
YEAR 2
YEAR 3
ETC.
(a)
UNIT OF LAND
INTERMITTENT
SOLE CROP
(b)
CONTINUOUS
SOLE CROP
(c)
A
CONTINUOUS INTERPOLATED
B
C
D
B
C
(d)
E
INTERMITTENT CONCOMITANT
E
E
F
F
F
(e)
G
CONTINUOUS OVERLAPPING
G
H
H

Figure 5.

Another problem is to differentiate between macrozonal and sole cropping systems, as this depends on defining the units of land and differentiating between a 'zone', as the term is used here, and a 'field'. This raises a basic question: 'How best do we define 'area' in order to encompass the huge range of actual dimensions involved?' when considering, for example, tropical peasant farming, temperate or tropical plantation agriculture, and tropical or temperate forestry. In all these cases it is possible to define 'area' in the following way.

- In relation to the boundaries of the systems or subsystems as defined by the species or species mixture being grown *and their management*.
- In relation to the extent of the plant interactions of the species, or species mixtures involved.

Spatial units

Only three basic spatial units of area are needed. A 'primary land unit' (plot); a 'management boundary' (field) and the 'total area' (farm). The equivalent forestry designations might be 'stand' (or 'plantation'), 'compartment', and 'forest' (or 'block'). The objective is only to have meaningful divisions which will enable us to relate the parts of the systems under any one form of management to the whole, whatever the actual sizes may be. 'Regional areas' and 'ecological zones' obviously form larger divisions, but these are related to whole land use classifications, and not to units of land under individual management or control.

A fourth division is needed when looking at economic aspects because it is usual to consider common activities as an entity, or as an 'economic enterprise', whenever they are located within the farm boundary. For example, if a farmer grows a particular cereal crop the areas used may be either spatially continuous or separated within the overall confines of the total area. For economic purposes, therefore, such space used for a common purpose might be termed an 'enterprise area' usually consisting of one or more 'management boundaries' (fields).

The primary unit. In tropical subsistence agriculture, or in small-scale horticulture anywhere, this will be what is commonly called the plot. That is, a homogeneous area in which a common species or species mix, and a common form of management is being practised. For zonal systems in agroforestry, however, plots or zones might better be defined as 'those regular shaped

Fig. 3 (*Opposite*) Crop succession, or land occupancy cycles. Showing basic (a) intermittent and (b) continuous forms (upper part of diagram). Continuous succession will have not more than a few weeks' gap between harvesting/clearing and sowing/planting. Examples (lower part of diagram) have different numbers of plant components in the systems. Examples (c), from agroforestry, could be a tree species A interplanted with a succession of herbaceous agricultural crops B,C,D, B,C,D, and so on. Examples (d) and (e), from agriculture, could be respectively, maize (E), interplanted with cowpea (F), and cassava (G) relay planted with sweet potatoes (H).

areas between which, at any one time, the population of plants of different species, including at least one herbaceous and one woody one, interact in some way' and/or 'between the boundaries of which man or animals can readily move primarily produced materials'. The second part of the definition is needed to cover macrozonal systems in which the tree/shrub components are used for browse or woody mulch. For example, rows or plots of trees between which plots of agricultural crops, or grasses, are grown as in alley or strip cropping systems.

The management boundary. Individual 'management boundaries', which need to be ecologically homogeneous, will be the 'field' in agriculture or extensive horticulture. In intensive horticulture a greenhouse or a common set of greenhouses, or a single piece of land within a common boundary but devoted to growing one crop (or crop mix). In forestry, it can be a 'compartment' with any divisions into 'stands' or 'subcompartments', for example by firebreaks or paths, being the 'primary units' mentioned above. Any single 'management boundary' (or field) is not continuously or intimately management-related in any way with an adjacent area; although this does not preclude the transference of material on occasion. For example, dung or straw, as in older temperate mixed farming systems. 'Fields', as larger units, can thus be considered largely self-contained, whereas agroforestry 'zones', as smaller ones, will regularly interact with their neighbours in some way.

In much of forestry, as in large-scale temperate sole crop, or tropical plantation crop, agriculture the 'primary unit' or plot, is not fundamentally required; but it may be in existence as a convenient division for management purposes. For example, for organizing pruning or lopping, spraying, or for fertilizing more efficiently.

Total area. This is the largest unit referring to the whole farm or forest system being considered. It will be the total of all the smaller divisions ('fields' or 'blocks'), which may or may not be divided into primary units: 'plots' or 'zones' and it is the sum of the various enterprises. Clearly, there are cases where, for example, with some form of agricultural or horticultural co-operatives, or with certain types of state farming, whole farm groups interact or are directly managed in a unified way. Such larger conglomerates are readily designated without misunderstanding in an appropriate way related to their management or oganization, as are the 'regions' and 'ecological zones' mentioned above.

In describing individual systems, more substance and precision can be given to *any* definition by providing actual spatial dimensions. From what has been said above, however, it can be seen that no unified classification of the plant aspects of land use systems covering temperate and tropical agriculture, horticulture, forestry *and* agroforestry can be satisfied by simple, absolute, or even relative, dimensional statements. Boundaries of common management, cropping periods and their relations to one another and, in some cases, the dimensions of the interactions between different plant species must be taken into account.

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AGROFORESTRY CLASSIFICATIONS

In agroforestry the extent of the differences between these interactions in various systems is considerable because we can be concerned with a very wide range indeed of both herbaceous and woody perennial species being grown together.

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SYSTEMS ANALYSIS IN PRODUCTION ECOLOGY

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ABSTRACT. In the context of plant research 'systems analysis' has come to mean the analysis of cause - effect pathways, as well as the construction and use of simulation models in complex systems. Simple conceptual or process models to develop hypotheses are also valuable. Examples of simple models are given and more complex agricultural examples of the holistic cause - effect approach to problem solving are outlined. The first of these uses an analysis of the growth and development of alfalfa (*Medicago sativa*) based on research data. The second is a conjectural cause - effect model of a maize-bean intercropping system. The same type of approach will be valid for agroforestry when the information to establish quantitative budgets is available. Meanwhile even fragments of knowledge about control functions can help to formulate hypotheses for interpreting agroforestry systems and to design improvements. In considering such models agroforestry should be viewed in a continuum with other agricultural and forestry situations.

INTRODUCTION

Production ecology is concerned with the integration of physiological processes such as photosynthesis which lead to the accumulation of biomass and crop yield. Knowledge of the plant - environment interactions which are involved helps us in two ways. On the one hand, a better job of farming can be done, since we have a rational basis for diagnoses and decisions on factors such as choice of cultivar, spacing, timing and the inputs of nutrients. On the other, the information can be used for designing improvements in the farming system.

Our understanding of some production processes is very advanced. Photosynthesis, plant nutrition and microclimatology can be placed in that category. In other areas, such as plant development and temperature responses, the information is still very primitive. Weaknesses also exist in our abilities for detailed integration of the cause - effect relations which

determine yield.

New methods are gradually emerging for prediction of yield from holistic analyses of component physiological processes. These methods have been termed 'integrative physiology' (Loomis *et al.*, 1979) and are one example of the increasing importance of 'systems analysis' in agriculture. Other examples are found in nutrient cycling (Frissel, 1977), grazing studies (Innis, 1978), and pest management (Ruesink, 1976).

Systems analysis has come to have two connotations: analysis of the cause - effect pathways in a complex system (Watt, 1966); and the construction and use of simulation models of complex systems (de Wit and Goudriaan, 1974).

The importance of simulation models was stimulated by the general availability of computers and by Forrester's (1961) introduction of state-variable methods. In the state-variable approach, the real quantities of various components of the system (such as the amounts of nitrogen in soils and crops) are the variables which describe the 'state' of the system. As in the real world, the state-variables are advanced in time according to the rates of various ecological processes (e.g. nitrogen uptake by plants, residue decomposition, and mineralization of organic matter). D.J. Connor (this volume) outlines the application of this method to the analysis of crop productivity.

Other kinds of models are also useful in ecological assessments. Since systems analysis involves development of hypotheses (models) about how a system works, very simple conceptual models, simple process models, as well as large state-variable models can be employed according to one's objectives. We can examine such models here briefly. What will emerge is that systems analysis is really a way of thinking about complex systems. This is an important point since it defines systems analysis as an important methodology for agroforestry research.

SIMPLE QUALITATIVE MODELS

A classic example of a simple qualitative model is the hypothesis that heritable traits are transmitted to the next generation in units termed genes. This very simple concept proved to have profound influences in biology. It seemed to explain many observed phenomena such as segregation, and it served as the basis for an enormous increase in experimentation. The concept led to a new way of looking at plants and animals. Particularly important, the hypothesis was vulnerable to tests, and once validated, it could be applied to nearly all aspects of heredity.

Most scientific disciplines are structured around similar conceptual models. In crop ecology, for example, vegetation is examined as a 'community', 'trophic chains' exist from crop to animal to man, and the relative growth rates of plant shoots and roots are controlled by 'functional balances'.

SIMPLE QUANTITATIVE MODELS

We can sometimes extend qualitative hypotheses into simple mathematical statements. The 'limiting factor' approaches common in crop ecology provide good examples. The idea that nutrients, temperature, light and water can simultaneously, or separately,

limit crop growth leads naturally to response functions describing increases in plant growth in relation to increasing levels of the limiting factors. Mathematically, we find that rectangular hyperbolas, Mitscherlich functions, polynomials, and a host of other expressions may fit nutrient response functions.

Fick's first law of diffusion provides another example because it applies so well to flux analyses (gas exchange by leaves, ion movement to roots, and so on). That law takes the form:

$$J = -k\ (dc/dx)$$

or, flux = a conductivity gradient.

The gradient is determined by the difference in substance concentrations between source and sink, the minus sign denotes movement from regions of high concentrations to regions of lower concentration, and the conductivity term, k, describes the capacity or ease of transport. The reciprocal, 1/k, takes the form of a resistance (r) to transport so that:

$$J = -(1/r)\ (dc/dx).$$

The resistance analogy is useful in thinking about water loss from plants (stomatal resistance) and relates readily to the Ohm's Law version of the flux equation:

$$I = E/R$$

or, electrical current = potential drop/resistance.

Water use efficiency (WUE) is an example, at a higher level of organization, of a simple quantitative model applicable to vegetation. Its basic form:

$$Y = k \cdot T$$

or, yield = WUE transpiration

seems to hold well in environments with moderate evaporative demand while a modified form:

$$Y = m \cdot T/T_o$$

where T_o is potential transpiration, fits better with high evaporative demand (de Wit, 1958). These simple generalizations can be derived from more basic considerations of Fick's law fluxes of water and CO_2 exchange by leaves. In this form, they serve as very practical tools in studies of crop production.

COMPLEX MODELS

The simple models generally deal with one or two important processes at a time. Yield formation by a community of crop plants is much more complex. We must now deal simultaneously with many processes and limiting factors. At this point, it becomes very difficult to assemble all of the relevant processes and state variables without some memory aids. In addition, the dynamic nature of plant - environment interactions requires frequent iteration of the assembled model until a final result is simulated. The use of computer models solves both problems: the retention of very large amounts of information, and the process of making very large numbers of calculations.

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Connor's example with wheat, in this volume, shows this clearly. It also illustrates that large models require a considerable knowledge of the system. In fact, one of the important uses of large models is the identification of missing information and this helps to establish research priorities.

SYSTEMS ANALYSIS AS A WAY OF PROBLEM SOLVING

Systems analysis is not limited to the more formal aspects of model conception and development. Returning to the idea of systems analysis as a holistic, cause - effect assessment of a complex system, we find a broad range of uses for systems analysis in the everyday efforts of agriculturalists. This is the area where systems analysis will have the most utility for agroforestry since systems thinking is particularly useful in problem-solving and in the exploration of new systems.

An example

This approach has been used by us in recent work aimed at characterizing the growth and development of alfalfa (lucerne; *Medicago sativa* L.) under Californian conditions. This perennial leguminous forage crop has been grown widely since Roman times. In California, it occupies 400,000 ha of irrigated land (4 per cent of total cropland). Yields range up to 30 mt of hay $ha^{-1}yr^{-1}$ although the average is only 12 mt.

The main issues in our research were to determine the factors affecting productivity and stand persistence over years. Our group had had relatively little experience with the crop so we adopted a two-tiered approach. At one level, we focused on specific issues such as leaf photosynthesis and root - crown anatomy which were known to be important. At the second level, we attempted an ecological description of what the crop does during regrowth after cutting. This was done through harvests at 5- to 7-day intervals in a commercial field to establish growth curves over several cutting cycles. Separation of plant parts at each harvest provided a view of photosynthate partitioning. The idea of this 'nonexperiment' was to establish a baseline picture of regrowth from which we might draw ideas regarding the controls of productivity.

Dry matter yields. The results of dry matter sampling for one of the cutting cycles are illustrated in Figure 1. The yield of oven-dry forage for this late summer cycle was 2950 kg ha^{-1}. Earlier cycles gave heavier yields while later ones were lower, following the pattern of solar radiation and the tendency for alfalfa to become dormant in the fall. Total yield for five cycles over the entire growing season was near 20 mt ha^{-1}.

In addition to stem and leaf fractions, we distinguished above- and below-ground 'crown' tissues (regrowth occurs by activity of axillary and adventitious buds on these stem and rhizomatous structures), and the central tap root. Only the upper 5 cm of the tap root was sampled; fibrous roots and nodules were not sampled. The yield was near 1500 kg ha^{-1}. This small portion of tap root totalled 1500 kg ha^{-1} so we estimate that the actual yield of the entire root system may range upwards from 3500 kg ha^{-1}.

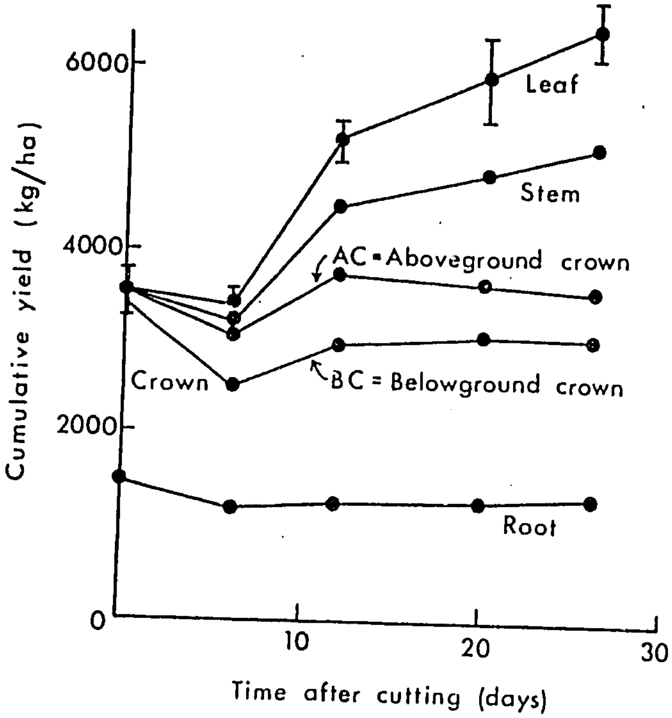

Fig. 1. The pattern of dry matter accumulation by an alfalfa (*Medicago sativa* L.) crop during a regrowth cycle. Sampling was conducted in a 3-year-old, commercial stand of a non-dormant cultivar. Each point is the mean of ten 0.1 m quadrats; standard errors were near 5 per cent of the magnitude of the means.

These rather simple results revealed a number of interesting points.

Lag period. There was no net production during the first seven days after cutting. During this first quarter of the regrowth cycle, buds were opening and cover was being re-established. The crown and root system showed negative growth. Analyses showed that this was due mainly to a decline in starch content and to the death of stem branches from which no regrowth occurred. The content of nonstructural carbohydrates in woody parts of the tap root declined from over 17 to about 12 per cent of dry weight during the first two weeks after cutting, and then returned to the original level during the last two weeks (an anatomical study is aimed at clarifying the role of the root cambium in providing new wood and bark tissues for carbohydrate storage).

Size of the perennial structures. Clearly, a very large amount of biomass is partitioned to perennial structures. Much more definition of the root system is required, and that has been given priority in current work. Since the total of perennial

structures seems to amount to 6000 or 7000 kg ha^{-1}, they represent a considerable reservoir of carbohydrates and nitrogenous materials to support regrowth. They also represent a potentially large cost in maintenance. At a relatively low maintenance requirement of 1 g glucose per 100 g root - crown material per day, as much as 70 kg photosynthate $ha^{-1}day^{-1}$ may be expended in maintenance respiration.

Peak growth rates. After the 7-day lag, crop growth rates (C; or slope of the total biomass curve) were positive, and biomass accumulated. The peak growth rate occurred during the second week and, for this cycle, reached 185 kg $ha^{-1}day^{-1}$. (Other cycles approached 300 kg $ha^{-1}day^{-1}$.)

Remarkably, this growth rate occurred with considerably less than full leaf cover. Many experiments with various crops have shown a linear relation between C and percent cover. Since cover increased from 12 per cent to only 50 per cent (0.3 to 1.9 leaf area index) during the second week, we expected C to increase above 185 kg $ha^{-1}day^{-1}$ during the third and fourth weeks as leaf area index increased to 3.7 and cover approached 100 per cent. But that did not occur. Rather, C declined to 77 kg $ha^{-1}day^{-1}$. The cumulative difference between 77 and 250 kg $ha^{-1}day^{-1}$, which might reasonably be expected during the last 15 days, is 2600 kg ha^{-1}. That behaviour seemed general for this field, and is also seen in data from other locations. However, there are other cases where yield accumulates continuously after the lag period.

Our attention quickly focused on possible explanations for the 2600 kg of 'missing yield'. This exercise in systems analysis led us to the following possibilities.

Water shortage. A growth decline of this sort could occur during drought. However, heavy irrigations were applied in the first and third weeks. Measurements of plant water status were made, but no visible signs of stress were noted and the plants used the soil moisture freely.

Nutrient shortage. Nitrogen, phosphorus and potassium are possible candidates as limiting nutrients. It is common for alfalfa forage to contain over 3 per cent N, 2 per cent K and 0.2 per cent P so the nutrient removal by a 20 mt crop can be very large. We do not expect deficiencies of K and P on this site and that was confirmed by the fact that plant analyses exceeded the critical nutrient concentrations used in the diagnoses of deficiencies.

The nitrogen analyses are presented in Figure 2. The standing crop of nitrogen and its distribution among plant parts followed a pattern very similar to that shown for dry matter. The main difference is the large proportion of nitrogen in leaves (5 per cent D.W.) at final harvest compared to stems and roots (2 per cent D.W.). The peak increase in nitrogen corresponds to peak C (second week). Here, we need data for the balance of the root systems and the nodules to establish a complete story. But it appears that the crop receives a single major contribution of about 60 kg N ha^{-1} during the second week, and very little thereafter. Whether that nitrogen is from the soil, fine roots, or nodules, is unclear. The nitrogen content of the crowns and

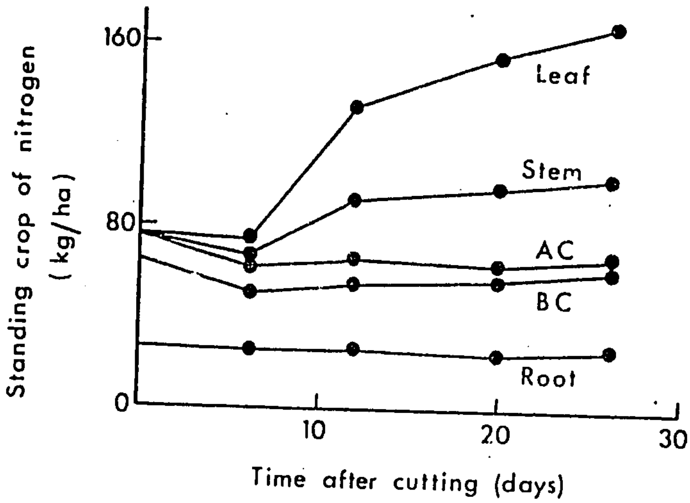

Fig. 2. Nitrogen yields for alfalfa crop presented in Figure 1.

sampled portion of the tap root declined from 2.0 to 1.8 per cent during this time. If the whole perennial structure (estimated at 7000 kg ha^{-1}) declined as much, that would account for 14 kg N ha^{-1} (0.002 × 7000). Perhaps cutting causes nodule and fibrous root decay, providing a single major release. The small gain in nitrogen during the last two weeks might reflect a re-establishment period for those structures.

Whatever the mechanisms, pulsations in nitrogen supply could account for the growth plateau seen in Figure 1 so nitrogen economy is being given a major emphasis in continuing work.

The diversion of photosynthate to replacement of nodules and to support nodule activity could contribute to the observed plateau effect in Figure 1. The actual cost of fixation, however, would not be great. The conversion of N_3 to NH_3 involves reduction of nitrogen by the addition of three electrons to each atom. Since respiration of a mole of glucose yields the equivalent of 24 moles of electrons, the ratio of assimilate use will be 3/24 mole glucose per mole NH_3 or (3 × 180) / (24 × 14) = 1.6 g glucose per g nitrogen. Thus, for the 60 kg N which appeared in this cycle, only 96 kg of photosynthate would be required. Even if we double that to account for nodule maintenance, the result is only a small fraction of the missing 2600 kg of yield. So we have to consider that fibrous root and nodule replacement as well as H_2 production by the nodules would be the major factors. Even if that accounts for the missing yield, one can still draw the interpretation that shoot growth came to be limited by nitrogen supply.

It is strange to think of a vigorous legume crop encountering a deficiency of nitrogen. This field appears to do very well in nitrogen fixation. With 20 mt of hay containing over 3 per cent N harvested each year for three years, more than 1800 kg N ha^{-1} has been removed. That amount is vastly greater than natural inputs through rainfall and dust. It also greatly exceeds the nitrogen which could be supplied from organic matter by this

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desert soil. The high apparent rate of fixation, plus the oft repeated failure of agronomists to obtain alfalfa yield responses through additions of fertilizer nitrogen, leads one to be sceptical regarding nitrogen limitations. But it would appear that small amounts of inorganic nitrogen seem simply to replace an equal amount of fixation. Nodulation and fixation are both repressed in the presence of inorganic nitrogen (Evans and Barber, 1977). So, to be effective in increasing yield, considerably more than 600 kg N ha^{-1} would have to be supplied as fertilizer. Such rates have seldom been employed with alfalfa; in other words, the possibility is that the nitrogen responsiveness of alfalfa has not been tested.

Net decline in photosynthesis. Leaf photosynthesis rates sometimes decline dramatically with age. However, this seemed unlikely as an explanation for the missing yield, since alfalfa stems elongate indeterminately until slowed by heavy flowering. At final harvest, the canopy was dominated by recently expanded young leaves in the upper strata. In addition, laboratory studies revealed that the difference in maximum net photosynthesis rates of the youngest and oldest mature leaves was only 25 per cent (2.5 and 1.9 n moles CO_2 $cm^{-2}s^{-1}$, respectively).

These photosynthesis measurements were made on leaves grown at moderate light levels in glasshouses and under a high level of nutrition. If nitrogen was in short supply carbohydrates might be expected to accumulate in stems and leaves. Certainly, if that had occurred, some type of 'feedback inhibition' (Neales and Incoll, 1968) might also be expected under high light conditions in the field. An additional possibility is that photorespiration might be increased in the presence of high levels of carbohydrate (see, L. Tieszen, this volume). Both possibilities are now being investigated with plants grown under conditions with high light and restricted growth sinks.

Accumulated dry matter, as observed in Figure 1, integrates leaf net photosynthesis with respiratory activities of the whole plant. As noted earlier, maintenance respiration would be expected to increase as biomass increased and this could be a significant drain by the end of the cycle. There is also the possibility that maintenance respiration is substrate dependent, increasing as substrate supply increases. In addition, Lambers (1979) suggests that a high carbohydrate status in plant roots may induce uncoupled respiration from those tissues. In that way as with H_2 production by nodules, assimilates might be wasted away instead of contributing to dry matter production. Again, we see the need for a great deal more information about the underground structures.

APPLICATIONS OF SYSTEMS ANALYSIS TO AGROFORESTRY

The alfalfa case outlined above provides an example of a type of systems analysis which should be very useful in agroforestry research. The effort at cause - effect analysis, coupled with quantitative budgets, leads to a well-defined set of hypotheses and research objectives. Many of these can be tested further in simple field experiments so prospects for clarifying the production processes of this crop seem very good. We need similar

quantitative descriptions for agroforestry situations: what are the yields; by what pattern of events and processes do they accumulate; how do the yields compare with biological and climatic potentials?

Particular attention must be given to nutrient deficiencies and their interactive effects with light environments. The possibilities for overstorey shade to serve as a balancing mechanism for nutrient limitations are important. Greatly improved yields have been obtained with several crops when shade is reduced and nutrient supply increased. However, nutrients are often a main limitation to yield in many tropical and subtropical environments, including those where agroforestry is practised. Water will also be limiting at many sites. It is as well to examine such elementary relations before assuming that more subtle synergisms occur in mixed cropping.

An example for mixed cropping

Unfortunately we do not, as yet, have sufficient data from agroforestry systems to outline an example of the use of systems analysis in the cause - effect manner described above. We can take an agricultural mixed cropping situation, however, which will serve to elaborate the essential approach.

The maize - bean intercrop common near Nairobi, and in many other tropical regions, provides an example of nutrient limitations. Without fertilizer, grain yields on small farms may range from 1100 to 1350 kg ha^{-1} (Ackland, 1971). Since the grain has a nitrogen content of about 1.6 per cent, some 18 to 22 kg N ha^{-1} are removed with the grain; the total is increased by an additional 8 to 10 kg N ha^{-1} if the stover is removed also. If yields are to be maintained, this amount must be supplied to the soil from rain, dust, fixation by free-living bacteria, animal manures, and residues from the leguminous companion crop. Those inputs are area-dependent and small in amounts so we must allocate a relatively large soil area per plant if the maize is to grow reasonably well. Maize stands are often as low as 10,000 to 20,000 plants ha^{-1} on smallholders' plots so that each plant occupies an area of 0.5 to 1.0 m^2. With a rooting depth of 1.5 m it has a soil monolith of from 0.75 to 1.5 m^3 to exploit.

At this spacing, the maize plants have only about half the amount of nitrogen they could use but that is enough to produce a modest yield of grain. But ground cover is by no means complete and only a portion of the incoming sunlight is intercepted by the maize. In addition, full utilization of available soil water is not achieved. Thus, a companion crop could beneficially be introduced to share these resources, *but it should be noncompetitive with maize for that crop's limiting factor, nitrogen.* Hence, an understorey grain legume is a promising candidate to provide a complementary yield and a possible additional input of nitrogen.

In this kind of very simple cause - effect modelling we may wish to alter the assumptions by changing estimates of grain yield, spacing, or nitrogen inputs, but the point to be made here is that such an assessment enables us to state a hypothesis. This can then be tested by some simple field experimentation. In this case, by adding fertilizer and by replacing the space occupied by the grain legume in the mixed crop with more maize. If the arguments are correct, then in the absence of any additional

nitrogen fertilizer, the yield of the maize crop will probably decline due to the smaller input of nitrogen; but with fertilizer nitrogen maize yields should increase drastically. One should also test whether a rotation of maize and legume monocultures would perform as well or better than the intercrop. At Davis, California, with 450 mm rainfall, and with nitrogen not limiting, 10 mt of maize grain has been obtained without irrigation and over 15 mt with irrigation. But, populations near 70,000 plants ha^{-1} are required to achieve this.

Interactions and factor identification

Plant population - nutrient - water - shade interactions are also likely to be very important in agroforestry. Such interactions are studied most easily with a succession of simple, single factor or double factor experiments. Experiments with a greater number of factors become almost impossible to interpret, except by using mathematical models. It is also evident that one may need to distinguish between shade and nutrient cycling roles for the overstorey trees. Nutrient analyses, fertilizer experiments, and shade removal are useful tools for that purpose. Clearly, problems of this sort are not studied easily in small plot situations with single plants in complex mixtures. One needs relatively large, uniform plots to establish nutrient cycling, water, shade and plant population responses. The resulting principles can be applied in the interpretation of small plots. Other factors such as convenience and risk are also important considerations in subsistence farming, of course.

The word *principles* is important. We are looking to identify the rules governing plant growth. Those rules will take various forms. 'Nitrogen is limiting; the nitrogen response function is a diminishing return.' 'Deciduous leaves from the companion leguminous tree will supply 10 kg N ha^{-1} each year, leaching is not a problem.' 'Shade lowers the harvest index of the crop.' And so on. These fragments of knowledge of control functions become the basis of our model of the agroforestry situation. We then have a foundation for monitoring and interpreting crop performance, and for designing improved systems.

CONCLUSIONS

Agroforestry is not an end in itself but a means to achieving safe, stable supplies of food, fodder, fibre, and other outputs, often from difficult environmental and economic situations. But we must be careful not to view agroforestry situations in isolation from the performance of the same plants grown in monoculture. The monocultures provide the basis for interpreting nutrient and plant population responses, and yield potentials. Mixed cropping with trees can be viewed, in a continuum wich other agricultural and forestry situations, as a system designed to accommodate to some biological, environmental or social limitations. Soil problems related to nutrient cycling and supply, or erosion, will be major factors. But the situations will be more complex and less transparent to analysis than the more conventional cropping systems. They will tax our abilities for systems analysis whether in problem-solving or in formulation of simulation models.

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DISCUSSION

KOZLOWSKI - Perhaps the alfalfa plants were water stressed. Did you measure stomatal aperture?

LOOMIS - No. But alfalfa has little stomatal control. Irrigation occurred at different times in different cycles with the same result. Water used seemed to match the potential Et of 6 mm of water day^{-1}. In general, the plants were never short of water.

KOZLOWSKI - The plants may have suffered some midday water stress.

LOOMIS - I agree. We are also considering that water use could relate to respiration rate (as an explanation of the falling off in crop growth rate). Maintenance respiration can amount to a loss equal to around 1 per cent of the biomass per day, due mostly to protein increases with temperature. But the lowered soil temperature and the high rate of water use at full cover kept temperatures low and should have minimized respiration.

OLDEMAN - Does alfalfa have much cambial activity?

LOOMIS - Yes. We are in the middle of a time analysis of root anatomy. But this was mostly included in the dry matter measurements. The system did not appear to be carbohydrate limited. It could be that nitrogen deficiency, or some other limit to cambial activity resulted in feedback inhibition to photosynthesis. That is, that the system was sink limited. It is not likely to be limited by transport.

HUXLEY - Do you not need active root growth in order to produce controlling hormones?

LOOMIS - I think of hormones as being like on/off switches. I do not see that they could explain the type of result we got.

HUXLEY - The effect of cutting alfalfa may be so drastic as to perturb the whole system; including the balance of hormone regulators. With regard to the comment on transport we traced nitrogen in cowpea throughout its life cycle and found that a problem was adequate transfer of nitrogen at pod filling.

NAIR - An important part of nutrient recycling, of benefit in agroforestry systems, could be the leaching of nutrients from leaves of the upper-storey plants, which are then intercepted in the lower storey.

LOOMIS - That is true. But it is interesting that there is a lower equilibrium of soil organic matter in forest systems (and thus of organic nitrogen) than there is under grass. This may be due to a different timing or pattern of residue decay with more chance for losses.

NAIR - More nutrient cycling is involved in intensive systems of production, therefore more nutrients could be lost.

LEYTON - Did you measure the leaf area index in your lucerne community?

LOOMIS - Yes, it rose from 0.3 at one week to around 2 at two weeks, and then rose to a maximum of about 5.

JACKSON - Did you actually measure light interception?

LOOMIS - Yes, but not very well. We first tried a system using the lambda 1 m silicon cell bar, but this was not easy to place in the alfalfa canopy. We subsequently used an indirect method using the vertically projected shadow areas taken from weekly photographs.

LEYTON - Are there published figures for net CO_2 flux for lucerne?

LOOMIS - There are a few studies. Most of the available information, however, involves growth measurements of recorded sward yield at each harvest.

OLDEMAN - Does alfalfa show phasic or rhythmic growth?

LOOMIS - That should not affect these results. Flowering had just begun at final sampling and we were well away from the dormancy traits which most cultivars show in full winter conditions.

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CROP MODELS: COMPONENTS OF AND CONTRIBUTORS TO MODELS OF AGROFORESTRY PLANT ASSOCIATIONS

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ABSTRACT. Simulation models of crop systems are only a summary of selected findings arranged to display relationships in a meaningful way so as to help the researcher focus on well-specified objectives. In doing this they often expose the need for more experimental work. Models must be made appropriate to each set of research objectives, however, and then the processes of *definition of purpose - model building - experimentation* offer a valuable repetitive loop.

Simulation models almost invariably contain a mixture of fact and fantasy (hypothesis) because some physiological processes are better understood than others. Models do not work well if they are too unbalanced in this respect, and simple models based on limiting processes are often the most successful.

Research in agroforestry should be able to capitalize immediately on existing crop models constructed to investigate responses to management and environment. Particularly with regard to canopy design, and water and nutrient budgeting.

INTRODUCTION

Over the past twenty years there has been considerable progress and some consolidation amongst the variety of approaches that have been tested in the development of simulation models of crop growth and yield (for example, Loomis *et al.*, 1979). Agroforestry research is in a position to take advantage of these developments, not only because crop models can be incorporated into models of the more complex agroforestry plant associations, but also because generally applicable principles and techniques have emerged.

The general objective of agroforestry research is to uncover the relationships between the performance of tree/non-tree mixtures, particularly their productivity and sustainability, in

response to climate, weather, management and the characteristics of the component species. It shares this objective with research in crop agronomy but, in addition to the further complexity that is introduced by the anatomical and physiological diversity between the cohabiting species, there is the important additional concern of the longer time scale over which the performance of the individual associations must be considered.

SIMULATION MODELS IN RESEARCH

The question is not whether simulation modelling is an appropriate companion activity to experimental work directed towards unravelling causal relationships in biological systems, but rather at what level should the modelling be undertaken? Biologists are, in general, far less quantitative than their counterparts in the physical sciences. Not only is their training often deficient in numerical approaches, but it seems often to emphasize the undoubted complexity of biological systems rather than the need for, and value of, simplification as an aid to the development of understanding. For this reason I feel that biologists have great difficulty in accepting the simple abstractions of high level simulation models, preferring often to seek explanation of system behaviour by reductionist research, rather than by integration at an appropriate level.

Models of crop systems are only a summary of selected empirical findings of plant physiologists. The purpose of a model is to provide a framework within which the mathematical representations of the hypotheses concerning the behaviour of component processes can act and interact. This aspect of empiricism is important because it is not the purpose of a crop model to reproduce reality by, for example, taking explanation of the growth responses back to the fundamental laws of molecules. Models cannot be built to answer any question at any level of complexity. Their purpose is to abstract a system for what must be in each case a well-specified purpose.

Simulation models are an important adjunct to experimental research. A simulation model cannot be constructed unless the model builder has clear objectives and the model building furnishes the opportunity to focus what might otherwise remain as an obscure mental model. In research it is much better to discover an approximate answer to an exact problem than to discover an exact answer to an approximate problem (see Paltridge, 1973). Model building can play an important role in problem identification. For these reasons it is important that experimenters are modellers and vice versa. There is of course room for some specialization, but success is most readily achieved when there is close co-ordination between these two aspects of research.

DIAGRAMMATIC REPRESENTATION OF CROP SYSTEMS

The physiological processes of photosynthesis, transpiration, respiration, nutrition and phenological development are those to be related to the community level transfers of radiation, biomass, nutrients and water. Forrester (1968) developed a technique of representing the state and activity of systems and, although his is not the only diagrammatic technique that has

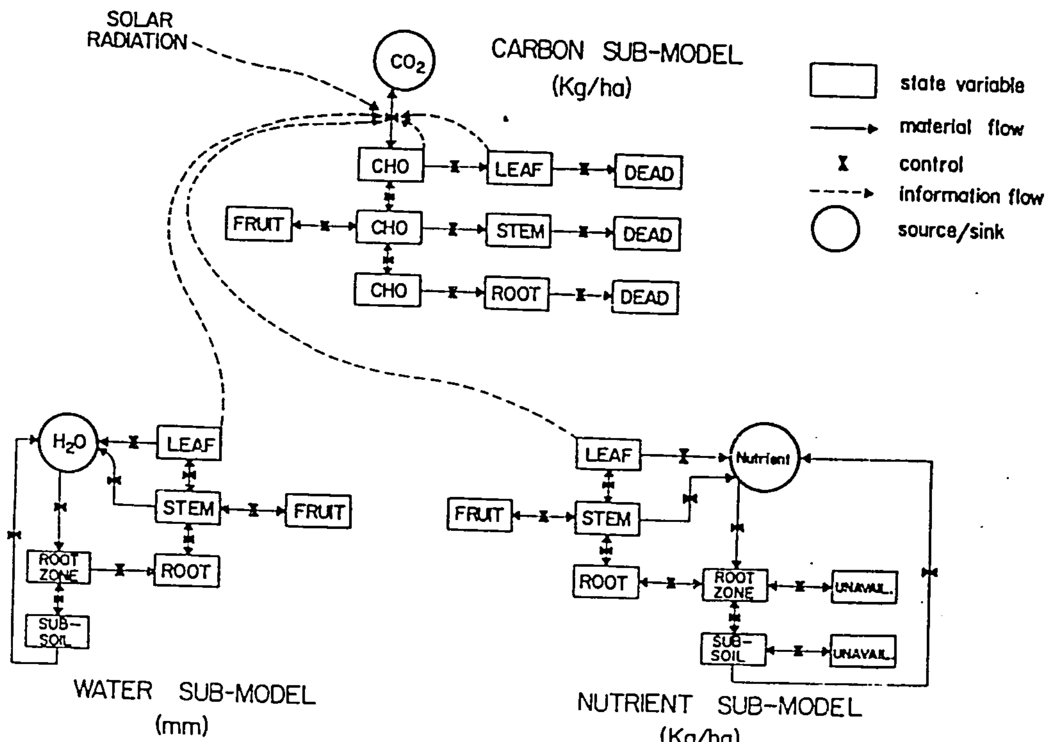

Fig. 1. A diagrammatic representation of a compartment model of the wheat crop. The model contains 24 state variables in the three submodels: carbon, water and one of a generalized nutrient. For simplicity only one example of the specification of information flow, namely to photosynthesis, is included.

been tried in agricultural and ecological modelling, it is the one that is currently considered to be the most valuable in building crop models.

To illustrate the technique a diagrammatic representation, suitable for the investigation of crop performance in relation to its environment, management and physiological properties, is depicted in Figure 1. This diagram is based upon a wheat crop simulator for which further explanation of structure and objectives can be found in Goutzamanis and Connor (1977). The important characteristics of the diagram are as follows.

- The system is comprised of subsystems each of which deals with a conservative quantity of the system. In this case water, carbon, and nutrients.
- Within each subsystem the modeller has chosen state variables which describe the distribution of the conservative quantities, and has defined the routes by which these materials can move around their respective subsystems.
- The flow of material between compartments is controlled by information which flows into the system from outside and which is generated within. Within the system there is no restriction on the flow of information. It may flow between as well as within subsystems and arise from the present or previous state of the system, that is, the values of the state variables or their rates of change in any combination.

The choice of state variables is the modeller's view of the system relative to his current objective. The abstraction of the system is enormous, in this case the biological intricacy of the wheat crop is replaced by 24 numbers, the values of the state variables (mm H_2O, kg ha^{-1} C, kg ha^{-1} N, and so on), which in this context completely define the system. The physiological and micro-environmental processes which determine the flows of material and information must themselves be treated at a level of detail determined by the choice of the state variables. There is, then, no one model of a wheat crop, or of an agroforestry association. There is a model appropriate to each set of objectives.

The diagrammatic presentation has been stressed because it is the first step in the development of a dynamic computer model. Also, it is often the only step that need be taken. If it is clear that insufficient empirical data is available to proceed with the construction of the model, then it has served the important initial purpose as an aid in the identification of the problem and of the level of abstraction of the system that is appropriate to its solution. Experimental work on system behaviour and process control within it has been defined, and its relationship to research objectives more clearly explained.

COMPUTER IMPLEMENTATION

There are four steps required to transfer a diagrammatic model of the type presented in Figure 1 into a dynamic model that can be used for experiment and prediction on a computer.

Identify equations for all flows of material and information.
Select values for all parameters that are included in definition of process and response.

- Set initial values to all state variables.
- Solve the equations at appropriate time intervals to calculate the current values of the state variables.

The value of the Forrester representation is that it is expecially suited to translation into mathematical form. This is further aided by the special purpose simulation languages (CSMP, SIMCOMP, ASCL) that have been designed to allow the modeller to concentrate his attention on the specificities of his own model, by providing for him the general framework that is common to the class of compartment model.

PROCESS SPECIFICATION

In this section I wish only to comment briefly on how well the flows of material and information can be specified in current crop models. Another way to put this is to ask: What mix of fact and fantasy (hypothesis) do they contain? Clearly the models provide a valuable way to test hypotheses concerning the behaviour of some parts of the system against the proven behaviour of the rest. However, if the content of hypothesis is too high, then the chance of using the model effectively is limited (Passioura, 1973).

The general answer to how well do we understand physiological processes at a level appropriate to building crop models is that it is very uneven. I expect that the papers to be presented during this meeting on physiological processes within agroforestry associations will confirm this.

Some processes such as canopy photosynthesis, crop water use, soil water balance, respiration, nutrient uptake and phenological development are relatively well understood and can be specified well in mathematical form. Modelling at various levels is actually contributing significantly to the development of understanding. This is seen particularly in the advances that have been made in the study of respiration and carbon balance generally (Penning de Vries, 1975).

By contrast, other processes are poorly understood and significantly the question of assimilate allocation between various functional parts of plants, for example to leaves, stems and roots, which goes to the very core of the problem of the dynamic simulation of crop growth, belongs to this class. In a very early model of pasture growth, Paltridge (1970) proposed that at each time step the plant might allocate the assimilate available to roots or leaves so as to maximize its growth capacity relative to the above- and below-ground restrictions that it is currently facing. There have been few other ideas and many crop models rely upon phenologically based allocation ratios often not responsive to environment. A sound experimental basis is available for sugar beet (Fick *et al.*, 1973), but for few other plants. Most plant physiological work on assimilate relationships is directed towards understanding the mechanisms and responses of translocation within the plant. Whilst this may ultimately explain allocation patterns in plants, it is not appropriate to the current requirements of stand level crop models.

One of the consequences of this uneven appreciation of the various component physiological processes is that models can easily become unbalanced. For example, great detail on canopy

photosynthesis may overwhelm the limited treatments of the other components of a model. This has to be avoided and simplification should ensure that the internal operation of the model is appropriate to the objectives. Very simple models which focus on limiting processes are often the most successful. Thus excellent productivity models can be built from water use models by incorporating the notion of water use efficiency (WUE, dm $ha^{-1} mm^{-1}$ water), especially if a separation can be made between the transpiration and soil evaporation components of evapotranspiration. This is so because WUE is more closely related to the transpiration component (Fischer and Turner, 1978).

CONCLUSIONS

Agroforestry research can capitalize on the progress made in simulation modelling to unravel the complexity of processes that determine the response of crop systems to environment and management. Techniques are readily available and, quite likely, some components of available crop models could be incorporated directly.

Even for crop species there is a shortage of appropriate empirical response functions, surely a serious limitation for the more varied, less studied species of agroforestry associations? However, if the systems approach is adopted at the outset there is the opportunity to design the experiments to collect the appropriate responses quickly and efficiently.

Definition of purpose, model building and experimentation offer researchers a valuable repetitive loop. Components from crop models could even now be used to answer specific questions about the performance of agroforestry associations. For example, issues relating to tree canopy design and the illumination of understorey species. And for environments short of water or nutrients simple budgeting should give important clues as to the long-term stability of various alternative tree/non-tree combinations.

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DISCUSSION

LEYTON - There seems to me to be a risk that in modelling we fail to see the wood for the trees. There are often too many peripheral factors brought in. Can we avoid some of these by identifying key physiological factors? For example, in considering plant and crop water relations the measurement of leaf water potential, leaf diffusion resistance, or, better still, crop diffusion resistance would enable us to replace a lot of other data. It is much more important to have a measurement of the water status of the crop than of the rate of water loss.

CONNOR - As I said in my paper, the type of modelling done must depend on the objectives of the modellers. In the example given our objective was to build a yield predictor based on site and weather without the need to take detailed plant records. The modelling approach is, however, very useful itself in determining which are the important plant parameters. For example, some recent very elegant work by Legg and others, which involved modelling, showed that stomatal activity was much less important than leaf area in the response of temperate cereals to water shortage.

JACKSON - This is the sort of question that modelling can answer very well. By using sensitivity analysis to see what happens if one factor varies, we can quickly determine the important ones.

KOZLOWSKI - Stomatal aperture is important, but something like the amount of water in the soil may have little effect on water stress in the plant. There can be water stress even with ample soil water, in fact waterlogged plants can wilt. The critical measurement is plant water status. For example, Thornthwaite did a series of experiments over a number of years, with apparently adequate irrigation, but found major differences in water stress because evaporative conditions varied from year to year.

CONNOR - I agree, but would point out that in some cases soil water can act as an adequate predictor and hence, in some circumstances, we can predict plant behaviour without the need for detailed plant records.

LOOMIS - I agree with Connor. Yield is formed when there is free transpiration and relative water content is high. Yield formation does not occur under stress.

KOZLOWSKI - Why use relative water content and not plant water potential?

LOOMIS - Because water potential shows hysteresis in relation to relative water content over the course of a day.

KOZLOWSKI - Even so water potential is a much better measurement of stress than is relative water content. The same relative water content in a young leaf and in an old leaf means very different things.

OWINO - What is the practical application of this work? Can models be used in crop - tree mixtures?

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CONNOR - Much modeling is still at the research stage but there are examples of practical application, usually of simple models or of model components in, for example, determination of irrigation strategy, predicting wheat yield, designing orchard structures and in pest management models. There has been little work on mixed crop communities, but the applications are certainly there.

HUCK - Many models deal with only one layer; a two-dimensional model is much more complicated.

CONNOR - But there are many others that deal with layers both above and below ground.

TIESZEN - Some ecological models do deal with complex situations.

LOOMIS - There are also some good row-crop model available.

THE ROLE OF TREES IN AGROFORESTRY: SOME COMMENTS

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ABSTRACT. In agroforestry land use systems the woody perennial components ('trees') play a role in both productivity and sustainability. Some general characteristics of woody perennials are outlined and the need to consider the possible advantages or disadvantages of these in relation to specific agroforestry systems is emphasized. In deciding about introducing trees on farm land the challenge is to answer the questions: What trees? How many? How are they best arranged? Answers to the first of these will arise from the many existing and planned trials with multipurpose trees now being established worldwide. This paper addresses mainly the second question: How many trees?

Three-dimensional diagrams are used to illustrate the effects of a replacement series (tree-crop, crop-tree) on changes in total productivity and soil status with time. The types of response surfaces produced are discussed and various 'scenarios' shown to illustrate the value of this approach. Such diagrams are less a predictive tool than a means of comprehending the plant and environment changes involved.

The final section briefly discusses tree/shrub arrangement, which will depend on management considerations, soil/water conservation needs, and biological aspects of optimizing productivity.

INTRODUCTION

Agroforestry is the term given to sustainable land use systems which involve more or less intimate and interacting associations of agricultural/horticultural crops and woody perennials (trees, shrubs, palms, vines, bamboos), all on the same unit of land. This form of land use has two main objectives: productivity, involving a multiplicity of outputs; and sustainability, which implies the conservation, or even improvement, of the

environmental aspects of the system. In some cases, agroforestry systems may be used to bring about restitution or improvement of soils, so as to broaden future land use options. Some common tropical agricultural and horticultural crops are themselves ligneous and may, if appropriately managed, fulfil this role.

Agroforestry, as a science, is a new discipline, or rather a new synthesis of existing disciplines. But it cannot remain purely descriptive for long, if it is to serve an active development function. Immediate programmes of investigation and research are needed to improve existing agroforestry systems, and to offer agroforestry substitutes for agricultural or forestry land use systems that are failing to fulfil either production or conservation needs.

A fundamental issue in agroforestry is the role of the tree (using this term in its broadest sense to imply any woody perennial), and this paper addresses itself to some of the more general questions related to this theme.

Characteristics of trees

Certain characteristics of perennial woody plants are common considerations in *any* type of land use system. For example, and rather obviously, woody perennials have lengthy actual and economic life cycles; thereby influencing investment patterns and restricting cropping flexibility. They are often dominated plants in plant associations in their juvenile phase, in an intercropping sense; whilst becoming dominant when mature. Compared with many common agricultural crops, seed dormancies are more prevalent and, because many woody perennial species are outbreeding, germ plasm is often highly heterozygous.

Tree seedlings frequently require to be raised with care, and land preparation is usually more demanding as compared with many herbaceous agricultural crops. The long-term persistence of trees in a land use system will influence pest management needs. Their permanent woody structure, with dormant buds, affords a wide choice of management techniques — training, lopping, browsing, pruning — with which to modify their shape and growth patterns, and flowering and fruiting behavibur. Relatively large permanent organs (branches, trunks and large roots) facilitate the storage of carbohydrate and nutrient reserves, thereby modifying nutrient requirements, and assisting survival during adverse environmental periods.

Characteristics of trees which are generally considered to be environmentally beneficial are: a continuity of plant cover, implying amongst other things, with some species at least, an ability to utilize incoming solar radiation which might otherwise be lost by seasonally sown plants; the capacity to enrich the microsite by depositing litter in the topsoil, which can then be exploited by more shallowly rooted species; and a capacity to modify the microclimate, which can bring about favourable effects on the soil and associated plant species. Offsetting these are strong plant competitive attributes, such as the capacity to shade understorey plants, and a tendency to dominate the water economy at the microsite.

These, and other features, form a 'mixed bag' of attributes some perhaps helpful, and others not, for any particular land use system. Certainly they need to be known, categorized and

thought about in relation to agroforestry.

Experimental evidence about tree/crop mixtures

In practice the net effect of mixing trees with herbaceous crops (or grasses) will depend not only on the 'richness' of the environment, and the ways in which the various plant types can share environmental resources, but also on characteristics, partly modifiable by man, such as the geometry of the system and various temporal relationships with regard to the phenology of the separate plant components. Two examples give the extremes. First, a temporal advantage in a tree/crop mixture is clearly shown by *Acacia albida*, a soil-enriching, leguminous tree of African savanna regions, which loses its leaves in the wet season. Associated crops of sorghum, millets, groundnuts, and so on, can thus gain the advantages of the enriched site whilst avoiding the worst effects of competition from the tree for light and water (Felker, 1978). Second, the canopy architecture of a plot of well-spaced, mature coconut palms readily permits light penetration to lower storey crops. Hence this ligneous species is useful with a large number of other plant associations (Nair, this volume).

Except for a few clear-cut examples like those above, we have as yet very little experimental evidence on tree/crop combinations that tells us whether the species mixtures will interact with mutual inhibition, co-operatively, or through one form or another of compensation (Willey, 1979). This information is going to be difficult to come by, because estimates of actual land equivalent ratios for tree/crop mixtures will have to be evaluated over many years. In any case, some adjustment is needed in calculating these to allow for the different land occupancy periods for the various plant components being compared; trees representing a much more 'permanent' type of occupancy.

Even if a particular tree/crop association were to be mutually inhibitory the mixture might, in practice, be encouraged by planners because of the long-term beneficial environmental effects of the tree components. However, such an association would prove even more difficult to promulgate than many agroforestry systems because of a poor productivity cost/benefit ratio during the early years.

Choice of agricultural crops

The agricultural crop components in any existing agroforestry system, or in any newly postulated one, will be largely restricted to species which satisfy existing consumer and market preferences in any particular region. Introducing completely new food or cash crops is generally a lengthy business! An exception to this might be in relatively infertile, semiarid ecozones where agricultural cropping is not generally considered viable, yet possibilities of nutrient transfer and improved water economy exist if trees are planted and the litter and mulch materials from them are carried to adjacent strips to support agricultural crops. In these circumstances cropping is a new enterprise, anyway.

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DECIDING ABOUT THE TREES

In most cases a considerable amount will already be known about the agricultural crop species in an agroforestry system, and about how to grow it. Much less is known about many of the tree species now being proposed for agroforestry systems (multipurpose trees), and on exactly how to define or evaluate their place in these systems.

Although agroforestry is concerned with the development of land use systems involving trees, it is not just 'scaled-down' forestry. This is more likely to be the case when developing community woodlots, or village fuelwood plantations, systems which might be termed 'microforestry'. The objectives, resources and socio-economic restraints underlying the adoption of tree-based farming systems will be more complex. Even the techniques of tree production and distribution could be optimized through quite different pathways in the two cases and, although the species used for fuelwood lots might well be the best adapted, adequately tested species selected for forestry purposes, many of these are decidedly *not* well suited to agroforestry systems on farmland. For example, *Eucalyptus* spp., which may be too competitive, poor at raising soil fertility, and inadequate in preventing soil erosion. Clearly, as a dominant partner, the role of the tree, and in many cases the individually spaced tree, is central to every agroforestry land use system. A challenge, then, is to answer the questions: What trees? How many? How are they best arranged? In the discussions that follow it is the position of trees in agroforestry systems suited to farm- or rangelands that is being considered.

What trees?

The current outburst of investigations on a whole new candidature of 'multipurpose' tree species is likely to provide a rich choice of different types for inclusion in agroforestry systems. Up to now many of these species have been noted as valuable only by ecologists. As their name implies they can be planted for a range of end uses and they can all be environmentally beneficial. Some genera currently being studied are: *Acacia*, *Albizia*, *Alnus*, *Azadirachta*, *Balanites*, *Brosimum*, *Cassia*, *Ceratonia*, *Cordeauxia*, *Gliricidia*, *Inga*, *Leucaena*, *Parkia*, *Prosopis*, *Sesbania*, and *Zizyphus* to name a few. Information about most of these has already been assembled (for example, National Academy of Sciences, 1980).

However, there is much still to learn about the characteristics of individual genera and species in relation to particular agroforestry situations. Important characteristics are: adaptability to soils and climate; rate of growth, particularly in the early stages; palatability as fodder; ability to withstand adverse conditions in the seedling/young plant stages; growth habit and spatial/temporal resource sharing characteristics, including rooting characteristics; shelter conferring and soil stabilization attributes; capacity to withstand lopping/pruning/browsing; vigour/productivity characteristics; nutrient cycling and/or nitrogen fixing capacity; and freedom from pests and diseases. A growing problem is to establish an adequate system, at both national and international levels, for collecting

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and distributing properly authenticated germplasm of such multipurpose species.

Chosing multipurpose trees for a particular site is not just a question of finding the most adapted and vigorous species. The requirements for outputs may vary even within the same local area (for example, mainly fodder, or fuelwood, or woody mulch, and so on). Furthermore, the ideotype and phenological behaviour must be suited to the characteristics of the other species, woody or otherwise, in any particular plant associations. Some way of characterizing multipurpose tree species within any agro-ecozone, and according to some form of selection index procedure may, for output products or services, ultimately, be the most satisfactory method.

How many trees of the chosen kind?

An inherent feature of many agroforestry land use systems is the trade-off between requirements for productivity and the sustainability of the system. Trees can impart environmental benefits to a system but often, and certainly in their early years, this may be at the expense of productive outputs. If the intention is to replace some proportion of an existing agricultural cropping scheme with trees, then what sacrifice will have to be made in existing outputs? What new mixture of outputs can be expected later? What happens to the sustainability of the system during the course of time? And what exact proportion of species is needed to achieve any particular set of requirements?

A precise answer to these questions can only be evaluated site-specifically. But can any first approximations be made, however crude these may be? The sequence of the steps proposed below divides the process into two, both in relation to time: first, an estimate of the effects of tree cover on the overall soil environment status (sustainability), and second, the effects on productivity.

Unfortunately, studies of enrichment of the microsite by the individual tree are, as yet, relatively scarce compared with the many investigations of changes in soil fertility / soil conservation status under natural forests or tree plantations, or on agricultural lands (but see, for example, Charreau and Vidal, 1965; Kellman, 1980). Thus estimates will have to suffice, in most cases, especially for newly introduced tree species.

Some assumptions can reasonably be made. For example, the ultimate level of microsite improvement of any particular tree species can be assumed to reach an equilibrium with time and it may be possible to estimate what this might be. Again, the current status of soil fertility, and the average productivity under any particular agricultural cropping pattern will be known, and some estimate can probably be made of the trend in soil fertility / soil conservation status under existing management practices.

A common unit to measure both soil productivity and soil environmental status can be the net present value of a unit area of test crop (say, maize) which is produced, or could be expected to be produced, at the site. If this unit is used for both estimates of sustainability and productivity it makes the diagrams which follow both dimensional and comparable.

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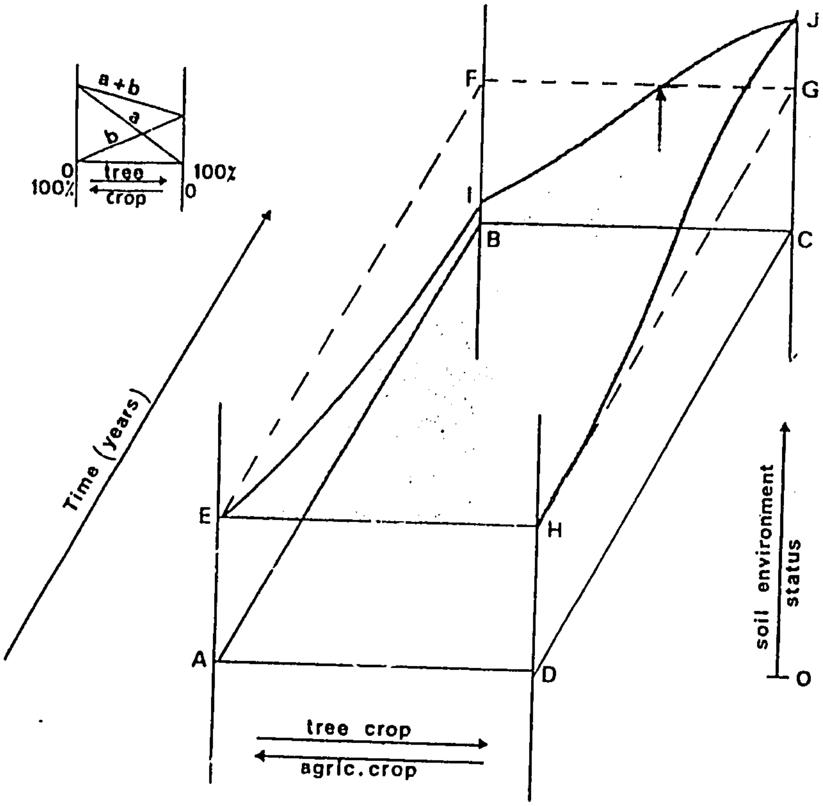

Fig. 1. Showing trends in the status of the soil environment with time. AD and DA represent a replacement series (see inset and Willey, 1979a, 1979b) which represents, at any one point on the x-axis, the sum of the effects that both species may have on the soil, depending on the percentage ground cover occupied by each. A-E (and D-H) indicate the current fertility/conservation status, and EIJH the response surface for all combinations of agricultural crop and trees (derived at any one time from a+b as in inset). See text for further details.

Soil environment status. Figure 1 indicates some postulated changes in the conditions of the soil (its fertility and state of conservation) for agricultural cropping, tree cropping, and all ratios of the two. ABCD represents a fertility level at which there is zero productivity, and the line E-H (also F-G) productivity at the current level of soil fertility. Projected soil fertility changes are then estimated for: continuous agricultural cropping (E-I), shown as declining; and the land under 100 per cent cover of trees of the chosen species (H-J), shown as improving with time.

EIJH then represents the response surface characterizing soil changes for all ratios of the agricultural and tree crops over time.

E-A should be known. And C-J might also be measurable if mature stands of the appropriate tree species are available on a similar, nearby site. Otherwise C-J will have to be estimated

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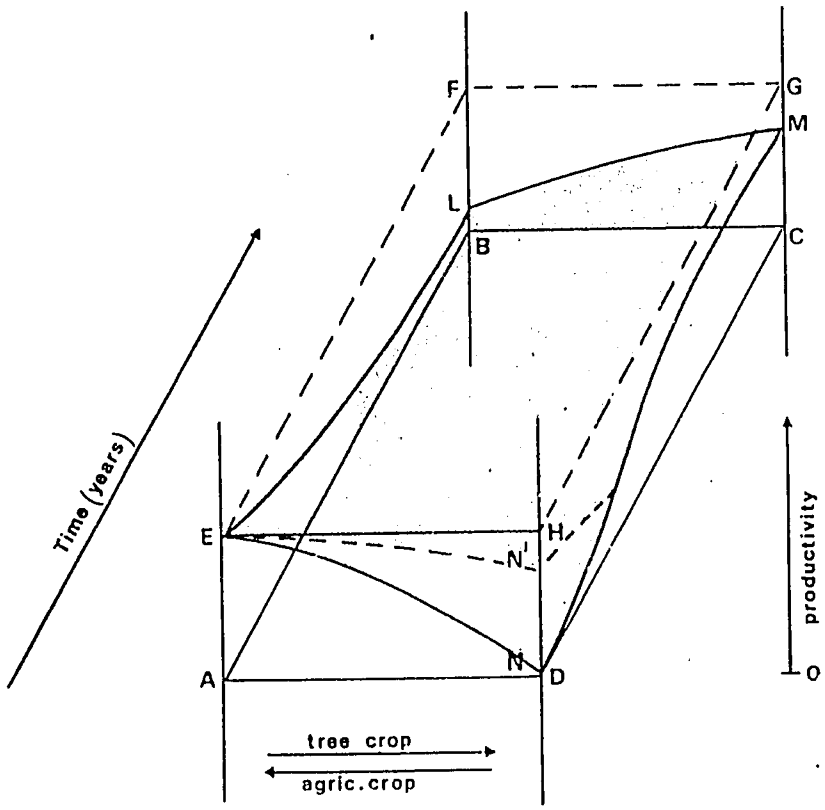

Fig. 2. Trends in total productivity with time, similar to Figure 1. At any one point on the x-axis (a replacement series) the response surface ELMD represents the combined productive output, of all kinds, for both species, (and see text).

from similar data in the literature. The same applies to the rate of decline of soil fertility, and so on, under continuous agricultural cropping. The time taken to reach the maximum improvement in the condition of the soil after planting trees may be unduly long, because an equilibrium state will be reached only slowly in the last few years. Thus C-J in Figure 1 may be taken, more pragmatically, to represent an estimated 90 per cent or any stated percentage, of the ultimate value. The time scale of the diagram will clearly depend on when it is estimated that this level will be reached. C-J minus A-E represents the amount by which the level of soil status under current land use falls short of what it could be under a mature stand of trees.

Productivity. Figure 2 indicates the changes over the same time in total productivity. That is taking into account the respective values of the total agricultural and tree products. As before, ABCD represents zero productivity. E-L shows the estimated changes of value with time for continuous agricultural cropping, and N-M that for 100 per cent tree cover (N, the value of the tree crop in the first year, has been taken as zero in this

example). Response surface ELMN then represents the total production of all the different proportions of the agricultural and tree crops. As the common unit used is market value, E-I represents the soil status in Figure 1 and it is the same as E-L, representing productivity, in Figure 2.

The value of the tree products will need to be averaged out if annual harvests are not taken. In Figure 2 the annual value of the tree products at maturity with 100 per cent tree cover (C-M) could be either greater or lesser than the value at the present time from 100 per cent agricultural cropping (A-E). This will depend on current agricultural yields, reflecting the present fertility status of the soil, as well as the expected outputs of the agricultural and tree products with time.

The diagrams obviously lend themselves to more detailed economic analyses in terms of, say, estimates of variable and fixed costs, or of calculating returns to labour inputs, and so on. Furthermore, there might be changes of inputs with time which should be taken into account. The productivity response surface in Figure 2 can be adjusted accordingly.

Time trends. The curves plotted on the axes in Figures 1 and 2 have been drawn to represent changing conditions, as far as these can be estimated at present. Only sets of actual experimental data will show if these estimates truly simulate real conditions or not. For example, in Figure 1 the reduction in soil fertility under continuous agricultural cropping (E-I) will generally reflect a decline in soil organic matter which follows a negative exponential curve (Ahn, 1979). But to this must be added any effects of soil erosion which will be hard to estimate and erratic in occurrence.

Then again, soil fertility changes after planting young trees (H-J) have been represented by a sigmoid curve to indicate a maximum rate of change in the middle years. Planting relatively widely spaced trees on agricultural land will bring about a mosaic of improved fertility in the topsoil beneath the tree canopies. The effect may be enhanced if the trees fix nitrogen, and if nutrient catchment from windblown dust is involved. It has been assumed that, where there are relatively few trees per unit of land, both their growth and fertility conferring benefits might be diminished compared with a situation where tree cover is more complete. To account for this I-J in Figure 1 is also shown as a sigmoid curve.

In Figure 2, representing the productivity response surface, the value of the output of products from a pure stand of trees (N-M) will be very little in the first few years and it will reach a plateau at maturity. In the early stages after planting out young trees the agricultural crop can utilize more of the shared environmental resources because the size of the trees is so small. E-N will be convex therefore and, if some form of taungya is practised in the first year or two, so as to take maximum advantage of this situation, there need be little loss of productivity (see E-N'). As one is seeking plant associations which, in a replacement series, show either mutual co-operation, or, where one of the components shows a level of compensation which gives an overall increase in productivity (that is a land equivalent ratio greater than one), L-M will also be convex under

such favourable circumstances.

Further considerations. Figures 1 and 2 show the two basic shapes of the expected response surfaces for soil and productivity changes, respectively. These may be useful to help visualize the complex trends which will occur with time in converting from agriculture to a mixed cropping agroforestry system. They also indicate where more research data are needed. Figure 1 can help, also, to suggest what proportion of mature tree cover is required in order to achieve, ultimately, any particular level of soil fertility in the mixed cropping system. For the situation depicted, the present-day level of soil fertility will be maintained if approximately a 60 per cent tree cover is arranged (arrowed where I-J cuts F-G). Obviously fewer trees will be required should the soil fertility decline less rapidly under continuous agriculture, and/or a tree species is used which raises soil fertility to a greater extent. On this basis Figure 3 shows some land use situations in which options for agroforestry may or may not be promising.

The extent to which any improvement in topsoil fertility under or around the trees can be exploited by associated crops while the trees are still growing needs to be the subject of experimentation for particular combinations of species. Some transfer of litter and nutrients away from the tree's immediate surroundings is likely, and its extent will be influenced by management practices. Such effects will, perhaps, increase productivity (C-M), and serve to make the productivity response surface even more convex at its further end (L-M) (Figure 2).

By substituting relatively large trees for agricultural crop plants the total population of plants per unit of land will be diminished and the diagrams should be constructed to indicate percentage ground cover ratios. In addition, substituting trees for herbaceous crops will change the land occupancy ratio. Such factors affect the way we should interpret the yield curves and the validity with which we can make comparisons between them. In view of the need to adopt a 'first approximation' approach, however, these difficulties can just be borne in mind at this stage.

The actual number of trees per unit of land will obviously depend on the species under consideration. Many multipurpose trees are of small to medium stature. If the appropriate canopy area at maturity is known 'percentage cover' can be roughly translated into 'numbers of trees per unit area'.

To find the answer to our question 'How many trees?' may still not be easy, but some of the considerations underlying the processes involved in reaching a conclusion are, at least, outlined above, and some 'scenarios' are shown in Figure 3.

How are the trees to be arranged?

Once the kinds and the numbers of trees required have been decided upon, in relation both to the land user's objectives and resources, then the question of optimizing their spatial arrangement has to be considered.

There are three main factors: management considerations, soil and water conservation aspects, and theoretical aspects of optimizing biomass and/or particular plant products.

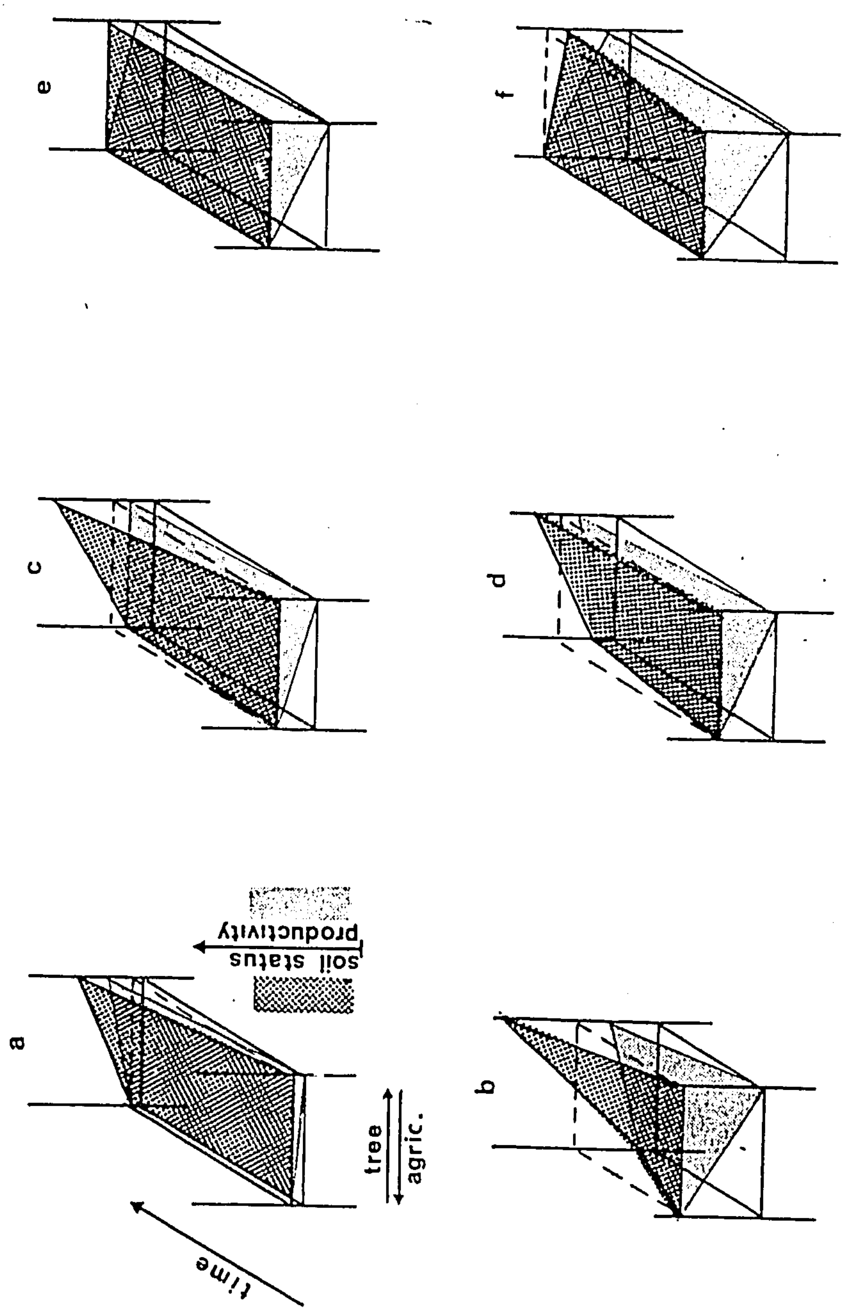

Figure 3.

Fig. 3 (*Opposite*) Some scenarios comparing different soil environment and productivity states for various agricultural crop/tree situations (linear trends drawn, for simplicity).
(*a*) Very low present fertility and productivity; for example, low rainfall rangeland undergoing desertification. Any attempt at agriculture fails to raise the soil environmental status or productivity except at great cost in terms of irrigation, fertilizers, and so on, but trees improve the soil and therefore, ultimately, enhance productivity. Agroforestry is definitely to be considered.
(*b*) Initially fertile land (for example, cleared forest) but agricultural cropping brings about a very rapid decrease in fertility and productivity. Note the shorter time scale. The tree species chosen, for example fast growing legumes, are supposedly very effective at enhancing even the initial high level of soil fertility. Agroforestry definitely to be considered as an alternative to hign input agriculture.
(*c*) Rather low initial level of soil fertility with a slow decline under the present agricultural cropping system. The tree species has been chosen to raise soil fertility level, but tree products are of low value for this species. Agroforestry may be worth considering if environmental conservation is important, and as an alternative to increasing the level of agricultural inputs; especially as a system using a relatively small amount of tree cover might still be effective.
(*d*) Higher initial soil fertility is postulated which agricultural cropping decreases at a faster rate than in (*c*). The tree species chosen is deemed not to be especially effective at raising soil fertility, but its products are more valuable than in (*c*). So that, ultimately, 100 per cent tree cover will provide an output more valuable than that from the agricultural system. Agroforestry is to be evaluated against loss of income during the development years, and the level of environmental conservation (or enhancement) required.
(*e*) A moderately good initial fertility which high input agriculture maintains equally as well as the tree cover, for example, a maize farming system using minimum tillage with the litter left on the soil. Productivity under trees is less than in the agricultural system, so there is no case for agroforestry unless the tree products are specifically required.
(*f*) A high initial fertility, which is maintained (or even improved) by high input agriculture (for example, coffee farming using fertilizers and mulch) to a greater degree than a multipurpose tree cover would achieve. Productivity under trees is assumed to be rather low. There is no case for agroforestry.

Management decisions. The first is whether to adopt a mixed or a zonal agroforestry system (see Huxley, p.163, this volume). This basic choice is an important one which will depend on both technical and social considerations. Zonal agroforestry is likely to simplify management procedures because each tree or crop component can be dealt with largely as a sole cropping enterprise within the system. 'Alley cropping' (Kang *et al.*, 1981), a form of zonal agroforestry, is one convenient way to arrange the plants. In zonal agroforestry the extent of plant-to-plant interactions will depend on the species involved as well as the overall land unit size and the size, shape and arrangement of zones within it. Between-species interactions, as found in the more intimately associated mixed cropping systems, will occur only at the interfaces between zones.

The transfer of materials (litter or mulch) can easily become part of the management procedures in zonal systems. Where there is already some information about the potential for introducing a suitable agroforestry tree species, but little or nothing is known of the interactions with agricultural crops, then a zonal system may offer a less committed, and more flexible approach, than that of more intimately mixed alternatives.

Soil and water conservation considerations. Information about the use of trees for soil conservation is available from various sources, for example Tejwani (1979). Although more quantitative data are required, especially for many of the 'new' multipurpose species which are now attracting attention. Trees can actually encourage soil erosion in some circumstances. For example, if the wrong species are used and/or they are planted in the wrong places (Wenner, 1981). Thus an important aspect of agroforestry planning must be a consideration of the spatial arrangements of trees in relation to soil and water conservation.

Optimizing the product. Finally, it is possible to draw on a vast body of information from a range of different plant science studies concerning the theoretical aspects of optimizing productivity through proper spatial arrangement and management of the component plant species. In particular the work on plant canopies and light interception (see Jackson, this volume), on plant ideotypes and competitiveness (or commensalism), and the growing body of information from agricultural intercropping studies (see Cannell, this volume).

Because trees and shrubs lend themselves to easy modification of shape and size there will be many opportunities to manipulate the growth of trees in agroforestry systems by training, pruning and lopping. The extensive knowledge we already possess about these procedures for existing tree crop species, both temperate and tropical, can form a useful basis from which to start.

What is immediately required for all aspects of tree arrangement and management is a new synthesis of existing information.

CONCLUSIONS

Agroforestry may be biologically more complex than many ways of

using land through agriculture or forestry, consequently such systems often require greater management skills. Certainly the development of agroforestry needs to embrace a combined technical and socio-economic approach from the very start; with the rural land user being intimately concerned with the available choices at every stage. These choices relate to requirements for particular kinds and levels of productive outputs, and to the potential for sustainability. The characteristic of all agroforestry systems is that they can provide both.

Diagnosis and evaluation of any agroforestry system *must* encompass predictions about its performance in the future. This implies a joint deductive/inductive approach to evaluation and prognosis which utilizes methods of survey and sampling concerning what is already on the ground (Steppler and Raintree, this volume), and also attempts to evaluate potential future trends using such information as is presently available. In these processes decisions about how to chose and handle the trees stand out as a priority. We can usefully approach this through the steps of: What trees? How many? How do we best arrange them?

The diagrammatic method outlined in this paper which can help to answer the second question is not intended as a predictive tool; far too much conjecture is implicit in the construction of such diagrams. Where they may be helpful is to illustrate the processes which have to be considered, and what type of experimental data we require before such an approach can be undertaken with confidence. Only when we have such data will it be possible to assess the productivity and sustainability roles of trees in any particular agroforestry system with any precision.

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DISCUSSION

CONNOR - The processes shown in the diagrams need a good deal of experimentation in order to establish actual curves. Such diagrams will be the output of actual models.

BRUNIG - These diagrams are useful in assessing the direction in which the systems are likely to move. However, they indicate only the trends; accurate and precise predictions are not possible.

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SECTION SIX

PART 6C

Glossary of terms for agroforestry research

PART 6C

CONTENTS

Glossary of terms for agroforestry research

- by P.A. Huxley
P.J. Robinson
P.J. Wood
et al.

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A GLOSSARY OF TERMS USEFUL IN AGROFORESTRY RESEARCH

This glossary has been compiled by Peter A. Huxley, Patrick J. Robinson and Peter J. Wood (with the help of numerous others), and recourse to existing glossaries. It will be revised and added to from time-to-time and should be considered, at this stage, as incomplete.

The intention has been to define terms that are commonly used in agroforestry research and, especially, to include these that are either newly-coined (still relatively few), and those that are sometimes used in rather different ways by poeple coming from different disciplines.

Except where a very generally-accepted definition has been given the initials at the end of each entry indicate the name of the author. Some 30 or so entries have been taken (in a shortened form) from the introduction to "A Preliminary Agroforestry Word List With Definitions" by R. Labelle (1983, ICRAF Working Paper No. 8).

TERM	DEFINITION	AUTHOR
Absolute growth rate (AGR)	Of a plant:the actual change in plant material (dry weight) per unit of time	PAH
Accuracy	How near the 'true' value the estimate is: accuracy involves both 'precision' and 'discrimination' (which see)	PAH
Adaptation	The process by which individuals (or parts of individuals),populations,or species change in form or function in such a way to better survive under given environmental conditions (also the results of this process)	RWA
Additivity	The response to treatments (and blocks,if relevant) being of the same kind and magnitude in the presence of other treatments (or blocks),that is no interactions occur	PAH
Agricultural system	A system with agricultural output and containing all the major components	CRWS
Agroecological zones	Zones of similar agricultural performance as defined by soil and climate	PW
Agroforestry spatial units	See 'Primary land unit'.'Management boundary' and 'Total area'	
Agroforestry system	A landuse system in which woody perennials (trees,shrubs,palms,bamboos) are deliberately used on the same land management unit as agricultural crops (woody or not) and/or animals,either in some form of spatial arrangement or temperal sequence.	BL

TERM	DEFINITION	AUTHOR
Agropastoral system	A landuse system in which crops and livestock(but not trees)are the only components	RL
Agrosilvicultural systems	An agroforestry system for the concurrent production of agricultural crops(including tree crops) and forest crops. The forest crops serve either in a productive or a service role,tree and agricultural crops are chosen first for their productive capacity	PKN
Agrosilvopastoral systems	All agroforestry systems which include trees or shrubs and herbaceous food crops and pastures and animals	FT
Air layering	A technique of propagating using an undetached stem to which the rooting medium is applied by securing it in an appropriate container (polythene bag). See also 'Layering'	PAH
Allele	One of a pair (in a diploid individual),or series (in a population or a polyploid individual) of genes located at the same locus on homozygous chromosomes and controlling the same character	
Allele	One of a pair or series of forms of a gene which are alternative in inheritance because they are situated at the same locus in homolgous chromosomes	RWA
Allelopathy	The influence of plants, other than micro-organisms,upon each other, arising from the products of their metabolism	SAF
Alley cropping	An agroforestry intercropping system in which species of shrubs or trees are planted at relatively close within-row and wide between-row spacings in order to leave room for herbaceous cropping between i.e. in the 'alleys'	PAH

TERM	DEFINITION	AUTHOR
Allometric relationships	Deal with the change in the ratio between two different dimensions of an organism ,such as roots:shoots,leaves:stems etc., with time	PAH
Allopolyploid	A polyploid containing genetically different sets of chromosomes,for example,sets from two or more different species	RWA
Amphidiploid	A polyploid whose chromosome complement is made up of the entire somatic complements of two species	RWA
Anemophilous	Wind pollinated	
Aneuploid	An organism whose somatic chromosome number is not an even multiple of the haploid number	RWA
Anisotropic	Describing a body that possesses different properties in the different direction: e.g. in wood,strength and shrinkage properties vary in the radial, tangential and transverse directions	JB
Annuals	Plants that flower and complete their life cycle in the same year that their seeds germinate: see also 'seasonal' plants	PAH
Anthesis	The opening of a flower bud: the exposure of stamens and stigmas to pollinating agents:the span of life of a flower	SAF

TERM	DEFINITION	AUTHOR
Apomixis	Reproduction in which sexual organs or related structures take part but fertilisation does not occur,so that the resulting seed is vegetatively produced	RWA
Apomixis	The production of seeds without fertilisation	
Aquasilvicultural systems	Agroforestry sys ems which combine trees with the raising of aquatic animals	RL
Assessment	The estimation of condition or performance, both qualitative and quantitative, of a situation, plant or animal, with ranking where appropriate	PW
Autecology	Deals with the study of the individual organism,or an individual species:with an emphasis on life histories and behaviour	EPO
Autogamy	Self-fertilisation	RWA
Autopolyploid	A polyploid arising through multiplication of the complete haploid set of a species	RWA
Available water capacity	A measure of the ability of the soil to supply water to plants the difference betwee field capacity and wilting point	PJK

TERM	DEFINITION	AUTHOR
Backcross	A cross of a hybrid to either of its parents. (In genetics a cross of a heterozygote to a homozygous recessive)	RWA
Benefits	In economics: goods and services(outputs) that increase the income of families or firms or increase the national income of the society	JPG
Bias	Any operation which allows a particular treatment, or replication, to be favoured or handicapped by some extraneous source of variation: a property of the sampling procedure	DJF
Biennials	Plants that only flower in the year following that in which they germinate from seed	
Biomass	The total weight of living material, of all forms	CRWS
Biosystematics	Taxonomic studies involving morphology, cytogenetics, ecology and phytogeography	
Biotype	A group of individuals with the same genotype (biotypes may be homozygous or heterozygous)	RWA
Block	A set of items or experimental units under treatment or observation, which have been grouped to minimize environmental effects or initial differences between items or units in respect of the variables being studied, e.g. a set of contiguous experimenta	

TERM	DEFINITION	AUTHOR
Blocks	A group of units:adjacent plots of land each subjected to an individual treatment,a single operator, a batch of plants from the same source - each can be considered as a 'block'	
Bole	A tree stem once it has grown to substantial thickness, capable of yielding timber or large poles	SAF
Boundary	The conceptual limits of a system,penetrated by outputs and inputs but not by feedback loops	CRWS
Breast height	By international agreement (through International Union of Forest Research Organisations) 1.3m from ground level at which the girth or diameter of trees are commonly measured. (1.37m is used in some parts of the world)	SAF
Breeding system	See 'Inbreeding' and 'Outbreeding'	
Breeding system	The natural processes by which sexual union occurs,including cytogenetic, morphological and physiological structures and processes:it includes the pollination system (wind,insects,self-pollination etc.)	JB
Browsing	A method of feeding by herbivores in which the leaves and peripheral shoots are removed from trees and shrubs	CRWS
Browsing	The feeding on buds, shoots and leaves of woody growth by livestock or wild animals. Browse is any material browsed or fit for browsing	SAF

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TERM	DEFINITION	AUTHOR
Budding	See 'Grafting'	
Buffer	In biological systems:to regulate against sudden change	PAH
Buffer action	The action of ionisable molecules in equilibrum with ions in solution in reducing pH variations that result from additions of acids,N bases, changes of concentration of a solution etc. The effect is to stabilize pH	SAF
Bulk breeding	The growing of genetically diverse populations of self-pollinated crops in a bulk plot with or without mass selection,followed by single plant selection	RWA
Bulk density	Of soil:weight per unit volume	
Bunding	The arrangement of organic material, e.g. agricultural waste, or soil, in lines along the contours of a slope, to control run-off or erosion	PW
Bunds	In India,any artificial embankment,a dam or dyke or causeway	SOED
Carrying capacity	Amount of animal life,human life or industry that can be supported indefinitely with available resources on a given area	HTO

TERM	DEFINITION	AUTHOR
Caulescent	More or less stemmed or stem-bearing,having an evident stem above ground	GHML
Certified seed	Seed used for commercial crop production produced from foundation,registered,or certified seed under the regulation of a legally constituted agency	RWA
Character	An attribute of an organism resulting from the interaction of a gene or genes with environment	RWA
Chemotaxonomy	The classification of plants on the basis of the presence and concentration of certain specific chemical compounds in them	PW
Chromosome	A small, elongated, deeply staining body found within the nucleus, consisting primarily of DNA and a protein sheath, and containing the genes or factors responsible for most hereditary traits	JB
Clines	Types of continuous character variations (genetically based) which are related to environmental gradients however the terms cline is not a taxonomic category	PJR
Clone	A group of organisms descended by mitosis from a common ancestor	RWA
Closed system	A system which does not exchange matter with the surroundings,it may exchange energy with the surroundings	CRWS

TERM	DEFINITION	AUTHOR
Co-incident cropping	A cropping sequence in which two or more species with similar crop durations are grown together on the same unit of land	PAH
Collar	The transition zone between stem and root, sometimes recognizable in trees and seedlings by the presence of a slight swelling	SAF
Combining ability	General. Average performance of a strain in a series of crosses	RWA
Combining ability	Specific. Deviation from performance predicted on the basis of general combining ability	RWA
Component	Of a system: an identifyable unit within a system,it may be capable of independent physical existence or be an entirely conceptual entity	CRWS
Composite (variety)	A mechanical mixture of strains bred and selected in order to provide a suitable range of genotypes giving a similar product but possessing a broader set of adaptability,disease resistance,etc. characteristics than would otherwise be the case	PAH
Concomitant cropping	A cropping sequence where two or more species ,one of which has a shorter crop duration than the other(s), are grown together on the same unit of land	PAH
Confounding	In the statistical sense:when the differences arising from a treatment(or set of treatments)cannot be distinguished,or tested statistically,from some other source of variation(e.g. blocks) or from another treatment (e.g. pooling higher order interactions	PAH

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TERM	DEFINITION	AUTHOR
Constraint	A requirement that a system has to satisfy if outputs are to be maximized(or,in human terms,optimised)	PAH
Continuous cropping	The growing of crops in succession without seasonal fallowing	DL
Continuous succession	See 'Crop succession'	
Coppicing	Cutting (broadleaved) trees close to ground level to produce sprouts or regrowth. Also occurs if trees are damaged	
Costs	In Economics: goods and services(inputs) that reduce the income of families or firms or reduce the national income of the society	JPG
Covariance	The mean of the product of the deviation of two variates from their individual means. A statistical measure of the interrelation between variables	RWA
Covariance analysis	Extension of the A of V where the dependent variable being analysed is a function of one or more independent variables not controlled in the experimental design but which have been observed(at each value of the dependent variable)	JB
Creeper	A trailing shoot that takes root mostly through its length sometimes applied to a tight-clinging vine	GHML

TERM	DEFINITION	AUTHOR
Crop growth rate (C)	The increase of crop material per unit area of ground covered by the canopy of the crop per unit time expressed,for example, as an absolute increment in kg per hectare per week, or grams per metre squared per week. C = NAR x LAI (which see)	PAH
Crop index	The proportion of the total plant biomass produced by a crop species that forms a particular,required (harvestable) plant part:usually expressed as a percentage	PAH
Crop succession	Relates to the occupancy of the land and the successive ways in which it is planted or sown crop succession can,basically, be 'intermittent' or 'continuous'	PAH
Cropping patterns	The yearly sequence and spatial arrangement of crops,or crops and fallow,on any given area (see also alley cropping etc.)	DJA/AHK
Cropping sequence	The time course of events among crop components utilising the same unit of land cropping seqences can be co-incident,concomitant,overlapping or interpolated (which see)	PAH
Cropping systems	The cropping patterns used on a farm and their interaction with farm resources,other farm enterprises and available technology which determines their makeup	DJH/AHK
Culm	The stem of grasses and bamboos,usually hollow exept at the swollen nodes	GHML
Cultivar	A cultivated variety	

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TERM	DEFINITION	AUTHOR
Cultivar	A variety or race that has originated and persisted under cultivation, not necessarily referable to a botanical species	GHML
Cultivar	An assemblage of cultivated plants raised or maintained by man which is clearly distinguished by some characters (morphological, physiological, cytological, etc) and which, when reproduced either sexually or asexually retain its distinguishing characters	PJR
Deciduous	Of a leaf: falling at the end of one season of growth or life:of a perennial plant, losing its leaves (or a proportion of them) at the end of a season's growth	GHML/PAH
Degrees of freedom	The number of independent comparisons that can be made in a set of data	RWA
Densitometry	The measurement of density, especially basic woody density, normally expressed as Kg/m3 or g/cc, by indirect methods e.g. using B or X-ray analysis	
Design	A method of arranging sample or experimental units to minimize the effects of uncontrolled variation caused by natural factors e.g. soil fertility, and to make it possible to estimate the magnitude of such effects in relation to those due to variations	
Design	A method of arranging sample or experimental units to minimize the effects of uncontrolled variation caused by natural factors (e.g.soil) so as to estimate the size of such effects in relation to those due to treatments	
Determinate	Of a stem:when continuing growth is stopped by the abortion (or permanent dormancy) of the apical bud.Of an inflorescence,when the terminal flower opens first and axis prolongation is thereby arrested (e.g. a cyme)	PAH/GHML

TERM	DEFINITION	AUTHOR
Deterministic	A deterministic situation is one in which g[illegible] inputslead to predictable outputs	CRWS
Development	For plants, that sequence of events that br[illegible] about full sexual maturity, leading to [illegible]ower[illegible] and fruiting	PAH
Dioecious	Plants in which staminate and pistillate [illegible] occur on different individuals	RWA
Diploid	An organism with two chromosomes of each ki[illegible]	RWA
Discounting	The process of finding the present worth of future amount:the present worth is determine[illegible] multiplying the future amount by the expres[illegible] 1+(1+i)to the power n when i= the discount (internal rate) and n= the year	PGR
Discrimination	The precise size of a unit which the method [illegible] differentiate	PAH
Dominance	Intra-allelic interaction such that one alle[illegible] manifests itself more or less,when heterozygous,than its alternative allele	RWA
Dominant	Generally an individual or species in the up[illegible] layers of the canopy	

TERM	DEFINITION	AUTHOR
Dominant plants	In intercropping,species or individual plants that,by virtue of their stature,form or functional processes, possess the ability to take a larger share of the available environmental resources than would otherwise be the case	PAH
Dominated plants	In intercropping: species or individual plants that by virtue of their stature,form or functional abilities find themselves with a smaller share of available environmental resources than would otherwise be the case	PAH
Dormancy	A period of quiescence when no apparent growth or development is taking place a form of growth regulation	PAH
Driving function	See 'Variables (Exogenous)'	
Dysgenic	Detrimental to the genetic quality of a population (as in creaming the best trees from a stand, leaving the poorer phenotypes to be parents of the next generation)	JB
Ecology	The study of the totality or patterns of relations between organisms and their environment	EFO
Economic analysis	An analysis done using economic values:in general economic analysis omits transfer payments(including credit transfers etc.) and values all items at their value in use or their opportunity cost to the society	JPG
Ecospecies	A sexually - reproducing population, the constituents of which produce vital and fertile descendants with each other but give rise to less vital or more or less sterile descendants when crossed with individuals of any other population	PJR

TERM	DEFINITION	AUTHOR
Ecosystem	Any unit that includes all the organisms(the 'Community')in a given area interacting with the physical environment so that a flow of energy leads to a clearly defined trophic structure,biotic diversity and material cycles within the system	EPO
Ecosystems	Systems which include both living and non-living substances interacting to produce an exchange of materials between living and non-living units	CRWS
Ecotype	Those products of the reaction between the genotype and the environment which are found as a result of the selective action of the predominant factors of the environment - a range of an ecocline	PJR
Edaphic	Pertaining to the soil in its ecological relationships	
Efficiency	A ratio of output (or performance or success) to the input(s)(or costs) involved,over a specified time and in a specified context	CRWS
Electro - focussing	Separation of amphoteric substances (electric charge varies with pH e.g. amino acids,peptides)in a liquid or gel in which there is both a voltage and a pH gradient:compounds migrate to where pH corresponds to its iso-electric point	
Electrophoresis	Separation of charged molecules in a fluid or gel by creating an electrical field which draws groups with positive charges to the cathode and those with negative charges to the anode.Molecular size and shape affect rate of migration	
Elite - tree	A tree of proven good combining ability (genetic breeding value), proven by progeny test	JB

TERM	DEFINITION	AUTHOR
Endemic	Native or confined naturally to a particular and usually restricted area or region biologically a relic of once wide distribution	GHML
Entomophilous	Insect pollinated	
Epiphyte	A plant growing on but not nourished by another plant	SAF
Error variance	Variance arising from unrecognised or uncontrolled factors in an experiment with which the variance of recocnized factors is compared in tests of significance	RWA
Eugenic	Beneficial to the genetic quality of a population, (as in classical "plus tree" or superior phenotype selection)	
Evapotranspiration	Loss of water by evaporation and transpiration	
Evergreen	Remaining green in its dormant season, sometimes applied to plants that are green throughout the year, properly applied to plants and not to leaves. but due to the persistence of leaves	GHML
Ex situ	When applied to tree plantations refers to a planting site distant from the seed collection site	

TERM	DEFINITION	AUTHOR
Exotic	Commonly used to refer a plant introduced from a foreign country. However, strictly,it should refer to a plant grown anywhere outside its natural range (synonymous with'Non-native')	
Experiment	An action or operation undertaken in order to discover something unknown,to test a hypothesis or establish or illustrate some known trends (SOED):may be part of an 'Investigation' and of more significance than a 'Trial'	PAH
Factorial	An experiment in which all levels of two or more treatments or factors are applied singly and in combinations so that the main effects and interactions can be observed	PJP
Fallow	Land rested from deliberate cropping,not necessarily without cultivation or grazing but without sowing	CRWS
Feedback (loop)	The use of information produced at one stage in a series of operations as input at another,usually a previous, stage	CRWS
Fibre	A general term of convenience for any long narrow cell of wood other than vessel elements and parenchyma. Includes the trachieds of gymnosperms and the libriform wood-fibres and fibre-tracheids of woody angrosperms	JB
Field capacity	The amount of water a soil will hold against gravity when given reasonable time to drain commonly taken as one third atmosphere tension(for clays).and one tenth atmosphere (for sands)	
Financial analysis	An analysis done using market prices	JPG

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TERM	DEFINITION	AUTHOR
Flow chart	A series of steps or procedures ,in logical sequence, indicating how to acheive a stated objective(s)	PAH
Flow diagram	The diagrammatic representation,usually with conventional symbols,of the structure of a system in terms of physical and information flows between compartments	CRWS
Flower	Strictly an angiospermous reproductive structure bearing pistils stamens or both, and usually sepals and petals. The so-called flower of conifers is the male or female strobilus before and during pollination	
Flushing	Of leaves and foliage etc.:their fresh growth, especially when rather sudden	SAF/PAH
Forb	Broadleaved herb (excluding grasses)	
Forbs	Herbaceous plants excluding grasses	
Forcing function	See 'Variables (Exogenous)'	
Forest gardens	A landuse form on private lands outside the village in which planted trees and sometimes additional perennial crops occur	KFW

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TERM	DEFINITION	AUTHOR
Foundation seed	Seed stock produced from breeder seed by or under the direct control of an (agricultural) experiment station. Foundation seed is the source of certified seed,either directly or through registered seed	RWA
Free growth	The situation where a tree or other plant has grown with its crown more less free from competition	
Gimete	A male or female reproductive cell, typically the product of meiosis, capable of uniting in the process of fertilisation with one of the opposite sex	SAF
Gene	The unit of inheritance	RWA
Gene	The basic unit of most types of inheritance occupying a fixed positin on a chromosome and consisting of a portion of a DNA molecule	JB
Gene frequency	The proportion in which alternative alleles of a gene occur in a population	RWA
Gene pool	The total genetic information possessed by the reproductive members of a population of sexually reproducing organisms	JB
Genecology	A combination of ecology and genetics to study the genetic variation among populations of a species that is correlated with habitat	JB

TERM	DEFINITION	AUTHOR
Genetics	Deals with the causes of resemblances and differences among organisms related by descent:takes into account the effects of genes and environment	
Genotype	The entire genetic constitution of an organism	RWA
Genotype	An individual's hereditary constitution,with or without phenotypic expression of the one or more characters it underlies:the genotype is determined chiefly from the performance of progeny and other relatives.Genotype x Environment = Phenotype	
Genotype	Individual(s) characterized by a certain genetic constitution	
Genotype x environment interaction	The failure of entries to maintain the same relative ranks and level of differences when tested in different environments. The tests are planted at more than one location or under more than one cultural condition	
Genus	A rather arbitrary category in the taxomomic hierarchy between that of family and species. Genera consist of one or more closely related species and are defined mostly on characteristics of the flower and /or fruit	PJR
Geometric design	A simple type of field layout for examining tree/crop interface (or transect) for measuring plant-environmental changes brought about by associating two or more species	PAH
Germplasm	The sum total of the hereditary materials in a species	RWA

TERM	DEFINITION	AUTHOR
Germplasm	The material constituting the physical basis of inheritance (seeds, cuttings, tissue cultures)	PvC
Germplasm	The sum total of the genes and cytoplasnic factors governing inheritanse: the hereditary material transmitted to offspring through the germ cells	JB
Gradoni - benches	Small bench terrace or narrow shelves cut along the contour(usually with an inward slope) .	PW
Grafting	Placing a portion of one plant in close cambial contact with another with the object of obtaining vegetative union between the two	PW
Gravimetric - methods	Density determinations by weight and volume (as opposed to densitometric determations by Beta-ray or X-ray analysis	JB
Grazing	A method of feeding by herbivores characterized by repeated removal of only a part (generally the leaf) of the plant (most commanly herbage)	CRWS
Green manure	Live plants grown for the purpose of being turned into the topsoil in order to improve its fertility	
Guard rows	A line of plants along the edge of a research plot which is not measured, with the object of minimizing the effects of one treatment plot on another	PW

TERM	DEFINITION	AUTHOR
Halophyte	A plant tolerant of rlatively high concentrations of mineral salts in the soil solution (including sodium salts)	
Haploid	A cell or organism with the gametic chromosome number	RWA
Herbaceous	Not woody, dying down each season	
Herbage	The vegetative parts of plants	GHML
Herbivores	Animals that feed on plant material	CRWS
Heritability	The proportion of observed variability which is due to heredity,the remainder being due to environmental causes. More strictly,the proportion of observed variability due to the additive effects of genes	RWA
Heritability	The degree to which a character is influenced by heredity as compared to the environment:more narrowly,it is the fraction of total variation that is contributed by the additive effects of the genes (the ratio of additive genotype to phenotypic variances)	
Heterosis	Hybrid vigour such that an F1 hybrid falls outside the range of the parents with respect to some character or characters	RWA

TERM	DEFINITION	AUTHOR
Heterozgous	Possessing different alleles at a particular focus. Derived from the union of gametes of dissimilar genotype. A heterozygous individual is called a heterozygote	JB
Heterozygous	Having unlike alleles at corresponding loci	RWA
Hierarchy	A structural relationship in which each unit consists of two or more sub-units,the latter being similarly sub-divided	CRWS
Home gardens	A landuse form on private lands surrounding individual houses with a definite fence, in which several tree species are cultivated together with annual and perennial crops,often with the inclusion of small livestock	KFW
Homeostasis	The maintenance of static or dynamic stability irrespective of external effects	JB/GP
Homozygous	Having like alleles at corresponding loci on homologous chromosomes	RWA
Homozygous	Possessing the same allele at a particular locus derived from the union of genetically similar gametes	
Hybrid	The product of of a cross between genetically unlike parents	RWA

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TERM	DEFINITION	AUTHOR
Hybrid	Offspring of organisms of dissimilar genotype often the offspring of a cross between different species	JB
Ideotype	A conceptual model of a plant type that will be best suited to a particular set of circumstances ideotypes can be defined in terms of both form and function. There can be 'Isolation','Competition' and 'Crop' ideotypes	PAH
Impementation flowchart	See 'Flowchart'	
In situ	When applied to tree plantations refers to seed planted in the same area as it was collected	PW
Inbred line	A line produced by continued inbreeding	RWA
Inbreeding	The mating of individuals more closely related than individuals mating at random	RWA
Inbreeding	A system of producing progeny sexually that limits the exchange of genetic material to that of the parent (isolated,self-pollinated plant) or to a relatively small group of parent plants at any one time self-pollination/self-fertility must be prevalent	PAH
Incompatibility	In breeding systems strictly the inability of gametes to unite and form a zygote. Frequently restricted to the inability of pollen to effect fertilization through pollen tube growth being arrested in the style inability of embryos to develop	JB

TERM	DEFINITION	AUTHOR
Increment	The increase in girth,height, volume,weight or value of individual trees or crops	SAF
Independence	The relationship between variables when the variation of each is uninfluenced by that of others	RWA
Indeterminate	Of a stem,where it continues to grow from the apex of an inflorescence,when the terminal flowers open last,hence the growth or elongation of the main axis is not arrested by the opening of the first flowers e.g.a panicle	PAH/GH MI
Indigenous	Native to a specified area not introduced	
Induration	Of soil:compacted or hard layers in the soil profile which offer resistance to root growth	PW
Inoculation	Of Rhizobium or Mycorrhiza :the deliberate introduction of material containing micro-organisms into soils,nursery composts,or living plants	SAF/PAH
Integrated pest control	The use,in a closey co-ordinated way, of both biological,chemical and (if appropriate) mechanical methods of controlling pests (plant pathogens,insect pests or weeds)	PAH
Interaction	A difference between two differences (see also 'non-additivity')	PAH

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TERM	DEFINITION	AUTHOR
Intercropping	Growing two or more crops simultaneously on the same field.Crop intensification can be both in space and time.	DJA/AMK
Intermittent succession	See 'Crop succession'	
Internal rate of return	The discount rate that just makes the net present value of the incremental net benefit stream,or incremental cash flow,equal zero	JPG
Interpolated cropping	A cropping sequence where two or more species are grown on the same unit of land but at least one species has a later sowing(planting) time and an earlier harvest than the other(s) refers to situations where species have very different crop durations	PAH
Investigation	A search or enquiry,a systematic examination (SOED): the whole set of activities undertaken in order to discover,establish,verify or substantiate a hypothesis may include literature searches,trials,experiments,data analysis,and so on	PAH
Isogenic lines	Two or more lines differing from each other genetically at one locus only. Distinguished from clones,homozygous lines,identical twins etc.,which are identical at all loci	RWG

TERM	DEFINITION	AUTHOR
Land facet	An area within which, for most practical purposes, biophysical conditions are uniform. All land within a land facet can be expected to respond similarly to management. They often occur in regular sequences, within a land system (hillcrest to valley floor)	AY
Land occupancy	See 'Crop succession'	
Land race	Genetically variant population originating through selection and propagation by individual farmers or in small areas of geographic isolation	JB
Land system	An area with a recurring pattern of land facets: initially identified and defined in terms of their landforms, then in tems of the full range of environmental factors involved (e.g. 'Undulating Hills'. 'Coastal Plain' etc.)	AY
Land unit	An area or type of land which posseses relatively homogeneous biophysical characteristics all land within a land unit has similar resource potential and hazards it is the basic unit for diagnosis of biophysical resource constraints and potentials	AY
Lapse rate	A measure of the decrease in temperature per unit increase in vertical height in the atmosphere	SAF
Latin square	Experimental design that attempts to remove two sources of positional error (row and column effects) from residual variation. A 5x5 square consists of 25 plots in 5 rows with 5 plots per row and each treatment occuring once in each row and column	PJR
Lattice designs	Incomplete block designs for variety or provenance trials in which the number of varieties must be an exact square: 9,16,25,49,64 (square lattice). Rectangular lattices allow 12,20,30,42,56 varieties analysis is fairly straightforward	PJR

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TERM	DEFINITION	AUTHOR
Layering	The rooting of an undetached branch or stem lying on or partially buried in the soil or other medium which is capable of independent growth after seperation from the mother plant (and see Air layering)	SAF/PW
Leaf area duration (LAD)	Leaf area index integrated over time	PAH
Leaf area index (LAI)	The area of crop leaf per unit area of ground covered by the crop: can also be estimated for single plants or hedgerows	PAH
Leaf area ratio (LAR)	The ratio of the area of the assimilatory material of a plant to th total weight of the plant:usually estimated as a mean LAR over the same period of time being used to examine NAR. LAR = SLA x LWR (whixh see)	PAH
Leaf weight ratio (LWR)	Of a plant:The weight of leaves compered with the total plant weight usually averaged over a period -see LAR	PAH
Leaf-to-total-gro wth ratio (LTGR)	The change in leaf area in terms of change in total plant (dry) weight per unit of time it indicates to what extent a plant is 'investing' its dry matter production in leaf as distinct from non-assimilatory parts	PAH
Ley farming	Rotation of arable crops with two or more years of sown pasture	DL
Ley pasture	A temporary pasture grown as a specific phase in a defined crop rotation sequence	PCW

TERM	DEFINITION	AUTHOR
Lianas	Vine-like climbing plants (also spelt 'Lianes')	PW
Line breeding	A system of breeding in which a number of genotypes which have been progeny tested in respect to some character or group of characters are composited to form a variety	RWA
Lopping	Cutting of one or more branches of a standing tree for fuel and/or fodder	PvC
Management boundary	A basic spatial unit suggested to embrace agriculture, horticulture, forestry and agroforestry: an ecologically homogeneous area set aside for a particular use (in agriculture= the'field')	PAH
Mass selection	A form of selection in which individual plants are selected and the next generation propagated from the aggregate of their seeds (with self-pollinated plants)	RWA
Mixed cropping	Growing more than one species on the same piece of land at the same time,or with a short interval between	WCB
Mixed farming	Farming involving crop and animal production	DL
Mixed gardens	A landuse form on private lands outside the village which is dominated by planted perennial crops,mostly trees,under which annual(seasonal) crops are cultivated	KFW

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TERM	DEFINITION	AUTHOR
Model	A quantitative representation which,if complex,may require algebraic and arithmetic manipulation such models are essential elements of systems analysis,ststistical analysis and many forms of computer simulation	JNRJ
Model	A simplified representation of a system (expressed in words,diagrammatically or by mathematical symbols)	CRWS
Model	A simplification of the real world that reveals the key processes necessary for prediction.Models may be verbal,graphic,mechanical or mathematical depending on the purpose and the need or otherwise for quantification	EPO/DR
Models (Analytical)	Ones in which all functional relationships can be expressed in closed form and the parameters fixed, so that the equations can be solved by classical methods of analytical mathematics	DH
Models (Continuous)	These portray continuous processes, in contrast with 'Discrete' models which include discontinuous or abrupt phenomena	DH
Models (Deterministic)	Non-stochastic in the sense that no random variables are recognised. Exact relationships are postulated,and the output is predicted by the input with complete certainty	DH
Models (Dynamic)	These portray time-dependent processes (as opposed to static,or time-invariant systems). Time being an irreversible,independent variable	DH
Models (Empirical)	Based on observed quantitative relationships among variables without any insight into the functional or causal operation of the system	DH

TERM	DEFINITION	AUTHOR
Models (Mechanistic)	Based on known mechanisms which operate within the model,such as the fundemental laws of physics and chemistry (may be a sub-class of 'Deterministic' models	DH
Models (Numerical)	Those in which the governing equations are solved by means of step-by-step numerical calculations, generally necessitating the use of a computer	DH
Models (Simulation)	Any of the types of models described herein that are described and investigated (usually with the aid of a computer) so as to imitate the essential features and behaviour of a real system	DH
Models (Stochastic)	Those in which one or more of the functional relations depend on chance parameters, and are hence related to a probability distribution	DH
Monoculture	Repeated growing of the same crop on the same land	DL
Monoecious	Staminate and pistillate flowers borne seperately on the same plant	RWA
Mulch	Plant and/or inert materials used for covering the soil surface	PAH
Multi-variate factor analysis	A mathematical method of analysing sets of data to discover which variables are statistically linked, by causative or other factors	JB/GP

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TERM	DEFINITION	AUTHOR
Multiple cropping	Growing more than one crop on the same piece of land during one calender year	WCB
Multiple regression	The relationship between specified values of two or more variables('Independent'variables) and the expected value of a random variable ('Dependent'variable)whose distribution depends on particular values taken on by the investigators	PJR
Multistorey cropping	Multispecies crop combinations involving both annuals and perennials with an existing stand of perennials:association of tall perennials with shorter statured crop species	PKN
Multivariate analysis	A loose term denoting the analysis of data that are multivariate in the sense that each number bears the values of k variables (e.g. Principle Component Analysis,Canonical Correlation Analysis etc.) -see also 'Pattern' analysis	PJR
Mutation	A sudden heritable variation in a gene or in a chromosome structure	RWA
Mycorrhiza	A probably symbiotic (or at least not parasitic) association between the root or rhizome of a green plant and a fungus (plural:Mycorrhizas)	PW
Net assimilation rate (NAR)	At any instant in time,the increase in plant material(dry weight) per unit of assimilatory material.Usually estimated as mean NAR per unit of time(e.g.over a week).A linear relationship between increase in leaf area and plant dry weight is often assumed	PAH
Net presen. value (worth)	The present worth of the benefits less the present worth of the cost.Discounted measure of the project worth	PGR

TERM	DEFINITION	AUTHOR
Nodules	Nitrogen fixing:root swellings of characteristic shape and size for particular leguminous species,which contain Rhizobium. If this is of an effective strain atmospheric nitrogen can be fixed which is readily utilizable by the plant	PW/PAH
Non-additivity	Leads to an expressed interaction (which see) - see also 'additivity'	PAH
Open loop	A control system in which corrective action is not automatic but depends on external intervention,control actions are made without reference to the present output of the system	JB/GP
Open system	A system that exchanges matter with the surroundings, it may also exchange energy with the surroundings	CRWS
Opportunity cost	The benefit foregone to an individual or society by using a scarce resource for one purpose instead of for its next best alternative use	JPG
Origin	For an indigenous stand of trees the origin is the place in which the trees are growing: for a non-indigenous stand the origin is the place from which the seed or plants were originally introduced	
Orthogonal	Keeping other factors constant when comparing any particular set of factors	PAH
Outbreeding	A system of producing progeny sexually that involves the freqent exchange of genetic material between individuals of a population outbreeding plants may be self-infertile and/or have mechanisms to ensure outcrossing	PAH

TERM	DEFINITION	AUTHOR
Outbreeding	Mating unrelated parents	JB
Outcross	a cross,usually natural,to a plant of a different genotype	RWA
Outcrossing	see 'Outbreeding'	
Overlapping cropping	A cropping sequence where two or more species are grown together on the same unit of land, and where the sowing (planting) times do not coincide and the harvesting of one extends beyond that of the other(s)(Relay cropping is an example)	PAH
Panmixia	Random mating without restriction	RWA
Paradigm	A pattern or example	JB/GP
Parameter	The characteristics of a population in some respect (strictly:'Beyond measure')	
Parameter	A numerical quantity which specifies a population in respect to some characteristic	RWA

TERM	DEFINITION	AUTHOR
Parthenogenesis	Development of an organism from a sex cell but without fertilisation	RWA
Pedigree breeding	A system of breeding in which individual plants are selected in the segregating generations from a cross on the basis of their desirability judged individually and on the basis of a pedigree record(with self-pollinated plants)	RWA
Perennials	Plants that continue their growth from year to year	CRWS
Permanent wilting point	The amount of water held in the soil when plants remain wilted even though when (for a short period) the aerial parts are kept in a humid atmosphere:usually taken as 15 atmospheres tension	
Phenology	The study of the time of appearance of chacteristic periodic phenomena in the life cycle of organisms in nature e.g. flowering or leaf fall,especially as influenced by environmental factors	SAF
Phenotype	Appearance of an individual as contrasted with its genetic makeup or genotype. Also used to designate a group of individuals with similar appearance but not necessarily identical genotypes	RWA
Phenotype	An organism as observed, i.e as judged by its visual perceptible characters resulting from the interaction of its genotype with the environment. Similar phenotypes do not necessarily breed alike	
Photosynthetically-active radiation (PAR)	From 0.4 - 0.7 nanometers in the electromagnetic spectrum. Equals approximately 45 per cent of the total short wave radiation received at the earth's surface from the sun (0.4 to 3.0 nanometers)	PAH

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TERM	DEFINITION	AUTHOR
Plot	Any type of experimental material that forms a unit	
Plot	Usually the smallest experimental unit in a replicated comparative experiment, e.g. one replication of one provenance in a trial of many provenances with several replications	
Plus tree	A phenotypically superior tree not yet proven genetically, as an elite tree, by progeny testing	JB
Pollarding	Cutting back in more or less systematic fashion the crown of a tree with the object of harvesting small wood and browse, of producing regrowth beyond the reach of animals, or of reducing the shade cast by the crown	PJW/SAF
Polyloid	An individual or a cell having (triploid), four (tetraploid),five (pentaploid) or more complete sets of chromosomes instead of two as in diploids	
Polyploid	An organism with other than two basic sets of chromosomes, that is monoploid,triploid,tetraploid and various aneuploids	RWA
Population	Genetically, a group of similar individuals related by descent and so delimited in range by environment or endogenous factors as to be considered a unit. In cross-bred organisms the population is often defined as the interbreeding group	
Population	The sum of all the variates of any one kind.The population need not actually exist but the term may refer to the aggregate of all individuals that might have existed under certain specified conditions	

TERM	DEFINITION	AUTHOR
Population	In genetics, a community of individuals which share a common gene pool.In statistics, a hypothetical and infinitely large series of potential observations among which observations actually made constitute a sample	RWA
Precision	Of an estimate:it is the closeness of agreement to be expected between a succession of independent estimates formed by a repetition of the sampling procedure	DJF
Primary land unit	A basic spatial unit suggested to embrace agriculture,horticulture,forestry and agroforestry: a homogeneous area in which a common species (or species mix) and a common form of management is being practiced (in agriculture= the'plot')	PAH
Primary production	Production of biomass by plants through the processes of photosynthesis and nutrient uptake	PAH
Procumbent	Trailing or lying flat,but not rooting	GHML
Productivity	A measure of efficiency relating output of a product to the use of a resource (including time)	CRWS
Progeny test	Evaluation of parents by comparing the performance of their offspring. Accuracy is usually gained because several to many offspring per parent are evaluated under more controlled conditions than exist for the parent	
Progeny test	A test of the value of a genotype based on the performance of its offspring produced in some definite system of mating	RWA

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TERM	DEFINITION	AUTHOR
Pr ,agule	A part of a plant with the potential for producing a new individual	PW
Protandry	Maturation of anthers before pistils	RWA
Protective plants	Plants grown to protect crops,soils or land from adverse environmental factors	DL
Proto-agroforestry	The basic concept of a landuse system involving a woody perennial species,a forb or grass species and man	PAH
Protogyny	Maturation ofpistils before anthers	RWA
Provenance	The place in which any stand of trees is growing. The stand may be indigenous or non-indigenous	
Pruning	The process of cutting back growth of plants (including roots) but more particularly side branches of trees	PW
Pure line	In breeding: a strain homozygous at all loci, ordinarily obtained by successive self-fertilisations	RWA

TERM	DEFINITION	AUTHOR
Pure line	A strain homozygous at all loci	RWA
Ramet	A propagule	PW
Randomness	Unselected,taken entirely by chance	MHQ
Range	The geographical and altitudinal limits within which a taxon occurs	SAF
Range	The limits of magnitude (of a set of data)	PAH
Recessive	The member of an allelic pair which is not expressed when the other(dominant) member occupies the homologous chromosome	RWA
Reciprocal crosses	Crosses in which the sources of male and female gametes are reversed	RWA
Recombination	Formation of new combinations of genes as a result of segregation in crosses between genetically different parents(also the rearrangement of linked genes due to crossing over)	RWA

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TERM	DEFINITION	AUTHOR
Recurrent selection	A method of breeding designed to concentrate favourable genes scattered among a number of individuals by selecting in each generation among progeny produced by matings among all the selected individuals (or their selfed progeny)of the previous generation	RWA
Registered seed	The progeny of foundation seed normally grown to produce certified seed	RWA
Relational diagram	A diagram used to show the inter-relationships of components and processes in a system	CRWS
Relative growth rate (RGR)	Of a plant: at an instant in time this is the increase in plant material per unit of plant material initially present.Expressed as a mean RGR as g/g/day.RGR = LAR x NAR (which see)	PAH
Relay cropping	Planting crops between plants or rows of an already established crop during the growing period of the first planted crop(s):one form of 'Overlapping' crop sequence(which see)	WCB
Replication	The number of times a treatment is repeated (in space or time):to halve the standard error four times the degree of replication is needed,so extraneous variability must also be identified and dealt with	PAH
Replication	Applying a treatment,or set of treatments, more than once to increase the precision of comparisons and to provide an assessment of the variability among experimental units treated alike	
Replications	One complete set of all experimental units in a comparitive experiment	

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TERM	DEFINITION	AUTHOR
Research	An investigation directed to the discovery of some fact by the careful study of a subject: a course of critical or scientific enquiry: the act of researching	SOED
Rhizobium	Type of bacterium which has the capacity of both invading the roots of certain species of the leguminosae, and of fixing atmospheric nitrogen which is subsequently used by the most plant	PJR
Rotational cropping	The repetitive cultivation of an ordered succession of crops, or crops and fallow, on the same land. One cycle often takes several years to complete (and see 'Crop succession')	DJA/AHK
Rotational grazing	Grazing systems in which the pasture is sub-divided into a number of 'enclosures' with at least one more of these than there are groups of animals	PCW
Row intercropping	Growing two or more crops simultaneously where one or more crops are planted in rows (and see 'Zonal agroforestry')	DJA/AHK
Sample	A part of a population, consisting of one or more sampling units selected and examined as representative of the whole	
Sample	Because of the variability in biological populations little infomation is to be gained by just measuring one variate so a number are taken to form a 'sample'. The larger this is the more closely its characteristics (mean etc.) represent the population	
Scanning electron microscopy	Examines the surface structure of a specimen at very high magnification and resolution	

TERM	DEFINITION	AUTHOR
Screening	Preliminary comparison of a large number of treatments to evaluate and eliminate obvious undesirable treatments (can be phenotype or physical input as variable)	PR
Seasonal plants	Plants that flower and complete their life cycle within the duration of a single wet/dry season combination (in equatorial regions): see a sdo 'annuals'	PAH
Secondary production	The production of biomass (by animals,mico-organisms or parasitic plants)through the use of primarily-produced plant materials	PAH
Seed source	See Provenance and origin	
Selection	As artificial selection:the choice by the breeder of individuals for propagation from a population. It may be for one or more desired characteristics and be based on the plant itself (phenotypic) or on progeny or relatiuves (genotypic)	
Selection	The plant actually selected	
Self-incompatiblity	Genetically controlled physiological hindrance to self fruitfulness	RWA
Sensitivity analysis	A method of discovering by how much the estimates used in a model can vary without changing the result	JB/GP

TERM	DEFINITION	AUTHOR
Sequential cropping	Growing more than one crop on the same piece of land with each crop being grown during a different time of the year(but see 'concommitent','overlapping' and 'interpolated' cropping)	WCB
Shrub	A woody plant that remains low and produces shoots or trunks from the base,not tree-like nor with a single bole:a descriptive term not subject to strict circumscription	GHML
Sibs	Progeny of the same parents derived from different gametes	RWA
Silvopastoral	The integration of trees with pasture	PW
Silvopastoral systems	All agroforestry systems which include trees or shrubs and pastures and animals	FT
Sink	A state variable outside the system boundary, that is not quantified, to which outputs may go	CRWS
Sole cropping	One crop cultivar grown alone in pure stands at normal density. Synonymous with 'solid' planting and the opposite of 'intercropping'	DJA/AH K
Solid planting	See sole cropping	

TERM	DEFINITION	AUTHOR
Source	A state variable outside the system boundary, that is not quantified, from which inputs are derived	CRWS
Species	One or more populations, the individuals of which can interbreed, but which in nature cannot exchange genes with members belonging to other species. A main category of taxonomic classification	
Specific leaf area (SLA)	Area of a leaf per unit leaf weight expressed as decimeter squared per gram	PAH
Specific leaf volume (SLV)	Volume of a leaf per unit weight of that leaf	PAH
Split plots	A form of factorial layout with the main effects confounded usually there is more precision in testing the treatments in the split plots than in the main plot treatments	PAH
Stand	A community of trees possessing sufficient uniformity of composition, consitution, age, spatial arrangement or condition, to be distinguishable from adjacent communities, so forming a silvicultural or management entity	
Stand	In agriculture: the percentage of plants that survive	PAH
Statistic	The characteristics of a sample in some respect	

TERM	DEFINITION	AUTHOR
Steady state	A non-equilibrium state of an open system in which all the forces acting on the system are exactly counter-balanced by opposing forces in such a manner that all its components are stationary in concentration although matter is flowing through the system	CRWS
Stochastic	A stochastic situation is one in which a given input leads to a number of possible outputs each with a probability of occurrence	CRWS
Stochastic	Having a probability attached to it.A stochastic process is one where the next event is probabilistically related to previous events	JB/GP
Stolon	A shoot that bends to the ground and takes root: more commonly, a horizontal stem at or below ground surface that gives rise to a new plant at its tip	GHML
Strain	A group of similar individuals within a variety	RWA
Strip cropping	Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation, but narrow enough for the crops to interact agronomically (a form of zonal cropping)	DJA/AHK
Stripling	Tall planting stock from which the lower leaves have been removed to reduce transpiration losses	PW
Stump	Planting stock in which the shoot and root have been cut back (usually 2-3 cm shoot and 10-20 cm root) to produce an easily-transported propagule	PW

TERM	DEFINITION	AUTHOR
Subpopulation	A subset of a natural or artificial breeding population, articifical subsets may be developed for different sites, characters or for security	JB
Subsystem	Often used to describe any part of a system contributing to the same output as the system itself	CRWS
Sucker	A shoot arising from below ground level	PW
Sustainibility	The capacity of land to maintain a constant output of chosen products	PAH
Synecology	Deals with the study of groups of organisms which are associated together as a unit, the emphasis may be on the fit of one organism into the system, on the relationships between organisms or on the whole system as a unit	EPO
Synthetic (variety)	A variety produced by crossing among all of a number of genotypes selected for good combining abiity in all possible hybrid combinations,with subsequent maintenance of the variety by open pollination	RWA
System	A part of the universe which can be distinguished from its surrounding environment by either physical or conceptual boundaries:it is composed of interacting parts	DH
System	A number of components linked together for some common purpose or function: see also agricultural system,agroforestry system etc.	CRWS

TERM	DEFINITION	AUTHOR
System	A number of components linked together for some common purpose or function	CRWS
System	An entity which consists of interdependent parts	JB/GP
Systematic design	An experimental design laid out with no randomization of treatment plots within a replication eg a Nelder fan or a fertiliser trial whereby adjacent plots have gradually increasing spacing or rates of application	PJR
Systematic sampling	A sample consisting of sampling units selected in conformity with some regular pattern(e.g. the sample formed from every 10th tree in a row, or from the intersections of a regular grid	PJR
Systems analysis	The orderly and logical organisation of data and information into models, followed by the rigorous testing and exploration of the models necessary for their validation and improvement	JNRJ
Taper	The decrease in thickness, generally in terms of diameter, of a tree stem or log, from the base up	SAF
Taungya system	Method of raising forest trees in combination with (seasonal) agricultural crops used in the early stages of establishing a forest plantation it not only provides some food but can lessen the establishment costs	
Taxon	A category in the taxonomic hierarchy	JB/GP

TERM	DEFINITION	AUTHOR
Taxonomy	Classification of organisms, including identification and nomenclature, according to a natural (chiefly morphological) system that seeks to depict evolvement. hence "taxon", any designated group within a classification (e.g. species, cultivar etc)	
Tie ridging	In contour furrowing or trenching, a narrow strip of ground left unexcavated (or ridged)	PW
Total area	A spatial unit suggested to embrace agriculture, horticulture, forestry and agroforestry: the complete land area being managed by a single landuser (or cooperating group),(in agriculture= the 'farm')	PAH
Transhumance	Situation in which farmers with a permanent place of residence send their herds ,tended by herdsmen, for long periods of time to distant grazing areas	CRWS
Transmission electron microscopy	High magification and resolution microscopy achieved by passing electrons instead of light, through the specimen. The image is recorded on a photographic plate or displayed on a cathode-ray screen	
Tree	A woody plant that produces one main trunk or bole and a more or less distinct and elevated head	GHML
Tree form	The degree and mode or taper in a tree or log. Also loosely applied to the general shape of the bole and its desirability for utilization	PW
Tree gardens	Multiple-storied agroforestry systems where a mixture of several fruit and other useful trees are cultivated, sometimes with the inclusion of annual crops (see also Home Gardens,Village-Forest-Gardens,Mixed Gardens etc.)	WKF

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TERM	DEFINITION	AUTHOR
Tree/crop interface	The spacial extent over which some form of interference occurs between the tree and crop components in an agroforestry system	PAH
Trial	An action,method or treatment adopted in order to ascertain a result (SOED): may be part of an 'Investigation', and usually of a shorter and/or less significant involvement than an 'Experiment'	PAH
Upland cropping	Crops grown on unirrigated land without storage of water	DL
Validation	The process of accessing the accuracy for a given purpose of a simulation model by comparing the model's predictions with independent results	CRWS
Variable	Any quantity or quality liable to show variation from one individual to the next in the same population	
Variable	A quantity able to assume different numerical values	CRWS
Variables (Endogenous)	Dependent,output variables in simulation modelling:they are generated by the effect of the exogenous variables on the system's 'State' variables	DH
Variables (Exogenous)	Input variables in simulation modelling that are independent of the internal state of the system they represent external factors imposed upon the system,and acting on it to induce changes within it(='Forcing' or 'Driving' functions)	DH

TERM	DEFINITION	AUTHOR
Variables (Rate)	These control the rate at which various responses are generated by various changes in the system's state.They represent the coefficients of the governing equations describing the dependence of endogenous variables on their controlling state variables	DH
Variables (State)	In simulation modelling, those that characterize the state of the system and directly determine the processes which bring about changes in the endogenous variables	DH
Variate	An individual observation or value of any variable	
Variate	A single obsevation or measurement	RWA
Variation	The extent of the differences between variables	
Variety	Taxonomically the term implies variants of a typical species which are not known to occur as distinct populations but appear sporadically in wild stands as single or isolated individuals. The term has also been used to describe the facies of a species	PJR
Variety	A subdivision of a species (see also 'cultivar'=cultivated variety)	RWA
Viability - seed	The capacity of a seed to germinate	PW

TERM	DEFINITION	AUTHOR
Village-forest-gardens	Larger than the Home Garden, less densely planted and not so well-tended planted with higher trees and often containing spontaneous species of herbs or liunes(derived from ancient orchards, West Java)	GM
Water potential	The free energy status of water:a concept of general applicability to the measurement of water in soils, plants and the atmosphere	
Watershed	A physiographic unit in the landscape defined by the drainage dividers around the area drained by a particular body of water: if a lake there is often one watershed with subunits for contributing streams, if a river it may be defined for any point or all	DR
Wilting point	The amount of water held(in fine pores) at the point when a plant starts to wilt	
Yield	Quantity harvested, necessarily related to a specified crop(s) or animal(s), or to an area, and to a period of time	CRWS
Zonal agroforestry systems	Spatial planting arrangements where the different species each remain contiguous to some extent i.e. as strips, plots or even alternate rows alley cropping is an example. Zonal planting can reduce the tree/crop interface compared with mixed planting	PAH

SOURCES

AHK	A.H. Kassam
AY	A.Young
BL	B. Lundgren
CRWS	C.R.W. Spedding
DH	D. Hillel
DJA	D.J. Andrews
DJF	D.J. Finney
DL	D. Leatherdale (AGROVOC)
DR	Dianne Rocheleau
EPO	E.P. Odum
FT	F. Torres
GHML	G.H.M. Lawrence
GM	G. Michon
HTO	H.T.Odum
HZ	H. Zandstra
JB	J. Burley
JNRJ	J.N.R. Jeffers
JPG	J.P. Gillinger
KFSK	K.F.S.King
KFW	K.F. Wiersum
MHQ	M.H. Quenouille
PAH	P.A. Huxley
PCW	P.C. Whiteman
PKN	P.K. Nair
PJK	P.J. Kramer
PJR	P.J. Robinson
PvC	P.von Carlowitz
PW	P.Wood
RL	R. Labelle
RWA	R.W. Allard
SAF	Society of American Foresters
SOED	Shorter Oxford English Dictionary
WCB	W.C. Beets

SPECIALIZED GLOSSARIES

For recourse to more detailed glossaries on specialized subject areas see the following:

Ford-Robertson F.C. (Ed) 1971. Terminology of Forest Sciences, Technology, Practice and Products. Soc. Amer. Foresters, Washington D.C.

Gillinger J.P. 1982. Economic analysis of Agricultural Projects. E.D.I./John Hopkins University Press, London.

Lawrence, G.H.M. 1951. Taxonomy of Vascular Plants. (see Botanical Glossary at the end) MacMillan, New York.

Spedding C.R.W. 1975. The Biology of Agricultural Systems. Academic Press, London, New York and San Francisco.

- to be completed

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ANNEX

PART 6C

A Preliminary Agroforestry
Word list

- by R. Labelle

Extract from ICRAF Working Paper
No 8

AGROFORESTRY DESCRIPTORS

This is a listing of terms, (some of which are defined) that are suggested as candidates for a controlled vocabulary of agroforestry, the terms chosen are considered to best represent agroforestry concepts. They are called descriptors.

The main objectives of listing are to:

i) permit the use of standard terms for the indexing and retrieval of bibliographic information, i.e. documents in the broad sense of the term, that deal with agroforestry.

ii) identify difficulties in agroforestry Terminology for further elucidation.

iii) show or suggest the hierarchical relationship of many of the terms selected.

Constructing the list

The terms were assembled on the basis of the analysis of about 3000 documents in the ICRAF reprint collection. Each document was described in bibliographic terms and subject descriptors were also assigned to them.

This was a 'free word' indexing effort and no single thesaurus was used. Further more, the selection of terms for descriptors was based on the documents assembled in the reprint collection. These documents have been acquired to answer specific requests for information about agroforestry and cannot be considered a random sample of the universe of knowledge about agroforestry. Therefore, some subject areas had been overlooked or not considered in sufficient detail.

In order to overcome this the Information Programme staff decided to evaluate the AGROVOC Thesaurus for it's suitability as thesaurus of agroforestry terms and also, to consult with the multidisciplinary specialists on the staff of the Council.

Using AGROVOC and ICRAF Staff Input

Info/Doc ICRAF decided to evaluate the application of the AGROVOC Thesaurus to the selection and use

of descriptors for indexing bibliographic information on agroforestry. The reasons for choosing the AGROVOC are as follows.

The AGROVOC Thesaurus is a structured vocabulary of agricultural terms devised to promote better dissemination of the results of agricultural research and, in particular to permit the more effective retrieval of bibliographic data included in the International Information System for the Agricultural Sciences and Technology (AGRIS), coordinated by FAO. Leatherdale, D (1982). The AGROVOC is also multilingual (English, French, German, Italian and Spanish) and permits the user to find the equivalents of any descriptor it contains in the above languages.

Furthermore, the AGROVOC is to be used for indexing by the AGRIS network, and is thus an international standard. The AGROVOC is not an extensive thesaurus.

This is to permit information centres working with more detailed areas of knowledge to fragment the concepts represented by the descriptors in order to afford more detailed description of these concepts. Leatherdale, D. (1982).

This possibility has been tested by Info/Doc ICRAF and was found to be valid for agroforestry. Beyond relying on modifying the free word descriptors derived from the subject analysis of 3000 reprints, an effort was made to obtain a more systematic coverage of the concepts that would generally be useful and to assign the appropriate descriptors to them. For this, the multidisciplinary staff of specialists at ICRAF was consulted. Staff were asked to review a preliminary computer-generated printout of the terms produced from the document search that had been adapted to suit AGROVOC. They contributed a list of terms thought to be generally relevant to agroforestry and based on the perspective of their own specialities.

The resulting comments and suggestions have been reviewed and included in this listing. Not every recommendation was accepted and changes to suggested AGROVOC terms have been resisted, although some changes have nevertheless been made. Many terms have also been added because they were not in the AGROVOC.

Of the 1006 terms in the data base, 564 are in the AGROVOC, and of these 36 are not considered useful simply because they are compound terms that can be replaced by combining simpler concepts, (for example 'nitrogen fertilizer' is replaced by fertilizers and nitrogen) as two separate terms

that can be used for retrieval. Some of these are simpler terms as well, i.e. tropical fruits is replaced by fruits.

Presentation of the list

In order to present the list for review and to quickly modify it DBASE II, a microcomputer based relational data base management system, was used with the OSBORNE 1 microcomputer.

Over 1000 descriptors were selected and each was described in a record containing three fields. The first field contained the descriptor, and is called 'DESCRIPT', the second field is a logical field capable of holding the binary information 'T' (true) or 'F' (false) depending on whether a given term was an AGROVOC descriptor. This field is called 'AGROVOC'. The third and last field was termed 'USE' and was reserved for listing scope notes or the relationships of descriptors to others used in the world list.

Structure of the descriptor data base

The descriptors data base has the following structure:

STRUCTURE FOR FILE: B:DESCRIP3. DBF
NUMBER OF RECORDS: 01006
DATE OF LAST UPDATE: 11/27/83
PRIMARY USE DATABASE

FLD	NAME	TYPE	WIDTH	DEC
001	DESCRIPT	C	035	
002	AGROVOC	L	001	
003	USE	C	055	
** TOTAL **			00092	

The 'Descriptors' field contains the actual term. The 'AGROVOC' containes the binary information 'T' or 'F' depending on whether the term is in AGROVOC thesaurus or not. Scope notes are used to clarify the use of a term and/or its relationship to other terms in the list. The following abbreviations are used under the 'scope notes' field.

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d: delete the term in use and replace it with other term. In some cases, the term is to be deleted and there is no reference to ther terms.

uf: used for

bt: broad term

nt: narrow term

rt: related term

Difficulties of terminology

Crop intensification techniques with trees and concepts related to the use of woody perennials by animals and humans are of particular concern here.

The agronomist's terminology has been borrowed and applied to cropping systems and cropping patterns with trees. Andrews and Kassam (1976), Beets (1982). However, the time scale for agroforestry is different and this has been reflected for some of the terms. See Nair (1979) and Huxley (1983) for more details. Huxley (1983) presents a detailed discussion about the termporal and spatial sequence of crops and/or trees in an agroforestry system and the reader should refer to that article for more detail than is presented in the definitions listed below.

A second area of difficulty refers to the use of the terms 'feeds', 'fodders', 'browse', 'graze', etc.

For the purpose of this list, the following terminology and relationships are proposed:

Feeds: What is consumed during feeding of animals (bt)

Fodder: animal food of plant origin that is cut and usually dry but need not be (nt)

Browse: animal food that is green and growing. It is the bud or young shoot of a woody plant and it is foraged for by the animal. (nt)

Graze: animal food that is made up of growing grass, herbage or forbs. It is foraged by the animal (nt)

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Feed crops: Plants producing feeds for animals.(bt)

Woody feed crops: trees or shrubs that are a source of fodder or that are foraged for browse. (nt)

Feed trees: trees that are a source of fodder or that are foraged for browse (nt)

Shrub trees: shrubs that are a source of fodder or that are foraged for browse. (nt)

Feed grasses, (nt)

Feed legumes, (nt)

Feed cereals, (nt)

Forbs. (non graminoid herbs) (nt)