Profitable Agroforestry Innovations for Eastern Africa

Experience from 10 agroclimatic zones of Ethiopia, India, Kenya, Tanzania and Uganda

Azene Bekele-Tesemma
Editor

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Foreword

Many note that scientists and practitioners have generated abundant agroforestry knowledge. They equally note that one major weakness has been the fact that the science and practice of agroforestry has not been effectively communicated to extension providers for wider application. As a result, agroforestry science has been constrained in transforming the wellbeing of African farmers.

In instances where agroforestry research has produced important advances, it has been challenging to obtain and interpret situation-specific feedback from implementers. This has limited the contributions by agroforestry practitioners to the refinement of the scientific agenda. One major problem in getting valuable situation-specific feedback has been the lack of analyses with respect to commonly understood physiographic dimensions.

Natural conditions—climate and soils—are the framework for land management and sustainable farming systems. This publication uses this framework to compile agroforestry innovations by agroclimatic zone suitable for countries in eastern Africa. Each of these agroclimatic zone classes can then be further customized to country-specific situations by using additional variables related to soil, natural vegetation, traditional moisture management, and cropping type and pattern. At the same time, the economic, cultural and social dimensions are equally important modifiers.

The book documents agroforestry innovations that are already in use, and thus provides a frame for further customizing the innovations to the farming culture and socio-economic variation within the major agro-climatic zones of the region. Priority has been given to agroforestry innovations that are profitable or judged to have the greatest potential for profitability.

The study also brought out a number of research questions and knowledge gaps that are related to further improvement of each innovation. Therefore, this work addresses not only the interests of the end users—smallholder farmers—but also the research community.

We are grateful to all those who participated in preparing the compendium, and the special efforts made by Dr Azene Bekele-Tesemma in co-ordinating the study and compiling the work. We look forward to seeing this handbook widely used as a basis for more rapidly accelerating the deployment of agroforestry to improve food security and increase rural prosperity among smallholder farmers in Africa.

Dennis Garrity

Director General
World Agroforestry Centre

Preface

It gives me a great pleasure to technically edit this Technical Handbook: *Profitable agroforestry innovations: experiences from 10 agroclimatic zones of Ethiopia, India, Kenya, Tanzania and Uganda*. With the committed work of my colleagues, the contributing authors, the handbook sets out experiences from 10 agroclimatic zones. It aims to provide development agents and farmers with agroforestry options. It equally lays the groundwork for cross-fertilization of agroforestry knowledge and expertise by harmonizing the areas where such innovations could be tried elsewhere in eastern Africa. I hope these innovations will be replicated widely and a lot of learning and improvement will be possible.

The handbook aims to help farmers and development agents do a better job in a multidisciplinary manner. Profitability goes beyond the farm context. Therefore, a number of policy and market issues are presented in relation to each of the agroforestry innovations. Policy and value-chain issues are equally at target. Everyone can have a share in sharpening the science and helping improve the innovations.

As much as the farmers and the development agents are targeted so are the academicians---researchers. Each of the agroforestry innovations presents the currently existing knowledge gaps and research questions.

I would like to thank the Swedish International Development Cooperation Agency (Sida) for financing this work by making it my activity in the RELMA-in-ICRAF project. I am grateful to the contributing authors and the many individuals who also contributed in one way or another to compiling this handbook.

I also thank Ms Susan Scull-Carvalho and Ms Helen van Houten of Jacaranda Designs for their extensive editorial help in preparing this handbook for publication.

Azene Bekele-Tessema

Editor

Abbreviations and terms

BoA	Bureau of Agriculture (Ethiopia)
COARD	Centre of Agricultural Research and Development (Uganda)
COVOL	Cooperative Office for Voluntary Organizations
dbh	diameter at breast height
DFID	Department for International Development (UK)
ETB	Ethiopian birr, valued at 8.6 to the US dollar in this book
FD	Forestry Department
GTI	Genetic Technology Institute
HCDA	Horticultural Crops Development Authority (Kenya)
ICAR	Indian Council for Agricultural Research
ICRAF	World Agroforestry Centre
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
INR	Indian rupee, valued at 41 to the US dollar in this book
KADI	Kamurugu Agricultural Development Initiatives
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute
KES	Kenya shilling, valued at 71 to the US dollar in this book
kharif	summer season, India
KU	Kenyatta University
masl	metres above sea level
MoA	Ministry of Agriculture (Kenya)
NAADS	National Agricultural Advisory Services (Uganda)
NAFRAC	Natural Forest Research Management and Agroforestry Centre (Tanzania)
NAFRP	National Agroforestry Research Project
NARO	National Agricultural Research Organisation (Uganda)
NGO	non-governmental organization
NUSPA	Northern Uganda Shea Nut Producers Association
PMA	Plan for the Modernization of Agriculture rabi winter season, India
SAARI	Southern Africa Agricultural Research Institute
Sida	Swedish International Development Cooperation Agency
SOFEM	Social Forestry Extension Model (Kenya)
TZS	Tanzania shilling, valued at 1304 to the US dollar in this book
UGS	Uganda shilling, valued at 1800 to the US dollar in this book
USAID	United States Agency for International Development
USD	US dollar

Part I

Introduction and how to use this book

Chapter 1 Introduction

1.1 Background to the study

Agroforestry has immense potential to help improve livelihoods of the rural poor, and lots of agroforestry innovations exist. Many are long-term research results and many more are local experiences that have been developed for many years in Africa and South Asia. Unfortunately, their spread in sub-Saharan Africa has not been satisfactory. Consequently, the potential of agroforestry has not been effectively tapped in this region.

One basic truth here is the fact is that most of the innovations are not documented for development facilitators and individual farmers to use. The little documentation that has been made in certain countries or institutions is site and country specific with no mechanism for associating findings to similar areas in another country or another place in the same country. It is very difficult therefore to visualize the utility of the innovation outside its origin. For instance, an important agroforestry innovation that might have made a difference in one country could not be easily tried in another country or another site in the same country. The problem has not been simply upscaling. Also lacking has been the possibility of cross-fertilizing agroforestry knowledge and expertise, and harvesting professional critiques among scientists and practitioners of different countries.

This study has been designed in view of these inherent problems of transferring knowledge and experience. Commonalities of agroclimatic zone between countries and areas within countries were analysed and mapped.

Differences and similarities in ecoregions inform a lot about the existence or absence of different trees and shrubs and of cereals. The study countries were thus partitioned into similar ecoregions by using broad but commonly understood parameters—altitude and rainfall. Similar agroclimatic zones were identified and mapped as shown in figure 1.1. Then study methodology and terms of reference for the study were developed. The following 11 issues were indicated as major considerations in studying and documenting each of the profitable agroforestry innovations.

1. Nature of the innovation: whether the innovation is a skill, a practice, a method, an approach or some other form of knowledge
2. Justification of profitability of the innovation as rated by the user (practitioner) or the direct beneficiary
3. Agroforestry components and interfaces (interactions) between components in the system
4. Minimum inputs that are necessary for functionality of the agroforestry innovation being documented

5. Characteristics of the place where it is found working effectively: rainfall regime and altitude range that suggest the agroclimatic zone to which it is suited
6. Major factors that make the innovation successful, such as ease of implementation (either in part or in whole), possibility of earning cash and saving labour (with specificity for which component of the innovation this applies), possibility of implementing it with minimum inputs (with specificity for which input and to which components it applies)
7. Direct and indirect beneficiaries and users of the innovation
8. Upscaling strategies being used and found working
9. Institutions promoting the innovation with specificity of direct promoters and their contributions as well as collaborators and their contributions
10. Research questions and knowledge gaps to be addressed in the future for even better performance of the innovation
11. Professional reflections and recommendations on the way forward for successful implementation of the innovation by farmers in similar agroclimatic zones elsewhere in eastern Africa

One senior agroforestry or forestry expert was identified from each of the five countries (Ethiopia, Kenya, Tanzania, Uganda, India) to document only seven innovations at most. India was included because it has been known for agroforestry innovations that farmers have implemented. It was decided to address the 11 issues of each agroforestry innovation and to document complete and concise information for each in only 7 pages. The contributing authors were oriented for common understanding and were provided with the agroclimatic zone map of the countries.

The seven profitable agroforestry innovations identified per country were then regrouped according to the agroclimatic zones for which they were most suited. Although a certain innovation is grouped under an agroclimatic zone to which it is most suited, the shading of the agroclimatic zone indicated in the top right corner of the page indicates the range of agroclimatic zones where this innovation can most probably be effective. No matter from which country the innovation is recorded, we assume that the innovation may be easily customized to any country containing the same agroclimatic zone.

The purpose of this work is to introduce agroforestry innovations that can be customized and upscaled in similar agroclimatic zones of eastern Africa. It can inform field practitioners of relevant agroforestry-related knowledge gaps and research topics. It can also be used as reference material in teaching agroforestry. It is a useful contribution in these three areas.

1.2 Agroclimatic zones

Eastern Africa has diversified ecological features. Its altitude ranges from 125 m below sea level at the Dalol depression in Ethiopia to 5895 m above sea level at the peak of Mt Kilimanjaro in Tanzania. The mean annual rainfall ranges from less than 200 mm to more than 2300 mm per year. The variation in temperature is similarly large.

The soils are varied in colour, texture and degree of degradation. Natural vegetation types include tropical rainforest, mountain steppe (alpine in character), woodland and plantation forest, savannah, bushes and shrubs, lowland woodland on the plains, and desert scrub in hot lowlands.

Due to the rugged mountainous ecology that deflects moisture-carrying winds, the local variation in rainfall amounts, density of land cover, rate of soil erosion and land degradation is enormous. This is further complicated by variations in human settlement, traditional land care and farming systems. Hence, land degradation and its associated threats to the ecological support system that underpins agricultural production are among the most serious environmental problems of eastern Africa.

The rugged topography, intricate ecology and diverse land degradation and deforestation problems have necessitated effective characterization of the agroclimatic zones, which may guide research and development facilitators in introducing effective agroforestry, soil and water conservation, and reforestation options in land-use systems. The gradation and nature of the soil and water conservation technologies as well as the types of plants recommended for effective agroforestry innovation indeed differ by agroclimatic zone. Although every site may be typical, its physical potentials and limitations are manifestation of its rainfall and altitude, which also manifest its temperature conditions. Therefore, for each operational area, optimal and integrated land-management and agroforestry expansion efforts could benefit from considering these climatic layers jointly within the agroclimatic zones.

Unfortunately, there has not been any commonality in classifying the agroclimatic zones of eastern African countries. Consequently, the knowledge and information generated in one country or in a certain agroclimatic zone of the same country cannot be borrowed by another country or another site in the same country. This has necessitated developing a harmonized definition of agroclimatic zones that is simple to understand and use across countries. Although these agroclimatic zones have intentionally been developed by using only two variables (rainfall and altitude), we hope that the different countries will further refine the qualification of each zone by using the following additional parameters.

- Indigenous trees and shrubs
- Soil colour and drainage situation
- Traditional moisture retention and disposal practices
- Traditional soil conservation measures
- Agronomic practices and cropping calendar

When agroclimatic zones are qualified with such information, development agents, students and farmers will not require any foreign tool or gadget for characterizing the area of work where they want to be. For such customized agroclimatic zone characterization, refer to the map (fig. 1.1) and table 1.1 developed for Ethiopia.

The utility of such agroclimatic zoning has been tested and improved in Ethiopia since 1986. More complete agroclimatic zone identification and mapping were done and used in framing land management options for Ethiopia in 2005 with ICRAF's technical support (Bekele-Tesemma and Sjoholm 2005). Professionals who had the opportunity to refer to this book appreciated its value and indicated that it could be used in the other eastern African countries if the same agroclimatic zonation was used. We have thus now prepared the agroclimatic zone maps of Ethiopia, Kenya, Sudan, Tanzania and Uganda with identical parameters. This technical handbook is another step in harmonizing the flow of knowledge and information, presenting profitable agroforestry innovations according to the agroclimatic zones to which they are best suited.

In categorizing agroclimatic zones of these countries and mapping, we used the following rainfall attributes for **rainfall classes** (annual amounts).

- < 900 mm for *Dry*
- 900–1400 mm for *Moist*
- > 1400 mm for *Wet*

The same procedure was followed for altitude. The following **altitude classes** were used for each country.

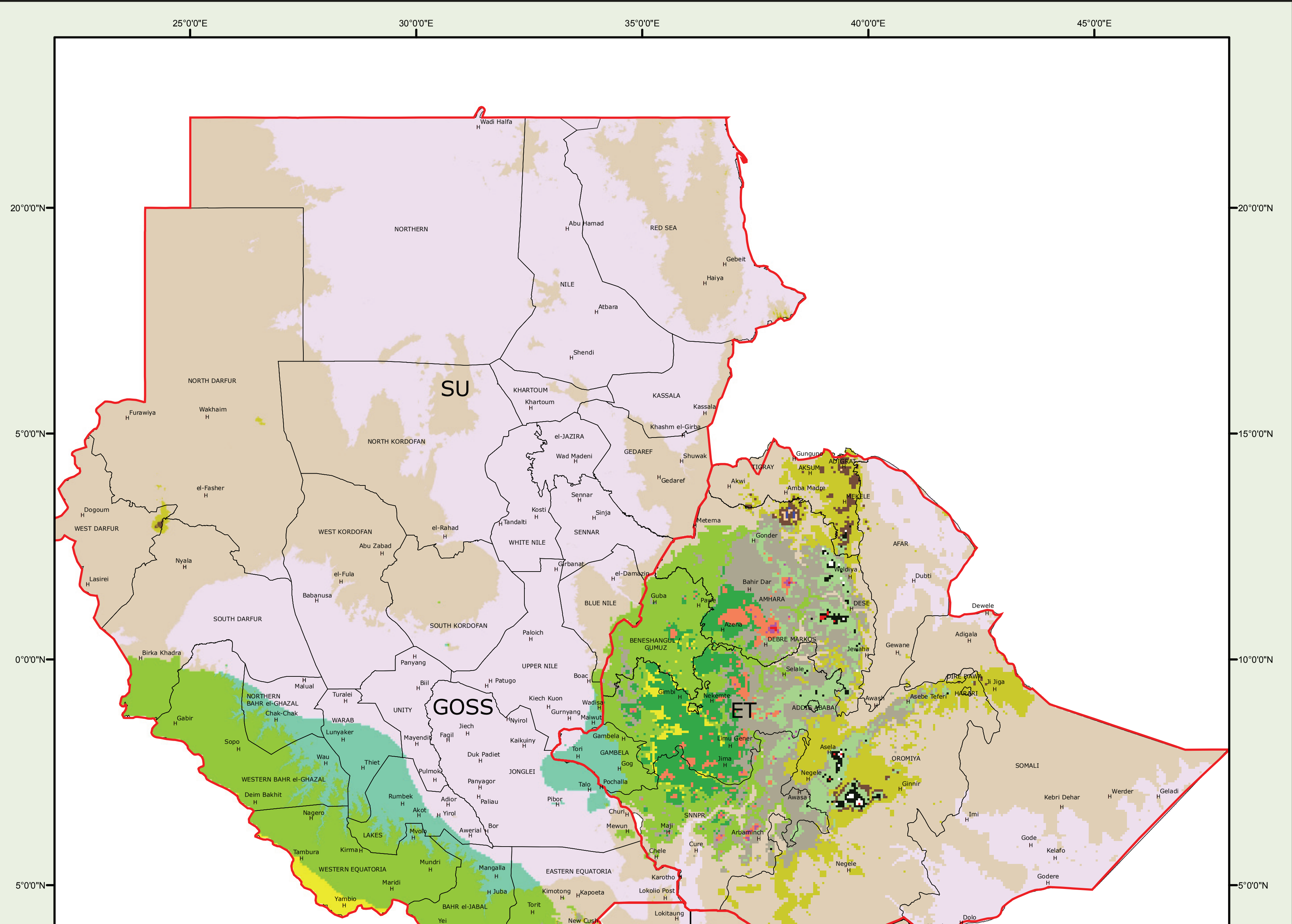
- < 500 m for *Hot Lowland*
- 500–1500 m for *Lowland*
- 1500–2300 m for *Mid Highland*
- 2300–3200 m for *Highland*
- 3200–3700 m for *Frost*
- > 3700 m for *Alpine Frost*

Later, information on rainfall regime and altitude zone was combined to give the agroclimatic zone map of eastern Africa (fig. 1.1), specifically developed for situating the profitable agroforestry innovations detailed in this technical handbook.

According to this agroclimatic zone classification, the maximum number of agroclimatic zones is 18, as in the diagram on the inside front cover. The number of agroclimatic zones may differ by country. For instance, among the five countries detailed in this handbook (Ethiopia, Kenya, Tanzania Uganda, India), only Tanzania has all 18 zones. Ethiopia has 17; Uganda has 12. Their location is shown in figure 1.1.

We assume that the agroforestry innovations found working in a particular agroclimatic zone in any of the study countries will have a relatively better chance of success elsewhere if implemented in a similar agroclimatic zone. This will save time and improve the success rate.

Further improvement done to customize the innovation to a new site within the same agroclimatic zone would be useful for refining the innovation. We hope such transfer of knowledge and expertise will help in refining the science and practice of agroforestry. Though the major aim has been to document profitable agroforestry innovations that are successful in eastern Africa, India was included to make use of the long agroforestry experience of the country. For this very reason, India was partitioned and mapped into similar agroclimatic zones. The overall study has covered 11 of the 18 agroclimatic zones that occur in eastern Africa. The experience in the remaining agroclimatic zones is equally interesting and worth considering.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SENNAR
WHITE NILE
BLUE NILE
UPPER NILE
UNITY
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WESTERN BAHR el-GHAZAL
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Abu Hamad
Gebeit
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Shendi
Khartoum
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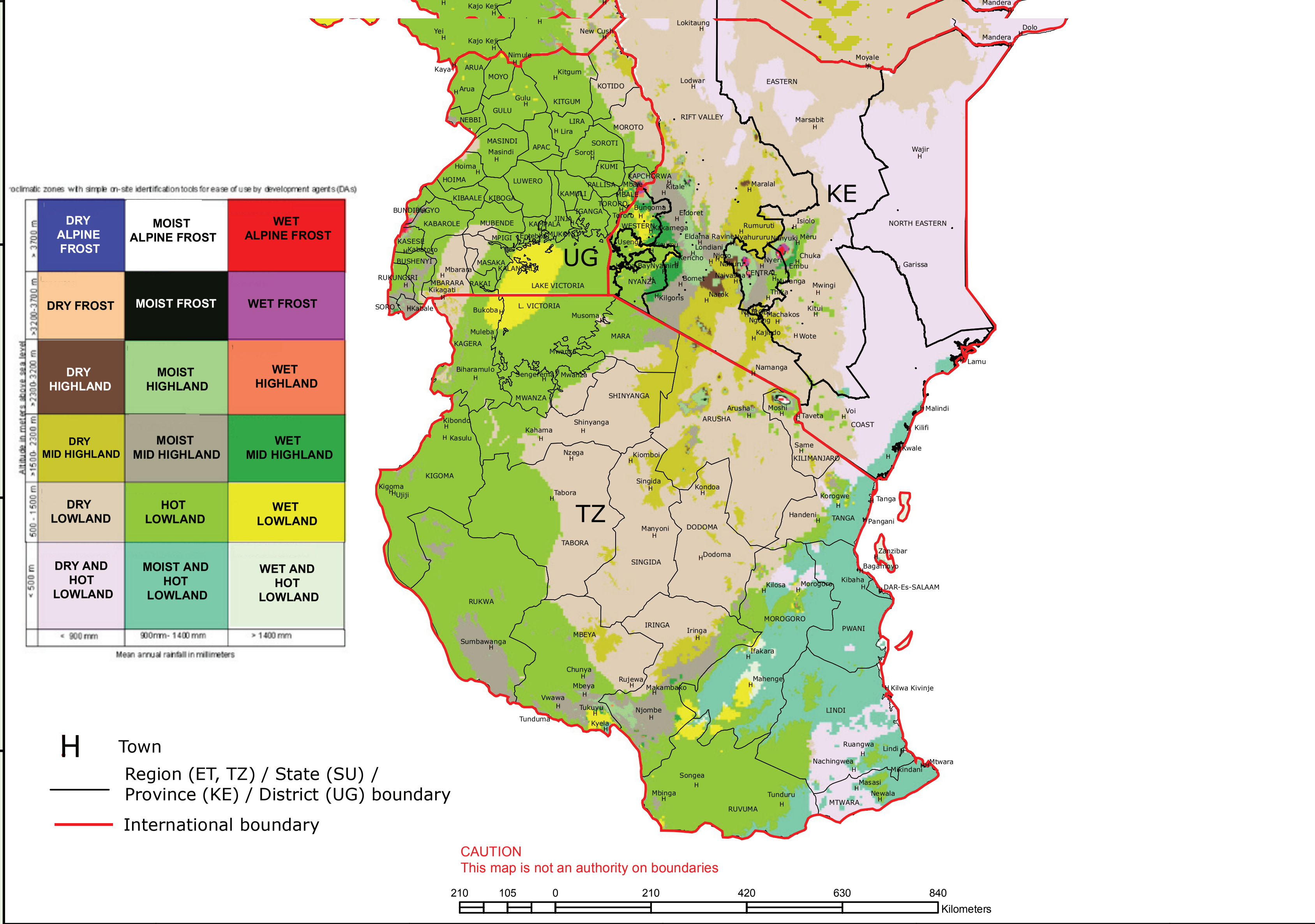


Figure 1.1. The harmonized agroclimatic zones of countries in eastern Africa.

Chapter 2 How to use this book

The basis for applying the innovations identified in this book is the agroclimatic zone for which each is relatively most suited. Therefore, the first step is to identify the agroclimatic zone of the area, which can be done in different ways.

Step 1. Use an altimeter GPS or topographic map of the area to know in which of the six altitudinal zones you are operating. This will allow you to identify one of the six rows the table shown in the legend for figure 1.1. Three agroclimatic boxes are found in each row, and to determine which one, you must know the mean annual rainfall.

Step 2. Get rainfall isohyets map of the area, consult the nearest weather station or refer to literature to ascertain the mean annual rainfall recorded for a close-by town or city. This will allow you to choose one of the three agroclimatic zone boxes of any row that you identified in step 1.

Often in remote rural areas, development agents and primary school teachers may not have easy access to either a rainfall map, a topographic map or any of the devices required. This presents a real problem, and experts need to customize this agroclimatic zone classification by identifying natural indicators such as traditional moisture management practices, indigenous trees and shrubs, soil colour and agricultural crops, which jointly represent a specific agroclimatic zone. For instance, Table 1.1 for Ethiopia documents the following parameters:

- Agricultural crops (A): Type of crop grown and number of harvests a year in rainfed agriculture system are helpful to identify different agroclimatic zones. For instance, unless irrigated, in Dry lowland and semiarid areas maize and sorghum are more dominant than barley and fababean. In addition, fababean and barley are highland crops, and it would be difficult to grow them in lowland or hot-lowland conditions. It is rare to experience double cropping in arid areas, different from moist and wet zones.
- Traditional conservation measures (C): If the area is dry, farmers may use water conservation measures such as tie-ridges or microbasins. In moist conditions, soil conservation measures will more likely be level terraces, level *fanya juu* or level bunds. Under wet conditions, measures are drainage furrows, traditional cut-off drains or other structures for disposing of excess water.
- Soil nature (S): Soil colour and texture can be indicative of rainfall regimes and altitude. In tropical countries, it is common to get soils

that are highly oxidized and leached in high rainfall areas as compared with dry areas. Therefore, the soil profiles in high-rainfall areas are well differentiated, becoming redder in the B horizon than the A horizon. In arid conditions, Aridosols and Rigosols are more common in dry agroclimatic zones, and Cambisols in moist conditions. Nitosols and Andosols are more common in moist to wet conditions.

- Indigenous trees and shrubs (T): Occurrence of indigenous trees reflects altitude (temperature), rainfall and soil conditions. Therefore, they can be useful habitat indicators. In extremely high altitudes such as the Alpine Frost Zone, one could get very limited vegetation types such as giant lobelia and *Hypericum* species. One can find species with buttresses and thick bark or other moisture storage facilities or with a thin film lining on the leaves to reduce evapotranspiration in Drys Hot-lowlands. Species such as *Adenium obesum* and *Hyphaene thebaica* are confined to such environments. The dominance of *Juniperus procera* and *Olea europaea* diminishes as we climb to higher altitudes while the dominance of *Haegenia abyssinica* and *Podocarpus falcatus* increases in these altitudes.

Only one of the above four parameters that are easily available to use in characterizing an agroclimatic zone may not suffice. However, if the four of them are considered jointly, it will be possible to identify the right agroclimatic zone without referring to altimeters or rainfall information.

We encourage agroforestry and forestry experts in the eastern African countries to develop the agroclimatic zone tables for their country similar to the one prepared for Ethiopia (table 1.1).

In this technical handbook, the agroforestry innovations are grouped by agroclimatic zone. Therefore, once the user has identified the agroclimatic zone of the area of interest, they will turn to the chapter that presents the choices available for that agroclimatic zone. Then specifics for choosing and upscaling the type of agroforestry option can be discussed with farmers. Unfortunately, for seven of the agroclimatic zones no option is provided. For Dry Hot-lowland, Moist Highland and Wet Highland, only a single innovation each is presented here. For the remaining seven agroclimatic zones, more than one option is provided. We hope a number of agroforestry innovations that are suited to those agroclimatic zones for which options are not provided will be made available in the near future.

Although the agroforestry options are grouped under the particular agroclimatic zone where each is relatively more fit, subject matter specialists can study each innovation and make minor adjustments to fit other agroclimatic zones. For instance, for using the conservation-based agroforestry innovation discussed in chapter 9 in areas in the Moist Dega agroclimatic zone, one may need to replace *Ehretia cymosa* (the fodder tree) with *Chamaecytisus palmensis* (tree lucerne), *Grevillea* (timber tree) with *Podocarpus falcatus* and *Citrus medica* (fruit shrub) with plum. The same kind of approach can be used to customize any one innovation discussed in this handbook to conditions in another zone. We recommend that development experts and basic and tertiary level educators make such adjustments for their own situation. This would also be an interesting exercise for students in these disciplines.

This technical handbook is also a reference for research professionals in that it presents a number of practical research questions. The 11th subtopic of every innovation gives an important clue as to what kind of problems exist that can be solved to improve use of the innovation.

Table 1.1. Harmonized agroclimatic zones with distinguishing characteristics for Ethiopia of agricultural crops (A), traditional conservation measures (C), soil nature (S) and indigenous trees and shrubs (T)

Altitude	**Dry** Less tan 900 mm	**Moist** mean annual rainfall 900-1400 mm	**Wet** More than 1400 mm
Alpine Over 3700 m	**Dry Alpine Wurch**	**Moist Alpine Wurch** *Crop* None but wildlife *Cons* None *Soil* Black, shallow *Veg* *Hypericum quartinianum, Hypericum roeperianum*	**Wet Alpine Wurch**
Wurch 3200-3700 m	**Dry Wurch**	**Moist Wurch** *Crops* Potatoes and barley single cropping per year *Cons* Drainage rare *Soil* Black, degraded *Veg* *Erica, Hypericum, Croton macrostachyus (dwarfed)*	**Wet Wurch** *Crops* Potatoes and barley, 2 crops per year *Cons* Widespread drainage ditches *Soil* Black, highly degraded *Veg* *Erica, hypericum spp.*
Dega 2300-3200m	**Dry Dega** *Crops* Barley, wheat, pulses *Cons* Traditional moisture conservation measures *Soil* Grey-brownish grey *Veg* *Olea europaea, Maytenus undata, M. senegalensis*	**Moist Dega** *Crops* Barley, wheat and pulses *Cons* Few traditional terraces *Soil* Brown clay *Veg* *Juniperus procera, Hagenia abyssinica, Podocarpus falcatus*	**Wet Dega** *Crops* Barley, wheat, nug, pulses, 2 crops/year *Cons* Widespread drainage ditches *Soil* Dark brown, clay *Veg* *Juniperus procera, Hagenia, Podocarpus falcutus, Arundinaria alpine*
Weyna-Dega 1500-2300 m	**Dry Weyna-Dega** *Crops* Wheat, tef, rarely maize *Cons* Terracing widespread *Soil* Light brown, yellow *Veg* *Acacia drepanolobium, A. seyal*	**Moist Weyna-Dega** *Crops* Maize, sorghum, tef, enset (rare), wheat nug, finger millet, barley *Cons* Traditional terracing *Soil* Reddish brown *Veg* *Acacia, Cordia africana, Ficus spp.*	**Wet Weyna-Dega** *Crops* Tef, maize, enset (in west), nug, barley *Cons* Widespread drainage *Soil* Red clay, deeply weathered, gullies *Veg* *Acacia, Cordia, Polyscias fulva*
Kolla 500-1500 m	**Dry Kolla** *Crops* Sorghum, rarely tef *Cons* Water retention terraces *Soil* Yellow, sandy *Veg* *Acacia tortilis, A. nilotica, A. bussei*	**Moist Kolla** *Crops* Sorghum, tef, neg finger millet *Cons* Widespread terracing *Soil* Yellow, silty *Veg* *Acacia, Erythrina, Cordia, Ficus spp.*	**Wet Kolla** *Crops* Mango, taro, sugar cane, maize, coffee, citrus *Cons* Ditches frequently *Soil* Red clay, highly oxidized *Veg* *Milicia excelsa, Cyathea manniana*
Bereha Under 500 m	**Dry Bereha** *Crops* Only with irrigation *Cons* Wind erosion common *Soil* Aridosols, regosols silty, sandy and gravelly *Veg* *Acacia senegal Acacia bussei Tamarix aphylla, Commiphora holtziana, Opuntia vulgaris*	**Moist Bereha** *Crops* Seasonal rainfed agriculture possible *Cons* Burning grasses common no wind erosion *Soil* Silty and clayey, mainly black *Veg* *Ziziphus pubescens, Antiaris toxicaria Erythroxylum fischeri*	

Crops : Main crops
Cons: Traditional soil conservation
Soil: Soil on slopes
Veg: Natural vegetation

Part II

Profitable agroforestry innovations of different agroclimatic zones

Chapter 3 Agroforestry innovations suitable for Dry Hot-lowlands

3.1 Prosopis-based agrisilvipastoral system in India

Nature of the innovation

This innovation has been studied in Dry Hot-lowland regions of India—Rajasthan, parts of Haryana, Punjab, Gujarat, western Uttar Pradesh and drier parts of Deccan Plateau, extending as far south as Tuticorin. In this region *Prosopis cineraria* (*khejri*) grows, confined to comparatively drier areas where the normal annual rainfall is less than 500 mm. In the most important areas of *P. cineraria* distribution, the climate is dry to arid and rainfall shows considerable variation, 100–600 mm annually, with a long dry season. This tree has succeeded in withstanding the odds by acquiring considerable drought hardiness. It grows on a variety of soils but is at its best on alluvial soils consisting of various mixtures of sand and clay. It is common on moderately saline soils but quickly dries out where the soil is very saline.

Typical *Prosopis cineraria* growing in this agroforestry innovation.

Rural communities encourage the growth of khejri in their agricultural fields, pastures and village community lands. Through experience, farmers have realized its usefulness and learned that it does not adversely affect crop yields; instead, it improves grain yield and produces biomass for storage. It is one of the chief indigenous trees of the plains of Haryana, western Rajasthan and Gujarat and is common in Bundelkhand and the neighbourhoods of Delhi and Agra.

The root system of *P. cineraria* is long and well developed. Growth aboveground is slow but belowground the roots penetrate deeper and deeper to reach subsoil water. Very deep roots help in securing firm footing and in obtaining moisture from deep soil layers. Taproot penetration up to 35 m depth has been reported. The tree is able to withstand the hottest winds and the driest seasons, and it remains alive when other plants would succumb. The tree is frost resistant. Because of its economic value, it is left standing in arable land. Farmers regulate its population by suitably adapting agroforestry management. It is a very useful tree, possessing great vitality and rapid growth in its natural zone and considerable power of reproduction from coppice shoots.

Justification of profitability

Historically *Prosopis cineraria* has played a significant role in the rural economy in the north-west arid region of the Indian subcontinent. As this tree is a legume, it improves soil fertility. It is an important constituent of the vegetation system. It is well adapted to arid conditions and stands up well to the adverse vagaries of climate. Camels and goats readily browse it. In areas open to goat browsing, the young plants assume a cauliflower-shaped bushy appearance.

P. cineraria provides wood of construction class. It is used for house building, chiefly as rafters, posts, scantlings, doors and windows, and for well construction, posts, agricultural implements, and shafts and spokes.

It provides fodder during winter months when no other green fodder is available. There is a popular saying that death will not visit a man, even in the time of famine, if he has a *P. cineraria* tree, a goat and a camel, since the three together sustain a man somewhat, even under the most trying conditions. The forage yield per tree varies a great deal. On average, the yield of green forage from a full-grown tree is expected to be about 60 kg with complete lopping leaving only the central leading shoot, 30 kg when the lower two-thirds of the crown is lopped, and 20 kg when the lower one-third crown is lopped. The leaves are of high nutritive value. Feeding the leaves during winter when no other green fodder is generally available in rainfed areas is thus profitable. The pods, a sweetish pulp, are also used as fodder for livestock.

P. cineraria is a most important species for feed, providing nutritious and highly palatable green as well as dry fodder, readily eaten by camels, cattle, sheep and goats, constituting a major feed for desert livestock. Locally it is called *loong*. Pods are locally called *sangar* or *sangri*. The dried pods, locally called *kho-kha*, are eaten. Dried pods also form rich animal feed, which all livestock like. Green pods also form rich animal feed, which is prepared by drying the young boiled pods. They are also used as famine food, known even to prehistoric man. Even the bark, having an astringent bitter taste, was reportedly eaten during the severe famines of 1899 and 1939. Pod yield is nearly 140 kg per hectare with a variation of 10.7% in dry locations. Its wood is reported to contain high calorific value and provides high-quality fuelwood. The lopped branches are good as fencing material.

Agroforestry components and interfaces

Studies conducted have concluded that the soil under *P. cineraria* has more organic matter, total nitrogen, total phosphorus, total potassium, available phosphorus and potassium, and available micronutients (Zn, Mn, Cu, and Fe) and slightly lower pH and electrical conductivity than the soil under field conditions without *P. cineraria* (Aggarwal 1980). Crops (millets and sorghum) grown within a 5- to 10-m radius around mature trees have been reported to yield 2–3 times more than the crops growing away from the trees (Shankaranarayanan et al. 1987) This increase in yield was mainly attributed to improvement in soil moisture and fertility under the trees. Puri and Kumar (1995) recorded that beneficial effects of *Prosopis* will start only after the trees are more than 10 years old. During the initial years there will be a negative effect of trees on adjoining crops.

Gupta et al. (1998) studied tree–crop interactions as affected by various densities of trees (666, 833 and 417 stems ha^{-1}) and different intercrops, such as *Vigna mungo* (mung bean), *Cyamopsis tetragonoloba* (cluster bean), *Vigna acontifolia, Marechal* (moth bean), and *Pennisetum glaucum* (pearl millet) at the Regional Research Station, Jaisalmer, of the Central Arid Zone Research Institute. During the tree establishment phase, *P. cineraria* did not compete with the associated agricultural crops nor was its growth affected by the intercrops. When the trees were 4 years of age, 417 stems ha^{-1} (4 × 6 m^2 spacing) was found to be the optimum density. Higher stem density adversely affected tree growth. Pulses (mung bean, cluster bean and moth bean) were better suited than pearl millet as intercrops.

Minimum inputs

Prosopis cineraria and other agroforestry models based on multipurpose trees are mostly adopted in subsistence type farming. This traditional agroforestry model has been followed in this region through the ages and seems to be in harmony with nature. This farming system is in general sustainable with low input applications. The perennials add considerable litter and enhance soil fertility. The roots, bark and leaf litter change the physical, chemical and biological properties of soils and prevent soil erosion. Cow dung is also recycled into the system. Thus the agroforestry models adopted by smallholder farmers generally require little outside input.

Agroclimatic zones

The hot and arid desert region of India is situated in north-western parts of the country, distributed in the states of Rajasthan, northern Gujrat, and the south-western part of Punjab and Haryana. This region is bordered by the irrigated Indo-Gangetic plains in the north and the central plateau region in the east. The major part of rainfall is received during the south-west monsoon period (June–September) with occasional rains in some parts from western disturbances. The production systems are constrained by low and erratic precipitation (100–420 mm per year), high evapotranspiration (1500–2000 mm per year), and poor soil physical and fertility conditions. Local farmers have evolved suitable land-use and management systems of farming, pastoralism and animal husbandry; of late, these local survival systems have become inadequate to fulfil ever-increasing needs. This has resulted in overexploitation of the resources causing rapid and widespread land degradation and decline in productivity.

The soils of the arid zone are generally sandy to sandy-loam in texture. The consistency and depth vary according to topographical features. The low-lying loams are heavier and may have a hard pan of clay, calcium carbonate ($CaCO_3$) or gypsum. The pH varies between 7 and 9.5. Underground water is scarce and occurs at great depths, from 30 to 120 m below ground level. Some of these soils contain a high percentage of soluble salts in the lower horizons, turning water in wells poisonous. They are poor in organic matter but contain various amounts of calcium carbonate.

Stretches of sand in the desert are interspersed by hillocks and sandy and gravel plains. Due to the diversified habitat, the vegetation and animal life in this arid region is very rich. About 23 species of lizard and 25 species of snakes are found here, several endemic to the region. Some wildlife species, which are fast vanishing in other parts of India, are found in the desert in large numbers, such as the great Indian bustard, blackbuck, Indian gazelle and Indian wild ass in the Rann of Kutch.

The natural vegetation is classed as Northern Desert Thorn Forest. These occur in small clumps scattered in a more or less open form. Density and size of patches increase from west to east following the increase in rainfall. Natural vegetation of the Thar Desert is mainly composed of the following tree, shrub and herb species: *Prosopis cineraria, Acacia leucophloea*, *Acacia senegal*, *Anogeissus rotundifolia*, *Callotropis procera*, *Salvadora oleoides*, *Tecomella undulata* and *Ziziphus numularia.*

Major factors that make the innovation successful

In desert region, cropping systems based on *Prosopis cineraria* have been adopted by farmers for many generations because of their economic, cultural and religious association with local people. Besides its utility as fodder (green foliage), vegetable (pods), cattle feed (dried leaves), khejri is retained or planted by farmers because it does not compete with crops. Being deciduous in nature, it sheds its leaves, so crop yields are not much affected. It protects the crops during scorching summers and also adds to soil fertility. Owing to these qualities it has been declared the state tree of Rajasthan. The main reasons of its acceptability:

- provides permanent cover to land surface, prevents soil erosion by winds and stabilizes sand dunes
- provides good-quality green fodder, which is in short supply in this region
- protects the environment and upgrades the soil quality through its deep root system; enhances organic matter through litterfall and root turnover
- improves the microclimate
- ensures rational use of soil moisture stored in deeper soil layers

Direct and indirect beneficiaries

Prosopis-based agroforestry models have proven to be ideal in this region and many benefits from practising them have been documented. The Indian desert region has poor natural vegetation because of harsh climatic and edaphic conditions. This biomass-starved region has witnessed many famines in the past. The agriculture here is rainfed and subsistence, and crop failures are common. Khejri based models have more adaptability owing to the tree's protective services. The tree provides shade to human beings, cattle and wildlife during scorching summers (May–June) when the temperature soars above 48 °C. Higher fertility levels under trees and reclamation of salt-affected soils are other important intangible benefits of this wonderful tree.

The nutritious and palatable fodder and utility of pods as vegetable and food also benefit dependent farmers, especially during famines and drought years. Income from the sale of trees during times of economic hardship is also beneficial for the farmers. In a nutshell, khejri and similar trees are the backbone of the rural population of this region, providing invaluable services of ameliorating the climate and conserving biotic diversity.

Upscaling strategies

Singh et al. (1988), while studying the effect of planting methods and amendments on growth of *P. juliflora,* found that growth was better when khejri was planted by auger hole and pit methods rather than in trench plantation, when the original soil was treated with gypsum at 3 kg plant^{-1} and then refilled. However, using 30 × 30 cm trenches filled with a mixture of original soil, 3 kg gypsum and 8 kg farmyard manure plant^{-1} appeared to be a promising method for establishing khejri plantations on highly deteriorated alkali soils. The effect of amendments on growth decreased in this order: 1) gypsum + farmyard manure, 2) gypsum + rice husk, 3) gypsum, 4) control. In 2 years, 37% of the khejri died in the trenches in which the original soil was left unchanged.

The work on genetic improvement of this species has also been conducted by many institutes. Progress has been made by selecting plus trees, evaluating germplasm and estimating genetic diversity. Study on the chemical composition and nutritive value of provenances has revealed significant differences (Arya et al. 1995). Mineral contents (except N and P), crude protein, and structural carbohydrates varied significantly ($P < 0.05$) between provenances, and the greatest amount of N, P, crude protein and lignin content were found in Hisar provenance. The in vitro dry matter digestibility varied from 18.2% in Gandhinagar provenance to 34.0% in Barmer provenance.

Kaur et al. (2002a,b) analysed the role of silvopastoral systems based on *Acacia nilotica*, *Dalbergia sissoo* and *Prosopis juliflora* along with grass species *Desmostachya bipinata* and *Sporobolus marginatus* on soil organic matter, microbial activity, biomass productivity, carbon sequestration and nitrogen cycling. In silvopastoral systems, microbial biomass carbon increased due to increase in the carbon content in the soil and plant system. The total carbon storage in the tree + grass systems was 1.18 to 18.55 Mg C ha^{-1} and carbon input in net primary production varied between 0.98 to 6.50 Mg

C ha^{-1} yr^{-1}. Carbon flux in net primary productivity increased significantly due to integration of *Prosopis* and *Dalbergia* with grasses. On the basis of improvement in soil and higher productivity in the tree + grass systems, agroforestry could be adopted for improving the fertility of highly sodic soil.

Institutions promoting the innovation

Many institutes have been working on developing agricultural technologies for this hot and arid region. The Central Arid Zone Research Institute (CAZRI) was established in 1959 under the Indian Council of Agricultural Research, New Delhi, with headquarters at Jodhpur. There are four regional research stations located in different agroclimatic zones to work on location-specific problems. The Arid Forest Research Institute, Jodhpur, is conducting research on developing agrisilvipastoral packages for arid tracts, and on natural regeneration in the national forests. The Central Soil Salinity Research Institute, Karnal, has also done wonderful research on planting techniques for *Prosopis cineraria* and its impact on soil properties and productivity under highly salt-affected soils.

The Maharana Pratap University of Agriculture and Technology, Udaipur, and the Rajasthan Agricultural University, Bikaner, have also developed several site-specific agroforestry models. Various NGOs are striving their best for ecological rejuvenation of arid regions. Worth mentioning is the role of an NGO, Bishnoi, which has active support of the local community for conserving khejri and the endangered blackbuck.

Research questions and knowledge gaps

For large-scale adoption of agroforestry models and for enhancing productivity in Dry Hot-lowlands, there is need to undertake further research and stress policy matters listed below:

- In situ rainwater conservation for establishing trees and enhancing crop productivity under agroforestry models. Water is the most limiting factor for productivity and sustainability in this arid zone. Once trees are established, other conservation processes start automatically, such as harvesting rainwater, encouraging more percolation, preventing soil erosion
- Standardizing optimum density of trees for getting the highest returns
- Undertaking research on selection of fast-growing genotypes having good fodder quality—palatability, crude protein, mineral contents, etc.

- Promoting organic farming. Although in the arid zone, using fertilizer and pesticides is negligible, if farm produce is produced as organic and promoted and sold as that, it can fetch more money.

Professional reflections and recommendations

With the existing technological knowledge, there is a vast potential for *Prosopis cineraria-* based agroforestry models under subsistence farming systems where rainfall is quite low, soils are sandy and no irrigation facilities exist. This is because khejri has been known for its adaptability to harsh climatic conditions and it protects the crops from such extreme climates. This system seems almost equally as productive as sole agricultural crops during years of high and well-distributed rainfall because it causes less competition to adjoining crops. Being less labour intensive and with multiple outputs from this tree component, the agroforestry model is economical in the long run, especially considering that droughts are quite common in this region.

The system is ecologically sound as it provides many invaluable services, such as ameliorating the microclimate, fixing nitrogen, adding litter, and preventing soil erosion. Khejri generally grows naturally and suits farmers whose ability to take risks is low. However, the full potential can be exploited only if genetically improved elite material is propagated and improved cultural practices are followed.

Under well-managed and irrigated conditions, agroforestry models based on high-value crops such as *Jojoba* should be adopted. They will have many times the productivity of either khejri or sole agriculture, provided governmental policy support (marketing, value addition, infrastructure, etc.) is there.

Chapter 4 Agroforestry innovations suitable for Moist Hot-lowlands

4.1 Agrisilvihorticultural system in the Central Plateau region of India

Nature of the innovation

This region is situated in the central parts of the country on the southern side of the Indo-Gangetic plains. It is made up of hard igneous and metamorphic rocks with pockets having fertile black soils. Indigenous land-use systems can provide valuable information for designing economically viable agroforestry systems. One such traditional system in Chattisgarh and Madhya Pradesh is to grow *Acacia nilotica* in upland rice fields. *Hardwickia binata* is another tree that does not significantly affect the economic yield of black gram and mustard for its first 6 years.

The soil is mixed red and black with low water-holding capacity. The most profitable among the agroforestry prevailing systems is the agrisilvihorticulture system comprising aonla (*Emblica officinalis*) as a fruit tree, subabul (*Leucaena leucocephala)* as a multipurpose shrub and black gram as an intercrop under rainfed submarginal lands. The aonla trees are planted at 10 x 6 m spacing. The subabul is planted in tree rows 2 m apart. Fruit-bearing

Integrating *Emblica officinalis* with gram crops is commonly used practice in this innovation.

in aonla starts after 4 years and stabilizes after 6 years of plantation. In addition, about 260 kg of grain are obtained from black gram every year.

Subabul in this system provides organic matter in the form of leaf litter and also fixes atmospheric nitrogen in the soil. It is cut twice a year, providing on average 1.32 t fuelwood and 0.79 t leaves per hectare per year. The leaves of subabul are utilized as mulch to minimize moisture loss from soil during summer, which is essential in Alfisols in rainfed areas. After 9 years of application, the organic carbon increased by 28.1% from the original value of 0.32%.

Justification of profitablility

In this region, various multipurpose trees such as *Eucalyptus tereticornis, Dalbergia sissoo, Leucaena leucocephala* and *Acacia nilotica* have good potential as a silvicultural component in the agrisilvihorticultural system. Along with *Leucaena,* various fruit trees such as ber, aonla and guava, and agricultural crops such as black gram, green gram and cowpea are grown (Solanki and Bisaria 1999). *Leucaena* trees are trimmed back twice a year to obtain fodder and fuelwood.

In an experiment, grain yield of black gram under aonla and subabul canopy was not affected significantly in the first 4 years after plantation at spacings of 10 x 6 m and 5 x 6 m. Thereafter, yield started declining gradually. After 9 years of plantation, the grain yield of intercrop (black gram) was 30% less in closer tree spacing than with wider spacing. Plantation aonla began to bear at the age of 4 years (Newaj and Shukla 1998). Among varieties Kanchan, Chakaiya, Krishna and NA-7, Kanchan gave highest fruit yield of 90.11 kg fruit per plant; next was NA-7. Chakaiya yielded the least. Subabul provided on an average 1033 kg fuelwood per hectare and 91 kg green leaves per hectare every year when harvested twice a year (Newaj and Shukla 1998). The leaves of subabul were used as mulch to minimize moisture loss from the soil during summer, a desirable practice for Alfisols in rainfed areas.

An agrisilvihorticultural system with various components such as aonla and subabul with black gram as an intercrop is the system most adopted in rainfed submarginal lands. Such systems provided 75–120 kg fruit per tree from aonla, 1033 kg fuelwood and 910 kg fodder per hectare from subabul and intercrops (black gram, green gram, seasame, pigeon pea) were included and initiated on submarginal soil under rainfed conditions. This system provided 1790 kg ha^{-1} fruit, 2130 kg ha^{-1} fuelwood, plus 1850 kg ha^{-1} fodder and 400–422 kg ha^{-1} grain yield from different intercrops. This system was proved the most profitable system under rainfed conditions. The gross income from the system was less during the initial year but with the start of fruiting in aonla, the gross income increased and reached up to INR 60,712 (valued at 41 to the US dollar) by the 13th year. The benefit–cost ratio at this age was 3.28 and on discounted rate it was 2.61, indicating that the aonla-based system is profitable in marginal lands under rainfed conditions (Anon. 2004).

Another aonla-based agrihorticulture system was developed for degraded lands. The most profitable variety Kanchan yielded 109 kg of fruit per tree under rainfed conditions (11-year-old plantation). Planted at 10 x 6 m spacing, the trees can yield about 12–15 tonnes of fruit per hectare after 10 years of age. In addition, the black gram intercrop yielded about 0.13 tonnes of grain. The aonla-based system gave a discounted benefit–cost (at 12%) of 3.62 as against 1.10 under a pure seasonal monocropping system (Kareemulla et al. 2003).

Agroforestry components and interfaces

The system comprises three main components, such as black gram as an intercrop and the fruit tree aonla and multipurpose subabul as perennial components. The aonla trees are usually planted at a wider spacing of 10 x 6 m and *Leucaena* is planted on farm boundaries. During the first 4 years of growth the competition between different components is almost negligible as tree crown and root system are not fully developed. After 9 years of tree growth, the grain yield of intercrop was 30% less in closer spacing than with wider spacing (Newaj and Shukla 1998).

The subabul trees are trimmed back twice a year to obtain fodder and fuelwood.

The leaves of subabul are used as mulch to minimize moisture loss from the soil. This practice plays an important role in minimizing the aboveground competition between annual and perennial components. In addition, the nutrients released from the decomposed leaves improve the fertility status of soil.

In another trial on an agrihorticultural system on a farmer's field, minimum interaction between different components was observed. Even after 10 years of growth, there were no significant differences in grain yield of wheat and groundnut in association with aonla, guava and ber. Among the three fruit plants, the growth parameters and fruit yield (6t/ha^{-1}) were maximum in aonla. For intercrops, yield of wheat was maximum in association with aonla (1.65t/ha^{-1}) followed by ber and guava; the yield of groundnut was maximum in association with ber 0.98 t/kg ha^{-1}) followed by ber and guava (Anon. 2004).

During the 13th year of plantation with 6 x 6 m spacing for aonla, the yield of wheat was 1.9 t ha^{-1} and the yield of groundnut 0.4 t ha^{-1}. The growth parameters of aonla during the 13th year showed plant height 6.75 m, and dbh 18.9 cm. Fruit yield of aonla was 8.7 t ha^{-1}.

Minimum inputs

This region has a water deficit and sparse forest cover. Thus, farmers face acute shortages of fodder, fuel, timber and other non-timber products of trees. Agricultural productivity is low, so a tree-based farming system has considerable potential to provide substantial sustainable income to the farmers.

In an agrisilvicultura system developed for rainfed conditions, effect of shoot pruning, fertilization and root barriers around subabul trees on intercropped sorghum and cowpea were studied. Crops grown with pruned trees attained higher dry matter production than those under unpruned trees. With pruned trees the 2-year mean yield of sorghum was 39% and cowpea 26%. These crops in an agroforestry system responded more strongly to fertilizer application than did the pure crops, suggesting an increased need to apply fertilizer in an agrisilviculture system (Osman et al. 1998).

Agroclimatic zones

This region is situated in central parts of the country between the Ganga on the north and River Godaveri on the southern side. It is made up of hard igneous and metamorphic rocks with pockets containing fertile black soils. The climate is largely semi-arid. The mean annual temperature is 26.5 °C with May–June (47.5 °C) as the hottest months and December–January (1.9 °C) the coldest. Average annual rainfall varies from 800 to 1200 mm, of which 80% is received during monsoon season (July–September). The rainfall pattern in this region is erratic and the quantity uncertain. The wide range of soils in central India is mainly sandy to loam in texture with gravels on the upper slopes and loamy soils on lower slopes. The National Research Centre on Agroforestry, Jhansi, at an altitude of 271 m, is the nodal institution for developing and improving this innovation.

Major factors that make the innovation successful

The decline in forest cover and productivity has created a shortage of fuelwood and therefore the dung produced by livestock, rather than becoming a good source of manure, is diverted for use as fuel. Irrigation facilities are limited. Livestock population has an important place in the economy of this region. Like food and fuel, fodder is important issue. With the introduction of agroforestry systems, sustainable development of such lands has been achieved. Introduction of fast-growing, multipurpose, nitrogen-fixing trees like *Leucaena leucocephala* in association with crops may provide sufficient fuelwood and green fodder to meet farmer requirements for fuelwood and fodder without much affecting crop yield including that of fruit crops (Deb Roy 1994).

There is social support for this system as products generated from all the components are intensively used by the local population and there is good market for the products. The high-yielding aonla varieties have further made the system economically more competitive with the traditional cropping system.

Direct and indirect beneficiaries

There are many direct and indirect benefits for this region in adopting this agroforestry system of aonla, subabul and black gram. Direct benefits include various products derived from the system such as aonla fruits, *Leucaena* fuelwood and fodder, and agriculture produce. In addition, trees modify the microclimate, improve nutrient cycling through processes such as litter dynamics and nutrient pumping, retard soil erosion and desertification, and maintain biodiversity and soil fertility. Such microsite enrichment is through improvement in the soil organic matter and mineral nutrient pools, which can be related to litter and fine root dynamics. Moreover, this multipurpose subabul tree is a nitrogen-fixing tree that improves the fertility status of soil by making the nitrogen available to plants. The leaves of subabul are used as mulch to minimize moisture loss from soil during summer, which is essential in Alfisols in rainfed areas. Farmers are direct beneficiaries of this innovation as this system provides them all their basic needs and improves their economic status.

Indirectly large-scale adoption of this innovation benefits all. Tree cover in this forest-deficit region will increase, which will improve the microclimate of plantation sites and the region as a whole.

Upscaling strategies

This agrisilvihorticultural system is replicated in different parts of this region. Consistently positive results are reported from different users of this technology. The users are satisfied socially, economically and ecologically. This is one system that fulfils the major requirements of food, fuelwood and fodder. Developers of the system are satisfied with its outcome and hope that it will be adopted in large tracts of land. Development of technology by the scientists at the National Research Centre on Agroforestry and the Indian Grassland and Fodder Research Institute, Jhansi, is the major factor contributing to the success of innovation. A system was required that would readily satisfy the basic needs of the local population, and the components of this system are socially acceptable.

Now even the progressive farmers are trying different options to further improve upon the system. They are establishing orchards at different spacings to observe the impact of interspace on crop yield. In addition, various modifications in existing cultural and management are tried to overall improve the feasibility of the system.

Institutions promoting the innovation

The scientists at the National Research Centre on Agroforestry, Jhansi, and the Indian Grassland and Fodder Research Institute, Jhansi, are making concerted efforts to develop and improve this agrisilvihorticultural system. Different cultural and management practices are being tested to improve the overall productivity of system. Different new varieties are being developed, and trials on irrigation schedule and optimum fertilizer dose are being conducted at the main research centre and on farmers' fields. Propagation techniques for fruit trees are being standardized to mass multiply superior planting material for farmers. In addition, research on different agrisilvihorticultural systems is going on in various other institutes such as Hissar Agricultural University, Hissar (Haryana), Indira Gandhi Krishi Vishwa Vidyalaya (Raipur), Gujrat Agricultural University, Sardar Krishi Nagar (Gujrat) and Rajasthan Agricultural University, Fatehpur-Shekhawati (Rajasthan). The technologies developed by different research institutes and universities are being disseminated to their actual users by organizing 'farmers fairs' in important seasons and through local newspapers and electronic media such as television. Local NGOs also play an important role in developing and promoting this technology. Other institutions like schools and municipal corporations have been involved in creating awareness among the public for planting trees and adopting agroforestry models.

Research questions and knowledge gaps

Earlier there were problems with agroforestry such as lack of awareness about the benefits, selection of tree species, non-availability of planting material, high cost of establishment, late economic returns from the tree components, poor marketing facilities and lack of packaged information on planting trees on farmland along with suitable crop combinations (Solanki and Bisaria 1999). These problems were solved to the maximum extent by selecting an agroforestry system that offers higher economic returns from the tree and crop components and that encourages farmers to develop their own necessary infrastructure for input supply and for processing and marketing their produce. The technology and management support required to make the system socially acceptable and both economically and ecologically viable is provided by research institutes, government and NGOs.

Basically this was low-input technology recommended for resource-poor regions. With the passage of time, the basic infrastructure has improved and irrigation facilities were made available to large areas. Now farmers are taking this innovation on a commercial scale using a high-input and high-output strategy. Thus concerted efforts are required to keep pace with the development and farmer requirements. It is necessary to develop new region-specific high-yielding varieties for both fruit and multipurpose trees. This is a multicomponent system, and during later years crop yield significantly reduces due to above- and belowground competition. Research efforts are required to develop suitable cultural and management practices to minimize competition and to improve the overall productivity of system. Likewise, shade-tolerant varieties of intercrops need to be developed to grow crops successfully for a longer number of years.

Professional reflections and recommendations

There is great potential for success of this agrisilvihorticultural system. Farmers have already taken it to a commercial scale and are getting good benefits. There is no doubt about the significant economic superiority of this system over the traditional cropping systems. Replicated results of these aonla-based agroforestry models from various parts of the region have validated this assumption. With the concerted efforts of various research institutes and universities, sufficient work has been done to develop packages and practices of this system. To maintain its superiority over traditional systems, government-certified nurseries should be set up to supply only quality germplasm to farmers. This will further help improve the productivity of the system.

Aonla fruit is in great demand, and there is little chance of glut of its produce in market. But state governments should be cautious about a such scenario and should regulate orchard plantations as per the demand of fruit in the market. Moreover, some processing plants should be encouraged in the region to maintain the great demand for this fruit in future. Financial institutions should be encouraged to ensure cash credits for farmers adopting agroforestry, especially during initial years until the trees start yielding.

4.2 *Cajanus cajan* cum millet farming in Uganda

Nature of the innovation

An agroforestry practice of *Cajanus cajan* and *Pennisetum glaucum* is found in the Lango farming system comprising the districts of Apac and Lira in northern Uganda. *Cajanus cajan,* of Indian origin, is believed to have come to East Africa during the slave trade. It derived its name 'pigeon pea' from the West Indies, where it was used as a bird feed (Van der Maesen 1986). It is a major pulse crop in the semi-arid tropics and was introduced in East Africa as far west as the Nile Valley. It is suited to the Lango and Teso agroclimatic zones, where it is now grown either as a sole crop or as an intercrop in the farming system.

The practice involves growing the leguminous pigeon pea with millet (*Pennisetum glaucum*) established at the same time or in sequence. The pigeon pea is established as a 2-season crop, during which it is harvested. Normally, the vegetation is ratooned and its biomass is allowed to decompose in the field. The millet crop is then introduced in the subsequent season to benefit from the soil fertility-replenishing ability of the pigeon pea, resulting in improved millet yields. It is most especially a source of protein for the rural

Cajanus cajan is often used in innovations for its edible seeds because it repennishes soil nutrients.

poor population who cannot afford expensive animal proteins (Areke et al. 1994; Obuo and Okurut-Akol 1994). It is used in many ways that include vegetable soup of immature green pods and seeds, flour, canned as green peas, dhal or cooked dry grain. Green and dry seeds are used to prepare such foods as *dek apena, agira/magira* and *onyobonyobo* in the Lango, Acholi and Teso subregions respectively (Singh 1994).

Justification of the profitability

There are two main products in this agroforestry practice—pigeon pea and millet. However, in the area pigeon pea has shown a higher commercial potential than millet. The latter, however, provides food benefits to the households. Growing pigeon pea and millet together tends to enhance millet production as pigeon pea provides the necessary soil nutrients. The decomposed crop residues from the early harvest of the millet crop improve soil properties necessary for the performance of pigeon pea, resulting in higher yields.

Current production estimates in Uganda show 74,000 ha were under the crop by 2001 (Statistical Abstract 2001) and average yields are 800 kg ha^{-1}. In the period 1980–2002, an average of 6333 hectares of arable land was put under cultivation of pigeon pea in Uganda per annum, producing a net annual mean production of 7045.5 tonnes. During the same period, 48,545 hectares of land, was put under millet production resulting in a net annual mean production of 73,000 tonnes (annual mean yield: 205.5 kg ha^{-1}) (ICRISAT/ESA 2005). The statistics clearly show that more land is put into producing millet than pigeon pea despite a better prevailing market for the latter.

The major world producers of pigeon pea are India, Uganda, Tanzania, Kenya, Malawi, Ethiopia and Mozambique. Currently India is the highest producer and consumer of pigeon pea and its products. Processing mainly involves dehulling in which the seed coat is removed and the cotyledons split into halves to make a product known as dhal. This improves the palatability, digestibility and acceptability, reduces cooking time and increases its market value (Agriforum 2002). Dhal is processed into flour for use in the confectionery industry and in various recipes developed to promote the product.

Whole grain is common in the market and is supplied by Ugandan farmers, while dhal is imported from Tanzania and India (Agona and Muyinza. 2004). In Uganda, small quantities of dhal are available in the market; it fetches a price considerably higher than whole grain. Although a lot of pigeon pea is produced in the northern and eastern part of Uganda, most of the dhal and packaged grain on sale in the urban markets are imported from Tanzania.

The demand for dhal outstrips the supply and that is attributed to low processing levels in Uganda. This is directly attributed to the unavailability of improved pigeon pea processing technologies and lack of marketing information and pricing among small-scale farmers in the country (Mutyaba et al. 2002).

The varieties of pigeon pea grown in Uganda, KAT 60/8 and SEPI I, are rich in protein, carbohydrates, vitamins and minerals such as calcium, phosphorus and iron (Agriforum 2002). Dhal soup from pigeon pea contains up to 28% protein. It contains 10 times more fat and 5 times more vitamin A than ordinary peas, making it a worthy supplement for traditional diets.

Over the last two decades, Uganda has been increasing acreage under pigeon pea, from 55,000 ha in 1980 to 78,000 ha in 2002. The increase in the annual yield has been a steady, from 26,333 tonnes to 78,000 tonnes. There is little likelihood for this trend to reverse, hence ensuring a continued supply.

Currently a few established companies are involved in buying and selling pigeon pea in Uganda. They include Wan Acel Produce Store, Akonye Stores and God Provides Stores, all based in Lira. Wan Acel and Akonye Stores each have the capacity to purchase 5 tonnes of good quality pigeon pea per year. The other credible supplier is the Kampala-based Victoria Munjani Co, Ltd, which can access external markets.

Agroforestry components and interfaces

The synergistic interfaces in this practice are mainly between the legume pigeon pea shrub and the millet crop. The fine weeding management required by millet benefits the pigeon pea crop, giving it a healthy growth that results in high yields and increased income for households. As millet is harvested earlier than the pigeon pea crop, its crop residues will decompose, adding organic matter to the soil; as pigeon pea is a legume, it contributes to the basic nutrients millet needs to perform well. The mulch from the leaf litter of the pigeon pea crop also helps the millet crop enjoy constant moisture conditions during the growth period. Thus the combination results in higher yields.

Minimum inputs

The major material requirements for this agroforestry practice include planting materials for millet and pigeon pea plus land, labour and draught power. Technically, pigeon pea is best established by direct sowing of seed in a well-prepared field. No pre-germination treatment of seeds is needed.

Table 4.1. Components of pigeon pea and millet intercrop and their interactions

Components	Pigeon pea	Millet
Pigeon pea	Good millet yields result in increased availability of quality planting material	Ability of pigeon pea to improve soil fertility enhances millet yield
Millet	Crop residues after the millet harvest decompose and improve the soil for pigeon pea; the fine weeding management of millet also benefits the pigeon pea	High millet yields subsequently contribute to household food security and increased incomes

Where seeds fail to germinate, for crop uniformity gaps should be filled with seedlings earlier grown in pots. Management involves weeding and removing dead branches from the pigeon pea plants. In some cases spraying insect pests may be necessary, and this implies financial cost in terms of chemicals and a knapsack sprayer.

Processing involves drying the pigeon pea on bare ground, threshing and storing it. Local processing methods involve splitting the seed using grinding stones, or pounding using a mortar and pestle, and winnowing before soaking and boiling. Improved pigeon pea processing methods include a stone or wooden *chakki* and simple fabricated manual machine dehullers. While the chakki is affordable for small-scale farmers, manual machine dehullers, although expensive, are more efficient.

In marketing, the pigeon pea grain must be of good quality if it is to command a good price. Buyers prefer well-dried grain (12–13% moisture content) free from foreign matter. Large-sized and brightly coloured or yellow dhal splits are much preferred. Marketing also requires producers to organize themselves into farmer groups, which enable them to bulk their produce and increase their negotiating power with traders. The traders too need to operate within associations to realize economies of scale and ensure high-quality standards.

Agroclimatic zones

Both pigeon pea and millet are crops of the tropics and subtropics, growing well between latitudes 30°S and 30°N and at elevations ranging from sea level to 200 m (ICRISAT/ESA 2005). The crop thrives in hot, dry environments. Its drought tolerance and ability to use residual moisture during the dry season make it important for the semi-arid tropics.

In Uganda, the *Cajanus–Pennisetum* agroforestry practice is found on Lake Kyoga shores covering the Lango districts of Apac and Lira. Rainfall in this area is bimodal with peaks occurring during April–May and August–October, with an annual rainfall range of 1200–2000 mm. The rain is usually convectional and comes in the afternoons and evenings. A short dry spell falls from June to July and a longer dry period stretches from December to March. The average minimum temperature is 22.5 °C and the maximum 25.5 °C. The absolute minimum scarcely falls below 13 °C. Within the harmonized agroclimatic zones, the practice fits in the moist and hot lowlands.

Major factors that make the innovation successful

Pigeon pea is a hardy crop that is widely adaptable to different environments; it is more tolerant to drought and high temperatures than most other crops. Its deep root system allows for optimum use of moisture and nutrients. It therefore has few incidents of loss, making the practice reliable and suitable. The pigeon pea crop provides yield stability, particularly in degraded soils and drought-prone environments where less-drought tolerant cereals often fail.

Pigeon pea is a self-pollinating crop and this puts farmers at an advantage as they are able to recycle any original seed variety for generations. The availability of a wide range of short-maturation varieties of pigeon pea means that farmers can still sow their post-rain cereal crop, thereby increasing the productivity of a unit of land. Also in the practice pigeon pea offers multiple benefits ranging from protein-rich seed (approximately 21%) to fuel, fodder, stakes or poles, and improved soil fertility and erosion control (ICRISAT/ESA 2005).

The practice also means year-round production in that the millet is usually harvested first while the pigeon pea pods are left to mature. There is maximum advantage in that the weeding applied to the millet is enough to take care of the pigeon pea, and this reduces production costs.

The early growth of pigeon pea is slow, making it an ideal, non-competitive intercrop with cereals such as millet. Pigeon pea stems are an important household fuel due to the plants high productivity, which compensates for its low specific gravity and high moisture content.

Millet and pigeon pea are both important as food crops and for generating income through sales. It is therefore certain that even in situations where the market is not available, farmers can use the produce for subsistence consumption. Improved manual machine dehullers replacing the cumbersome use of local methods of grinding stone or mortar and pestle go a long way in saving time and energy it takes to process pigeon pea into dhal.

Direct and indirect beneficiaries

In northern and eastern Uganda, pigeon pea is the most important grain legume and major source of protein among resource-poor small-scale farmers. From a nutritional perspective, it is an important supplement to the local diet. Dhal soup improves body weight and can improve the health status of weak children and adults (Agona and Muyinza 2004).

Women do all the harvesting, threshing, sorting and drying of pigeon pea. In some instances when labour is hired for these activities, it creates rare employment opportunities for women. Men are more involved in marketing the produce.

Other indirect beneficiaries from the practice include produce dealers, transporters, fabricators, vendors of processed products (e.g. bagiya) and confectionary industries. The local administration and seed companies also benefit from the practice through revenue generation and sales of seed respectively.

Upscaling strategies

Most of the scaling-up work has been done by the COARD Project of NARO. Farmers were trained and equipped with skills and knowledge of quality control with emphasis on pest management, both in the field and during storage. Farmers are also informed about market requirements of quality, quantity and sustainability.

Under the DFID-funded COARD Project, research work was carried out comparing the effectiveness of individual farmer and group seed-delivery systems. This project established demonstrations and carried out field days in strategic public places such as along main roads and at subcounty headquarters, marketplaces and schools to expose the innovation to wider audiences. This approach worked well, due to the fact that the farmers managed the demonstrations themselves.

Another initiative under the same funding was promoting improved handling, processing, use and marketing of pigeon pea in Apac District. This project used a participatory approach that progressively changed the attitude of the farmers towards the crop. It also equipped them with technologies to improve and increase use of the crop, thus increasing its potential as a household income earner.

The other approach was based on gender analysis of pigeon pea production, processing and marketing. Preliminary analysis indicated that mainly women farmers process the pigeon pea while men mostly determine when to sell and how to utilize the market proceeds. For this reason, farmer groups were organized to comprise at least 30% women. The women were involved in training, decisionmaking and sharing of the benefits accruing from the work. Thus benefits to women came through reduced drudgery, improved nutrition for their families, and household food security.

Institutions promoting the innovation

Table 4.2 shows the major institutions that are promoting the practice and the various roles that they play.

Table 4.2. Major institutions promoting the practice in the country

Institution	Roles and functions
Research (SAARI, COARD)	Carry out breeding experiments to develop early-maturing varieties
	Develop strategies for scaling up pigeon pea production
Local governments	Provide an established system for mobilizing farmers
NGOs	Promote the practice through training and by providing planting materials
Farmer groups	Acquire planting material and grow pigeon pea
Traders	Provide market for pigeon pea and its products
Extension agents	Build capacity and transfer technology

Research questions and knowledge gaps

As more farmers realize the economic value of pigeon pea, and as processing technologies are improved, more land is likely to be opened for growing it. However, more land is not feasible considering the current growth in population. This then poses a challenge for research to develop early-maturing varieties that can be grown twice in a year. Research is also needed to develop pigeon pea products, since local and regional markets exist.

Professional reflections and recommendations

In Uganda, as in most parts of Africa, pigeon pea is grown as a subsistence crop for local consumption. This makes commercial production risky because the absence of large market outlets causes significant price fluctuations. This calls for establishing links with national, regional and international markets.

There are clear indications of a huge potential existing for pigeon pea as a tradable commodity within the domestic, regional and international markets. To fully exploit the market, however, adding value in the form of dhal is a primary prerequisite. It is therefore important that the right technologies for producing, processing and marketing pigeon pea and its products are made available to farmers. This process can better be done if farmers form groups, enabling them to take advantage of economies of scale.

The prevailing low production levels of pigeon pea are due to lack of adequate and appropriate storage facilities, thus constraining the sustainability of the niche market. This means production needs to expand to meet market demands and production groups need to establish appropriate storage facilities to produce quality grain for the domestic market.

Chapter 5 Agroforestry innovations suitable for Dry Lowlands

5.1 *Melia volkensii* cum food crop farming system in Kenya

Nature of the innovation

Growing and using *Melia volkensii* (melia) is part of an indigenous agroforestry system in Kenya that is already widespread in the semi-arid areas of eastern and central Kenya. Melia, belonging to the family Meliaceae, has been described by many authors (Dale and Greenway 1961; Noad and Birnie 1989; Beentje 1994) as a deciduous open-crowned tree. Different heights have been reported for mature trees, ranging from 6 m to 20 m (Beentje 1994). The usefulness and value of melia products, combined with its short rotation period, make it the most suitable cash tree crop for dryland agroforestry in Kenya (Kidundo 1997a,b,c; Juma 2004a). This species is considered as a potential plantation and agroforestry tree species for timber and fuelwood production in semi-arid areas and has widely been used in afforestation programs in the drylands of Kenya.

Melia volkensii trees, integrated with maize and sorghum grow to up to 30–40 cm diameter at breast height in 4 years.

As an agroforestry tree species, melia is locally grown by farmers within different agroforestry practices and systems in semi-arid areas of Kenya, and for different products and uses. It is regarded as a golden tree by farmers in this region due to its ability to provide cash (mainly through sale of timber), compatibility with many crops and ability to provide many other products (Juma 2004a). Some of the services provided by melia include soil erosion control due to roots, mulching effect, and windbreak (boundary planting). It has a deep rooting habit that makes it drought tolerant and thus adaptable to the harsh environment of the drylands. All these factors make farmers prefer it.

Justification of profitability

Socio-economic surveys (Shepherd 1989; Stewart and Blomley 1994), an ethno-botanical survey (Riley and Brokensha 1988) and an indigenous fodder tree survey (Roothaert and Kidundo 1996) in Mbeere District have reported that melia is among the most valued of indigenous species, being managed for timber, fodder and other products. It is mainly intercropped within the cropland with a variety of food and tree crops. These include grain legumes (cowpea, green gram, pigeon pea, beans), maize, sorghum, millet, root crops (cassava and sweetpotato) and tree crops (mango, guava, papaya). Intercropping with a variety of agricultural enterprises reduces risk in these drought-stricken areas and raises the profitability of the system.

Melia grows fast and quality timber can be achieved in less than 10 years (Kidundo 1997a,b,c). It is usually harvested for sale when money is needed, such as to buy food and pay school fees. The species timber is termite resistant, the major reason it is becoming the most highly valuable timber species in drylands, where termite infestations are lethal for the construction industry. The timber is durable and has a coarse texture, with close-grained wood; it works easily, planes well, has a density of about 0.62 kg per m^3 (Dale and Greenway 1961) and is usually converted in situ by pit sawers (Kidundo 1997a,b,c). Carpenters compare it favourably with *Ocotea usambarensis* and *Vitex keniensis*. The timber is used locally for making window- door frames, doors, shutters, rafters and furniture. Melia timber and products are usually the most expensive in the Kibwezi area. For example, a bed made from melia timber was sold at KES 8000 (USD 106) while that of *Cupressus lusitanica* sold for KES 4500 (USD 60) (Juma 2004b).

Cultivating melia in agroforestry systems is treated as an enterprise by farmers; 70% of households in Kitui and 50% of those in Mbeere Districts were found to sell melia tree products either locally or externally (outside the districts) (Mulatya 2000). In some areas, such as Taita Taveta, Makueni and Kitui Districts, it is treated as a living bank that provides revenue in

Producing timber but competing little with the crop grown under it is an additional benefit of growing *Melia volkensii*.

times of cash shortage, and booking by buyers in advance is common (Maina 2004). A comparison of prices of products made from melia and those from other species showed that melia products fetched prices higher than those of the exotic species in local markets and were often at least twice as expensive as the exotics (Mulatya 2000). For example, a doorframe of melia cost KES 350 (USD 5), of *C. lusitanica* KES 140 (USD 1.80), and of *Pinus patula* KES 120 (USD 1.60) in local markets in Mbeere. In the same region, a bed of melia cost KES 5000 (USD 67), one of *C. lusitanica* KES 3500 (USD 47) and of *P. patula* KES 2500 (USD 33).

Studies conducted to assess profitability of melia cultivation by farmers have shown that it is a profitable activity. Using annuity value to calculate net present worth, a simple cost-benefit analysis of melia–maize intercropping system was carried out (Mulatya 2000). In this study, melia timber rotation of 8 years and a clear bole of 6 m aboveground with standing tree value of KES 1500 in the final year is used. In addition, firewood value of KES 100 per year and maize yield loss per year (4%) due to melia effect on one hectare and maize price of KES 18 per kilogram were used. Results indicated that four trees per hectare offset crop yield loss and were profitable on farmers' fields.

In another study (Maina 2004), financial analysis for melia timber production showed a discounted value of KES 160,120 ha^{-1} (USD 2135) at the current management practices on the farms, and a value of KES 197, 807 ha^{-1} (USD 2637) under forest department recommendations. These values are close, and considering that there is high management for forest department trees the author concluded that it is a profitable enterprise. The difference in values between Forest Department guidelines and the current system adopted by farmers was attributed to differences in management and pricing. The sale of melia wood products had high potential to generate more cash than crop production, especially when appropriate management operations were followed (Maina 2004).

Melia production and marketing could, however, be made more profitable through increased processing as timber, as this is currently confined to only a few farmers. There is potential for grading its timber using international standards as a naturally termite-resistant timber through assistance of the Forestry Department of Kenya and KEFRI. Also, marketing and pricing could be improved through farmers adopting melia as their cash crop. Currently marketing seems to be confined to the regions where it is being cultivated—Mbeere, Kitui and Kibwezi Districts. This is evidenced by a recent survey carried out at Embu (Lumumba and Ouma 2004), about 50 km from Mbeere District. It found that melia was not among the timber species being sold by timber traders. There is therefore potential for grading and labelling melia as a high-quality product from semi-arid areas and encourage its transportation and sale outside the districts where it is being cultivated.

Melia is used widely as a multipurpose resource, supplying products throughout the year. This is because apart from timber, melia has other valuable uses such as for fodder, fuelwood, poles and posts, beehives, wood carving, as a pesticide; its nectar produces good honey (Tedd 1997). The fodder for livestock is obtained by pollarding trees, commonly done during the dry season. Leaves from melia have been reported by farmers and confirmed by analyses to provide high-quality fodder for goats and cattle (Roothaert et al. 1998). Traditional beehives for apiculture are carved from the wood. Poles and posts are by-products when the trees are pruned, and rafters mainly used for boma and granary construction can also be obtained from the branches (Riley and Brokensha 1988). The poles are particularly preferred for corners and doorposts for local houses (Riley and Brokensha 1988) and pieces that are too short to be poles are converted into posts for fencing.

Various extracts from melia are widely reported in the literature to posess antifeedant and growth inhibitory effects (Rajab and Bentley 1988). Larvicidal and growth inhibitory effects have been also observed against mosquitoes *(Culex pipiens)*, while Milimo (1990) also reported favourable effects of melia leaf extracts on *Anopheles arabiensis*, a major malaria vector.

Agroforestry components and interfaces

As already discussed, farmers in these semi-arid regions of Kenya plant melia trees mainly on croplands. Farmers in Mbeere believe that the tree is compatible with crops so long as good silvicultural practices like pruning and pollarding to reduce shading effect on crops are carried out (Stewart and Blomley 1994). Its deep roots, besides pumping the soil moisture (soil nutrients) from the water table to the surface horizons to make it available for food crops, minimize interference with crops, and do not hamper ploughing.

Trees in the croplands are usually pruned to prevent competition with crops, particularly for light that would otherwise adversely affect light-loving crops such as sorghum and millet. However, crops like beans and root crops that are shade tolerant do well even when melia is not pruned.

Farmers have also observed that melia is capable of increasing crop yields due to heavy leaf fall, during the later stages of crop development, especially after the leaves start to decompose (Juma 2004b). Canopy litterfall under melia trees in Kitui District made soils more fertile than the soil in open fields, increasing maize yields (Mulatya 2004). However, a study by Mulatya (2000) revealed that melia does compete with field crops. The value of melia products has probably encouraged farmers to ignore its competitive effect on crops.

The income melia generates through short-rotation timber cycles apparently compensates for the reduced crop yields (Ong et al. 2000). Many farmers in Mbeere were reported to leave a large number of trees on their farms willingly, knowing that the benefits they reap from the trees will more than offset the value of crop forgone (Mulatya 2004). Other positive attributes of the tree are enhanced nutrient cycling, soil conservation, improved microclimate and environmental protection.

Minimum inputs

Melia has seeds that are problematic to germinate, but once the seedling establishes, it grows fairly quickly even with scarce soil moisture. Seeds of melia do not germinate easily because they exhibit dormancy (Milimo and Hellum 1989). Most of the trees (90%) on farms in Kitui and Mbeere were reported to have been established through natural regeneration and sapling transplants (Mulatya 2000). Melia saplings are uprooted from under the melia trees, from either other farms or parklands and transplanted in farmers' fields. There has been little success with vegetative propagation using stem cuttings.

Farmers cite several problems in trying to establish melia:

- The hard fruits are difficult to crack, making germination difficult.
- Fallen seeds do not germinate because they are not yet mature (aborted seeds).
- Seeds have to stay for 2 to 4 seasons or more in the soil before they can germinate. This may be to enhance physiological maturity in the seeds.
- Farmers of this region do not know about seed vigour and seed viability.
- Physiological dormancy enhanced by the plastic-like papery layer around the cotyledons does not allow moisture to penetrate.

Due to these problems of seed germination, growing development organizations have provided seedlings. In a two-thronged approach, 1) organizations raise the seedlings and sell them to the farmers, and 2) they encourage farmers to raise seedlings in individual or group nurseries.

Due to the high demand for melia products, especially timber, the rate of harvesting has been higher than the rate of planting. For example, in Mbeere District, many trees on the farm are 3 to 4 years old, mainly planted recently through a private agency working in the area, Kamurugu Agricultural Development Initiative (KADI) Project. A major input is thus required to promote tree planting. Farmers will need to be able to raise their own seedlings through training in new methods of breaking dormancy that KEFRI has developed.

Agroclimatic zones

Melia occurs naturally across the drylands of eastern, northern and coastal areas of Kenya (Milimo 1989; Kidundo 1997a,b,c; Mulatya 2000). To the north it extends beyond Somalia and to the south into southern Tanzania (Milimo 1986). Because of its usefulness as a source of timber and other products, it has been depleted in communal lands and is now found only along farm boundaries and scattered as single trees within fenced parklands and cultivated lands in many areas (Mulatya 2004).

In Kenya the elevation at which melia may be found ranges from sea level to 1000 m with annual rainfall 330–600 mm. In the eastern part of Kenya, the melia agroforestry system is predominant at altitudes 600–1000 m and mean annual rainfall 300–800 mm (dry lowland). The soils in these areas are sandy, clay and shallow stony soils. Good drainage appears to be a common characteristic although Milimo (1994) reported to have observed stands on sites classified as imperfectly drained in Tharaka-Nithi and Isiolo in Kenya.

Major factors that make the innovation successful

Farmers have developed their own traditional propagation methods for planting on farm (Kidundo 1997a,b,c; Juma 2004b): transplanting wildings, using root cuttings, and pretreating seeds such as by scarifying them or using seeds collected from goat sheds. Also during ploughing, injured lateral roots develop tufts or sprouts during rains and these are carefully removed and transplanted. Once planted, the young trees are fenced to protect them from goat damage.

For good timber, a high level of tending the trees is necessary to ensure good form and growth. Over 95% of households in Mbeere and Kitui Districts were found to prune their melia trees (Mulatya 2000). Lateral branches are pruned from the first year onwards to produce a clean and straight bole free of knots and imperfections. Pruning also enhances diameter increment. Where trees naturally regenerate closely, weaker or crooked ones are removed. Also trees raised through coppicing and destined for timber are thinned to enhance diameter growth.

At planting, trees on croplands are pruned heavily to reduce competition with food crops, particularly for light. The prunings are used for various purposes: leaves are used for fodder, mulch for soil fertility improvement, and twigs for firewood. Pruning is also sometimes done when fodder is scarce to provide feed for livestock.

Unmanaged tree canopy is broad and thick, and crops such as millet and sorghum, which are not shade tolerant, would not do well due to heavy shading. Pollarding (complete removal of the crown) is therefore another common management practice farmers adopt to reduce the shading effect. Pollarding also enhances production of more bushy succulent fresh fodder for goats in dry seasons.

Arrangement and spacing of melia trees vary among farms and among fields, depending on the crop planted and method of propagation. When naturally regenerated saplings are protected, they tend to be scattered within the cropland but at times farmers uproot them and plant them in a line arrangement along contours. Woodlots are also common, especially in areas of the farm that are degraded and far away from home.

Direct and indirect beneficiaries

For the local people of eastern and coastal provinces, Melia is a tree of many purposes producing a range of products. The main reasons farmers give for cultivating it are to provide both products and services needed to serve household needs. Its multipurpose nature makes it benefit all members of a household. However, males usually control timber sales, and females mainly benefit from firewood from the prunings. Men prune and pollard the trees while planting and women weed the crops.

It is evident that children benefit from melia grown in agroforestry systems. Several authors (Kidundo 1997a,b,c; Maina 2004) have reported that melia trees are usually sold to pay school fees. Also, children benefit from food crops harvested from the system, especially the grain legumes (cowpea, pigeon pea) that have high nutritive value.

Upscaling strategies

Several strategies have been used to scale up planting of melia by farmers. As mentioned earlier, propagation is one of the main problems farmers experience. A strategy therefore that development agencies use is to provide seedlings. Also these institutions encourage farmers to start their own nurseries, managing them individually or in groups.

Other scaling-up approaches are forming partnerships with other development agencies and government departments such as the Forestry Department, training farmers and following up to assess their practices, setting up demonstrations, and sensitizing farmers on the profitability of melia.

Scaling-up activities require extra resources and donor funding has been sought. For example, projects funded by Japanese and Belgium governments enhanced scaling-up activities from 1998 to 2004 in Kitui District where the Social Forestry Extension Model (SOFEM) operated, and in Kibwezi District, where the Integrated Natural Resource Management Project operated.

Another strategy that these partners adopted was to sensitize farmers on adding value to farm products and taking farming as a business. Farmers were encouraged to sell processed timber rather than whole trees. Selling processed timber can potentially earn a farmer almost 4 times the amount earned by selling the tree whole. When farmers adopted this approach they earned more cash and as a result felt encouraged to plant more trees.

Institutions promoting the innovation

There has been increased awareness of melia's timber potential in the face of dwindling status of other hardwood species in the humid and subhumid areas of Kenya (Juma 2004a). Realizing this trend, most dryland afforestation projects within government departments, developmental partners and private initiatives have embarked on melia afforestation programs. The most interest has been shown by KEFRI projects working in Ukambani (Kitui, Makueni, Machakos, Kibwezi), where melia propagation and trial plantations have aggressively been done on both farms and government lands. In Kitui and Kibwezi KEFRI promoted melia cultivation through donor-funded projects involving several partners.

The Tana River Development Authority is another institution that has embarked on melia seedling production as one of their initiatives of promoting melia in the dryland districts through which the Tana River flows.

A major institution that has consistently promoted growing of melia over the years is the Forestry Department, which has operated in all the dryland regions. In Mbeere District, KADI in collaboration with other partners has been actively promoting the growing of melia and has trained and sensitized farmers on the new tree propagation techniques.

Research questions and knowledge gaps

Propagation of melia remains problematic. Currently, farmers overcome the shortage of seedlings by obtaining their planting materials from natural regeneration in various forms. There is need for research to develop low-cost propagation methods because the nutcracker developed by the SOFEM Project that was hosted at KEFRI's Regional Research Centre at Kitui between 1994 to 2003 is far too expensive for farmers. Further research is also needed to develop technologies that will improve survival of planted trees, growth performance and quality of the end product. There is need for research to evaluate tree–crop interactions at different distances from the trees to come up with spacing and arrangements that optimize productivity of the system.

The cost–benefit analysis of planting melia on farmers' fields needs further evaluation to include cost of planting and tending trees and crops and the value of the products. Further research should focus on melia tree management practices such as root and shoot pruning, and pollarding effect on timber growth and quality and on crop yields.

Research is needed to determine the optimum rotation age at which melia trees can be cut for timber without compromising quality. This can be achieved through testing fibre quality at different ages.

Timber is the main product that makes growing melia profitable. Processing of timber mainly by pit sawing and use of power saws is wasteful with recovery rates of less than 35%. Research should therefore aim at developing equipment and mechanisms for processing timber with high recovery rates.

Finally, the remaining superior trees in the wild have been reported to be rapidly disappearing (Mulatya and Muchiri 2004). Research should therefore be carried out to determine the best ways of conserving these superior trees.

Professional reflections and recommendations

Melia volkensii is a multipurpose tree highly treasured by farmers in semi-arid areas of Kenya, such as Kitui, Kibwezi and Mbeere Districts for its valuable, durable, termite-resistant timber. In addition, it provides essential products such as firewood, dry-season fodder, pesticides and beehives for which there is household need and strong local markets. There is great potential to extend melia-growing to all dryland areas of Kenya. Indeed the director of KEFRI's Regional Research Centre at Kitui has a vision of having all timber requirements for Kenya coming from melia trees planted in the drylands of Kenya and preserving the highlands as water catchments (Kimondo, pers. comm.).

Profits from timber tend to be greater for dealers and processors than for farmers, who mainly sell whole standing trees. Where possible, farmers should be encouraged to at least semi-process their timber on-farm to maximize their profit. Additionally, improved marketing systems and collaborative ventures among farmers could increase income that tree products generate. Consequently, cooperative societies or farmers' groups should be formed to produce, process and market melia products in each area where it is grown. Such a venture would require government intervention in terms of training farmers on how to process timber as well as creating an enabling environment to promote processing.

Farmers in semi-arid areas are among the poorest in Kenya due to the harsh climate. In its endeavour to eradicate poverty, the government should consider promoting melia timber as an enterprise that could earn farmers cash. This would require training farmers in effective processing technologies and formation and managing group marketing organizations. For a start, microfinancing to enable farmers to carry out timber processing in bulk could be necessary. Government and non-government organizations working in the area should spearhead this.

5.2 Improved mangoes and mixed cereal farming in Kenya

Nature of the innovation

The mango (*Mangifera indica L.*), because of its attractive appearance and the very pleasant taste of selected cultivars, is claimed to be the most important fruit of the tropics (Griesbach 2003). Mango is a large evergreen tree, belonging to the family Anarardiaceae, which may live for over 100 years (Cobley and Steele 1976). It is native to tropical and subtropical south-east Asia and was introduced in East Africa during the 14th century (Griesbach 1992). Its shape and height vary according to variety and management. Due to its unique taste, it occupies a prominent place among the fruit crops of the world and its fruits are in great demand worldwide (Sharma 1981).

Integrating high-value fruit trees such as *Mangifera indica* in farming systems is one target of profitable agroforestry innovations

Improved (grafted) mango varieties have become important as a cash crop for smallholder farmers in the semi-arid areas of Kenya where they are grown in integration with food crops. In addition to increasing household income, mango-growing in this area is appreciated for combating nutritional disorders. Before 1980, farmers used to grow inferior mango varieties that could not easily be intercropped and had low market potential because they produced low-quality fruits that could only be marketed locally at low prices. Farmers have increasingly adopted imporved types because they grow faster than the local types and the fruits are easy to market. They also fetch good prices and this has greatly increased profitability of this system.

A wide variety of crops is grown in association with mangoes in various intercropping systems such as strip planting and cropping among scattered mango trees. The crops include grains, legumes, cereals, root crops and even other tree crops such as papaya and guava. Farmers intercrop in this system deliberately to increase their profitability by selling fruits and crops.

Justification of profitability

Mango cultivation in the semi-arid areas of Kenya is a very important enterprise as was revealed by an enterprise-ranking exercise where farmers ranked mango production first (DAREP 1994). In eastern and central Kenya the improved mangoes are mainly grown in the districts of Kitui, Kibwezi, Machakos, Makueni, Mbeere and Tharaka. Both the government and NGOs began promoting growing improved mangoes in these semi-arid areas because the mango is important for generating cash income for farmers and providing them with food and employment.

World trade in mango has been increasing over the years and both exports from Kenya and local consumption are currently expanding (HCDA 1996). This has facilitated increased growing of mangoes by farmers due to easy access to markets. A gross margin analysis shows that mango growing is a profitable enterprise. Farmers are growing selected varieties that have been found to be good for both export and local markets. The major varieties currently grown include Tommy Atkins, Kent, Keiit, Apple, Van Dyke and Haden. Most of these mangoes are being exported to the Middle East and Europe (Ouko 1997).

Before improved mangoes were introduced, farmers were cultivating locally propagated varieties that took 7 years to start producing after planting. These varieties had poor marketing potential due to the low quality of the fruits. The improved (grafted) varieties start to produce in the 3rd year after planting and start producing commercial yields by the 5th year. By the 9th year, mango tree in full production can yield between 250 and 600 kg per tree, or about 500 to 1300 fruits per tree, depending on the variety and the season. If one fruit is sold at a conservatively estimated price of KES 10, then one tree would give a total of KES 5000 (USD 70).

The local market consumes more than 95% of total produce with only 1% being exported (Ouko 1997). The major outlets for fresh fruits are in the rural and urban centres and processing industries. It has also been reported that consumption of mango fruits is increasing in the urban centres (Ouko 1997). Availability of local markets is an advantage to the farmers (producers) because it eases transport costs.

In most areas farmers market their fruit mainly through marketing groups but in other areas, especially where planting started recently, they market individually. Formation of these marketing groups has mainly been facilitated by agencies promoting mango enterprise, such as the Ministry of Agriculture (MoA) and Horticultural Crops Development Authority (HCDA). To control fruit quality, especially for the export market, management programs and guidelines are developed that all farmers in the group are supposed to followed. To ensure these programs are followed, selected members of the group do follow-ups that also include assessment of estimates of fruit yields for the season. One of their by-laws is that farmers who do not follow the programs will not be allowed to market their fruits through the group.

The initial marketing groups formed in collaboration with development agencies have catalysed formation of other groups through farmers' own initiative. This is as a result of farmers realizing the benefits of marketing as a group. A good example of a farmers' initiative is in Kitui where the Social Forestry Extension Model (SOFEM) project hosted at Kenya Forestry Research Institute (KEFRI)'s Regional Research Centre at Kitui promoted mango growing by farmers from 2000 to 2003. A farmer, Joseph Kibelenge, is among the many who participated in training sessions on propagation and management offered during the project phase. By the end of the project in 2003, Mr Kibelenge had about 200 mango trees but by 2005 he had increased his mango trees to 400 through his own initiative. Through mango sales in 2004, he earned about KES 26,000 (USD 350) and through a self-initiative campaign he has managed to form a mango marketing group with other farmers in the area growing mangoes.

The potential exists for increasing productivity and profitability of this system by processing the fruit. Mango fruits can easily be processed into juice or dried in the sun. Adopting such processing procedures adds value to the fruits and reduces losses that are likely to occur in cases of overproduction. These processed products would definitely fetch better prices in local and world markets. Processing could be instituted at two levels. One is where the private sector could be involved, for example, in establishing a juice processing plant that would use produce from the farmers. The second is where farmer groups would start small cottage industries for making products such as juices, jams and dried fruit slices. Professional advice could be sought for packaging and branding such products.

Agroforestry components and interfaces

Most of the intercropping systems adopted by farmers are beneficial. For example, mango trees intercropped with grain legumes such as beans, pigeon pea, green gram, and cowpea benefit from nitrogen fixed by the legumes. Also in most cases, after the grain is harvested, the legume stover is used as mulch for the mango trees, contributing substantially to conserving soil moisture and improving soil fertility. In addition the grain legumes contribute to the overall benefits of the system because they are easily marketed locally and therefore an important source of cash.

Mango shade is heavy and is not good for intercropping with light-demanding crops such as sorghum and millet (Tengnäs 1994). This is one of the reasons why farmers have adopted growing improved dwarf varieties that have less negative interaction with crops than the local varieties, which tend to develop huge crowns. In addition some of these improved varieties such as Kent tend to have an upright and open canopy that allows light to penetrate to the ground. Under Kent varieties, beans do well due to the light shading. One of the ways farmers manage the interactions is to prune the mango trees, but only slightly so as not to adversely affect their production. Sometimes strip planting is adopted to maximize production from both mango trees and the crops.

In these semi-arid areas, animal manure is the most commonly used input for fertilizing mangoes and crops. Inorganic fertilizers are rarely used. The manure applied is shared among the trees and the crops in a synergistic manner because the food crops with their shallow rooting systems use nutrients in the topsoil while the trees utilize nutrients that the crop roots cannot reach.

Minimum inputs

Introducing improved varieties to farmers requires institutional support in terms of providing quality planting materials, advisory services, training and facilitating marketing.

Planting clean grafted propagules is recommended for successful mango cultivation as this controls pests and diseases (KARI 2000). It is therefore recommended to get the planting material from a registered nursery. To get good propagules, rootstock raised from local varieties needs to be prepared at the nursery before it is grafted with clean scions. Therefore, providing good rootstock material and scions is critical to the success of mango cultivation. Most of the farmers who are currently growing these mango varieties have been trained on raising rootstock and grafting techniques.

Control of pests and diseases is necessary in mangoes. The most common pests are the mango weevil and fruit flies while the most common diseases are powdery mildew and anthracnose (Mugwe et al. 1998). Farmers need to be trained in control measures, especially on rates and application frequencies of chemicals.

Agroclimatic zones

Mangoes do well in the lowland to upper midland zones (Dry Lowland). They grow well at altitudes below 1000 m, and rainfall of 500–1000 mm is sufficient for successful cultivation. A distinct dry season before and during flowering is considered ideal, as rain during flowering seriously reduces fruit setting (Clarke and Clarke 1987). After a mango tree is well established, it is drought resistant, especially when the taproot has reached the water table.

Above an altitude of 1200 m, trees are susceptible to disease and some develop rust. Mangoes do best at an average annual temperature of 15–30 °C. As temperatures fall below 15 °C, growth slows and fruit quality decreases, and the incidence of serious diseases like powdery mildew and anthracnose increases.

Generally, temperature, rainfall and humidity have a greater bearing on mango production than irrigation and soils (Griesbach 2003). The two important considerations for mango cultivation are a dry period at the time of flowering and sufficient heat during the time of fruit ripening. For optimum growth and productivity 20–26 °C is believed to be ideal.

Mango is adapted to many types of soils but prefers deep soils (at least 3 m) that are fertile, loamy textured, and well drained for good growth. The optimum soil pH is between 5.5 and 7.5 (Griesbach 1992). In Kenya, the most suitable areas for cultivating mango are the coastal area, Migori, Lake Victoria, Kitui, Murang'a, Thika, Kajiando, Isiolo, Taveta, Makueni, Machakos, Mbeere, Tharaka and the Kerio Valley. If irrigation is available, mango can be grown in drier areas such as along the Tana River in Garissa.

Major factors that make the innovation successful

In semi-arid areas where soil moisture is limited, mango is well adapted because it develops a deep rooting system necessary for moisture extraction from deep soil layers. The hot environment is conducive because pests and diseases such as powdery mildew occur less often than in a humid environment (Griesbach 1992).

Mango trees are planted either in association with crops (intercropped), or in fruit orchards where the field is intercropped only during the initial years of establishment. The main crops found associated with the mango include maize, sorghum, millet, cassava, pigeon pea, green gram, cowpea, groundnut and at times other tree crops such as papaya and guava. In these intercropping systems, farmers do not mind losing a bit of the crop because benefits from the mango outweigh what they would get from the crop alone. Sometimes the mango trees are deliberately planted along internal farm boundaries dividing the cropland. Planting in the cropland makes it easier for fruits to be collected any time and mango trees can be watched over to prevent theft of fruits.

Improved mangoes exert less negative interactions because they develop narrow crowns and production is higher per unit area (Gachanja 1993). Intercropping is therefore possible and this increases the productivity of the system. The local types that farmers used to grow presented problems of negative tree–crop interactions as these trees developed very large crowns and a large area beneath the tree was left uncropped due to heavy shading (Murithi et al. 1993).

The formation of farmer marketing groups is a major factor that has spurred mango growing in the semi-arid areas. Marketing groups have committees who are responsible for searching for markets, advising farmers on likely prices, and how best to manage their fruits. In addition to coordinating the groups, the committees are also in charge of ensuring that all the farmers maintain good quality of fruits. In some areas, processing the fruits to add value is an upcoming initiative. For example, the Kamurugu Agricultural Development Initiative (KADI) project, operating in Mbeere, has recently developed a resource centre to demonstrate and train farmer groups on mango drying using solar driers.

Farmers greatly appreciate the role mango plays in their livelihoods. Farmers note that with mango, one will always have something to sell even in drought years. Farmers use mango money to pay school fees, buy food and meet other family obligations. Mango fruit has great diversity of types, which permits considerable manipulation for various purposes and markets. This is a very favourable characteristic for commercial crops as markets are generally dynamic.

Direct and indirect beneficiaries

Major benefits accrue from commercializing the system. Cash income obtained from the sale of fruits benefits every member of the household either directly or indirectly.

Consumption of mango fruits contributes to improved nutrition, especially for children. Rice et al. (1991) noted that the mango is an excellent source of vitamins A and C, a fair source of thiamin and niacin, and contains small amounts of riboflavin, calcium and iron. Kiptot (1996) also reported that children benefited in terms of improved nutrition.

Women usually are responsible for the crops grown in the mango fields. They are in charge of planting, weeding and harvesting. Because mango trees have to be manured and fertilized, the woman benefits from the resultant increased crop yield.

In Kenya, men own farms but women have user rights. In growing and selling mangoes, women have been found to participate fully. For example, in Mbeere District where KADI is operating, women form more than 50% of the membership in most mango marketing groups.

Upscaling strategies

Scaling-up strategies have mainly concentrated on providing suitable planting materials, training farmers, and assisting in marketing. The training at times has first been of extension officers who need to learn the skills of propagating and managing trees. Using farmer trainers to train other farmers is an approach that has been used in some projects such as the Integration of Tree Crops into Farming Systems Project (ITSFP).

The export market requires high-quality fruits. This in turn requires a high level of management of the mango trees. To achieve this, the promoting agencies such as KADI in Mbeere, HCDA and MoA have been working in partnership in offering farmers training on tree propagation, management, control of pests and diseases, and post-harvest management. These agencies have used various methods and approaches such as field days with demonstrations, and production of posters and leaflets.

Farmers in semi-arid areas are poor and may not afford purchasing a seedling of grafted mango that currently costs KES 100 (USD 1.30). Therefore, one of the activities adopted by the promoting agencies has been to show farmers how to produce their own seedlings in a sustainable manner. One grafting technique that has greatly contributed to scaling up of mango growing by farmers is that of 'top-working' wildings already established on farms. This method is farmer friendly as it is cheap and the success rate has been high. Through this method, farmers who could not have afforded a grafted seedling worth KES 100 are able to pay KES 20–30 to a fellow farmer to do the top-working.

Another strategy adopted was to provide seedlings to farmers at subsidized prices. KADI in Mbeere District sells seedlings at KES 60 instead of the market rate of KES 100. Also, forming producer and marketing self-help groups to increase bargaining power has helped farmers get better access to markets and market information. The advantage of these groups is that farmers sell their fruits at better prices than individual farmers because they are able to negotiate their prices. For example, a trader collecting fruits from a farmer would pay KES 5 per fruit while the same fruit would be sold for KES 10 or KES 15 through the marketing groups. This is because in most cases, where farmers market individually, the middleman comes with a predetermined price and the farmer is not given an opportunity to negotiate. Overall, these marketing arrangements have spurred farmers' interest in cultivating the improved mangoes.

Institutions promoting the innovation

A number of institutions have been involved in enhancing cultivation of improved mangoes.

Research organizations, a major one being Kenya Agricultural Research Institute (KARI), which hosts the National Horticultural Research Centre at Thika, and donor-funded projects, for example, the National Agroforestry Project, which operated from 1991 to 2004, have been involved in both research and dissemination activities. Research has mainly concentrated on evaluating adaptability of cultivars to different regions and controlling pests and diseases. In Kitui and Kibwezi, the Kenya Forestry Research Institute (KEFRI) branch based at Kitui has played a crucial role in promoting mango growing through training and providing planting materials.

Government ministries, for example, the Ministry of Agriculture and the Ministry of Environment and Natural Resources, mainly in collaboration with other agencies, have been strongly involved in mobilizing communities and training farmers in propagation methods.

Non-governmental organizations have also played a major role in encouraging farmers to grow mangoes. In Mbeere District, the KADI project is one of the leading organizations facilitating development and transformation in semi-arid areas. To date it has trained 5000 farmers in mango grafting, planting, management and tree training. In addition to promoting mango production, it has also been involved in marketing and processing, currently working with 70 mango marketing groups.

The agencies mostly developed partnerships with other stakeholders in their scaling-up activities. For example, the research bodies have been working closely with the Ministry of Agriculture and various NGOs. HCDA has mainly been involved in sharing germplasm, marketing, storage and processing. It also assists in providing marketing information and organizing marketing, especially for export produce. Private companies, especially those dealing with agrochemicals and irrigation technologies, have been major stakeholders in promotional activities. Their main role has been in supplying chemicals and training farmers how to use them properly.

Research questions and knowledge gaps

Growing mango has an economic advantage, which drives the farmers towards selecting it as high priority in agroforestry systems. If full potential in its systems is to be realized, localized research is required. Issues of research include:

- Investigating interaction between the mango trees and field crops with respect to shade, rooting patterns, competition for moisture, optimum nutrient requirements in mixed cropping systems. This should aim at identifying optimum densities as well as planting patterns for optimum production
- Identifying ways of having staggered fruit production periods by growing varieties that reach maximum maturation at different times or by management
- Screening more varieties to come up with the most adaptable and those that are less susceptible to pests and diseases
- Developing integrated pest and disease management to maximize profits and meet international standards
- Evaluating profitability of growing different varieties under different prevailing local conditions

Professional reflections and recommendations

Mango growing is a profitable enterprise for semi-arid areas that have limited agriculture options due to unreliable rainfall. Despite this, only a small area of the semi-arid regions is cultivating mango and there is therefore a need to put more effort into promoting mango growing in other suitable areas.

Considering its potential to generate cash, improve nutrition and provide employment, the government of Kenya should consider a fruit development strategy that would also include other fruits like papaya and citrus, also suitable for semi-arid areas. Currently developing a sustainable horticultural subsector to support both the fresh fruit market and a fruit processing industry in the country is hampered by a myriad of problems. These include inadequate availability of high-performance disease-free planting materials in the right quantity and quality, inadequate advisory services, and lack of private sector participation. A development strategy should therefore encompass the concept of optimal productivity, marketability and profitability that would directly benefit and sustain livelihoods of the rural poor in these areas. That strategy should include:

- Multiplying and distributing high-quality planting material for establishing nurseries and mother gardens for multiplying disease-free planting materials and a sustainable link to the source of new materials
- Strengthening farmer groups and organizations for organized marketing in each targeted zone, and increasing access to clean planting materials and advisory services
- Undertaking a commodity systems analysis and market studies to establish market chains and specific market preferences for fruit types and varieties
- Enhancing partnerships and networking among stakeholders to exploit the development of a fruit enterprise
- Continuing to build capacity of farmers through training, facilitation, exposure visits and input supply
- Increasing awareness of farmers and other stakeholders about the potential and the benefits of fruit trees
- Enhancing knowledge and sharing information about fruit trees
- Generating and disseminating information on cottage industry processing in the fruit sector

Currently, although there have been some uncoordinated interventions to improve marketing of mangoes by various stakeholders, lack of farmer market-oriented organizations to penetrate the market remains a constraint in many regions. This greatly limits the capacity of participating farmers to get more income. To address this, a government policy prioritizing mango growing and marketing by small-scale farmers as an appropriate means for tackling poverty is one way that could enhance better marketing and pricing of the fruits. Such a policy should take into consideration issues of enhancing productivity, improving marketing systems, and at the same time processing fruits. This should be backed up by supporting strategies for achieving the goal of reducing poverty through increasing farmer income from mango farming. One way of doing this is by enhancing partnerships and networking among stakeholders that include private sector participation.

5.3 Banana-based multistorey gardens of Ethiopia

Nature of the innovation

Banana-dominated homegardens are common features of the district farming system. The practice is locally designated as *yeguwaro atikilt,* the term that denotes various homegarden crops. Various fruit species are integrated into banana gardens to diversify and maximize food and cash crop production. This multistorey agroforestry system is also practised in open fields farthest away from homegardens, thus characterizing the entire farming system of the district. The farmers possess the complete required skill and knowledge in successfully establishing and maintaining the system.

Establishing the practice in open fields commences with clearing the existing vegetation and ploughing. Maize crops are sown after the soil is loosened to the desired tilth. Wide pits are dug 2 days later at a spacing of 1.5 to 2 m and planted with banana. Young banana plants grow along with the maize crop during the first cropping season. Ordinary cultural practices like weeding and hoeing are employed during the growing season. On fields with poor soil, farmers chop leaves of various species and bury them beside banana corms to improve soil fertility. In successive years various fruit species, commonly avocado and mango, are planted between banana clumps. After the fruit trees mature, all nearby banana clumps likely to be smothered by tree canopies are removed.

Moringa represents another important feature of this agroforestry practice. Although sparse, it is grown in almost all farms, both for its food and for its medicinal and wood products. Moringa is established in the farm by placing single seeds in small pits prepared at desired intervals. Its leaves are eaten as a sauce and people decoct them and drink as medicine to treat various health disorders. Leaves are also sold in the market as cabbage to generate cash income. Moringa wood is used mainly for fuelwood and fencing.

Other components of the system include *Cordia africana, Citrus limon*, coffee and papaya, which are mainly used for household consumption and cash generation. A few farmers grow castor for its leaves and stems. The leaves are used for silkworm forage and the stems are used for staking banana fruit stalks. Fruit trees are managed mainly to earn cash and occasionally for household consumption of the fruit. Dried wood from fruit trees can also be used for fuel and fencing.

Banana crops serve multiple purposes; they provide fruit for household consumption and they generate cash. Banana crops may often be the major source of household cash income all year round. Their stems and leaves are used for soil fertility improvement.

Tropical homegarden agroforestry where bananas are integrated with many other fruits and timber trees.

Justification of profitability

The banana-based agroforestry system in the district is primarily market oriented. Most components are managed for cash. Household consumption of fruits is considered only subsidairy. Farmers often sell fruit to raise cash and purchase supplementary food from the market. During the early stage of establishing the system, food crops are grown in open areas between fruit trees and bananas grown mainly for household consumption.

The weather and soil conditions are conducive for growing various fruit species that have good market demand and relatively good price. High mean annual temperature and shallow ground water help provide good growth and fruit yield throughout the year. A shallow water table also helps the trees to survive extended drought and shortage of irrigation water. Good and continual access to perennial streams and wells enables continuous cultivation of fruit species and lower canopy crops. Favourable growing conditions also improve the quality of the products.

As compared wih food crop production, fruit production is less labour and capital intensive. In addition, it provides marketable products throughout the year. Well-managed banana clumps, for instance, up to 6 harvests. Farmers can obtain about ETB 10,500 (ETB 8.6 = USD1) per hectare annually from the sale of bananas (that is, ETB1750 every 2 months). This is a much better economic incentive than other commonly grown annual food crops, which are grown only once or at most twice per year. Such a production system also has an advantage of providing quick returns to the investment.

Growing avocado and mango within banana fields diversifies product lines and reduces risks. Those fruits also provide an alternative source of income when other products are not available for sale. Mango trees produce fruit twice a year. A single mango tree yields up to 10–15 sacks (depending on variety). A sack of mango fruit costs ETB 40–60. Thus fruit from a single tree may earn ETB 800–1800 per year. With 100 mango trees, a farmer may earn 80,000–180,000 birr per year, which is exceptional when compared with other land-use systems.

Similarly, a single avocado tree produces about 6 to 12 sacks (again, depending on variety) of fruits. Each sack of fruits from the local variety sells for ETB 20–25, whereas that from a hybrid variety earns 40–50 birr. Farmers can thus obtain ETB 2,000–60,000 annually from selling avocadoes harvested from only 1 hectare.

Some farmers integrate lemon trees into the system, both to eat in the household and to sell. A single lemon tree produces up to three sacks, selling for ETB 30–40. Like mango, lemon trees fruit twice a year; thus 100 lemon trees on a hectare earn a farmer about ETB 18,000–24,000 per year.

With adequate balancing of the number of each of these components, farmers can earn a substantial amount of uninterrupted cash year round. An added economic advantage of the system is that it requires minimum external input and minimum maintenance needed after it is established. The major management work after the system is well established includes clearing weeds during the rainy months, working the soil at the beginning of the dry season, and watering during the dry months. Including leguminous species in the system maintains soil fertility sustainably without any negative effect on fruit yield.

As a flat terrain characterizes the area, transportation during dry months is not a problem. Farmers thus benefit from the marketing opportunities readily available in the district. Small trucks are able to enter deep into fields far from the main road and load fruit products. Etfruit, a wholesale organization, also purchases fruit products to retail in different towns. It usually offers lower prices than private traders but does not cheat on weight. Private traders provide up to ETB 0.25 more per kilogram but often deceive by as much as 25–30 kg from every ETB100 kg of fruit. If a farmer attempts to strictly control the weighing procedures to minimize cheating, he may lose marketing chances in the future. Intermediate brokers are influential in connecting the farmers with the traders; they are the ones who grab the cheated kilos.

Proximity of the district to a major city like Arba Minch is also an advantage. Easily perishable fruits like banana can be sold in local markets in case the main traders arrive too late or are entirely absent. Farmers never complain about lack of market since the traders and brokers are regularly searching for matured fruit crops and they can purchase instantly either on-farm or at central loading stations.

Agroforestry components and interfaces

The system is mainly composed of fruit species. Such agricultural crops as maize, tef, potato, and sweetpotato are grown during the establishment phase of the fruit garden or as a sole crop between fruit gardens. Cotton and coffee are grown for household use and for sale. Coffee is commonly grown under the partial canopy cover of taller trees and shrubs such as *Cordia africana* and moringa. A few *Combretum* trees are retained within or on the periphery of croplands for their durable wood.

Well-grown avocado trees should not be grown close to banana clumps. Banana plants easily succumb and die from excessive overhead shade. Moringa cannot tolerate the heavy shade of avocado trees. Papaya is known to be gregarious with shorter crops or crops of about the same height. It grows well with coffee, maize and cotton. However, it poses a moderate threat to adjacent coffee plants if overthrown by wind. Avocado and mango trees grow well only when they are spaced far apart to avoid both below- and aboveground competition.

Moringa is light crowned and thus can be grown with maize, cotton, and coffee without any significant negative impact. Coffee plants benefit from partial shading of moringa trees when they grow together. Banana grows and fruits well when grown in the open. The growth rate and productivity of banana are seriously hampered if the plants are heavily shaded. Shaded banana stems are often infested with small ants and produce stunted fruits. Unfavourable growth conditions may expose banana plants to viral diseases that wilt both the leaves and the fruits.

The major damage under this configuration occurs to crops in the lower and intermediate canopy classes. Trees in the upper canopy tolerate partial overlapping as long as optimum spacing between adjacent trees is maintained. It is thus essential to carefully study the shade tolerance level of any low-growing species to be planted in the system. Light-demanding crops cannot be grown in the well-established banana-based garden system. Such crops should be grown in the open as monocultures. See table 5.1 for possible configurations.

Table 5.1. Interfaces among component in banana-based multistorey gardens of Ethiopia

	Avocado	Mango	Banana	Maize	Coffee	Cordia	Moringa	Cotton
Avocado	Strong competetion for space	Strong competition for space	Strong suppression	Heavy shade reduces yield	Casts heavier shade than needed	Competes for space	Competes for space	Stunted growth and low yield
Mango	Strong competition for space	Strong competition for space	Strong suppression	Heavy shade reduces yield	Casts heavier shade than needed	Competes for space	Competes for space	Stunted growth and low yield
Banana	For mature trees, no problem	For mature trees, no problem	Clumps compete for space	Under closed canopy	Competes for space	For mature trees, no problem	OK	Strong suppression
Maize	OK	OK	OK	Space	Competes for nutrients	OK	OK	Space
Coffee	OK	OK	OK	Space	Space	OK	OK	Space
Cordia	Competes for space	Competes for space	Reduces growth and yield	Low density, OK	Promotes growth and yield	Space	Space	—
Moringa	OK	OK	Very few trees, OK	OK	OK	Space	Space	Sparse trees, OK
Cotton	No serious effect	No serious effect	OK	Space	Space	No effect	No effect	Space
Papaya	OK	OK	OK	Space	Space	OK	OK	Space
Combretum	Competes for space	Competes for space	Reduces yield at narrow spacing	Reduces yield at narrow spacing	Shade benefits coffee	Competes for space	Competes for space	Reduces yield

Minimum inputs

Major inputs from the beneficiaries include traditional hand tools used for clearing vegetation, ploughing, preparing the seedbed, planting, weeding and soil cultivation. Most commonly used hand tools for these practices are the axe, spade, machete, sickle, hoe, plough, and soil cultivation tools. In waterlogged areas excess water is drained off the field through cut-off drains. Fruit and grain products are transported from field to weighing and loading centres as well as to homes by modern donkey-drawn carts. Land is an important input from the beneficiaries.

The other major input from the beneficiaries (either family members or wage labourers) is the continuous provision of labour both for maintenance and supervision. The multistorey field requires uninterrupted supervision from the household head and regular weeding and soil-working operations. Perishable fruits require timely harvesting and marketing. Damage from external agents like wild animals, humans and environmental hazards need to be controlled through regular precautionary measures.

Basic policy support includes providing seedlings of improved fruit species. Farmers differentiate local and hybrid fruit species and perceive that the hybrids are by far more productive than the local species. Therefore, they seek seedlings of currently available improved varieties. There is also an urgent need for further investigation on the system to identify alternative means of improving its productivity and easing management tasks.

Likewise, introduction of new crop species of more economic significance and higher global market demand has great potential in the area. Farmers claim that the area is suitable for oil crops whose current market demand is very high. Carefully analysing of possible alternative species of high value and providing their propagation materials would greatly enhance farmers' cash income and boost their livelihood.

Formal and informal training helps farmers improve their technical knowledge in effectively managing the complex system. Training can be either on site by technical experts or by taking farmers to demonstration plots and other farmers' fields to help them gain new knowledge and see new practices. Integrating several components in a system requires diligent vertical and horizontal component arrangements, well-planned cultural practices, and harvesting and marketing of diverse products. The entire management work of such diverse components is much more complex and challenging than that of the monocultural cropping system. Growth requirements of individual components need to be well understood and provided accordingly. Successful establishment and execution of the system requires continuous upgrading of farmers' technical and traditional knowledge.

Farmers also keenly demand technical advice and support in post-harvest technology and marketing of products. Appropriate storage facilities need to be established to enable farmers to temporarily store excess products and to match selling with better market prices. Farmers have complained about marketing fraud by local brokers and external traders; therefore, marketing processes need to be well organized and supported to enable farmers to get the right price for their products.

Cotton-growing farmers envision better marketing procedures in the Arba Minch textile industry. The industry often declines to purchase from private farmers. On the other hand, farmers are not organized by any individual farm product to offer a particular product in the large quantities the customer needs. The local cooperative office the or Bureau of Agriculture could help organize farmers to save them from unnecessary exploitation by outsiders.

Technical professionals are required to establish detailed studies on the system. Component arrangement and management regimes need to be well refined by reinforcing with scientific evidence. The mode of integrating components and the spacing between individual plants of the same component and between plants of different components need to be explored under farmers' prevailing production conditions. Crop yield improvement is also possible through selection and breeding programs. Agricultural economists should investigate marketing possibilities and advise farmers on alternative means of product marketing. Entomologists and pathologists need to thoroughly explore existing pest and disease problems and possible risks and investigate remedial measures.

Agroclimatic zones

The innovation has been recorded from Arba Minch, Zuria District Kolla (5°52′N, 37°27′E, 1150 m altitude). This practice best performs in the moist lowlands where mean annual rainfall is over 850 mm. Altitudinal ranges could vary between 1000 and 1500 m. The maximum temperature should not rise far beyond 32 °C. Well-drained soil with moderate fertility supports the system. Soil nutrients, intensely extracted through well-distributed root systems of various crop plants, need to be replenished by green manuring and applying animal fertilizer.

Flat to moderately sloping land best supports this system. Natural vegetation of the area is composed of such trees as *Cordia africana*, *Acacia* species, and *Combretum* species. Major crops grown in the area include maize, tef, sweetpotato, banana and enset.

Major factors that make the innovation successful

This system represents an intensive land-use method in which diverse products are produced on a small unit of land. As well as being highly market oriented, the system uniformly distributes marketable products over the year. Adequate maintenance of the system also provides harvestable food for household consumption all year round.

Successfully setting up and establishing the system is not an easy task. A new starter can resort to the already-established structure of successful practices. However, even such farms should not be taken for granted as a well-refined and climax stage of the system. Its historical development has depended very much on a series of farmers' trial and error component arrangements and species selection. It has never been supported by problem-oriented research. Farmers continue to alter the system to maximize overall productivity and adjust products and services to household and market needs. The high diversity of financially lucrative fruit species that properly fit into the system makes it attractive to the local farmers.

Once the system is properly established, the financial benefits regularly derived by far outweigh the costs involved in maintenance. Dense vertical and horizontal structures of the vegetation and constant litterfall suppress dense weed growth and thus reduce the need for frequent weeding operations. Litterfall from *Cordia* and other tree species helps pump nutrients from deeper soil horizons and deposit them on the soil surface. Effective nutrient cycling facilitates better availability of nutrients for shallow-rooted crop plants. Nutrients that otherwise cannot be accessed by ordinary shallow-rooted crops are retrieved and used for growth and yield improvement. This is also a good means of attaining sustainable agricultural production and managing land resources.

The system is also praised for its minimum need for external inputs. As the soil fertility is continually replenished through litterfall of diverse species, there is no need to apply chemical fertilizers. Once the system is well established it requires low capital and financial investment. A local farmer's estimate indicates that an investment of only 10% of the total income from the system suffices for its adequate maintenance. Good rainwater infiltration into the soil improves drought tolerance during extended dry seasons. Susceptibility to recurrent droughts of most farming systems in Ethiopia is exposing the rural community to seasonal food shortages and loss of lives. Developing a drought-tolerant farming system or means of rainwater harvesting has been the primary target of the government during recent years. This naturally water-conserving farming system proves very attractive to the habitually risk-averse farming community.

Conducive physical environmental conditions and good marketing infrastructure increase farmers' interest in the system. Relatively higher year-round temperatures and sufficient rainfall accelerate the growth and development of major lowland fruit species. Local soils are enriched with alluvial deposition from the highlands and thus are relatively well off in basic nutrient composition. In addition to shallow water tables in the area, perennial streams from forested highlands provide adequate irrigation water during the dry season. There is also an easy access to marketing centres. Medium-sized trucks roam on cleared patches between fields to load bulky fruit products. Farmers can also transport small-size products to central loading centres along the main road by donkey carts throughout the year. An additional motivation is the virtually stable market price of banana fruits throughout the year. Higher production in any season thus equates correspondingly with higher cash revenue for the households. This is the direct opposite of grain crop production, whereby a good cropping season is instantly followed by a sharp fall in market prices.

Partial technical advice and provision of seedlings of some fruit species by the Bureau of Agriculture (BoA) also motivated farmers to promote the system. The BoA initially provided seedlings of improved varieties of banana, coffee, avocado and mango. Farmers also received training in vegetable, maize and cotton production as well as beekeeping. Farmers benefited to various extents from the technical and material support provided by the BoA in their efforts to promote the system.

Direct and indirect beneficiaries

Major access to the fruit garden is limited to male household heads. Men are responsible for managing and have access to the major products. Household heads decide what fruit is to be gathered for household use. Women are given a portion of the money from the fruit sales rather than permission to collect and sell fruit products. Fruits like lemon that are more abundantly produced and accrue less cash income per unit weight are given to women for marketing and household use. Banana sales by women are very rare. Grownup children can be entrusted with the task of selling fruit products. In other cases, children are allocated a small portion of the farm to establish and manage their own fruit garden, from which they enjoy the full benefits.

Household consumption of banana is often confined to fruits from trees overthrown by natural hazards. Some fruits can also be set aside for home consumption during the major marketing season. While banana production is the dominant part of the system, household banana consumption appears to be minimal compared with that of other fruits. This is attributed to its large-scale production and selling it wholesale to local markets and for transport to Addis Ababa. This compels every farmer to offer for sale as many bunches as possible, overriding household need.

Avocado fruits are more consumed in the household than offered for sale. This is mainly because avocado has not yet been offered in large scale for market and transported over long distances. Therefore, avocado sales are often limited to local and nearby town markets. Mango can also be picked for household consumption for the same reason. Papaya is claimed to have low market demand and thus can also be used for household consumption. As more and more farmers are taking up cultivation of avocado, mango, and papaya fruits, and as the number of on-farm trees increases, large-scale marketing of almost all products will become inevitable.

All household members must have good access to the grain crops grown within or on the peripheries of the fruit gardens. Women may also market them for purchasing household needs.

Upscaling strategies

As pointed out in the foregoing sections, this system is very much limited to the lowlands with good rainfall and soil conditions. Towards the extremes of this agroecological zone, the fruit trees become either stunted or barren. The lucrative nature of fruit production and recent promotional efforts through government extension programs has prompted most farmers to adopt and promote banana-based multistorey gardens. Every farmer has thus recently expanded the system out of homegardens deep into cultivated fields.

Farmers have also realized the increasingly higher financial benefits of the system. A farmer in the district articulated the economic significance of the fruit garden in contrast to maize cultivation as simply unparalleled. Maize can be harvested twice a year and banana six times a year with each clump producing up to three bunches of fruits at a time. Because of well-established marketing channels, farmers trust the unfailing market demand throughout the year and the fairly stable market price. Guaranteed market prices seem to have played a key role in rapid adoption and dissemination of the system in the district.

Relatively lower management costs and the good soil-replenishing nature of the system provide farmers with an attractive incentive. Production of grain crops calls for applying chemical fertilizers regularly, the practice that put many farmers in government debt. In some cases, poor farmers were deprived of their farmlands for failing to repay the debt. Being rid of the anxiety of extreme price fluctuation and of being trapped in government debt has become an important incentive for farmers to full-heartedly embrace the practice.

Institutions promoting the innovation

Farmers took the primary initiative in promoting the system. The gradual rise in the culture of fruit consumption in Ethiopia and subsequent stable market price served as an indirect incentive in widespread expansion of the system.

The only external institution that supported the farmers in promoting the system is the district BoA. Initially it provided seedlings of improved banana variety free of charge. The variety is more productive and produces more tasty fruits. The bureau also provided seedlings of new system components like coffee. In addition, it assisted rapid dissemination and expansion of the system by providing seedlings of avocado, mango, and various vegetables. Technical advice and training on different crop production techniques were also offered to selected farmers.

Research questions and knowledge gaps

As stated in the preceding sections, farmers developed the current developmental climax of the banana-based multistorey system through years of trials and errors. No systematic and detailed studies have ever been undertaken to characterize and improve the system. Selection of candidate components and their spatial arrangements is wholly governed by farmers' traditional technical knowledge and experience. Thus there is an apparent knowledge gap in how to select and improve plants, and how to position the components efficiently within the vertical and horizontal matrix of the system. The extent of yield reduction or enhancement due to synergistic component interactions has not yet been established, and so extension workers cannot properly advise farmers.

The economic and ecological functions of the system can still be improved through scientific investigation on alternative means of mixing possible species. Integration of new nitrogen-fixing shrub species greatly enhances soil fertility. There are also opportunities to alter current species assortments to enhance the overall product quantity and quality. The by-products of the system could be used more economically for productive purposes. The vertical and horizontal arrangements of various species have not yet been refined with series of experimental investigations. The system could also be gradually modified to help fit into the wider aspects of the agroecological zone. All these aspects call for competent professional investigation to further enhance the productivity as well as sustainability of the system.

Integration of livestock into the system will produce desirable synergistic interactions. While the various crops provide diverse and nutritious forage, the animals provide useful manure for soil fertility maintenance. Animals also substantially contribute to the overall household cash income and risk reduction. They are often regarded as important household capital that can be liquidated whenever a major need arises for cash.

Creation of proper marketing channels for farm products and saving farmers from unnecessary exploitation of urban vagabonds appears to be a noble task of agricultural economists and local administrators. Abolishing unfair and exploitive marketing of farm products and eliminating unethical robbery by intermediate brokers need immediate attention. Investigation into the possibilities of establishing marketing cooperatives to help farmers overcome such inexcusable exploitation is imperative. The local government is supposed to provide the necessary technical and infrastructural support to enable farmers to reap the rewards that they legitimately deserve.

Professional reflections and recommendations

The banana-based multistorey system appears to be one of the most financially lucrative agroforestry systems identified during the present survey. Apart from the financial advantage of the system, it is practised on relatively larger areas, because the population density appears to be lower than that in many highland areas. It involves intensive soil working and seedbed preparation. Selection of the right components and their appropriate positioning in the system require careful planning and execution. Once the system is well established, it does not demand more work or material inputs than any other similar system. The only additional task could be the more frequent and regular harvesting of fruit products, resulting in a positive return.

The working team is convinced that there are ample opportunities, with competent and professional experimentation, to improve both the economic and ecological benefits of the system to the adopting communities. Possibilities still exist of replacing many of the local species within the system with improved and more productive varieties. Component arrangement patterns, spacing, and cultural practices can also be modified both to improve the quantity and quality of products and to reduce input requirements. Introduction of additional production lines including livestock, valuable oil crops, and leguminous shrubs further improves the performance of the system.

There is an urgent and dire need to rectify the faulty and exploitative marketing procedures of farm products. Farmers need to be supported to obtain what they rightly deserve from their efforts. They should also be advised in money saving and banking processes. Furthermore, they should be encouraged to invest their money in productive and profitable sectors outside agriculture. This would enable many of the young generation to engage in industrial sectors rather than queuing to share increasingly fragmented land portions.

With competent and professional intervention to design and execute well-thought experimentation on the economic and ecological aspects of the system, it will be possible to greatly enhance the benefits and services accrued. Positive government policy dedicated to promoting the system and improving rural livelihoods can highly boost the economic and social stands of the community. Strong policy interventions are sought in facilitating and rewarding marketing processes, developing pertinent infrastructures, providing the basic tools and necessities, and inspiring problem-oriented and competent research experimentation. Exploring alternative marketing channels (both local and international) can increase the market demand and bring farmers financial benefits. Establishment of producers' cooperatives and installation of cold storage will likely increase the farmers' bargaining powers and economic benefits.

5.4 Improved fallows of Tanzania

Nature of the innovation

Improved fallow is an agroforestry technology where soil-rejuvenating trees or shrubs are planted in land going to fallow with the aim of improving soil fertility in a short time (Chamshama et al. 2006). Temporal arrangements of tree and crop component reduce competition for soil moisture and nutrients (Rocheleau et al. 1988; Thijssen et al. 1992) making the improved fallow technology appropriate for semi-arid sites as exemplified by its extensive practice in the central plateau agroecological zone in Tanzania. The type of tree species planted has been noted to have great influence on soil fertility, crop and wood yield, fallow duration and type of annual crop (Jama et al. 1998).

The predominant soils are Ferralic Cambisols having a Cambic B horizon with ferralic properties. These soils are characterized by sandy or loamy soils with a high infiltration rate and low water-holding capacity, while deeply weathered soils often susceptible to erosion are dominant on hills or mountain slopes. Most of the areas are mainly covered by moderately deep sandy or loamy soils with poor moisture-storing properties, susceptible to surface capping. The crop's rooting depth and usable moisture reserves may be restricted by impervious and poorly drained subsoils.

Low soil fertility and lack of fertilizer used on food crops are mainly responsible for food insecurity and poverty in rural Tanzania (Gama et al. 2004). Therefore, agroforestry research has concentrated on developing options that replenish soil fertility and improve production on smallholders' farms.

In Kenya, tephrosia is left to grow for a few months after the main crop is harvested. Its biomass will be incorporated during land preparation for the next cropping season. It replenishes the soil nutrients used by the cereal crop grown earlier.

Justification of profitability

Low soil fertility is one of the major constraints to agricultural productivity (Kwesiga et al. 1999). The major soil fertility problems in the country are nitrogen and phosphorus deficiencies and low organic matter content. Phosphorus is limiting in highly weathered soils because of fixation and also in sandy soils dominant in many parts of the country. Potassium and micronutrient deficiencies occur only locally. In the dry and hot lowlands in Tanzania, soil fertility problems are aggravated by the present land-use activities, which also lead to severe deforestation. In Tabora, the problems are partly related to tobacco (*Nicotiana tabacum)* farming, which needs wood for curing, and this has lead to destruction of miombo woodlands. The chief cash crops, cotton (*Gossypium* spp.) in Shinyanga and tobacco in Tabora, require substantial amounts of major plant nutrients.

The area experiences a semi-arid climate with mean annual rainfall of 499 mm and highly degraded, nutrient-poor soils (Chamshama et al. 2000). A 2-year improved fallow increased soil pH, organic carbon, extractable P and total N relative to initial levels. Chingonikaya (1999) found that improved fallow has a high potential to meet N requirement for maize production at Gairo. In addition, it was found that soil fertility improvement under improved fallow varied significantly with the fallow period, presumably due to differences in the duration of trees and shrubs in recycling nutrients. The improved fallow studies at Gairo indicated that 2 years was the optimum period for replenishing nutrients, particularly N and P required for maize production (Chingonikaya 1999; Mgangamundo 2000; Chamshama et al. 2000).

Studies also have indicated that in a 2-year improved fallow, total aboveground biomass usually increased with the length of the fallow period. It was highest in *Sesbania sesban* and lowest in *Cajanus cajan.* Declining biomass yields in the 3rd-year fallow of *Sesbania sesban* is associated with increased mortality as reflected by a 46% drop in survival (Mgangamundo 2000). Furthermore, it has been found that wood production ranged from 3.43 to 51.76 t ha^{-1}, indicating high potential of the improved fallow to provide fuelwood in addition to improving soil fertility. However, biomass yields of tree and shrub species in these studies were generally lower than values reported in the literature, mainly due to influences of rainfall, soil, species types and planting density (Chingonikaya 1999; Mngangamundo 2000).

Maize crop yield studies by Mgangamundo (2000) have shown that fertilization with N and P further increased maize grain yields in all fallow types, suggesting that fertilizer supplement is necessary for optimizing crop yields because green manure alone is not an adequate source of nutrients, particularly of phosphorus. Interaction of fallow types and inorganic fertilizers on maize yields revealed that application of half rate of N with either half or full rate of P after 1–3 years of fallow of the tested species was sufficient to optimize maize grain yields in Gairo (Chingonikaya 1999; Mgangamundo 2000). These results imply that improved fallow has the potential to cut down fertilizer costs by 50% without compromising crop production.

Most farmers under subsistence agriculture cannot afford to buy and use industrial inorganic fertilizers due to their exorbitant prices. Their use in recent years has been limited to cash crops and high-value crops such as vegetables. Other reasons for the drop in fertilizer consumption include lack of credit facilities, heavy taxation, lack of a remunerative price for crop produce, high transportation costs, and uncertain crop response (Kwesiga et al. 1999). This necessitates the search for cheaper and sustainable sources of nutrients for the benefit of resource-poor farmers.

According to Karachi and Matata (2000) as cited by Chamshama et al. (2006) *Sesbania sesban* was found to be tolerant to root-knot nematodes even when planted with a nematode-susceptible vegetable such as tomato. These results suggest that *Sesbania sesban* and *Gliricidia sepium* are suitable species for improved fallow in semi-arid conditions because of the highest foliage and wood biomass (Chamshama et al. 2000).

Agroforestry components and interfaces

The initial objective of having improved fallows is basically to increase soil fertility for better crop productivity. On improving soil fertility several outcomes feature (table 5.2). These include improved biodiversity due to increased variety of introduced trees and other vegetation that grows from natural regeneration. Fuelwood is consequently available, as is fodder for livestock. All these when brought together improve the lives of everyone in the area and make the surroundings alive and conducive for life.

Minimum inputs

The impact of agroforestry options at present is limited to the few areas where projects exist. Initiatives to expand this practice to other areas are important. There should be a strategy for tree seed production and tree nursery establishment to ensure the spread of tree planting among farmers. Training of farmers and capacity building among extension staff needs to be intensified.

Agroclimatic zones

Agroclimatic zones in which improved fallows work in Tanzania:

- Dry lowlands
- Dry mid-highlands
- Moist lowlands
- Moist and hot lowlands

Major factors that make the innovation successful

Improved fallows work due to their potential to increase soil fertility, the issue that will help farmers to increase crop production and hence improve food security in their households. This motivates the farmers to continue with the technology and persuade others to adopt it. It is also important to note that a number of research projects have been done to identify the

Table 5.2. Interface among components of improved fallows of Tanzania

	Conservation	Multipurpose trees	Agricultural crops	Livestock
Conservation	Reduced runoff, increased land fertility, improved biodiversity	Fuelwood, poles, reduced runoff, improved land fertility	Crop production, reduced runoff	Improved animal and crop productivity
Multipurpose trees	Poles, fuelwood, reduced runoff, improved fertility	Fuelwood, poles, improved biodiversity	Fuelwood, poles, crop production	Poles, fuelwood, fodder, animal products
Agricultural crops	Improved crop productivity, reduced runoff	Increased land fertility, increased agricultural crop production, poles, fuelwood	Rotational cropping	Zero-grazing, fodder storage technology, organic farming
Livestock	Fodder banks, hedge rows	Fodder trees planting	Organic farming, zero-grazing, fodder storage facility and technology	Necessitates fodder banks

types of trees and agricultural crops that can be used in this system. This gives the farmers confidence in the cultivation and planting processes that they are doing because they are supported by scientific evidence.

Farmers get fuelwood, which is always a big concern among the rural communities and households. It is a great relief to women's workload and it can restore the social harmony within families. This means women in rural communities, who have since time in memorial been recognized as the major contributors to family survival, are strongly involved in implementing improved fallows.

Direct and indirect beneficiaries

The beneficiaries of this innovation include communities in the areas where the practice is being undertaken. Fodder, fuelwood and food crops are produced together in the same farm. Soil fertility is also increased due to reduced runoff during the heavy rains. With time, degraded land is restored and the vegetation cover is increased, thus influencing positively the livelihood of the people concerned. The government benefits because its strategy is to conserve and improve soil fertility so as to increase crop productivity and to develop the agricultural sector at large.

Upscaling strategies

Development of collaborative institutions such as the Natural Forest Research Management and Agroforestry Centre (NAFRAC), ICRAF and Africare, who are working in the affected areas, has given the communities a lot of progress. Processing fruits to produce jam, juice, wine and medicine and marketing these products have shown that things can always happen.

Institutions promoting the innovation

In view of the above constraints for crop production, emphasis on soil fertility research in the country in the 1980s was shifted to organic sources of nutrients including animal manure, green manure and crop rotation. The World Agroforestry Centre (ICRAF) initiated an agroforestry research project in collaboration with the Tanzanian research institutions at Tabora and Shinyanga. Since inception of the project in the late 1980s, several agroforestry technologies aimed at improving soil fertility have been developed, tested and disseminated. These include improved fallows, mixed intercropping, biomass transfer, alley cropping, and rotational woodlots.

Research questions and knowledge gaps

Research has concentrated on a few areas. There is a need to incorporate other areas so that the practice can appear in more areas than the few studied. Training and community sensitization extension programs should be intensified, for most people are ignorant of ways to improve their livelihood. Again, the majority of the people believe in waiting for the government to provide community services, and if it does not happen they continue blaming the government. Self-help schemes if initiated and supervised can assist in changing this attitude and cultivate the attitude of doing things for production for both income generation and food production. Then people request external food aid only when it is necessary.

Professional reflections and recommendations

Two-year improved fallows on *G. sepium* and *T. vogelii* are recommended to improve soil fertility, wood and maize yields in Gairo and other semi-arid areas. However, where arable land is scarce, a 1-year narrow-spaced improved fallow of rotational improved fallow is an appropriate agroforestry technology if well designed to minimize competition and increase tree or shrub foliage biomass production per unit area (Chamshama et al. 2000, 2006).

In places with severe scarcity of arable land like Gairo, farmers can hardly afford to fallow their farms for 2 or more years. This problem may partly be addressed by using either the 1-year improved fallow at narrow spacing or rotation of leguminous species (Chamshama et al. 2000, 2006).

Crop production under rotational improved fallow in semi-arid areas may be adversely affected by competition for growth resources, particularly moisture and nutrients between trees or shrubs and crops. However, with appropriate designs of spacing and time of planting the tree and shrub components, competition among components may be reduced substantially.

5.5 Rotational woodlot farming systems of Tanzania

Nature of the innovation

Rotational woodlot technology is an agroforestry option that attempts to simulate the traditional fallow system in shifting cultivation in which trees contribute to maintaining soil fertility through nutrient cycling during the fallow phase. Rotational woodlots effectively combine the principles of crop production and forest management to provide multiple products that have direct bearing on farming households and the environment to provide products and services with valuable economic, social and environmental benefits (http://www.icrafsa.org/innovations/woodlots.html).

Rotational woodlot technology involves growing trees and crops on farms in three interrelated phases: 1) an initial tree establishment phase in which trees are intercropped with crops, 2) a tree fallow phase, and 3) a cropping phase after tree harvest (Nyadzi et al. 2003). The establishment phase involves establishing multipurpose trees in association with food crops such as maize, sorghum, millet and cassava. During intercropping, trees benefit from land preparation, weeding and other crop management operations. This phase lasts for 2 to 3 years. Cropping is discontinued when tree root systems and the canopies are fully developed and competition for light, water and nutrients does not permit economic yield. Duration of the intercropping phase depends on tree species, tree density, and management practices such as branch pruning and type of the associated crop. Cropping is discontinued in the fallow phase and the established trees are left to grow to the desirable size. The fallow phase may last for 2 to 4 years, depending on the tree species, environmental variables such as rainfall, and intended use of the trees. At the end of the fallow phase, whole plots or parts of the woodlot can be clearfelled, depending on intended use.

A rotational woodlot helps replenish soil nutrients when it is alternated with agroforestry innovations that integrate herbaceous legiumes in the system.

Justification of profitability

Rotational woodlots present an excellent example of a sequential or intermediate tropical agroforestry system with great promise for reducing deforestation as well as increasing crop production in a sustainable manner. However, rotational woodlots are normally established primarily to address fuelwood deficit problems in semi-arid conditions. A number of tree species have been evaluated to assess their potential for wood production, maize yield, nutrient use efficient and export (Kimaro et al. 2006a,b). Nutrient use efficiency, defined as the ratio of biomass productivity to nutrient uptake, is a measure of the efficiency with which tree species use soil nutrients for growth (Marschner 1995; Herbert and Fowes 1999). It provides a basis for comparing nutrient costs of biomass production (Kumar et al. 1998) and the potential of plant species to grow well under conditions of limited soil nutrient supply (Marschner 1995). High wood production was observed in *Acacia crassicarpa* and *Gliricidia sepium* in the dry lowland agroclimatic zone. Based on a firewood consumption rate of 10 kg per week for an average family of six members in a miombo woodland (Biran et al. 2004), wood produced from a rotational woodlot would be sufficient to meet the household fuelwood demands for about 7 to 16 years. The result indicates a high potential of this system to contribute to satisfying firewood demand in the region, and would in turn reduce subsequent harvesting pressure of the natural forests (Kimaro et al. 2006a). Highest maize grain yields after wood harvesting were observed in *A. polyacantha, Leucaena diversifolia* and *Gliricidia sepium* fallow, probably reflecting marked improvement in soil nutrients during the fallow period and large amounts of nutrients, particularly N, released from slash applied as green manure (Kimaro et al. 2006b). Among exotic *Acacia* species, *A. mangium* fallow produced relatively high maize grain yields, probably due to comparatively high soil nutrient improvement and more nutrients released during the cropping season (Kimaro et al. 2006b).

These studies suggest that *A.crassicarpa, A. leptocarpa* and *A. mangium* are appropriate species for improving soil fertility and maize yields under the rotational woodlot system. Fuelwood can be obtained during the fallow phase if trees are branch pruned periodically or thinned selectively to widen spacing between trees. Undergrowth of palatable herbaceous grasses and shrubby species can be encouraged and used for feeding livestock. Other value-added outputs for which the system can be managed are honey, beeswax and mushrooms. The fallow phase may last for 2 to 4 years.

Agroforestry components and interfaces

The technology is very sustainable because several things develop from it (table 5.3). In a combination of multipurpose trees, species that are fast growing should be selected to produce the required biomass to fertilize the soil. At the same time these trees should produce fuelwood for domestic use. The selected trees should also have a nitrogen-fixing quality that will intensify soil improvement. When multipurpose trees are planted for soil and water conservation, it is necessary to promote the construction of conservation structures, especially on sloping areas.

When we have agricultural crops alone on the farm, it is necessary to intensify farm management through intercropping and rotational cropping technologies and practices. Leguminous crops are recommended for intercropping or planting in a rotational basis to ensure that the soil nutrients are not overexploited by one crop. Alley cropping practice and technology should be included in areas where agricultural crops and soil and water conservation innovations are expected to be developed. This will give room for crops to grow while getting shade, preventing water runoff and increasing soil biomass. In soil and water conservation practice, multidisciplinary actions are required. Where gullies are found, it is not possible for one professional to do the work alone. We need several disciplines.

Table 5.3. Interfaces among components of rotational woodlot farming system

	Multipurpose trees	Agricultural crops	Soil and water conservation
Multipurpose trees	Fast-growing trees with large biomass and fuelwood production	Improved soil fertility through increased biomass and nutrient cycling and fixing	Selection of tree species for conservation; technology for the construction of soil and water conservation structures
Agricultural crops	Tree species with nitrogen-fixing qualities	Rotational cropping and intercropping technologies	Alley cropping technology to be intensified
Soil and water conservation	Selection of relevant tree species	Increased practice and technology on construction of conservation structures and contour bands	Multidisciplinary actions

Minimum inputs

Farmers, researchers, extension systems and the private sector in Tanzania have started networking to establish seed orchards, disseminate seeds, and exchange information on establishing nurseries and managing the woodlots. Future research and development efforts need to focus on how to reach more farmers who can benefit from this agroforestry innovation.

Agroclimatic zones

Rotational woodlots work effectively in three agroclimatic zones in Tanzania:

- Dry lowland
- Dry mid-highland
- Moist and hot lowland

Major factors that make the innovation successful

A significant amount of firewood can be obtained from fast-growing species such as *Leucaena* and *Acacia (A. polyacantha, A. crassicarpa, A. julifera, A. auriculiformis).* Food crops grown following the tree harvest are expected to benefit from the increase in soil organic matter, nutrient cycling and nitrogen fixed by the leguminous trees. Coppicing the trees is allowed and if necessary they are pruned to reduce competition for light and nutrients with the food crops and to provide organic material to incorporate into the soil. The coppice growth may be used either for fodder or for improving soil fertility. Depending on land availability and rates of decline in soil fertility, the cleared woodlot plots could be cropped for 3–4 years before trees are allowed to regenerate and revert to the fallow phase. Various coppice management systems can be developed to minimize labour costs while maintaining vigour of the trees (http://www.icrafsa.org/innovations/woodlots.html). Where farmers' interest is to maximize production of both wood and crops, as in areas with scarcity of arable land, *A. polyacantha* and *A. diversifolia* would be alternative species because of their high potential to produce wood and improve maize yield.

The government of Tanzania in the National Forest Policy (MNRT 1998) states:

> Establishment of private woodlots and plantations for woodfuel production will be encouraged and supported through research, extension services and financial incentives.

This policy statement motivates individuals and organized groups to initiate woodlot plantations because they are ensured of their security and ownership of the wood products.

Direct and indirect beneficiaries

Farmers benefit from fuelwood, fodder and improved soil nutrients; thence they increase food crop productivity. Financial income can also be accrued from sold wood. The society at large benefits since the ease to get fuelwood and building material reduces family disputes and increases harmony among the communities. It is said that what we consider as small simple local actions extend to the region and finally the environmental impact is felt globally. This is reflected in the fact that when these woodlots are established on empty land, the soil is covered and vegetation grows. Consequently soil erosion is prevented and to some extent vegetation for carbon sequestration is created. This means the global community also benefits from this innovation.

Upscaling strategies

The National Forest Policy (MNRT 1998) promotes establishing individual, private and community woodlots and forest plantations. This is a strategy for the government to increase environmental conservation and availability of natural resources to its people. Integrated management of natural resources is being advocated in the country through training extension staff to ensure collaboration among professions in community development activities. However, resources to enable the extension staff to reach the farmers have been a big limiting factor.

Institutions promoting the innovation

Africare Tanzania, which began its activities in the country in 1994 with a major aim of developing water resources in Dodoma Region (Central agroecological zone) have spread efforts into several dry and semi-arid zones with war refugees in the western part of the country. Africare also gives life-saving assistance to families in Kongwa District of Dodoma Region. In 1998, Africare began a natural resources management project for communities adjacent to the Ugalla Game Reserve in Tabora Region (central agroecological zone).

CARE Tanzania is an international organization that works for humanitarian relief and development. It was started in Tanzania in 1994 to provide emergency relief to the Rwandan refugees in western Tanzania. Care has since then expanded its scope to include projects in environmental protection, food security, education and health. Sensitization and assistance to communities in establishing woodlots has consequently been among the activities for environmental protection in both central and western parts of the country.

Research questions and knowledge gaps

Research on indigenous tree species that can be used to establish rotational woodlots needs to be intensified, especially on the silvicultural and management practices of these tree species. Making this knowledge available will be helpful for the organizations that are doing extension work.

Professional reflections and recommendations

In Tanzania, where 32,500 ha are under tobacco production, rotational woodlots have the potential to save 37,793 ha of forest each year (Gama et al. 2004). Although a lot of research work has been conducted in the miombo woodlands, most is still on the shelves. There should be initiatives to translate research findings into simpler language that farmers can understand, and to prepare leaflets and brochures that will assist extension staff in disseminating the information to the farmers. Adaptation and spread of the technology is to some degree limited by lack of enough information on tree species and awareness of possible strategies for alleviating poverty.

5.6 Apiculture-based farming system of Tanzania

Nature of the innovation

The honeybee is an insect that belongs to the order Hymenoptera. Honeybees are social insects, characterized by good colony structure. A typical hive is divided primarily into worker bees and drones, ruled by the queen. In the wild they create elaborate nests called hives, which may be located in dead logs, tree crevices or branches.

The honeybee is important to humans due to its role in the natural world. They provide us with honey, beeswax, royal jelly and propolis. They are the prime pollinators of the planet. It was and still is common practice for honey hunters to collect honey from the wild by using fire.

Traditional beekeepers started domesticating bees, using various types of hives depending on the location, log and basket hives being the most common in Tanzania. However, honey hunters continued to use fire in honey harvesting, and when such fires went out of control they resulted into bush fires that destoyed vast areas of vegetation.

Although traditional beekeeping has been practised all over the country, it has been prominent in the Western and Central agroecological zones—the semi-arid areas characterized by miombo woodlands. The tree species in these zones produce good bee fodder, and thus intensifying more bee products come from here than from other parts of the country.

The development of beehives in Tanzania has taken several phases. Initially traditional beehives were encouraged to increase production. As beekeeping became professional, different improved box beehives were developed—the Tanzania transitional hive, the Kenya topbar hive and the Langstroth hive. The intent is to get a beehive that makes managing bees

Agroforestry innovations include vegetation whose flowers can serve as bee feed. Using improved beehives makes beekeeping more profitable.

during harvesting, inspection and management of apiaries easy and that destroys a minimum of the hive structure. (An apiary is a bee farm in which a number of bee colonies are kept in hives and farmed.)

Bee equipment has been developed. This includes smokers to smoke the bees during inspection and harvesting instead of using open fire. Personal protective equipment may be overalls, special gloves and boots, and a veil plus helmet or hat. A hive tool is required for opening the hive, glued by propolis. Honey and beeswax processing equipment has also been developed in the Small Industries Development Organization (SIDO) in the country. Honey is in high demand both within and outside the country. The demand for beeswax is comparatively low locally but in high demand in export markets. Other bee products have yet to be widely recognized.

Justification of profitability

Honeybees provide humans with honey, beeswax, royal jelly and propolis. They are the prime pollinators of the planet. Honey can be defined as a sweet, viscous fluid that bees process from the nectar of plants and store in their combs as food. It consists essentially of different sugars, predominantly glucose and fructose. It also contains protein, amino acids, enzymes, organic acids, mineral substances, pollen and may include sucrose, maltose, melezitose and other oligosaccharides (including dextrins) as well as traces of fungi, algae, yeasts and other solid particles (UNCTAD/GATT 1977). Other minor components are pigments, substances producing flavour and aroma, alcohols, colloids and vitamins. This group of components constitutes about 2.2% of the total.

As a food, honey is a tasty and easily digestible source of carbohydrates. It is a natural food and a good source of quick energy. Traditionally, honey has been used as medicine on its own or crushed herbs have been incorporated in it for treating several human diseases and for healing burns. It is also used in preparing a local brew the Maasai in Tanzania drink in social and cultural occasions.

Beeswax is secreted from four glands on the underside of a worker bee's abdomen. Major uses are in making cosmetics and candles. International markets record a myriad uses for beeswax—in lotions, cold creams, ointments, salves, lipsticks, rouges, pill coatings, waterproofing, coatings for electrical apparatus, floor and furniture polishes, leather polishes, arts and crafts items, adhesives, crayons, inks, basketball moulding, grafting wax, ski wax and ironing wax (http://www.insecta-inspecta.com/bees/honey/index.html). In Tanzania small-scale women's groups process candles, ointments and lotions as a value-adding program. Most beeswax produced in the country is exported through business intermediaries.

Bees gather propolis from trees and other vegetation. They use it to seal cracks and crevices in the hive. Propolis is sticky when it is warm and difficult to deal with when it is hard. It is used as an ointment for healing animal cuts and wounds. If propolis is mixed with mineral spirits, it can be used as a natural varnish (http://www.insecta-inspecta.com/bees/honey/index.html). However, in Tanzania, there is very little information on how to collect and use this hive product.

Bees have been domesticated on farms. This is mainly for honey production but large-scale farmers use bees to pollinate crops, to increase productivity.

Agroforestry components and interfaces

A number of agroforestry components interface in this system—the bees, the perennial trees and other vegetation, the crop and the land on which the crops and other plants grow interact for common resources. Underground, they interact and compete for commonly needed soil nutrients and moisture. Some give while taking while others benefit in other ways.

Aboveground, they compete for the common resources of light and air. Those photosynthesizing compete for the position where they will best capture active radiation. Some, like the bees, benefit (by gathering nectar) while they provide some of the inputs (CO_2) required for photosynthesis. They also help by pollinating. Table 5.4 provides relevant information on this interaction.

When the technology emphasizes the bee component, the farmer may produce more bee products, going further into processing and adding value to the raw products. This requires knowledge, skill and equipment for quality control, and some insight on how to market the products. If strategies are set to get such requirements then the beekeepers will be motivated to keep more bees and the whole practice will be sustainable.

Beekeeping can easily be practised on farms where leguminous and other nectar- and pollen-producing crops are planted. Such practice is important; the bees pollinate the plants and in turn benefit because they get their food, which they store, and the beekeepers ultimately exploit as bee products. What is important here is to ensure that there is integrated pest management (IPM) where the use of pesticides is controlled—otherwise the bees will be killed.

Table 5.4. Interface among components of apiculture-based farming systems

	Bees	Trees and other vegetation	Agricultural crops	Environmental protection
Bees	Beekeeping technology	Bee and apiary management, bee fodder	Integrated pest management approach	Improved beekeeping technologies, equipment and practices
Trees and other vegetation	Biodiversity conservation and protection	Biodiversity conservation and protection	Selection of appropriate tree species for farmland and agroforestry	Biodiversity conservation and protection
Agricultural crops	Selection of appropriate agricultural crops; integrated pest management approach	Selection of appropriate MTPs trees, crops and agroforestry practice and technology	Intercropping technology; rotational cropping practice and approach	Construction and management of conservation structures on farm
Environmental protection	Apiary management	Biodiversity conservation	Soil and water conservation; land-use management and planning	Biodiversity conservation

Minimum inputs

Most of the bee equipment used for efficiently managing bees can be produced locally with local materials. But the honey processing and value-adding machines are sophisticated and need to be imported. If they are not imported, at least the equipment design needs to be imported, so that SIDO can learn to manufacture the machines necessary for beekeeping farmers to add value to their products. Technology in value addition is required so as to improve farmer income. Capacity building in research activities specializing in bees and bee products is required.

Farmers need to be shown how to produce high-quality bee products that will fetch good prices in both local and international markets. Extension services should give intensified training in harvesting, handling, storage and packaging bee products. There should be a small industry or factory for making beekeeping equipment. Such equipment should be readily available, accessible and sold at a reasonable price.

Beekeeping is environmentally friendly when done using improved technologies. Fires that have traditionally been recognized as the means of handling bees but that also are believed to have been the cause of most wild fires will finally be eliminated. This will ensure biodiversity conservation and protection in the forest and game reserves where the government of Tanzania has given the mandate to farmers and beekeepers surrounding these reserves to establish apiaries to intensify the beekeeping industry in the country.

Agroclimatic zones

Agroclimatic zones in which the innovation works effectively:

- Dry Lowlands
- Dry and Hot-lowlands
- Moist Lowlands
- Moist and Hot-lowlands
- Moist Mid-highlands

Major factors that make the innovation successful

Agro-apiculture works efficiently in Tanzania because there are large expanses in the semi-arid areas that are vested with vegetation types favourable for bees. Secondly, the semi-arid areas are not prominent for agriculture. This makes farmers take up beekeeping as an alternative way to survive.

The initial investment is the limiting factor for most farmers. Initial investment includes purchasing hives and acquiring enough land to place hives that can be managed commercially. Most farmers in areas where apiculture is incorporated place their hives in the family woodlot or in a homegarden. The practice has been for home consumption. The government of Tanzania through the Ministry of Natural Resources and Tourism has adopted a beekeeping policy that ensures the practice is developed in the country. The National Beekeeping Policy (MNRT 1998) states:

> To enable participation of all stakeholders in conserving and managing honeybees, individual beekeepers and organized communities will be encouraged under government guidelines to establish, manage and own bee reserves for carrying out sustainable beekeeping activities.

Direct and indirect beneficiaries

Communities benefit from this system through income generated by the sale of bee products, chiefly honey and beeswax. Dealers who are involved in marketing honey and beeswax outside the country also benefit from this business. The government earns money from taxes and export duties. Beekeeping has been mentioned as an important income-generating activity for both the government and commercial beekeepers.

Upscaling strategies

A number of policy statements issued in the National Beekeeping Policy (MNRT 1998) by the Ministry of Natural Resources and Tourism indicate the government's aim to develop the beekeeping industry. It should also be noted that Tanzania started giving certificate and diploma training in beekeeping in the early 1970s at the Forestry Training Institute Olmotonyi. Currently, beekeeping training is incorporated in the forestry curriculum to produce a forester who also has knowledge of beekeeping. This is in recognition of the potential of the industry in the country. Consequently, there are beekeeping professionals who can advise the farmers. There is also a research institution under the Wildlife Division.

Institutions promoting the innovation

A number of institutions involved in the development of this industry are found in the Western, Central and Coastal semi-arid zones in Tanzania. These include:

- DIAP—Diocesans Integrated Agroforestry Project found in Handeni within the Coastal zone
- BDP—Beekeeping Development Project, under the Ministry of Natural Resources and Beekeeping in Handeni District in the Coastal zone, Manyoni in the Central zone, and Kigoma in the Western zone
- TAB—Tabora Association of Beekeepers, which has existed since the 1960s; currently not very effective because of the problems most cooperative societies have faced of inefficient management and lack of community training and empowerment
- Africare—also operating in Ugalla, Tabora Region, in the Central zone
- Gold Apis—working in Mpanda District, Rukwa Region, involved in direct training and marketing of bee products

Research questions and knowledge gaps

There is lack of enough research in the development of little-known bee products such as propolis and royal jelly. It is important to note that most people trained in beekeeping at the diploma level take that as a bridge to join Forestry at Sokoine University of Agriculture. Therefore, although the government is trying to train people in this sector, most soon join other sectors. A simple social study should be done to study the reasons why these people do not continue working in the sector.

Again, a study is required to determine how the beekeeping industry is distributed in the country and to evaluate the contribution of the industry to the GDP and GNP. Value addition for honey and beeswax requires intensive research to make the practice more profitable.

Professional reflections and recommendations

If beekeeping, or agro-apiculture, is to prosper, forestry and agricultural training should include beekeeping training in their curricula. This will increase the number of extension staff who will encourage farmers to include beekeeping. Quality control of honey and beeswax needs to be followed up to ensure products are of proper quality. Because of the high demand for honey in the country, some processors have adulterated their honey to increase the volume. People therefore need to be careful of the source and adulterators should be found out and penalized.

Chapter 6 Agroforestry innovations suitable for Moist Lowlands

6.1 *Vitellaria paradoxa* cum millet agroforestry in Uganda

Nature of the innovation

An agroforestry practice using *Vitellaria paradoxa* and *Eleusine coracana* (finger millet) is found in the Lango and Teso farming systems of north-eastern Uganda. *Vitellaria paradoxa,* commonly known as the shea butter tree, is indigenous in Uganda. *Eleusine coracana* is the most common annual food crop grown in association with the tree. *Vitellaria paradoxa* is divided into two subspecies: *V. p. nilotica,* found primarily in Uganda and Sudan, and occasionally occurring in Ethiopia and Zaire, and *V. p. paradoxa,* found in areas

Vitellaria paradoxa ia tree that can be integrated with crops, yields commercuially profitable fruit from which shead butter is rendered.

from Central African Republic to Senegal (Hall et al. 1996). The difference between the two is in the consistency of the fat content found in its nut (Boffa 1999). *V. p. nilotica* occurs at higher elevations than *V. p. paradoxa*.

Vitellaria grows widely and naturally in wooded grasslands in north-eastern Uganda. It is a dominant tree, forming almost pure stands in some cases (Katende et al. 1995). Farming households, aware of the trees' value and of their positive interaction with companion crops, especially millet, normally leave them growing scattered on farms (Barrow 1996; Boffa 1999). The tree is an important component of traditional agriculture. However, due to increasing social, economic, political and environmental pressures, this traditional agricultural system is becoming less viable; now the trees are being cut down without adequate regeneration (Okullo et al. 2004b).

Justification of profitability

The positive association between the shea tree and millet leads to profitability through increased production of shea fruit and thus increased shea butter production. The presence of the millet crop in gardens where shea trees are found enhances ownership and control. They are managed well, leading to improved production of shea nut kernels. The presence of trees in the gardens improves the productivity of the millet crop (Bayala et al. 2005). Farmers therefore benefit from both food security and increased income from the system.

The cosmetics industry prefers the oil of *V. p. nilotica,* said to be of superior quality. However, it is currently available only in small quantities on the world market due to civil unrest prevailing in the region. Several other countries, including Israel and Germany, have attempted to replicate this variety without success. Shea nut kernels vary in quality, and individual companies specify their quality standards. A recent study in Uganda found that for every given quantity of shea nuts on local markets, 50% were of high quality, 35% were of moderate quality and 15% were of poor quality (Ferris et al. 2001). This implies that about 85% of shea nuts produced in the country meet the quality world markets require. For this to happen, the shea nut kernels produced need to be graded so as to meet these qualities. The benchmark composition of the shea nut butter required by export markets is that oil content be 45%, free fatty acids 6%, moisture content 7%, and latex content 4–10% (Harris 1998).

The biggest problem currently facing shea butter production and promotion in the country is weak farmer organization at the production level. It is important to have credible suppliers who can enter contracts with processors and exporters. Currently there are a few such organizations, one of them the Northern Uganda Shea Nut Producers Association (NUSPA). More such organizations are needed and should be strengthened to be able to link up with export markets directly so as get better prices for processed products. This is an area on which the government and the private sector need to focus if the high quality of Uganda shea butter is to benefit the farmers of the country.

Private sector companies and agencies interested in expanding Uganda's shea market industry include the Cooperative Office for Voluntary Organizations Limited (COVOL), NUSPA, Guru Nanak Oil Mills (GNOM), and Mukwano Industries. GNOM, in Lira, has built a pilot shea extraction plant. It has supplied small quantities of the extract to local cosmetic manufacturers and established contact with several cosmetic manufacturers in the USA. Mukwano Industries is also developing a shea extraction plant that will process up to 2000 tonnes of oil per year (about 5000 tonnes of shea nuts). Companies like AVIS, Despro and UKI Ltd have a potential for local cosmetic manufacture. All these factors can ensure increased and continued production of shea nuts through this agroforestry practice, provided social, economic and policy issues mitigating the scaling up of the practice are addressed.

Farmers, local organizations, processors and exporters rate this practice as one of the country's most profitable enterprises. However, insecurity in the northern parts of the country has greatly hampered the scaling up. Despite this drawback, farmers and local organizations in the region are actively practising and promoting it.

Agroforestry components and interfaces

In this agroforestry practice, there is positive interaction between *V. p. nilotica* and *Eleusine coracana*. The tree provides light shade to the millet crop but allows adequate light and rainfall to reach it; the accumulation of leaf litter under it adds organic matter to the soil, thereby enhancing its fertility (Bayala et al. 2005). The presence of the millet crop in the gardens where the shea trees are found reinforces ownership and control over the trees. It also gives the authority to the owners of the crop to restrict others from accessing products from these trees. As result of secure ownership, the shea trees are given better management leading to their improved productivity. Table 6.1 summarizes the interaction between the two components in this agroforestry practice.

Table 6.1. Main components in the *Vitellaria* and millet agroforestry practice

Components	*Vitellaria paradoxa nilotica*	Millet crop
Vitellaria paradoxa nilotica	The tree benefits from the management applied to the millet crop such as weeding; this results in higher fruit and nut yields of good quality, thus better harvests and income	Millet being a cereal crop that thrives well in soils with high organic matter, it benefits from the decomposed leaf litter from the tree; the tree shade also protects the soil from erosion and helps prevent nutrients from leaching
Millet crop	The post-harvest residues from the millet crop later decompose and benefit the *Vitellaria* tree	The increased millet production in this agroforestry practice ensures food security and increased household income

Minimum inputs

This practice requires only a minimum of material inputs as the shea nut trees grow naturally. The main inputs are restricted to millet production and include land, good-quality seed, human labour, draught power (oxen) and other farm implements like ploughs, pangas and hoes. There is occasional need to hire labour and purchase implements. The shea trees begin to bear fruit after 15 years and yields become optimum at 25–40 years. Each tree can produce up to 50 kg of nuts per year.

The only tree management required is protection from grazing livestock (when trees are young) and wild fires. However, farmers believe that controlled fires can increase flowering of the tree, hence increase its productivity (Okullo et al. 2004a). The tree propagates naturally and farmers leave the regenerating seedlings to grow as they cultivate their gardens.

Processing requires the nuts, embedded in a soft fruit, to be buried in a pit, which causes the pulp to ferment and disintegrate. The nuts are dried for a few days and then shelled, winnowed and dried to reduce moisture content from about 40% to about 7%. Various methods of producing shea butter have been developed (Vermilye 2004).

The traditional method involves fermenting, boiling, drying nuts (roasting), dehauling, drying the kernels, pounding and washing with cold water to separate the liquid and the solid butter (Hall et al. 1996). The total time required to process shea butter using this method, excluding harvesting and drying times, is usually 5–6 hours (Hall et al. 1996; Boffa 1999). It is labour intensive and requires large amounts of water and fuelwood. Due to limitations of this method, semi-mechanized processing of shea nuts using hand-operated oil presses has been developed. It takes less time and labour and eliminates the use of water and firewood. Fully mechanized processing plants use machine presses or chemical solvents or a combination of the two, to extract the oil. Although there are a few such plants in Africa, the vast majority of mechanized processing takes place abroad (Chalfin 2004). By introducing presses and improved processing, manual labour of women has been reduced and the quantities of fuelwood required for processing are eliminated.

Currently shea butter has a local market that is limited to northern Uganda, where it is mainly used for cooking and as body oil. Shea nuts and oil are also valued on the international market, primarily in manufacturing chocolate (Boffa et al. 2000). The cosmetic industry offers a niche to producers from African countries due to the growing demand for natural and organic beauty products (Akosah-Sarping 2003). In regard to this niche, international organizations such as the UN Fund for Women (UNIFEM) are working to secure more of the profits for local communities by encouraging, through loans, a higher level of village processing (Spore 2002). For the market system to function effectively, it is important that farmers are organized into groups that are able to produce, process and package economic quantities of shea nut. These groups need to be linked to local, regional and international markets.

Agroclimatic zones

The agroforestry practice is found in the Lango and parts of the Teso farming systems in north-eastern Uganda. Rainfall is bimodal, 1200–2000 mm annually, with peaks occurring during April–May and August–October. It is usually convectional and occurs during afternoons and evenings. A short dry spell occurs from June to July and a longer one from December to March. Average minimum and maximum temperatures are 22.5 °C and 25.5 °C. The soils are underlain by undifferentiated acid soils.

The tree thrives on dry sandy-clay soils that have good humus, but occurs in a variety of soil types (Hall et al. 1996). Annual rainfall in its natural range varies, 600–1500 mm) (Maydell 1990), while the subspecies *V. p. nilotica* occurs mainly between elevations of 1200 m and 1500 m. It does best on agricultural land where it is protected from fire and livestock (Kater et al. 1992). In the harmonized agroclimatic zones of eastern and central Africa, the practice can work in moist lowlands.

Major factors that make the innovation successful

There are over 150 non-timber forest products on the international market, one of which is shea butter (Carr et al. 2000). *Vitellaria* trees regenerate naturally and although they may be aided by being protected from fire or grazing livestock, traditionally they are not planted (Hall et al. 1996; Boffa 1999; Kritensen and Lykke 2003).

The ease of implementation through normal land tillage that requires minimum inputs makes adopting the practice easy. The fact that millet is a staple food in the area gives it priority over other crops during production. Generally, *Vitellaria* trees on private land and near homes are given more protection than those in more remote places (Okullo et al. 2004b). They normally yield more than those found in the bush, fallow land or near swamps. Tree management practices include digging or slashing around the trees to reduce competition, reducing seedling mortality, and protecting them from fire.

In some areas in northern Uganda, sacrifices are offered to please the gods so that fruit production from the trees increases. It is believed that if one cuts a branch or the whole shea tree without good reason, that person dies. To prevent such death, a black goat has to be sacrificed to please the gods and request them to allow heavy fruit production (Okullo et al. 2000b).

Products from the shea nut, both solid fat and liquid oil, are used as raw materials in cooking oil, margarine, cosmetics, soap, detergents, candles, chocolate and the confectionery industry (Ezema and Ogujiofor 1992; Ezema and Ozoiko 1992). Shea nut products command an important position in the diet of rural people in northern Uganda. Thus children and women commonly eat the fruit, while the processed crude oil is used as a food supplement. Trading in shea also provides an important source of income that rural households use to purchase food, thus contributing to household food security.

Processing shea nuts for butter enables farmers to add value to the product before marketing. For industrial processors, shea butter is a low-cost substitute used mainly for making chocolate. Companies are increasingly interested in shea butter for high-value cosmetics. Shea nut remains a wild crop and is collected and processed by women in remote rural areas. For the cosmetics industry, this is enough incentive to pay premiums for processed shea products. In addition, the tree grows in natural parkland systems, lending it natural organic qualities that are favoured by industrial companies.

Direct and indirect beneficiaries

This agroforestry practice directly benefits farm households involved in millet growing and in processing shea nuts. Shea oil plays a significant role in household food and income security in northern Uganda, especially in the districts of Lira, Katakwi, Kitgum and Kotido. This region is one of the poorest areas of Uganda, and therefore any increase in income through the sale of shea butter will have significant economic and social benefits.

The shea fruits and nuts are gathered, processed and retailed mainly by women and children. This therefore makes shea an important source of income for less privileged groups (women, children and disabled). Children can also gather shea nuts, sell the kernels in local markets, and use the proceeds to buy clothes and other necessities. But processing and exporting shea butter tends to benefit the wealthy, as the processing equipment requires heavy capital investment.

The government, at both local and national levels, is greatly benefiting from the shea butter trade through the collection of taxes from the processors and exporters. Other indirect beneficiaries include local artisans, traders and transporters. The other major benefit of the practice to farming communities is the increased millet production that greatly contributes to increasing household food and income security. Millet, a major staple food crop in these areas, is mainly used in millet bread and also in making the local brew, *ajon*. There is also a big local market for millet in Uganda.

Upscaling strategies

Since the practice occurs in the natural shea belt, there has been no upscaling beyond this region. However, upscaling within the belt has involved commercializing shea butter production and processing. The USAID-funded COVOL project spearheaded the development and promotion of shea butter production in north-eastern Uganda (Masters 2000). It has developed and disseminated technologies for enhancing the production of shea butter and through these technologies, households would realize increased income from the shea trees that in return would encourage conserving them (Lovett 2003). Meetings and workshops for various stakeholders were organized to increase awareness about the tree and increase the capacity to manage the resource. In addition, several posters and leaflets were also used as promotion materials by the project.

An indigenous production and marketing body, NUSPA, was established by the project. It is an umbrella organization, with over 200 members, for small and village-based shea-processing groups and has played a significant role in promoting the use and conservation of the shea nut tree. It has helped form and develop women's groups for collecting and processing shea nuts and establishing a cooperative. It has also facilitated the introduction and promotion of modern equipment for processing shea butter, organizes training for members, and links them to others working in the shea industry.

Other approaches that have been used in the scaling-up process have included efforts by NGOs and district departments in areas where the agroforestry practice is found. Awareness of the usefulness of the tree and the need to conserve it has been created, especially with the COVOL project. Major factors that have helped to scale up the practice include the readily available local and international markets for shea butter and its products, the natural occurrence of the tree in the region and its ability to grow in association with crops.

Institutions promoting the innovation

The main institutions that promote the practice and their respective roles and functions are shown in table 6.2.

Research questions and knowledge gaps

The optimum number of trees per hectare that can give economic yields under northern Uganda conditions is not known and needs to be established. The long period before the tree bears fruit and reaches maturity discourages planting (Ferris et al. 2001). However, there have been attempts to shorten this period by genetic improvement (Maydell 1990) and grafting (Sanou et al. 2004). There is need to adopt these technologies for mass propagation of the species. Better understanding of the interactions between the seas tree and crops grown in these systems is also needed.

There is a lot of interest in developing the shea industry in the country. However, no attempts have been made to domesticate the tree, which has remained a wild fruit gathered by local communities. Recent studies in the area show that farmers select better populations of shea nut trees (Okullo et al. 2004a,b), as do farmers elsewhere (Lovett and Haq 2000). They eliminate unwanted woody species and leave behind only the trees that meet their criteria for fruit production, based on local knowledge (Maranz and Weisman 2003). This knowledge can provide a basis for domesticating the tree and can also be used in developing sound resource management policies and extension services.

Compared with the commercial production of shea nut in West Africa, production in the country remains at low levels, with little documentation on the market dynamics. In addition, data and information on production, processing and export of the crop is scanty. There is need to gain a better understanding of the market forces at play and ensure that activities in the shea industry are monitored and documented. There is also a potential for exploiting regional markets in the cosmetics industry currently existing in the East African region. This industry is well developed and has the capacity

Table 6.2. Institutions promoting the *Vitellaria* and millet agroforestry practice in north-eastern Uganda

Institution	Roles and functions
Farmer groups	Collect and process shea nuts Access training and link farmers with advisory services Provide better environment for marketing of crop Ensure quality products
Research	Document indigenous knowledge on the practice Conduct propagation studies on the shea butter tree
Extension service	Create awareness of the potential of the practice Provide technical advice (information, knowledge and skills) Build capacity of farmers and farmer groups
NGOs such as the Northern Uganda Sheanut Producers Association (NUSPA)	Facilitate formation and development of women's groups Provide service delivery pathways Promote and support community-based shea butter production
Development partners USAID, McKnight Foundation	Provide financial support
COVOL	Develop product and technology Diversify products such as soaps, lotion, cosmetics Extend credit scheme facility to farmer groups at zero interest
Advanced Development Initiative (ADI)	Commercialize dryland fruits Build capacity in managing, processing and marketing shea nuts
Private processors (GNOM Lira, Mukwano Industries)	Purchase nuts and process shea butter Export shea butter and its products

to develop new products. There is thus need to exploit the opportunity of producing shea products for this industry.

Local markets for shea products are restricted to the northern districts of Uganda. However, opportunities for establishing a domestic market for local and value-added products in the form of food, oils and cosmetics have not been determined. Similarly, product testing of export formulations has been limited and there is no information on products being tested in Uganda.

Professional reflections and recommendations

Currently, there are a number of threats to the productivity of the *Vitellaria*–millet agroforestry practice in north-eastern Uganda. Charcoal-burning is the major threat to the practice (Okullo et al. 2004b). The tree is being used as fuelwood and charcoal as a result of increased wood and energy shortages, and the diminishing income-generating opportunities in the region. It is a major source of income in the area, especially after the loss of cattle and other livelihood options due to insecurity (Okullo, pers. comm.). There is need, therefore, to put in place short-term interventions to address these issues such as introducing of fast-growing multipurpose trees to provide wood and energy requirements in the region, while preserving the shea tree for generating income through shea nut production.

The other threat is the insecurity that has affected the region in recent times. This has caused many rural people to move to towns, leaving *Vitellaria* stands without proper management. As a result, wild fires are reducing these tree populations, leading to low shea nut yields. Appropriate government policies and serious efforts are needed to address this problem and thereby enable the farmers to manage their land in order to improve shea nut production.

The current market sector in Uganda can be described as traditional with low levels of collection and consumption. There are several reasons why an industrial supply has not emerged, such as low concentration of trees, high levels of local oil consumption, and soft shea butter. Uganda is a landlocked country, so its transport costs are high as compared with countries in West Africa. Lack of security in the Uganda–Sudan shea belt has also reduced investment and obviously hampers the supply chain support and activities. Most importantly, the country lacks a traditional partnership between local producers and users in industrialized nations. Despite these problems, the market potential for Ugandan shea is high as its qualities are suited for the high-value cosmetics markets.

Market chain analysis indicates that marketing shea butter is a lucrative business, particularly for wholesalers. However, due to low volume of sales by individual households, overall incomes are relatively low. There are considerable seasonal fluctuations in market prices, and expanding interseasonal storage would help reduce large price movements. Prospects for expanding the shea butter market in the country would be contingent on moving from very small and irregular production to substantial and sustainable supplies of shea nut and its products. Future progress in the shea industry will require strong support services in product development, extract testing, market testing of new products, and linkage between local processors and international buyers. A number of government and non-governmental organizations institutions such as the Food Science Research Institute (FOSRI) of NARO, Foodnet of IITA, and the IDEA Project of US-AID can greatly assist in this endeavour

6.2 Banana–calliandra integrated agroforestry in Uganda

Nature of the innovation

Banana (*Musa* spp.) is the major food crop and source of income for most farmers (75%) in Uganda and is the most important food crop in central, western and eastern Uganda (IITA 1995). Most of the crop is cultivated near homesteads where it is intercropped with other crops. Traditionally, farmers mulch the bananas to suppress weed growth, maintain soil fertility and conserve soil moisture (Bekunda et al. 1997; Lekasi 1998). However, increased intercropping in older plantations has led to accelerated soil nutrient depletion (Bekunda 1999), resulting in declining productivity of the banana.

In some parts of central and mid-southern Uganda, farmers have integrated calliandra shrubs into banana plantations to add organic manure. This is especially so in the districts of Masaka and Mbarara. The shrub, a native of Central America, was introduced in Uganda 15 years ago (AFRENA Project Uganda 2000) and has been widely planted as hedgerows to provide fodder for livestock, recycle nutrients into the soil (Bekunda et al. 1997) and check soil and water runoff (Bagoora 1990) in the banana plantations.

Justification for profitability

There are several benefits that result from integrating calliandra into banana production. The shrub contributes directly to soil fertility enhancement as organic manure (AFRENA Project Uganda 2000) and indirectly through improving the quality of kraal manure, all of which boost banana production. It can also be fed to livestock, thereby saving money from purchase of dairy meal while at the same time increasing milk yield production. The practice increases both banana and milk yields resulting in improved household incomes from the sale of banana and milk products, while ensuring food security.

Banana integrated with *Calliandra calothyrus*.

The main banana cultivars grown in Uganda are the East African highland bananas (Musa AAA–EA) that are unique to East Africa. The country has high production and market potential for banana (Chandler 1995). The diversity of banana types grown, ranging from *matoke* (cooking banana) to *bogoya* (desert banana), *ndiizi* (apple banana), *kayinja/mbidde* (beer banana) and *gonja* (roasting banana), provide an enormous commercial opportunity for the country. Most of these banana types meet the quality the local market requires, especially the cooking, roasting, desert and brewing bananas, as they are widely consumed in the country (FAO 2004).

Quality is as important as price in banana marketing. Besides strict quality regulations, consumer preferences are particularly strong in terms of colour, firmness and taste. Achieving high quality is crucial in international markets. In some cases the taste and origin of the banana is of highest importance. Other consumers have specialties such as organic bananas, fair-trade bananas and dried fruits (Kiiza et al. 2004). Despite having a small market share, their growth rates are extraordinarily high and amount to as much as 60% per annum. Uganda meets most of the quality requirements for organically grown bananas and dried fruits.

Uganda has a huge potential for banana production but this potential is not fully exploited, neither in terms of income generation at farm level nor in terms of export earnings (Kiiza et al. 2004). Uganda produces about 10 million tonnes of bananas annually, ranking it second in world banana production, behind India (FAO 2004). About 30% of Ugandan cropland is dedicated to banana growing (Gambeki et al. 2003). Banana is an important food crop but also an important cash crop, with 50–85% of it being traded locally and in neighbouring countries (Kiiza et al. 2004). Because most urban residents in Uganda consume a lot of cooking banana (matoke) (220 kg per person), it is the one most traded locally (FAO 2004).

Worldwide, Uganda ranks second in banana production yet in terms of banana exports it is ranked only 40th. Uganda exports many more desert bananas (1560 tonnes) than cooking bananas (matoke), which are officially close to zero (FAO 2003). However, other sources indicate that 12,000 tonnes of matoke annually cross the border to Rwanda and about 6600 tonnes of desert bananas go to Kenya.

Potential global markets for Uganda are Europe as well as the Middle East, due to its proximity to Africa. Other markets that may determine world market dynamics are the Americas and East Asia, especially the emerging Chinese market. Desert bananas have the most promising global market. Imports of desert bananas by Eastern Europe are expected to increase by 20%, while the demand for imported bananas in the Middle East will increase by 25% and in the Far East including China by 40% (FAO 2004).

There is great potential for a sustainable supply of bananas for local, regional and international markets. A majority of farmers in central and mid-southern Uganda grow a lot of bananas for consumption and sale. What is required for sustainable supply is to organize farmers into producer groups to guarantee the required quantity and quality. This would ease transportation and marketing of the crop. If the farmers are organized into associations, they would be able to process and market the banana in the right quantities, at the right time to the desired markets locally, regionally and internationally.

Agroforestry components and interfaces

In this practice there are synergistic interfaces between *Calliandra calothyrsus* (tree), bananas (crop) and livestock (cows). The outcomes of these interactions are shown in table 6.3. Bananas benefit from soil fertility enhancement and soil and water conservation accruing from calliandra. The tree in turn benefits from the good management accorded the banana such as weeding and mulching. Banana residue is fed to the livestock, whose manure is later applied to the banana garden to enhance soil fertility.

Table 6.3. Main components in the banana–calliandra agroforestry practice in Uganda

Components	Calliandra	Banana	Livestock
Calliandra	Calliandra shrubs are more effective for conserving soil and water, and improving soil fertility when planted as hedges or blocks rather than as isolated trees	The banana crop performs better as a result of soil improvement of the shrub Some trees can be allowed to grow and provide poles for supporting banana plants that have fruited	Improved fodder availability on a sustainable basis results in increased milk yield
Banana	Tree benefits from proper management accorded to the banana, such as weeding and mulching	Availability of quality planting material from healthy plantations increases	Banana residues like the peelings and stems act as supplementary fodder for livestock
Livestock	Some of the manure from the livestock benefits the calliandra plants	Increased quantity of quality manure from the livestock can be applied on the banana	Income from sale of milk increases

Minimum inputs

Material requirements for this practice include calliandra seedlings, banana suckers and land. Bananas are established using suckers about 1.5 m high with a 45-cm girth at the base, free from pests and diseases, and the usual spacing is 3 m by 3 m. Technical skills required for banana production include mulching, pruning of banana leaves, and removing post-harvest stools.

Material requirements for calliandra include seeds and pruning knives; the technical skills needed include establishing a nursery, and managing and harvesting the crop. The shrub is cut after 9 months of growth at a height of 0.5 metre. In banana gardens, calliandra is planted in hedgerows along the contours in between the banana lines.

Generally, few people consume processed banana products in the country. In Uganda there are about 200 processed banana products and they include juice, wine (*tonto*), gin (*waragi*), banana-pulp-based bakery and derivatives from fibres and stems (Kiiza et al. 2004). However, only a few of these products are fully developed and industrialized as most of them are produced locally, in small scale and often are of poor quality. Pancakes made of cassava flour and banana pulp (*kabalagala*) are the most common products, followed by juice and its derivatives like gin and beer. Banana-flour-based bakery is less common, and so are banana chips.

As far as marketing is concerned, reliable transport and good road networks are a must so as to minimize damage to the perishable bananas. It is also necessary to ensure large-scale production to give sufficient quantity for export. A ready market and easy access to port facilities for banana and its products are needed if losses due to perishability are to be minimized. In addition, cooling and packaging facilities are a must to overcome issues of long distances to ports or markets. There is also need to have good knowledge of national, regional and international markets. Last but not least quality control and certification of products to ensure quality products that meet market requirements is paramount for the success of the practice. Generally, the production and marketing of banana and its products requires a well-structured market system that ensures timely delivery.

Agroclimatic zones

This agroforestry practice is found in south-central Uganda commonly referred to as the Lake Victoria Crescent. It consists of hills and ridges dissected by streams and swamps. Altitude ranges from 1100 to 1400 m. Typically, the soils of the area are Ferrasols that are old, highly weathered and of low inherent fertility. Consequently, sustainable use of the soils for agriculture depends on maintaining high levels of organic matter (Lekasi 1998). Agriculture is rainfed, with bimodal rainfall (March–May and August–November) averaging 1218 mm annually. The average annual minimum temperature is 15 °C and the maximum 27.5 °C. The area receives a lot of rainfall and is generally warm and humid.

The zone is ideal for banana growing. Calliandra thrives well at altitudes ranging from sea level to 2000 m and where annual rainfall is more than 1000 mm (ICRAF 2001). It has thrived in the Lake Victoria Crescent. In the harmonized agroecological zones of east and central Africa, this practice can work in the moist lowlands and in some parts of moist highlands.

Major factors that make the innovation successful

Banana is a perennial crop that can be grown on the same piece of land for up to 50 years. This makes it important for food security and income generation for the farmers who produce more than 90% of the crop in Uganda (Karamura 1998). For a long time, farmers have mainly used suckers to propagate but recent advances have resulted in clonal propagation.

Land pressure has increased the practice of intercropping in older plantations, which has meant declining productivity. This calls for intensive land use through intercropping and integration of other components that have positive interactions in the system. Even alternative staple crops such as maize and cassava do not perform well in nutrient-depleted banana gardens. The way forward therefore is to continue with banana production with relevant soil amendment practices, one of which is growing calliandra.

The integration of calliandra into banana plantations is an effective way of sustaining banana production without compromising soil fertility. The practice is easy to implement as most of the activities are undertaken during the establishment phase. Farmers appreciate calliandra because it grows rapidly even on poor soils, grows back after cutting, conserves the soil and improves its fertility, is excellent as a fodder supplement for livestock, and produces fuelwood (Franzel et al. 1998; AFRENA Project Uganda 2000; ICRAF 2001).

The practice also fits in well with traditional banana management where trees are integrated into plantations to provide shade. Also farmers give banana plantations high levels of management compared with the other crops. This indirectly benefits and improves the performance of other components, a situation that minimizes risk of total production failure. Another underlying factor is that, despite decline in production, banana is still the preferred staple food in many regions of the country and commands a relatively high price in urban markets. The system also works because bananas have a ready market at national and regional levels.

Direct and indirect beneficiaries

The practice fits well into intensive farming systems characteristic of areas experiencing land shortage. It enables smallholder farmers to sustainably integrate crops (banana), livestock (cattle) and trees (calliandra) on small pieces of land. Traditionally, women are the managers of the banana plantations in farming households. Thus, integrating calliandra into the banana plantation and the subsequent improvement in the productivity of these enterprises will ease women's farm management tasks.

Children commonly undertake the task of grazing livestock or providing fodder for it. Increased availability of fodder on farm will reduce the drudgery involved in carrying out this task. Ultimately, the milk and improved banana yields will greatly improve household food security, nutrition and income. The majority of traders and transporters of bananas are men, while mainly women sell the bananas in the urban markets.

The direct beneficiaries of the system are farmers, traders, transporters and market sellers. These groups generate income from the sale of bananas and milk—income used for various household expenditures such as school fees, clothing, medical care, and for building better housing and meeting social obligations.

Indirect beneficiaries include local governments, local cottage industries, restaurants and peri-urban small-scale livestock keepers. Local governments benefit through levying taxes on bananas that are exported from their areas; cottage industries process banana into various products for sale to generate income. Restaurants rely heavily on banana, and small-scale livestock keepers on the banana peelings.

Upscaling strategies

The practice is currently being promoted in the districts of Mbarara, Masaka and Rakai. Most of the promotion and upscaling of the practice has been by government departments, NGOs, farmer groups and the National Agricultural Advisory Services (NAADS). One such NGO was Uganda Land Management Project (ULAMP) in the Ministry of Agriculture,, which was active in the then Mbarara District. The project actively promoted the practice through having demonstration plots, training farmers and conducting exchange visits for farmers. The soil conservation component of the Lake Victoria Environment Program (LVEMP) also actively promotes the practice in Rakai District. They have used mainly the print media (posters, fliers) to promote the practice.

Various efforts have been made to improve marketing of Uganda banana products at national, regional and international levels (IDEA Project 2001; Kiiza et al. 2004). This is aimed at improving the processing and marketing systems in the banana sector, especially in favour of small-scale farmers and producers. The project Improvement of Banana Marketing and Utilization in Uganda (IBMU), implemented by the NARO Banana Programme, Makerere University, and IITA has been one such venture.

Factors that have contributed to the adoption and replication of the practice include the availability of calliandra and banana planting materials, ready availability of markets for banana and milk products, cultural attachment to banana by the communities, the development of elite banana varieties from the research process, and improved processing and packaging of banana products.

Institutions promoting the innovation

The major institutions involved in the practice and the roles that they play in developing and promoting the practice are shown in table 6.4.

Research questions and knowledge gaps

There is a fairly large amount of information on banana production in Uganda, though a lot of gaps exist in areas of processing and marketing. Currently, production of bananas is being threatened by the outbreak of banana wilt, which has spread to several districts in the country. However, research efforts and resources have been channelled by both government and development partners to abate this threat. This has resulted in formulating management strategies, for example the use of clean planting materials and quarantines, and development of tolerant varieties. Despite this, the disease still poses a serious challenge to banana production in the country and therefore further research on it is required.

A lot of local processing of banana products is taking place in the country, but the quantity and quality of these products are low. This has resulted in low consumption of these products (Spore 2005). Most are sold in small shops or market stalls; supermarkets do not play a big role in the trade. In addition these products are not advertised (Kiiza et al. 2004), thus limiting the market outlets. There is need, therefore, to conduct research into processing, packaging and marketing these products to meet national, regional and international market requirements.

Marketing of banana is greatly constrained by its perishability, resulting in low prices for farmers. Perishability also causes losses to traders as ripening bananas are often sold at low prices. Therefore, research into the best ways to preserve the product while in transit and storage needs to be done.

Professional reflections and recommendations

To meet the quantities and qualities of banana and its products required by the markets, it is important to organize banana producer and marketing associations in the farming communities. This approach ensures that farmers get increased revenue from the sale of banana and its products as these groups will have strong negotiating powers.

Table 6.4. Institutions involved in the banana–calliandra agroforestry practice

Institutions	Roles and functions
Farmer groups	Access training and link farmers with advisory services Acquire improved planting materials Provide better environment for marketing of crop Ensure quality products
NGOs	Upscale production by providing planting material and technical advice Organize farmers into groups for better production and marketing Facilitate exchange visits Set up demonstration plots
Extension & Advisory services	Train farmers and build their capacity Provide improved planting materials Provide technical advice Create awareness of the practice
Research	Develop improved varieties Manage pests and diseases Develop good management practices Research market and product development
Uganda Land Management Project and Lake Victoria Environment Program	Create awareness Establish demonstration plots Train farmers Conduct study tours and exchange visits for farmers
Traders	Buy the bananas from farmers Sell bananas to market vendors
Transporters	Facilitate the movement of bananas from farmers to urban markets
Local governments	Access and multiply improved planting materials Support farmer organizations through building their capacity and forming groups Formulate by-laws regulating production and marketing of crop
Market vendors	Sell bananas to consumers
Cottage industries	Process and package various banana products Promote bananas through sale of various products
Export Promotion Board and Uganda	Link Uganda banana producers to regional and international markets
Investment Authority	Promote investment in the processing of banana products and Formulate regulations regarding marketing of the crop

Market information (national, regional and international) needs to be disseminated to enable successful negotiating. At the same time, storage facilities at both ends of the chain have to be established to reduce the risk that is involved with the perishability of bananas. Such storage should be organized alongside associations, and the same would hold for finance and payment schemes that would enable farmers to obtain credit.

Processing has various promising perspectives, especially for juice and alcoholic beverages. By improving quality of processing and packaging products and better marketing, quantities sold as well as prices can be increased. Small-scale industries can be set up in rural areas to foster rural development. In international trade, Uganda faces high competition in saturated markets, in which Uganda has still to establish itself. Key factors here are reorganization of domestic production to obtain quantities and qualities required on the global market. Seasonality of prices is another crucial aspect of markets. Usually prices are lowest in summer but highest in winter when local production in importing countries is low. So targeting banana production and sales at the right time or season of the year can earn premiums of 25% or more.

The constraints for Uganda in global banana markets are many. The country being landlocked means access to harbours only by long transport on poor roads. Lack of cooling and packaging facilities leads to poor quality of the products. The distance to target markets like Europe is about one-third longer than from West Africa. Small-scale and scattered production alongside poor local infrastructure imposes difficulties in gathering sufficient quantities for export, let alone stability of supply over a long period. Knowledge on international markets is often poor—on potential trading partners, prices and quality aspects as well as on regulations. Lack of national quality control and certification bodies leads to expensive quality control and certification procedures.

6.3 *Populus deltoides*–based agroforestry in the Indo-Gangetic plains of India

Nature of the innovation

This region has been transformed from jungles and thorny forests into the cereal-growing belt of the country because of highly productive land, better irrigation facilities, innovative research, and the hardworking attitude of farmers. The land-use system witnessed a drastic change during the second half of the last century. Annual crop cultivation is the major land-use system because of three major developments—advent of canal irrigation, consolidation of land holdings, and era of the green revolution, resulting in fast disappearance of traditional trees on farmlands. To increase the area under tree cover and search for economically viable crop diversification options, various agroforestry practices became popular with farmers.

This region covers fertile low-lying plains formed by alluvium carried down and deposited by the major rivers of India. It extends about 2500 km from the Satluj River in the west to the Brahmputra River in the east and is distributed in the states of Punjab, Haryana, Uttranchal and Uttar Pradesh. Although trees have largely given way to crops, still on marginal and rainfed lands, trees such as *Acacia nilotica, Mangifera indica, Azadirachta indica, Dalbergia sissoo, Morus alba, Ziziphus* spp., *Melia azedarach, M. compacta* are retained by farmers on farms and around tubewells and homesteads (Grewal and Dhillon 1994).

Populus deltoides can be effectively integrated with wheat.

The profitable agroforestry innovation in this region comes under the broad category of agrisilviculture. Short-rotation fast-growing exotic tree species such as *Populus deltoides* and *Eucalyptus tereticornis* are preferred along with various *rabi* and *kharif* crops. The decision to select an appropriate crop under or alongside tree species is affected by many factors such as age of plantation, tree-row direction, tolerance to shade, availability of labour, cultural and management practices, demand of produce, marketing scenario. The trees are planted either on the field boundary in a single row or in multiple rows or as a block plantation. Farmers with small landholdings prefer a boundary plantation and those with medium- to large-sized landholdings go for the block plantation. Usually farmers with large landholdings divide the total land to be cultivated under agroforestry into a number of blocks equal to the number of years in tree rotation cycle. Every year they bring one block under agroforestry practice; the year the last block is planted, the trees in the first block are ready to harvest. Thus, farmers get a regular income from an agroforestry practice.

Justification of profitability

According to an estimate, approximately 11.48 million hectares of Punjab, Haryana and terai region of Uttranchal are under poplar- and eucalypt-based agroforestry practice (Pathak and Pateria 1999). In general, farmers have concluded that association of trees is causing damage to crops This has been proven in studies from the region: *Acacia nilotica* caused severe reduction in yield of wheat (Puri and Bangarwa 1992; Dhillon et al. 1994) and mustard (Yadav et al. 1993). Likewise, wheat yield reduced up to 50% has been observed during the 5th and 6th year after poplar planting. However, returns from trees at end of rotation often compensates for the reduced crop yield, provided the market price of wood is above the threshold level.

To validate the assumption that a poplar-based agroforestry system is economically viable as compared with the wheat–rice cropping system, an intensive survey and research trials were planned. The salient findings of the study have put forth some conclusive observations (Gill et al. 2006). Comparative economics have been worked out on three situations in Punjab: 1) wheat–rice rotation, or A; 2) poplar in block + pearl millet fodder + wheat, or AF-I; and 3) poplar in boundary + pearl millet fodder + wheat, or AF-II. Gross returns (GR), total (variable) costs (TC), net returns (NR), present net worth (PNW), annuity value (AV) and benefit–cost ratio (BCR) of the three situations were considered. To calculate the economics the current price was taken of different components such as poplar wood (INR 375 per 100 kg for > 60 cm girth and INR 320 for < 60 cm girth), wheat (INR 650 per 100 kg), paddy (INR 530 per 100 kg) and pearl millet fodder (INR 65 per 100 kg) (INR 41 = USD 1).

Of the three situations studied, NR (INR 7,05,623 ha^{-1}), PNW (INR 4,10,588 ha^{-1}), AV (INR 94,288 ha^{-1}) and BCR (2.93) were highest for AF-I (Gill et al. 2006). This clearly indicates that economic returns from a poplar (block plantation)-based agroforestry system (AF-I) are more than from a sole-cropping system (wheat–rice). The NR, PNW and AV are higher for AF-I than for A by 64%, 55% and 55%, respectively. When a comparison between agriculture (A) and poplar (boundary plantation)-based agroforestry system (AF-II) was made, it is clear that a sole-cropping system is more economically viable than AF-II. Although the AF-II system was not as economically viable as 'A', for small farmers (those who cannot afford high costs), it can be a viable option on the basis of environmental improvement.

Similarly, in another study of economic analysis of different agroforestry models adopted by the farmers of Haryana and Uttranchal, the recorded B : C ratio of different models on a 6-year rotation was between 2.35 and 3.73 (Kumar et al. 2004). Maximum returns in a 6-year rotation were recorded from a poplar–sugarcane–turmeric block plantation model followed by poplar–sugarcane–wheat–sorghum–potato–maize–bajra and poplar–sugarcane–potato–barseem–sorghum block plantation models. Another study in Uttar Pradesh recorded the maximum net returns per hectare from a poplar–paddy–tomato system (INR 44,164) followed by poplar–groundnut–tomato (INR 43,568) and poplar–sugarcane (INR 17,285) agroforestry models (Jain and Singh 2000).

The demand for poplar and eucalypt wood as a raw material in various industries is huge. Poplar wood is intensively used in plywood and for match wood. In August 2006, poplar wood was sold at an attractive price of INR 5250 per tonne. Based on calculations with economic parameters it has been observed that a poplar-based agroforestry system is economically viable compared with the traditional adopted wheat–rice cropping system, provided the rate of poplar wood remains at more than 2800 per tonne (Gill et al. 2005). Similarly, there is great demand for eucalypt wood, which is used for poles and timber and in the paper and pulp industry. Thus depending upon market demand, trees can be harvested at any age between 3 and 15 years.

Agroforestry components and interfaces

Broadly speaking there are two major components—trees and crops. As already discussed the tree component comprises mainly fast-growing short-rotation trees such as *Populus deltoides, Melia composita* and *Eucalyptus tereticornis*. But the wide range of crop components is wide—cereals, pulses, oilseeds, high-value crops, fodders, vegetable, flowers. Different crops have different levels of tolerance to shade; thus it is important to select appropriate crops during the different years of tree growth. During the first 2 years almost any crop (soybean, menthe, etc.) except rice can be grown with trees. Annual crops such as sugarcane and turmeric can be successfully grown during the first 2 years. *Populus* and *Melia* are winter deciduous and shed their leaves during winter; thus rabi crops such as wheat, mustard, oats, barseem, lucerne and potato can be grown successfully under these trees throughout the rotation. However, their yield reduces year after year due to increase in both above- and belowground competition.

During the kharif season (summer) when trees are leafed out, grain crops should be avoided after first 2 years, as there is a sharp reduction in grain yield under shade. However, fodder crops such as maize, sorghum, bajra, guinea grass, cowpea and guara can be grown. It is not economical to plant any kharif crops under poplar after the 4th year and plantations can be left fallow during later years.

In addition, various vegetables (carrot, ginger, colocasia, cabbage, sugarbeet, sweetpotato, spinach, garlic), flowers (marigold, *Dimorphotheca*, *Dianthus, Calendula*) and high-value crops (mentha, celery, fennel, fenugreek, coriander, turmeric) can be successfully grown in a poplar-based agroforestry system (Dhanda et al. 2006). However, it is important that market prospects for a particular crop be studied before it is adopted on a commercial scale.

The performance of pulses such as mung bean, mash, arhar and soybean, and oilseeds such as groundnut and sesame sown during the kharif season was quite poor, as these crops need sufficient sunlight for their growth and development. Thus, such crops should not be grown under poplar from the 3rd year onwards.

Preliminary studies indicate that the flowering plants such as *Dimorphotheca*, *Dianthus* and *Calendula* require partial shade for higher seed production and can be successfully grown in a poplar block plantation (Gill et al. 2005).

Among the various vegetables tested in a poplar plantation, the performance of cabbage and palak was significantly better than radish and cauliflower for the first 3 years of the plantation. Under poplar tree shade, these vegetables remained fresh for a long time, and the leaves of palak remained soft longer than those of palak grown under open conditions. During the kharif season, okra could be grown successfully during initial years (up to 3 years) in a poplar plantation. Under the shade of trees, the fruits remained fresh for a longer time and number of pickings were more than for the control crop.

Fodder crops are better suited for intercultivation with poplars during the kharif season. Wider spacing (7 x 3 m or 8 x 2.5 m) is less suppressive than the closer spacing (5 x 4 m) farmers widely use. Among the different crops screened under poplar, the performance of cowpea was significantly better than that of guara or sesbania (*dhaincha*) (Gill et al. 2004).

The yield of various high-value crops—dillseed, coriander, ajwain, fenugreek, fennel, celery—was higher with wider spacing (8 x 2.5 m and 11 x 3 m) than with close spacing (5 x 4 m) of poplars in the plantation. Fenugreek performed comparatively better than other crops. The performance of turmeric was evaluated in 3- and 6-year-old poplar block plantations. Maximum yield was with 8 x 2.5 m spacing. The reduction in yield increased from 38% under 3-year-old poplar to 82% under 6-year-old poplar in 5 x 4 m spacing. Turmeric is a shade-loving crop, but it can be economically grown under poplar even during poplar's initial years (Dhanda et al. 2006).

Minimum inputs

Success of any program depends on the quality of planting material used, adoption of adequate cultural and management practices, and finally the marketing of produce. Direct beneficiaries of forest produce are wood-based industries. Coordination between wood producers and raw material consumers is of utmost importance to ensure regular supply of produce to industries and better economic returns to farmers. Presently there is no such coordination, and intermediaries are exploiting the situation, causing loss to both producers and consumers. This is the main reason behind the wide fluctuations in the market price of wood during the last 5–6 years. The market price of poplar wood in Punjab wood market during 1999 was INR 4250 t^{-1} and there was steep fall in prices (INR 1530 t^{-1}) during 2004; presently the price is around INR 5000 t^{-1}.

There is an urgent need to formulate policies to promote agroforestry practices. Government should plan the production in a way that will bring demand and supply into equilibrium. This will keep wood prices lucrative, for the producers as well as the wood industry. Forestry is a long-term program, so to get better returns later on, it is vitally important to have good-quality planting stock. Nurseries providing planting material should be certified so that only quality material is sold to farmers. When short-rotation trees are grown on agricultural land, the timber should be considered agriculture produce and exempted from various taxes as is other agricultural produce.

There is a strong need to further strengthen research activities to improve the productivity of agroforestry practices. This would help in large-scale adoption of economically viable practices. The genetic base of commercially planted clones of *Populus deltoides* is very narrow; according to an estimate about 80% of the poplar plantations in the region are raised from only three clones. Due to such limited genetic diversity, this monoculture could be hazardous in case of insect pest outbreak. Tree improvement work is required to find more high-yielding, site-specific and pest-resistant clones. Poplar can produce 57.5 m^3 per hectare annually on riverine tracts in 5-year rotations on well-managed and cultivated conditions, compared with 9.5 m^3 under neglected conditions (Dhanda et al. 2006). Thus it is worthwhile mentioning that poplar is sensitive to neglect but responds well to adequate cultural conditions and management practices. Farmers should be made aware of the importance of various practices that help improve the overall productivity of this practice.

Agroclimatic zones

In social and economic terms, the Indo-Gangetic Plain is the most important region of India. The plain is a great alluvial crescent stretching from the Indus River system in Pakistan to the Punjab Plain (in both Pakistan and India) and the Haryana Plain to the delta of the Ganga (or Ganges) in Bangladesh (where it is called the Padma). Topographically the plain is homogeneous, with only floodplain bluffs and other related features of river erosion and changes in river channels forming important natural features.

Two narrow terrain belts, collectively known as the *terai*, constitute the northern boundary of the Indo-Gangetic Plain. Groundwater from these areas flows on the surface where the plains begin and converts large areas along the rivers into swamps. The hills, varying in elevation from 300 to 1200 metres, lie on a general east–west axis. Average annual rainfall increases moving west to east from approximately 600 mm in the Punjab Plain to 1500 mm around the lower Ganga and Brahmaputra. Very good performance has been noticed only in the areas lying north of approximately 28°N latitude in the states of Jammu and Kashmir, Punjab, Haryana and Uttar Pradesh.

Major factors that make the innovation successful

Although *Populus* is an exotic tree, it fits well with the cropping system of the area. It can grow well in this subtropical climate where temperature extremes are not too severe. During summer adequate irrigation facilities are required to counter the drought. A well-drained, fertile soil with texture ranging from loam to sandy loam is suitable. Sites with coarse sand, heavy clay, low water table and that are drought susceptible are unsuitable for poplar cultivation. Poplars prefer neutral soils and can grow on soils with pH 5.5–7.5. Saline and alkaline soils are not suitable for poplar cultivation. Poplars have a high rate of root respiration as compared with other woody species. The oxygen required for root development is obtained from the soil atmosphere. Compact soils and stagnant water during the active growing season interfere with normal tree development. This region fulfils most of this tree's basic requirements. In addition, the tree characteristics such as short rotation, fast growing, straight stem, narrow crown and its deciduous nature favour its large-scale adoption as an agroforestry tree. Adding a tree component on farmlands leads to efficient use of permanently employed farm labour. No additional inputs are required to grow trees. The normal inputs such as irrigation and fertilization given to crops are also used by the trees. Insect pest attack under intercropped conditions is significantly lower than in poplar block plantations in which no intercultivation is done. Most of the silvicultural practices required to grow trees are standardized by the research workers and disseminated to farmers. Thus farmers do not face any technical difficulty in raising and managing trees. A large number of plywood industries has come up in this region, making it easy for farmers to sell their produce. During last couple of years some fluctuations in timber price were observed, but they were short lived. Moreover, wood is not a perishable commodity that the producer has to sell immediately. If the market price of timber is not attractive farmers can hold their product for another year or two. This has no negative effect on timber quality; rather, the weight of the timber will increase, resulting in higher economic returns to the farmer.

Direct and indirect beneficiaries

There are many direct and indirect beneficiaries of a poplar-based agroforestry practice. Broadly speaking, the whole area benefits by adoption of this practice, especially in the agriculture-intensive states of Punjab, Haryana and Uttranchal, as this practice means an increase in tree cover. The National Forest Policy (1988) suggested that to maintain ecological balance at least one-third area of country should be under forest. However, the total forest and tree cover in Punjab is only 6.3% rather than the required minimum area of 20%. Thus, the state is quite deficient in forest cover. But the demand for timber, fuel and other tree-based products is increasing day by day. Moreover, the Supreme Court of India has put a blanket ban on green felling in 'production forests'. Thus, there is a strong need to find a suitable system that can meet the wood-based needs of the local population. As already stated about 83–84% of the total area of this state is under agriculture, it is not possible to convert fertile arable land back to forest. The only feasible alternative is to adopt agroforestry practices, as this is the one system that can provide both wood and food while at the same time conserve and rehabilitate the ecosystem. Moreover, adopting this practice will fulfil certain wood-based needs and lessen the pressure on natural forests. Local industries such as for plywood, matches and fruit boxes get raw material from such plantations. This practice is providing employment at primary, secondary and tertiary levels—raising seedlings in nurseries, planting in the field, pruning, managing the plantation, harvesting, transporting and converting logs to end products. This practice has improved the economic status of farmers. Both small and large farmers benefit from this practice. In addition, the microclimate of area is improved by reducing the temperature extremes during both summer and winter.

Upscaling strategies

This practice is being adopted by farmers at a commercial scale on sites where suitable climate, soil and irrigation facilities are available. Impressed by the economic returns and ease of management, more and more farmers are adopting this practice. In some areas, farmers have even diverted from the traditional wheat–rice cropping system. Good results are obtained repeatedly, and farmers are realizing better returns after each rotation. They are trying to sort out limitations by bringing changes in cultural and management practices. Initially farmers planted trees in a block at 5 x 4 m spacing; now they prefer wider spacing of 7–8 m between tree rows and narrow spacing of 2.5–3 m within rows. Thus they accommodate almost same number of trees per unit area but leave more space between the tree lines to grow crops for a longer time by minimizing above- and belowground competition. A major factor contributing to adoption success is the development of superior fast-growing, short-rotation clonal material. Most of the traditional tree species in this region were slow growing with a long rotation period. Such trees are not economical to grow in small landholdings. Moreover, farmers were interested in a practice that would give returns in a shorter span of time.

Institutions promoting the innovation

Forestry departments in state agricultural universities (Punjab Agricultural University, Ludhiana; University of Horticulture and Forestry, Solan; GB Pant University of Agriculture and Technology, etc.) play an important role in promoting such practices. Basically these are research institutes where both basic and applied research is being conducted on promising agroforestry practices. Practices that hold promising results are passed on to the farmers for adoption. The universities have a strong network of extension that helps in timely dissemination to farmers of different cultural and management practices. In addition, there is strong network of state forest departments. Their role is to produce and distribute genetically superior quality planting stock. They also provide funds to research institutes for ad hoc research projects to work on specific problems such as the development of suitable agroforestry models in different agroclimatic zones. Forest departments have one training wing in each state to impart training to staff and farmers on latest innovations. Subject matter experts are invited to share their experience and make farmers aware of new technologies.

The Indian Council of Forestry Research and Education, Dehra Dun, developed a network project to promote poplar in India. This institute played a major role in importing and testing superior germplasm from different countries. The Indian Council of Agricultural Research (ICAR) is the nodal agency at the central level that promotes agroforestry throughout the country. The All-India Coordinated Research Project on Agroforestry was initiated in 1983 in 37 centres all over India, comprising different (ICAR) institutes and state agricultural universities. The new technologies developed by each centre are discussed and the viable technologies are passed on to farmers where applicable. In addition, various NGOs are promoting poplar-based agroforestry in this region. Other institutions like schools and municipal corporations have been involved in creating awareness among the masses for planting trees and adopting agroforestry models.

Research questions and knowledge gaps

There is a need to find suitable crops in different seasons under different-aged plantations. In preliminary research, a few cereals, fodders, vegetables, flowers and high-value crops have been identified, but to further improve the productivity and gain better economic returns more research is required. Appropriate high-value crops for cultivation under poplar block plantation during different years need to be standardized based on shade tolerance of the understorey crop. Further, farmers need to process their raw, farm-derived products to achieve better returns. If processing is expensive, either government should subsidize it or farmers should form groups to share expenses. To improve the marketing scenario, either a buy-back arrangement should be made in advance with prospective buyers or a cooperative should be organized, excluding exploitative intermediaries. In the region, where cultivation of rice year after year is adversely depleting groundwater and negatively affecting the natural resources, a poplar-based agroforestry system could be a viable alternative to crop diversification.

Professional reflections and recommendations

With the existing knowledge poplar-based agroforestry has great potential. The characteristics of the tree are suitable and the economics of the practice are viable, compared with commonly adopted cropping systems. The only drawback for the time being is the marketing scene, which is quite erratic. If the government makes policy favourable to ensure buy-back of forest produce, large tracts of land could be brought under this agroforestry practice. Wood-based industries need incentives so that new units come up in these areas. This will in return provide a better price for farmers and promote large-scale poplar-based agroforestry plantations. This will especially encourage small-scale and marginal farmers, who have less ability to take risks. Overall, this practice is a viable option for crop diversification if wood prices for poplar remain at more than INR 2800 per tonne. Financial institutions should be encouraged to ensure cash credits for farmers adopting agroforestry, especially during the initial years until the perennial trees start yielding products.

6.4 Maize–grevillea system in the coffee zones of Kenya

Nature of the innovation

In the moist lowland, which in Kenya is the main coffee zone, the *Grevillea robusta* agroforestry system and use of *Calliandra calothyrsus* for fodder are discussed. Grevillea is grown in close association with crops, mainly along farm boundaries, to provide timber, fuelwood, poles, leaf mulch and dry –season fodder. Farmers usually market whole standing trees for timber. Calliandra has widely been adopted by smallholder farmers for feeding dairy animals as a supplement to the basal animal diet or to substitute for commercial dairy meal. Other uses of calliandra include conserving the soil, especially when it is planted along contours, providing fuelwood, and improving soil fertility.

Grevillea robusta (silky oak), a tree species native to Australia, has become an important agroforestry species adopted into farming systems of the central highlands of Kenya. It is widely planted, found in about half of all Kenyan districts (Ongugo 1992; Kamweti 1996). Grevillea is the agroforestry tree of first choice for farmers in Embu, Meru and Kirinyaga Districts, who prize it for its many useful products (Spiers and Stewart 1992). It is also common in agroforestry systems of other districts, in Eastern and Central Provinces (Kerkoff 1990). Grevillea was introduced in Kenya in the late 19th century from India and Sri Lanka, where the species was used as a shade tree in tea, coffee and cinchona plantations (Harwood 1989).

Grevillea is grown mainly on farm boundaries in close association with food crops and provides a range of useful products that include timber, poles, firewood, leaf mulch and dry season fodder. The highest concentration of grevillea in Kenya is in an estimated area of 750,000 ha of a maize–grevillea agroforestry system in the central highlands (Muchiri 2004). The species is

In Kenya, maize is often integrated with *Grevillea robusta* , thus prodcing income from both sources.

so intensively planted in this region that it is the dominant tree, especially on the eastern and southern slopes of Mt Kenya. Kamweti (1996) estimated that *G. robusta* comprised 37% of 14,746 trees found in 254 farms that were randomly sampled at Embu District, and Tyndall (1996) counted 77 *G. robusta* trees per hectare on farmlands in Kirinyaga District. Also Thijssen et al. (1992) found grevillea present on 96% of the farms within the coffee and tea zones in Embu District.

Justification of profitability

Income-earning potential is a major motivating factor for farmers to plant grevillea, which is mainly grown to produce timber, poles and firewood. The species has successfully been planted on farms because it grows rapidly, is easy to propagate and establish, has good form, provides economically viable products, and is not significantly affected by pests and diseases (Harwood 1989). In eastern Africa, under good conditions it has been reported to grow at an annual rate of 2 m or more during the first 5 years after planting and its wood dries fast; thus it is suitable for firewood (Milimo 1988). Farmers primarily plant the species for fuelwood and 64% of the farms surveyed in Kirinyaga District were found to be self-sufficient in fuelwood needs, mainly obtained from grevillea trees on their farms (Tyndall 1996). The fuelwood comes from pruning and pollarding the trees, and it is estimated that 60% to 80% of the total yield of grevillea trees is from repeated pollarding (Poulsen 1983). With pollarding every year or two, depending on the site, 10 healthy trees are enough to provide domestic fuelwood for a family of eight on a sustained basis (Kamweti 1992). The annual fuelwood requirement per person is about 2 m^3 of stacked wood (Newman 1983); a tree yields about 1.6 m^3 of stacked branch wood, an equivalent of 0.8 m^3 per tree per year.

Early conceptualization and promotion of agroforestry was economically motivated, especially to provide multiple products. Grevillea was a candidate species due to its ability to provide a host of economic needs (fuelwood, construction wood, timber, fence material, fodder). In Embu District, a major reason for cutting down grevillea trees is to sell timber to address immediate cash needs (Mwangi 2003). According to farmers in Embu, fuelwood was the most important reason for planting grevillea (Kamweti 1989; Tyndall 1996) and its importance as timber for market has come as a result of a series of circumstances: decline in management of plantations, closure of the forest, collapse of the coffee sector, and lack of alternative income. Use of on-farm timber has increased recently due to serious scarcity of wood resources, resulting from a ban on logging in government forests in 1999 (Onchieku 2001; Mwangi 2003).

The increase in timber marketing from farms since 1999 was confirmed by a census of 184 timber businesses. This census found that these businesses, irrespective of where they previously got their timber (forest, plantations or farms), were now sourcing from farms. The category of businesses surveyed were sawmills, timber yards, and furniture shops. Processing timber was either by mobile saw benches or of whole logs delivered to sawmills in towns.

A partial budget analysis, which looked at the additional costs and benefits of adding the grevillea to a typical farm in Kirinyaga District, showed that added benefits were 73% greater than added costs (Tyndall 1996). In this study, an enterprise budget analysis that compared a hectare of maize and beans without grevillea and maize and beans with grevillea found that the enterprise with grevillea was 4% more profitable. About 77% of the revenue comes from the prunings and the remaining 23% from timber. When grevillea was compared with other trees and with maize, beans or coffee in terms of intangible economic benefits and costs such as effect on soil, grevillea was found to have net tangible benefits equal to those of maize and beans, and more benefits than coffee, eucalyptus or cypress trees (Tyndall 1996). According to Ling (1993), growing grevillea is a very good investment because a minor investment of USD 7 on 12 hectares would yield a timber value of USD 910 in 20 years, and the farmer is also supplied with firewood from the 5th year onwards. The value of firewood over the rotation period minus labour cost is estimated at USD 1205 ha^{-1}. Crop yield loss is estimated at USD 1.9 ha^{-1}. It also increases economic security of farmers because they spread the risks among more products by selling timber and firewood.

Grevillea produces good timber, although it is not durable for outdoor applications unless treated. The timber is, however, important for furniture making and general construction because it is relatively easy to work and presents an attractive appearance because of the prominent rays characteristic of timber from the Proteaceae family. It is greatly valued by sawmillers in Meru District, because they think that the heartwood is superior and durable and good for coffee.

Grevillea leaves and twigs are frequently used for mulching in coffee to supplement manure. One large tree is enough to mulch five coffee plants. There is normally a heavy leaf fall from grevillea in October just before the rains, which is then dug into the soil during routine cultivation. Also, grevillea mulch is usually put in cowsheds to enrich manure in terms of quantity. However, the mulch contains low amounts of nitrogen and decomposes slowly. During dry periods, grevillea leaves are fed to livestock though nutritive analysis has shown low fodder value (Thijssen et al. 1992). Grevillea is also important in conserving the soil, retaining soil moisture due to it shading, and increasing the amount of organic matter in the soil with its mulch and litter (Raju 1992).

According to Kamweti (1992) the income from these trees is like a bonus because once the trees are planted, little labour or material need be invested in them. During the growing period, before cutting the tree for timber, the tree will provide fuelwood and fencing material when pruned and pollarded. When the tree is mature, it is the buyers who harvest the trees, unlike with other crops, for which farmers incur the expenses of harvesting and transporting to market.

Agroforestry components and interfaces

Farmers reported that grevillea had overwhelmingly more positive than negative side effects (Spiers and Stewart 1992). There is also considerable evidence that grevillea grows faster than other agroforestry tree species (Jama et al. 1989) and is less competitive with adjacent agricultural crops when compared with other trees available to the farmer (Lott et al. 2000). Little competition with crops could be attributed to its ability to harvest water in the deeper horizons beneath the crop-rooting zone and to develop a cluster of roots that acquire nutrients from soils deficient of phosphorus (Harwood and Booth 1992; Ong 1994). Biologically, the tree has few lateral roots that interfere with crops and it has a small crown, thus minimizing the shading of crops (Harwood and Booth 1992).

Farmers manipulate competition for resources between crops and grevillea by pruning the branches and roots or by pollarding, completely removing the crown) (Harwood and Booth 1992). These management practices are important to reduce negative tree–crop interactions and to provide the multiple wood products (timber, fuelwood and poles). According to Spiers and Stewart (1992) farmers in Embu and Meru use highly developed tree management practices that show an acute awareness of tree–crop interactions.

Another way of manipulating the interactions is to manage the number of trees per unit area. Models developed recently (Muchiri et al. 2002) indicate that heavy competition by trees decreased maize yields considerably, but at the field level the decrease was small with normal stocking of about 200 trees per hectare.

Effects of grevillea trees on soil include soil conservation, soil moisture due to shading and the mulch it provides, and increase in the amount of organic matter in the soil from the decomposing leaf litter (Raju 1992). Trees are rarely fertilized but they benefit from fertilization of the crops and from weeding as the crops are weeded (Muchiri 2004). Indeed, lack of weeding has been isolated as one of the factors causing poor performance of grevillea in plantations where weeding is not done.

Minimum inputs

Use of natural regeneration through wildlings is a common method farmers use to establish grevillea. However, to avoid narrowing the genetic base, it is advisable that wildlings be bulked by making collections from under different trees in various farms.

Though the tree is a prolific seeder, proper timing of seed collection is necessary to avoid fruit opening and releasing the seeds (Omondi et al. 2004). Seeds should be harvested from healthy trees that are not less than 10 years old and not older than 40 (Harwood and Booth 1992).

For farmers to realize full benefits from agroforestry practices based on grevillea, legal constraints such as on-land tenure should be removed, and low-cost technologies for seed and seedling acquisition and distribution, and decentralized seedling production should be encouraged. Also there should be a properly developed market and marketing system for the products.

Agroclimatic zones

The highest concentration of grevillea is within the coffee zone, with mean annual rainfall of 1200–1500 mm in bimodal distribution and altitude of

1000–1500 m (moist lowland). The soils are predominantly of volcanic origin, classified as Humic Nitisols. Grevillea does not withstand waterlogging but does well on sandy loam and loamy clay soils that are well drained with a pH range of 4.5–7.5 (Harwood 1998). However, because of its favourable agroforestry characteristics, grevillea is spreading rapidly to lower and upper areas, altitude 850–2500 m and annual rainfall 900–2000 mm (Spiers and Stewart 1992). When grown in suboptimal conditions, especially in semi-arid areas, it suffers from termites and drought stress.

Major factors that make the innovation successful

One of the major reasons why grevillea has been planted widely in the agroforestry systems of central Kenya is its compatibility with food crops (Chavangi and Zimmerman 1987; Kaudia 1992; Getahun and Reshid 1992; Muchiri 2004). It is common knowledge that farmers give priority to food production, so species that compete heavily with food crops are not readily adopted.

In Embu and Meru Districts the most popular niche and method of planting grevillea is on external and internal boundaries in a single row (Mugwe and Wanjiku 2003) followed by cropland in intimate mixtures with the crops (Spiers and Martin 1992). In Embu and Meru, 85% of the farmers interviewed had planted their grevillea trees on boundaries while 64% had planted in the cropland (Spiers and Martin 1992). Grevillea was also found in 60% of the farms in external boundaries, grown in Kirinyaga District as an upperstorey tree at heights of 10–15 m (Tyndall 1996).

Almost every crop grown in the area is grown with grevillea, the most common being maize, beans, and coffee, then banana and potato. In coffee plantations, grevillea trees are frequently scattered apparently at random (10–20 m apart). The trees are mostly wildlings that have been permitted to develop in convenient locations on the farm.

Pruning and pollarding are the major management practices farmers adopt for managing grevillea (Tengnäs 1994). Pruning usually starts before the trees are 4 years old, mainly to reduce shading of crops, improve timber quality, and improve tree growth and form. The tree is capable of withstanding repeated and complete defoliation and removal of branches (pollarding) and this is done every 2 years or once a year, mainly to open up the canopy and give fuelwood.

There is potential for formation of grevillea timber marketing groups with an aim of selling high-value processed timber. Processing grevillea timber is a two-pronged approach: saw the tree into timber instead of selling whole trees as is the practice currently, and treat the timber against insect attack to give it a longer shelf life. This would greatly raise the value of grevillea timber and thus fetch higher prices. There is a further potential for an organized group to start a timber-marketing business, processing timber of various sizes in bulk to sustainably meet both local and outside demand.

Direct and indirect beneficiaries

It is evident that grevillea trees on the farm serve the interests of both men and women. Access and activity control profiles during a survey carried out in Embu District showed that men, women and children used grevillea products (Mugwe and Wanjiku 2003). Men usually benefited from use and revenue of timber and pole and to a lesser degree pruning revenues, while women benefited from the firewood. Grevillea on the farms was reported to save women effort and time by eliminating the need to collect firewood from a distance (Tyndall 1996).

Upscaling strategies

According to Kaudia (1992), reasons that could be advanced for the high adoption rate of grevillea by small-scale farmers in the central highlands of Kenya is that farmers have learned from experience of the excellent attributes of the tree. Field extension workers have made repeated mention of the species attributes, and farmers have learned from demonstrations in other farms. Farmer-to-farmer learning has been strong in that farmers have devised and developed management practices that have diffused through farmer observations of what happens in other farmers' fields. The success could also be attributed to promotion by many organizations that have been interested in tree growing. These include the Forestry Department, the Ministry of Agriculture, the Kenya Forestry Research Institute (KEFRI) and NGOs dealing with afforestation and agroforestry programs.

The presence of grevillea has been described by Tyndall (1996) as a case of induced adoption due to population pressure and land reform policies where the Kikuyu tribe's response was to revive their precolonial tradition of putting plants on boundaries. According to Castro (1991) and Haugerud (1984) the Kikuyu have a precolonial tradition of marking clan lands through boundary vegetation. In an 89-farm survey in Kirinyaga, 91% of the farmers had grevillea on their outer boundary and 62 had most of their grevillea on the outer boundaries (Tyndall 1996). The concept of boundary marking on newly settled land as a major factor to enhanced adoption of grevillea boundary planting is also shared by Kamweti (1992), who reported that farmers preferred planting exotic trees to indigenous trees because they considered the former to be more valuable than the latter.

Institutions promoting the innovation

KEFRI has been the main body dealing with research on grevillea. The National Agroforestry Research Project (NAFRP), which was collaborative between KEFRI, Kenya Agricultural Research Institute (KARI) and the International Centre for Research in Agroforestry (ICRAF), operated in central Kenya between 1991 and 2004. One of this project's activities was raising grevillea seedlings at a tree nursery at KARI's Regional Research Centre, Embu, and selling them to farmers at subsidized rates.

The Forest Department has concentrated its efforts in promoting grevillea through providing planting materials to the farmers. Most of the seedlings that are raised in Forestry Department nurseries consist of grevillea species. For example, since 1982, government nurseries in Meru District produced over 2.5 million grevillea seedlings, primarily for distribution to farmers (Spiers and Martin 1992). In addition, NGO extension nurseries were also producing a significant number of seedlings.

The Ministry of Agriculture has mainly promoted grevillea for soil conservation, especially through the Sida-funded project on Soil and Water Conservation. In this program, one of the activities was to initiate nurseries to produce seedlings and in most cases grevillea was the species that these nurseries promoted.

Research questions and knowledge gaps

Though grevillea has done well in the agroforestry systems of the central highlands of Kenya there is need for research:

- To identify and introduce a wider variety of timber species that grow fast and produce high-quality timber and increase the range of species that farmers can choose from.
- To guide farmers in forming efficient and effective cooperative societies that will help solve the problem of gathering for market trees from widely scattered farms in areas difficult to access to improve on timber marketing.
- To identify mechanisms for continuously making available to farmers current timber pricing and marketing information, to enable them to value their trees according to prevailing market prices.
- To increase the genetic diversity of grevillea in Kenya because the African landraces have been found to have less diversity than natural populations. Introduction of a broad genetic base from Australian natural provenances will be an important part of strategies to improve grevillea performance.

- To evaluate timber use and preservation methods for grevillea timber.
- To address the poor tree-pricing and marketing organization that has contributed to loss of potential income to farmers.
- To assess and formulate appropriate management guidelines of trees on farms that optimizes productivity of the system. Though farmers believe that pollarding helps increase tree diameter, it has been shown that removing the entire crown markedly depresses tree girth (Kiriinya 1999). Kamweti (1996) also reported that pollarding trees before they attain maximum height tends to reduce overall tree yields.

Professional reflections and recommendations

Grevillea robusta is popular with farmers of the central highlands of Kenya because it provides economically viable products, is easy to propagate and establish, does not compete strongly with adjacent crops, and tolerates heavy pruning of its branches. Farmers grow grevillea mainly for producing timber, poles and firewood. Other important attributes of grevillea include its ability to withstand pollarding and to provide leaf mulch and dry season fodder.

Most of the cash from grevillea is obtained from selling the timber when the tree is 15 to 30 years old. However, from the 5th year onwards, the farmer is also supplied with firewood from pruning and pollarding the trees, making grevillea a very good investment. It increases farmer security since risks are spread by having at least two products (timber and fuelwood).

Farmers usually sell unprocessed timber in form of whole tree or firewood. Farmers would get more profits if they sold processed timber and there is need to sensitize them on the advantages of local processing. Also, farmers do not always get the full value of their investment because at times they lack knowledge on the value of their trees. There is need to develop and disseminate farmer-friendly methods of valuing standing trees. Farmers should look at a tree as a product in which they have invested land, time and money and consequently they need to sell their trees at market prices.

Currently farmers sell their trees individually to intermediaries who collect the produce from the farm. The farmer my lack the opportunity to bargain as some intermediaries have predetermined prices. Farmers should therefore be encouraged to form timber- or tree-marketing groups where intermediaries come to negotiate prices. An even better alternative would be for farmers to treat timber-marketing as a business and organize to process and store timber with an aim of selling at best prevailing market prices.

Market value for grevillea will probably increase in the next 5 to 10 years because the supply of other species such as pine (*Pinus patula*) and cypress (*Cupressus lusitanica*) from forested areas is rapidly declining. The government and other development partners should use this opportunity to encourage on-farm processing of grevillea timber by farmers since there is a ready market. Development of timber-processing technologies has been going on at KEFRI at Karura, and the proven technologies need to be disseminated to farmers. Government policy should consider organizing workshops and meetings to promote this.

6.5 Jatropha-based agroforestry in Tanzania

Nature of the innovation

Jatropha curcas is a small tree or large shrub that can reach a height of 5 m. It is a drought-resistant species that is widely cultivated in the tropics as a living fence (Kakute/JPTL 2006). The seeds are toxic to humans and many animals. The branches contain latex that communities in the northern parts of Tanzania have traditionally used to heal fresh cuts. Normally, five roots are formed from seeds, one central (taproot) and four peripheral. Cuttings, when planted, do not form a taproot. The plant is monoecious and flowers are unisexual. Pollination is by insects. Jatropha has a life span of more than 50 years (Kakute/JPTL 2006).

The jatropha variety in Nicaragua has fewer but larger fruits. The yield per hectare seems to be the same. A non-toxic variety that exists in Mexico is eaten after it is roasted. The variety existing in Tanzania is not edible. Single trees are planted for medicinal purposes, but usually jatropha is planted to form protection hedges. Often it is planted as a hedge to demarcate fields or roads, reducing the potential for boundary disputes.

Jatropha can be propagated both from seeds and vegetatively through cuttings. In principle, cuttings can be planted in plastic bags to accelerate their development before they are planted out in the field. Direct seeding can be done but best survival is realized when seedlings are prepared in a nursery in polythene pots. Nursery planting is said to accelerate the installation of a plantation by at least 3 months (Kakute/JPTL 2006). Small plastic bags are filled with soil with a high concentration of organic material (compost) about 3 months before the beginning of the rainy season. One seed is planted in each bag. If well watered every 3 days, the seeds start germinating after about 9 days. After 3 months, at the beginning of the rainy season the plants, 15–20 cm high, can be planted out. They can produce seeds after only two rainy seasons. Because of difficulties of transport (weight of the

Jatropha. which can procduce biofuel, can be grown as fencing or as plantation in moist lowlands.

bag) these plants are not suitable for hedges. For a jatropha plantation a distance of 3 m between rows and 2.5 m between plants is appropriate.

It is advised to make sure that enough spacing is provided between plants. The jatropha plant is not edible, thus it is not consumed by animals, except for golden flea beetles that attack the leaves. If the leaf attack is more than 40%, the yield can be affected (Kakute/JPTL 2006).

Justification of profitability

In recent years, jatropha has been recognized as producing a myriad number of products varying from cosmetics to petroleum products. Consequently, propagation and planting of jatropha in large-scale plantations has generated much discussion among big commercial farmers in Tanzania.

Jatropha as a plantation for seed production is not common. Farmers look for the dual advantage of crop protection combined with seed production. Plantations of up to 40 acres can be found in Moshi, in the northern part of Tanzania.

Jatropha seeds can be pressed into non-edible oil with many uses (Kakute/JPTL 2006)—soap making, for lighting, lubricating, and burned in jatropha oil stoves. If used as an alternative source of energy, jatropha can reduce the use of firewood and charcoal, thus minimizing the cutting of trees and conserving the environment. After the oil is extracted, the pressed seed-cake can be used to make compost manure and methane.

As a crop, jatropha can be cultivated in areas with harsh climatic conditions. Jatropha cultivation costs minimally compared with other crops. When they plant commercially, farmers can increase their income where markets are available. The soap produced from jatropha has some medicinal properties and has been found to reduce skin problems. As a live fence Jatropha reduces soil erosion from wind and water.

In Tanzania, jatropha has become common talk among large-scale farmers, who intend to establish plantations in all the agroecological zones. Plantations have been clearly marked in Kilimanjaro but these have now extended among the Maasai in Monduli District and coffee farmers in Arumeru District. Large-scale farmers are expecting to start planting jatropha in the Coastal Region around Bagamoyo, cutting the closed forests to give room for jatropha because of its high prospects of being used in bio-energy products.

Agroforestry components and interfaces

For jatropha to be used in bio-energy production and in the cosmetic industry seeds are crushed to get oil. According to the farmers, some jatropha shrubs produce just a few seeds per season and some shrubs grow big and produce lots of seeds. The interest here is in seed production.

The communities around Lake Victoria in north-western Tanzania grow vanilla as a cash crop and use jatropha to support the climbing vanilla. Now that jatropha is discovered to have multiple uses, it becomes important to the farmers because what was used just as a support for vanilla has high value. These farmers, with their long experience in intercropping, have only to intensify their management and expand the amount of land under jatropha to increase their earnings. The practice is sustainable. Farmers need to be able to process the seeds and find markets for semi-processed products. See table 6.5 regarding jatropha uses.

Minimum inputs

Capacity building through training and research for research and extension professional (both agricultural and natural resources) is required. An immediate strategy to monitor and evaluate the progress of this plant and

Table 6.5. Interface among components in jatropha-based agroforestry

	Development of vanilla crop in Kagera Region	Bio-energy products	Cosmetic industry	Live fence	Traditional medicine
Development of vanilla crop in Kagera Region	Relationship between vanilla and jatropha	Processing and marketing of vanilla and jatropha products	Quality control and marketing of jatropha products	Production of propagative material including seed production	Research on medicinal properties of *Jatropha curcas* (both scientific and traditional values)
Bio-energy products	Silvicultural technology on jatropha species	Bio-energy production technology developed; jatropha silviculture intensified	Technology in various uses of Jatropha in cosmetic industry developed	Live fence management for production of propagation material including seeds for large-scale planting	Alley cropping on farmland and live fence planting and management
Cosmetic industry	Quality control of various products from vanilla produced in the cosmetic industry	Management of large-scale jatropha farms	Development and management of small-scale cosmetic industries; credit facility and marketing procedures	Live fence management for production of propagation material including seeds for large-scale planting	Research on value of *Jatropha curcas* and related plants
Live fence	Management of live fence with vanilla	Seeds and other propagation materials for large-scale plantations	Seeds and other propagation materials for large-scale plantations	Protection qualities for a homestead	Gene bank for several species and types
Traditional medicine	Values of *Jatropha curcas*	Processing technology of jatropha products	Processing technology of jatropha products	Values of jatropha	Research on values of *Jatropha curcas*

assess its profitability for farmers and the environment is required. Efforts to explore prominent markets for both seeds to reach the developers and industries that are involved in processing for petroleum products production should be in place.

Agroclimatic zones

Agroclimatic zones in which the innovation works effectively:

- Moist lowlands
- Moist highlands
- Moist mid-highlands
- Moist and hot lowlands
- Wet lowlands

Major factors that make the innovation successful

The global fuel crisis is motivating the invention of alternative sources of energy to replace petroleum products from fossil fuels. World markets for petroleum products have long and continuously been fluctuating. This is why globally it is termed the 'fuel crisis'. Farmers have high anticipation for a market that will use jatropha seeds to help produce petroleum products.

Direct and indirect beneficiaries

Big commercial farmers who have access to land for extensive planting of jatropha may benefit from this system. When researchers exploring other potential *Jatropha* species and propagation methods gain more scientific knowledge of the plant, others are certain to benefit as well. At present, much in-depth knowledge is lacking.

Upscaling strategies

Not much research has yet been done on this plant. Research work is urgently required due to the enthusiasm that has rapidly developed among prominent farmers. Extensive education for the public on areas where jatropha can successfully be grown is important, because large-scale farmers have gone to the extent of cutting out coffee in the northern highlands on high fertility soils to replace it with jatropha. In the coastal zone, closed forests are being cleared for jatropha planting.

Institutions promoting the innovation

The National Environmental Management Council in a project sponsored by UNDP and Kakute organizations has been working effectively among women's groups on jatropha in semi-arid areas of Arusha Region. The Alternative Resource Income (ARI) project in Monduli District, Arusha, is coordinating and facilitating the project in this particular location.

Research questions and knowledge gaps

The jatropha plant has not yet been the subject of agricultural research to improve the yield. Figures given in the pertinent literature on the production of seed vary from 2 kg to 2.5 kg per jatropha shrub in a plantation setting (Nyami and Amuodo 2007). Special initiatives should be in place to educate farmers on areas suitable for jatropha planting before enthusiasm about the shrub influences farmers to destroy delicate ecosystems because of the global petroleum crisis. Studies on propagation, management and marketing of jatropha should be intensified before farmers engage themselves too much with this plant.

The species and varieties of jatropha are not well known. A study to identify and classify the species is required.

Professional reflections and recommendations

Although not much research has been done on the plant, farmers should be advised to work with what knowledge there is. It is widely understood that jatropha is a drought-resistant plant. This means if planted in fertile soils with good rains it will thrive, growing into a tall shrub, with many dark-green and succulent leaves. But during the present survey, on-farm visits showed that plants grown on fertile land with high rainfall do not produce many seeds, which is the targeted product. It is therefore recommended that jatropha be grown with caution until enough research has been done to ensure that forested land is not cleared for short-term economic benefits. This is important to protect the environment.

Chapter 7 Agroforestry innovations suitable for Wet Lowlands

7.1 Eucalyptus-based agroforestry system, Southern Plateau region, India

Nature of the innovation

There was a myth that eucalyptus is water intensive and destroys soils and the underground water table. Studies have shown that eucalypts consumed 0.48 litres of water to produce a gram of wood, compared with 10.55 litre for siris, 0.77 litre for shisham, and 0.88 litre for kangi. Thus it is more water efficient than many indigenous Indian species. Moreover, it is a hardy tree that can grow on almost any type of soil.

Impressed with the marked difference in productivity among eucalyptus and indigenous tree species, farmers have taken up growing it in plantations on a large scale. This tree species gets a further boost with the success of clonal technology. Mass multiplication of elite germplasm has been achieved successfully using mist chambers. Significantly higher mean annual

In wet agroclimatic zones, eucalyptus trees are productive partners that cohabit with crops such as pulses and vegetables.

growth (8–40 m^3 ha^{-1}) of eucalyptus has been achieved as compared with the average of 0.5 m^3 ha^{-1} for indigenous trees.

To further improve the productivity of the system, different rabi and kharif crops are grown under eucalypts. This clonal eucalypt-based agrisilviculture system is successful in both rainfed and irrigated regions. During initial years when the tree canopy is small almost any crop can be successfully grown; during later years fodders are preferred.

Justification of profitability

A revolution has taken place in profitability of plantations through clonal eucalypts, whose productivity is more than double that of seed-raised plantations. Under irrigated conditions eucalypt-based agroforestry models are more profitable than agricultural crops. The risk and labour associated with agricultural crops are greater than for tree crops.

Intensive studies have been conducted in rainfed and irrigated areas of the Indo-Gangetic plain (Sapra 2006). Under rainfed conditions, the productivity of a 6-year clonal plantation is 37.4 t ha^{-1} yr^{-1}, which is about 179% of the productivity in seed-raised plantations (13.4 t ha^{-1} yr^{-1}). The profitability of a 6-year clonal plantation in rainfed farmland is INR 68,122 ha^{-1} yr^{-1}, which is about 3 times the profitability of a seed-raised plantation (INR 23,955 ha^{-1} yr^{-1}). Under irrigated conditions, productivity up to 32 t ha^{-1} yr^{-1} was achieved in a 4-year-old plantation. The productivity can be improved by a further 25% if the plantation harvesting is delayed by one year, that is, harvesting in 5th year. The profitability of a 4-year-old clonal plantation with sugarcane is INR 57,192 ha^{-1} yr^{-1}, whereas the profitability of agrisilviculture further improved (INR 68,417 ha^{-1} yr^{-1}) if the plantation is harvested in 5th year.

The Indian Tobacco Company, Bhadrachalam, has made a significant contribution in popularizing a clonal eucalypt-based system in the southern parts of the country. Under irrigated conditions, clonal eucalypts intercropped with chilli are giving a net income of INR 71,737 ha^{-1} yr^{-1} in Southern Plateau Region.

The mean annual increment (MAI) in volume overbark of *E. tereticornis* on medium quality sites at age 8–10 years is about 15 m^3 ha^{-1}. A review of the performance of this species from 8-year-old plantations throughout India showed an MAI of 1.3–19.8 m^3 ha^{-1}, depending on stocking and site quality. Highest wood yield of 105 t ha^{-1} in 5 years has been reported in red sandy clay loam soils, under irrigated conditions in Karnataka. On an experimental scale, the best provenances on the best sites in Bangladesh yielded over 60 m^3 ha^{-1} per year after 5 years, at a planting rate of 10,000 stems ha^{-1}.

Under special trials in China, MAI at 5.5 years for *E. tereticornis* was 11.3 m^3 ha^{-1} in Guangxi 1provenance, although the better-performing provenances reached 26.6 m^3 ha^{-1} in 4.4 years. The sale price of a well-grown eucalypt after 7 years is about INR 100–150 per bole. The sale price of wood at the farm gate varies at INR 800–1000 per tonne (Anon. 2005).

Agroforestry components and interfaces

The two main components of this system are trees and crops. There is a strong above- and underground interaction between and within components. To minimize effect of trees on crops the spacing between tree lines is usually kept at 4 m, and the distance within trees line is kept at 2 m. Crops such as cotton, chilli, tobacco, pulses, vegetables and even dryland paddy can be cultivated during the initial years (Kulkarni 2004). On the Indo-Gangetic plains sugarcane is successfully grown during the initial 2 years and after that fodder can be grown. Eucalyptus is a fast-growing dominant evergreen tree that negatively affects crop yield during later years of growth due to underground root competition and aboveground shade. It is advisable under trees to prefer fodders such as oats and berseem instead of grain crops, especially during the latter years of growth.

The economic yield of chickpea, lentil, wheat, cauliflower, barseem and toria in a strip 12 m wide to the south of 8 1-year-old *Eucalyptus tereticornis* shelterbelts (three different locations) was reduced by more than half (Singh and Kohli 1992). Among all the crops under study, the yield of chickpea was reduced the most. The content of soil phytotoxins was maximum in the litter-free topsoil surface, compared with that at depths of 30 or 60 cm, at all distances from the eucalypt row. Maximum content of phytotoxins was found at 1 m from the tree line for all depths. These soil phytotoxins impaired the germination of *Lens esculenta*, thus indicating an allelopathic effect. It is concluded that the poor performance of crops in the sheltered area is related to an allelopathic effect of the eucalypts.

Interactions between component species in 3-tier agroforestry systems were studied for 3 years on sloping laterite soils of South India (Ghosh et al. 1989). The wood yield of eucalypts was found to increase in association with the intercrops, with cassava + groundnut resulting in best eucalypt growth. Cassava intercropping restricted both spread and mean length of lateral eucalypt roots. The tree species was found to reduce the tuber yield of cassava and also the pod yield of both the seasonal crops when grown in association. Soil fertility fell considerably after 3 years of cultivation of the tree species. The nutrient uptake by cassava was low when grown in association with perennial species. Both runoff and soil loss were effectively reduced when cassava was grown in staggered mounds under eucalypts.

Minimum inputs

Eucalypts, generally raised for industrial plantations, mainly for pulpwood, firewood or poles, are maintained with a shorter rotation of 5–7 years. For commercial plantations, intensive site preparation by ploughing or deep ripping on compact sites is beneficial. On wet sites moulding should be adopted to improve root aeration and provide well-drained conditions that facilitate planting. Spacing adopted is 2 m x 2 m or 1.5 m x 1.5 m (high-density plantations). In case crops are cultivated between the rows (agroforestry), wider spacing of 4 m x 2 m; 6 m x 1.5 m; or 8 m x 1 m are recommended. Nursery-raised seedlings and clonal plantlets in polybags may be planted at the onset of the monsoons, in pits 45 cm x 45 cm x 45 cm. Organic manure mixtures along with fertilizers containing 25 g of NPK (3:2:1) and 50 g of phosphate should be applied in the planting pit at the time of planting. Protective irrigation is essential, if monsoons fail, in the first 2 years of plantation. Eucalypt are intolerant to shade and do not compete well with grasses for water and nutrients, thus hand weeding and working the soil 2–3 times in the initial stages is essential. The tree has a deep taproot system with mycorrhizal associations that increases its ability to draw nutrients and water.

Being a fast-growing plant, eucalyptus is a heavy feeder and requires supplements in form of organic and chemical fertilizers in successive years. Deficiency of nitrogen in soils is a limiting factor for growth and can reduce the yield even up to 60%. In order to maintain soil fertility, it is advisable to raise these trees with legumes as an intercrop.

Harvesting is done by clear felling the stand in 6–7 year. Once the tree is felled, the stump throws out many coppice shoots, which should be singled out to keep only one vigorous stem per stump, which will form the second crop. It is advisable to change the planting stock after the second harvest, as there is loss in vigour in coppice from the third coppice onwards.

Agroclimatic zones

Eucalyptus was introduced in India by the British in 1843 in Nilgiri Hills as an experiment to find high-yielding species for fuel and timber. It soon became favoured by foresters and commercial plantations, owing to its fast growth, non-browsable and drought-resistant nature, and adaptability to a variety of agroclimatic conditions. *Eucalyptus* is versatile, demanding of light, drought hardy, and fast growing. It adapts to a wide range of soils and climate. *E. tereticornis* has the most extensive latitude range (9–38°S), is moderately salt tolerant and relatively fire resistant. The range of agroclimatic conditions of the widely grown *E. tereticornis*, is given in the next sections.

Climate

● Altitude range	0–1000 m
● Mean annual rainfall	500–3000 mm
● Dry season duration	0–8 months
● Mean annual temperature (range)	10–27 °C
● Mean maximum temperature of hottest month (range)	22–42 °C
● Mean minimum temperature of coldest month (range)	–2–19 °C

Soil and physiography

● Soil texture	light, medium, heavy
● Soil drainage	free, seasonally waterlogged
● Soil reaction	acidic, neutral
● Special soil tolerances	saline
● Soil types	alluvial, gravely, red, sandy

Thus eucalypt-based systems can work in a wide range of edaphic and climatic conditions. The clonal eucalypt-based agroforestry system under irrigated conditions competes or is even economically better than the traditional cropping system.

Major factors that make the innovation successful

Adaptability of eucalypts to a wide range of edaphic and climatic conditions make it a tree suitable for different regions. It thrives well under both rainfed and irrigated conditions. However, wood productivity is substantially higher under irrigated conditions and agroforestry is recommended only under irrigated conditions. Another reason for its large-scale adoption is that it requires minimum cultural and management practices. The tree has a narrow crown and sheds its branches on its own; thus it suits well into an agroforestry system, especially during the initial years. In addition, the tree has the following commercial uses:

- Eucalyptus, one of the fastest-growing trees, is an excellent timber for paper and pulp, particleboard and hardboard.
- It is an excellent source of fuelwood and charcoal.
- Eucalyptus wood is used for light and heavy construction, railway sleepers, bridges, piles, poles and mining timber.
- Indian standards are available for use, after treatment, of *E. tereticornis* timber for door frames, window shutters, furniture, cabinet, tool handles, packing cases and crates.
- Leaf extracts of some species have pesticidal properties and can be promoted as a biopesticide.

- The leaves of the species are rich in essential oils that have many medicinal uses. *Eucalyptus globulus* can be grown commercially for eucalyptus oil.
- *E. tereticornis* is a major source of pollen in apiculture and produces an amber honey of distinctive flavour.
- The wood has a tannin content of 6–12% and the bark 3–15%, although it is not used commercially as a source of tannin.
- The tree may be used as an agroforestry species. Eucalyptus in combination with pineapple has given excellent results in China.

Direct and indirect beneficiaries

Various commercial uses of eucalypts have been mentioned above. Thus, a range of products can be made from eucalypts—paper pulp, timber, fuelwood, biopesticides, oils, etc. Developers of clonal technology, that is, pulp and paper industries, and users of technology, that is, farmers, are benefiting from the adoption of a eucalypt-based agroforestry system. Industries are undertaking mass production of elite germplasm. Although such clonally produced elite germplasm is expensive as compared with seedling stock, farmers have still adopted this technology. Various studies have proved that plantations raised from elite germplasm produce about 2–3 times more merchandisable wood than what is produced on seedling-raised plantations. Increase in productivity ensures raw material for industries and better price for farmers. This innovation is providing employment at primary, secondary and tertiary levels. In addition to these direct benefits, some indirect benefits are achieved by a substantial increase in area under eucalypt clonal plantations.

Upscaling strategies

There were some myths regarding excessive water uptake and desertification by eucalypts. Although various studies have proven such myths wrong some farmers are still hesitant to voluntarily plant these trees on farmland. Now when their fellow farmers are realizing higher productivity from the clonal eucalypt-based agroforestry system, large-scale adoption of this technology is on the way. Superiority of clonal plantations in terms of wood production has been well documented from the results of plantations harvested in various regions. Thus, there is no problem in getting better results in different regions. The only caution for getting the better results as replicated is to choose the right clone. Different site-specific clones have been developed and tested by various industries. Initial screening, testing and mass multiplication of site-specific elite germplasm is the major contributing factor for the successful adoption of this innovation. Further, growing crops in the block plantations of clonal eucalypts has improved the economic viability of this practice. Although field crops can be successfully grown only for an initial 2–3 years, even then they substantially contribute to the overall productivity and economic viability of the system.

Institutions promoting the innovation

Private institutions played an important role in India in promoting clonal technology. The Indian Tobacco Company, Bhadrachalam; Paper & Paper Board Ltd, Khamman, A. P.; West Coast Paper Mills; JK Paper Mills, etc., all initiated commercial-scale production of elite germplasm of fast-growing tree species such as eucalyptus, leucaena, casuarina and bamboo. They imported seeds from different countries and raised provenance trials. Candidate-plus trees were selected from government and farm forestry plantations. Selected plus trees were propagated vegetatively from coppice cuttings in mist chambers. Root trainer technology was adopted to produce plants (Kulkarni 2004). Inter- and intraspecific hybridization was carried out between selected best clones and other species of eucalypts. Half and full-sib progeny trials were laid out. Promising hybrids were cloned and planted in multilocational trials. Genotype x site interaction studies for various clones were carried out on normal and refractory sites. The proximate analysis was done and strength properties of wood for pulp and paper were determined. Different crop combinations with eucalypt clonal plantations of different ages were screened at the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, and Acharya NG Ranga Agricultural University (ANGRAU), Hyderabad. Crops such as cotton, chillies and watermelon, and fodders such as oats and berseem performed better in the initial screening process. Other institutions like schools and municipal corporations have been involved in creating public awareness for planting trees and adopting agroforestry models. State forest departments and NGOs play an important role in promoting this innovation.

Research questions and knowledge gaps

Significant results have been achieved in the last couple of years clonal technology and development of site-specific elite germplasm of eucalypts. There is a strong need to debate on controversial issues and myths regarding eucalypts and educate farmers about the facts. The extension wing of state forest departments and state agriculture universities can effectively play this role. Further, farmers need to learn about the economic status of clonal eucalypt-based agroforestry models, especially to compare them with their traditional cropping systems.

More research is definitely required to find which crops can be successfully grown under trees. Eucalypts are known to have an allelopathic effect; thus only resistant crops should be selected. Moreover, this is an evergreen tree that shades significantly during the later years of its growth. Usually farmers do not grow any crop during the latter years of the rotation. Research is required to find shade-tolerant crops or determine changes in management practices of trees and crops that will minimize yield reduction. One option could be to increase spacing between tree rows but maintain the same number of trees per unit area, such as 4 x 2 m, 6 x 1.5 m or 8 x 1 m. This will allow more interspace to cultivate crops for longer duration. Thinning within tree rows may be recommended during the latter years if competition within the tree component is heavy.

Professional reflections and recommendations

There is great potential for the success of this agrisilviculture system. Replicated results of eucalypt-based agroforestry models from various regions have proved this assumption. To maintain the superiority of this system over the traditional systems, Government certified nurseries should be set up to supply only quality germplasm to farmers. This is important in any forestry venture where results are expected after 5–6 years. Suitable crops that can be successfully grown in interspaces need to be screened for different edaphic and climatic conditions. There is great demand for eucalypt wood for poles, paper pulp, timber, etc. Thus there are less chances of glut of this wood in the market. But state governments should be cautious about such a possibility and should regulate plantations as per the demand for wood in market. Accordingly, the area within a region to be brought under plantation each year should be planned. Financial institutions should be encouraged to ensure cash credits for farmers adopting agroforestry, especially during the initial years until the trees start yielding.

7.2 Multipurpose trees and spice-based agroforestry in the Coastal region of India

Nature of the innovation

The coastal regions of India are known for their diverse land-use systems that integrate woody perennials with other life forms. Agroforestry is often perceived as the predominant land-use system in this region. Coconut (*Cocos nucifera)* is grown on about 6 million hectares in the tropics. The coastal area is about 1.6 million hectares, calculated to produce 12,355 million nuts. Because coconut is an open-crowned tree, other tree species mainly multipurpose trees (MPTs) are used in plantation programs. They have rapid juvenile growth, produce dry matter efficiently in terms of water and nutrient input, and their crown characteristics maximize interception of solar radiation and ease of regeneration (Kumar et al. 1998*)*. Important MPTs in the region are *Acacia auriculiformis, Ailanthus triphysa, Casuarina equisetifolia* and *Leucaena leucocephala. Ailanthus* is a deciduous tree with a tall cylindrical trunk and height of about 30 m with small compact crown that intercepts only a small fraction of the incident radiation (Mathew et al. 1992*)*.

An important MPT species such as ailanthus can be successfully interplanted in an older coconut plantation (preferably above 30 years of age), often in association with other field crops including spice plants such as ginger.

Typical complex agroforesty systems that involve many different spices.

Depending on the space available (between coconut palms), one or two rows of multipurpose trees can be accommodated in the middle (spacing 1–2 m between plants) (Anon. 2002). Thus on a single unit of land three components can be suitably accommodated, leading to added economic advantage to grower.

Justification of profitability

The system consists of coconut (*Cocos nucifera), Ailanthus* and ginger (*Zingiber officinale).* The compact crown, moderate root system and deep-rooting tendency of coconut and ailanthus is thought to be less competitive with associated crops (Mathew et al. 1992; Kumar et al. 1999). Ginger is an important shade-loving spice crop grown as an understorey crop.

Ailanthus is a multipurpose tree that provides various direct and indirect benefits. It has light, soft wood that is used for making cases, catamarans, toys, drums and matches. The wood has sale value in the region. This tree is less competitive with associated crops, especially during early years of growth, due to its compact crown and deep root system. Ginger is a spice that can be profitably cultivated under the partial shade of Ailanthus trees. A detailed study was conducted to evaluate ginger quality and yield under different plantation densities, varying from about 1000 to 3000 trees per hectare (Kumar et al. 2001). Under controlled conditions, the rhizome yield of ginger was 3.5 t ha^{-1} **[are megagrams tonnes?]** but under 3-year-old *Ailanthus* in a block plantation (2 x 2 m) it was significantly higher (5 t ha^{-1}).

Overall ginger leaf production, leaf retention and leaf size were greater under shaded conditions. This rhizome yield that was approximately 40% higher under trees may be due to the shade-loving nature of the crop. Essential oil and oleoresin contents of ginger are two quality products for which ginger crop is valued. Essential oil contents ranged from 0.91% to 0.98% and oleoresin from 2.5% to 3.98% of the dry rhizome. Sole crop of ginger gaved the highest essential oil and oleoresin concentration despite having the lowest rhizome yield. However, the differences were not significant. There might be an inverse relationship between biomass production and chemical quality. Similar results were observed by Varughese (1989) whereas Babu and Jayachandran (1994) observed that ginger grown under shade may have higher essential oil and oleoresin concentration. In addition to income from ginger crop, farmers get a handsome income from selling trees at rotation age.

Agroforestry components and interfaces

Broadly speaking, the system has two major components:perennial multipurpose trees and spices. During the initial period of growth (up to 5 years) the interaction between the components is synergistic. No negative influence of one component on the other was observed. In an agroforestry system, trees, the dominant component, often benefit from the cultural and management practices used to grow the understorey crops. The rhizome yield of ginger was significantly more under closely spaced (2 x 2 m) block plantation of ailanthus. This could be attributed to the fact that the ginger crop was getting 60% of the light of open conditions. However, no significant effect of shade on quality and concentration of essential oil and oleoresin was observed.

To acquire information on the nature of belowground interactions in an intercropping system involving ginger and *Ailanthus triphysa*, their root activity was evaluated based on ^{32}P recovery by each species in mixed and sole-crop situations (Thomas et al. 1998). Treatments included two Ailanthus densities (1111 and 3333 trees per hectare) and four lateral distances of ^{32}p application (10 and 20 cm from the treated ginger plant and 20 and 40 cm from the treated Ailanthus trees). Recovery of ^{32}P suggests that tree density is probably not a strong determinant of belowground competition in the well-fertilized, manured and mulched system studied (at least until 4 years after tree planting). Ailanthus trees absorbed a substantial portion of the ^{32}P supplied to ginger, suggests that the effective root zones of ginger and *Ailanthus* may overlap. Data on ^{32}P uptake of ailanthus suggest that 41% to 59% of the root activity is concentrated within a zone of about 40 cm distance from the trunk. Observations also suggest that competition between the tree and the herbaceous crop for nutrients applied to the tree component is unlikely in the ailanthus–ginger mixed species system studied. Therefore, from a crop management perspective, it is better to fertilize the herbaceous component of the mixed species system adequately, as it will also benefit the tree component. Nutrient use efficiency may be higher under such situations.

The magnitude of root competition that 17-year-old coconut palms suffer from 3-year-old interplanted multipurpose trees *Ailanthus triphysa* and kacholam (*Kaempferia galanga*), a herbaceous medicinal plant, was evaluated based on the extent of absorption of applied ^{32}P by the palms in sole- and mixed-crop situations (Kumar et al. 1999). The (MPTs) species were grown under two planting arrangements: single row and double row. The widespread root proliferation of coconut and multipurpose trees that occurs in well-fertilized kacholam beds was tested by excavating the roots. Interplanted MPTs substantially altered absorption of ^{32}P by coconut. Ailanthus exerted a modest depressing effect. Single rows of MPTs also favoured ^{32}P recovery by coconut, presumably because of the increased root densities in the subsoil. ^{32}P absorption by MPTs was generally higher closer to the trees owing to the greater root concentration of the MPTs, which in turn suggests possible root interference between MPTs and coconut. Hence selection of tree species with low root competitiveness or trees with complementary root interaction is of strategic importance in agroforestry.

Minimum inputs

To make any system economically viable one has to take into consideration important factors such as the quality of planting material used, adoption of adequate cultural and management practices, and finally marketing of the produce. Forestry being a long-term venture, proper planning in selecting appropriate tree–crop combinations is of utmost importance. Coordination between farmers and raw material consumers is a must to ensure a regular supply of produce to consumers and better economic returns to farmers. The farmers are usually not organized to collectively decide the price of their produce, and intermediaries take advantage of this situation and exploit the farmers.

Government should formulate policies to promote agroforestry practices. There is a need to maintain balance between demand and supply of produce. This will keep the price of wood and other products from trees lucrative not only for the wood consumers but also remunerative for the producers. To achieve better returns from trees it is very important to have good-quality planting stock. Nurseries providing planting material should be certified so that only quality material is sold to farmers.

Inputs from research workers are required to study the tree–crop interaction at different levels and to minimize adverse effects by timely execution of various cultural and management practices. Farmers should be made aware of importance of various practices that help improve the overall productivity of a practice. This would help in large-scale adoption of economically viable practices.

The growth rate of trees is quite fast during the initial years, and their demand for nutrients is also high. Thus fast-growing trees actively withdraw soil nutrient reserves during the early phase of growth, but after canopy closure the system may be self-nourishing through nutrient cycling (Kumar et al. 1998). To minimize competition for water and nutrients, an additional supply should be provided at crucial stages of development so that trees and crops do not suffer due to lack of management.

Agroclimatic zones

Tropical regions of India are characterized by diverse land-use systems that integrate woody perennials with other life forms. Agroforestry is often perceived as the predominant land-use system in the tropics. A narrow strip of coastal plain lies in the west along Arabian Sea and in the east along Bay of Bengal. The total length of this coastline is approximately 5600 km. The mean minimum temperature is 21–29 °C and the mean maximum temperature 29–36 °C. The soil is an Ultisol. The region receives maximum rainfall during the south-west monsoon (June–August); mean annual rainfall is around 2500 mm. Agroforestry practices in this region are not likely restricted by moisture stress, except on soils with low infiltration rates and moisture retention capacities. The experimental area in Kerala was between 11°21′30″ and 11°21′50″N latitude, 76°21′50″E longitude and at 60–70 m above sea level. This system is broadly suitable in the western coastal area, particularly in Kerala State. Such intensive, integrated land-use systems are characterized by a high degree of complementary or competitive interactions (Kumar et al. 1999). Competition for light, water and nutrients are cardinal production-decreasing functions in mixed-species systems. Root competition is of particular significance in this respect. Depending on the space available (between coconut palms), one or two rows of multipurpose trees can be accommodated in the middle (spacing 1–2 m between plants).

Major factors that make the innovation successful

There are many social, economic and ecological factors responsible for the wide popularity enjoyed by agroforestry in this region. Agroforestry is socially acceptable because it fits well with traditional farming systems and established village lifestyles (Kumar et al. 1992). The multiple goods and services agroforestry provides aim at ecological security, increased productivity and sustainability. A major economic reason for agroforestry is that it is suitable for resource-poor situations. The economic advantage can be summarized as low capital and labour costs, increased value of outputs including high-value crops, diversified range of products from a given area, thus increased self-sufficiency and reduced risk from diverse climatic, biological and market effect on particular crops or products (Arnold 1987).

Coconut does not ordinarily use incoming solar radiation completely (Abraham 1993). Limited lateral spread of its roots leading to suboptimal utilization of belowground resources (Kumar and Wahid 1988) also facilitate intercropping, allowing various combinations of annuals and perennials with coconut. The crown characteristics of upperstorey tree components (coconut and ailanthus) allow partial shade conditions that are optimal for better ginger productivity. This situation is especially true during the initial period of tree growth (up to 5 years). Further the application of silvicultural practices such as lopping or pollarding is important to prevent any possible interspecific competition between the multipurpose tree component and the coconut palm.

Direct and indirect beneficiaries

There are both direct and indirect beneficiaries of the coconut + ailanthus + ginger agroforestry system. Farmers are the direct beneficiaries as such a system is socially acceptable. It fits in well with the traditional farming system and established village lifestyle. The system provides fruits from coconut, and from ailanthus soft wood and a highly viscous aromatic resin, widely used as incense and in indigenous medicines. With a view to develop a low-input sustainable production system, multipurpose trees are systematically interplanted in coconut plantations (Nair 1983). The understorey ginger is regarded as an important spice crop. Trees modify the microclimate, improve nutrient cycling through processes such as litter dynamics and nutrient pumping, retard soil erosion and desertification, and maintain biodiversity and soil fertility. Such microsite enrichment is through improvement in the soil organic matter and mineral nutrient pools, which can be related to litter and fine root dynamics.

Upscaling strategies

There is a great scope for upscaling this coconut-based agroforestry system. This system is not new; farmers have long been using it. They are socially and economically satisfied with its various components. The high-value crops in the system substantially improve net returns. Multiple components in a system reduce risk to income. Presently this system is replicated on a vast tract of land in the state of Kerala. Thus, there is no doubt in the repeatability of positive results. Major contributing factors for successful adoption in this region:

- Climatic and edaphic factors
- Social acceptability of different components
- Economic viability of system as a whole
- Ecological security
- Sustainability of system

Institutions promoting the innovation

Scientists at the Department of Silviculture and Agroforestry, College of Forestry, Kerala Agricultural University, are actively involved in developing and improving this multitier agroforestry system. To determine the underground interaction between different components isotope studies are being conducted. This would help to refine the cultural and management practices applied from time to time to improve productivity of the system. Research workers at other state agricultural universities in the tropics such as Tamil Nadu Veterinary and Animal Sciences, Kattupakkam and Tamil Nadu Agricultural University, Coimbatore are also involved in agroforestry research. Scientists at the Indian Council of Agriculture Research institute such as Central Agricultural Research Institute, Port Blair (Andaman and Nicobar Islands) are also involved in multistorey component research on agroforestry. In addition, the officials of the state forest department and the Kerala Forest Research Institute, Peechi, are collaborating with the university scientists in development and extension of developed technology. The Indian Council of Forestry Research and Education, Dehra Dun, also provides necessary help when required in terms of resources such as work force and land, financial assistance in the form of ad hoc projects, etc. Other institutions like schools and municipal corporations have been involved in creating awareness in the general public about planting trees and adopting agroforestry models.

Research questions and knowledge gaps

Most of the studies are concentrated on young ailanthus plantations where the competition between the different components is less. Thus the system seems profitable, particularly until the ailanthus trees are 5 years old. Although the coconut trees in the upperstorey are 30 years old, their crown structure is such that it does not interfere much with the understorey vegetation. The reduced light reaching the ground level at this stage is considered optimum for better production of ginger. There is a need to refinement in silvicultural treatments, cultural and management practices that will be applied during the later years of Ailanthus growth to minimize above- and underground competition between various components. Information is needed on the compatibility of multipurpose trees with coconut.

Various studies suggest that competition between tree and herbaceous crop for nutrients applied to the tree component is unlikely in the ailanthus–ginger mixed-species system studied. Therefore, from a crop management perspective, it is better to fertilize the herbaceous component of the mixed species system adequately, as it will also benefit the tree component. Nutrient use efficiency may be higher under such situations. Further, there is a need to quantify nutrient application to achieve maximum productivity. In addition, there is need to work on important agroforestry strategies such as selecting tree species with low root competitiveness (eventually supplemented with shoot pruning), trees with complementary root distribution to the crops, reduction in root density by trenching or tillage and rotations (compared with tree-crop combinations).

Professional reflections and recommendations

The coconut-based agroforestry system with MP's and understorey spices is widely adopted in this region. The main reason is the social, economic and ecologic support of this system. Economic superiority is mainly due to low capital and labour costs and increased value of high-value crops. The diversified range of products from a given area increases self-sufficiency and reduces risk to income. Thus there is great potential for the success of this agroforestry system. Study of interaction between different components and adoption of suitable cultural and management practices to minimize below- and aboveground competition will further improve acceptability, productivity and economic viability of the system. Further efforts are required to develop management practices in participation with farmers that will maximize complementary interactions and resolve the location-specific constraints to widespread adoption of this technology. Financial institutions should be encouraged to ensure cash credits for farmers adopting agroforestry, especially during initial years until the perennial trees start yielding. Overall, there is a great potential for large-scale adoption of this system.

7.3 Improved fallow innovation for soil fertility improvement in western Kenya

Improved fallow technology found in the wet lowlands has been widely adopted by farmers in western Kenya to improve soil fertility. The main species being used are *Tephrosia vogelii* and *Crotalaria grahamiana.* Farmers have recorded huge increases in maize yield during subsequent seasons following the fallow period.

Nature of the innovation

Traditionally, shifting cultivation with long fallow periods was practised to restore soil fertility, but with increased population pressure, fallow periods have been reduced and are no longer effective in maintaining soil fertility (Sanchez 1995). The term 'fallow' as conventionally used refers to agricultural land lying idle, either abandoned or as a means 'to rest tired soils' (Sanchez 1999). A natural fallow is land resting from cultivation, usually used for grazing or left to natural vegetation to restore soil fertility lost from growing crops (Nye and Greenland 1960). Improved fallows, on the other hand, consist of species, usually legumes, planted deliberately with the primary purpose of enriching soil within a shorter period than with natural fallows. This is mainly through N_2 fixation when N_2 fixing trees are used, deposition of recycled nutrients through litter fall, or when biomass harvested at the end of the fallow period is incorporated into the soil (Sanchez 1999). Through collaborative research between the Kenya Forestry Research Institute (KEFRI), the World Agroforestry Centre (ICRAF) and the Kenya Agricultural Research Institute (KARI), improved fallow technology was developed and farmers in western Kenya have adopted it as a means to improve soil fertility. The fallow species are leguminous trees, shrubs or herbaceous cover crops.

Farmers are using improved fallow technology as an alternative to inorganic fertilizers to improve soil productivity. The recommended fallow period for the improved fallows is one season, during the short rains, when yields are lower and less reliable than during the long rains (Rommelse 2001a). Thousands of farmers in western Kenya are now practising improved fallows and have increased their crop yields tremendously. The tree species or shrubs used for the fallows are selected based on farmers' preferences. Commonly used are the fast-growing *Tephrosia vogelii* and *Crotalaria grahamiana*. After improved fallows of such fast-growing species, maize yields can be twice as much as with continuously cropped maize with no fertilizer added. Farmers tend to replant improved fallows every season, either on the same plot or by shifting plots.

Justification of profitability

Large quantities of N (100–200 kg N ha^{-1}) can be accumulated in situ by improved fallows and returned to the soil as leaf and root litter (Giller and Wilson 1991; Giller et al. 1997) mainly by retrieving inorganic N from subsoil layers (Hartemink et al. 1996). The increased N consequently results in increased yields of the crop following the fallow phase. Qualitative analysis in farms that had adopted improved fallows in western Kenya indicated that farmers were pleased with the maize yield responses to fallows because they realized progressive increased yields (Omosa et al. 2002). However, the yield response of crops following improved fallows normally depends on the biomass and N accumulation of the fallows (Phiri et al. 1999). Fallows of only 6 months duration typically accumulate N to produce a yield response of the subsequent season while longer-duration fallows, 2–3 years, accumulate larger quantities of N and provide a residual effect on two or three subsequent crops (Szott et al. 1991).

An economic analysis by Swinkels et al. (1997) reported that farmer assessments indicated that improved fallows almost always doubled on-farm maize yields, with yield increases of 100–200%, although economic returns vary for different farmers. As hiring labour is common in the area, even among farmers with low yields, some farmers grow maize at a loss and would financially gain by leaving land fallow. The foregone maize yield during the fallow is partly compensated by the savings in crop labour and other inputs and therefore becomes more profitable (Swinkels et al. 1997). Data also indicate that poor households use improved fallows at a much greater rate (30%) than they do fertilizer (8%), although on average, the size of fallow plots remains small, at 440 m^2 (Swinkels et al. 1997). These authors reported that, because improved fallows requires less labour than continuous cropping, the break-even maize yield for improved fallow, compared with continuous maize, was generally lower when the analysis was based on returns to labour instead of on returns to land. The saving in labour combined with greater productivity leads to significantly higher returns to labour from improved fallows than from continuous cropping with no nutrient inputs (Place et al. 2004).

A synthesis across all trials undertaken at Maseno found improved fallows to be more profitable than continuous cropping and natural fallow practices. Also, results of on-farm trials showed that a crotalaria fallow of 7 to 9 months was more profitable than continuous maize cropping with returns to land 45% higher and to labour 33% (Rommelse 2001b). Crotalaria fallow with 50 kg P ha^{-1} added gave return to land of KES 26,250 (USD 350) compared with KES 14,175 (USD 189) from continuous cropping with the same fertilizer added.

In a farmers' workshop held in Siaya District to discuss the effect of improved fallows (Place 1999), farmers identified saving labour as a major effect. Households were reported to like improved fallows because annually they saved labour. Farmers noted that labour for land preparation was saved because soils were easier to work following improved fallow periods. In eastern Zambia, also, farmers reported that they liked improved fallows of *Sesbania sesban* because the soil on the land planted with improved fallows was easy to work on (Kwesiga et al. 1999).

Apart from improving crop yields by increasing soil fertility, shrubs and trees used in improved fallow systems provide firewood, contributing significantly to the fuelwood needs of many households in western Kenya, where the shortage of fuelwood is severe. A 2-year sesbania fallow can produce 10 t ha^{-1} of fuelwood (Sanchez 1995) and therefore use of sesbania fallows can avoid the need for gathering fuelwood from adjacent forests or woodlands and the drudgery of transporting it to the household.

Another benefit of the planted fallows is reduction in the amount of weeds. This is because the fallow species grow fast and prevent weed species from growing, which in turn reduces the amount of time required for weeding. The parasitic weed striga (*Striga hermonthica* and *Striga asiatica*) infests an estimated 160,000 hectares of farmlands in western Kenya (Oswald et al. 1996). Improved fallows help control these weeds by stimulating the germination of weed seeds in the soil. The germinated plants soon die because the fallow species are not their natural hosts (suicidal germination), and this consequently reduces the number of striga seeds in the soil. Woody fallows of *Sesbania sesban* reduced the occurrence of *Striga asiatica* in subsequent maize crops in Zambia (Kwesiga et al. 1999) and reduced the seed pool of *Striga hermonthica* in western Kenya by promoting suicidal germination and by increasing soil N (ICRAF 1996; Gacheru et al. 1999).

Tephrosia and crotalaria are legumious shrubs often preferred for imporoved fallows for enriching the soil because they produce biomass in quantity.

Agroforestry components and interfaces

According to Sanchez (1995), sequential improved tree fallow systems are more robust than simultaneous agroforestry systems such as alley cropping. This is because competition for light, water, and nutrients between the improved fallow and the crop is minimized by the relay intercropping or sequential agroforestry systems. Also, the deep-rooted fallow species are able to use subsoil water and nutrients inaccessible to annual crops during the dry seasons and droughts (Hartemink et al. 1996; Torquebiau and Kwesiga 1996). Consequently, much of the biomass accumulation of improved fallows can occur during dry seasons and during unreliable short rainy seasons.

An improved fallow technology is more efficient in improving the chemical and physical properties of the soil than a natural bush fallow. This is because in addition to supplying nitrogen by the N_2 fixing legumes, improved fallows supply other nutrients to crops. A sesbania fallow alleviated K deficiency in a subsequent maize crop in western Kenya (ICRAF 1998). Fallow species retrieve nutrients from subsoil, particularly mobile ions such as K on high base status soil, and then recycle them through fallow vegetation to subsequent crops. Improved fallows also improve soil physical properties. For example, use of improved fallows in western Kenya resulted in improved soil physical properties and water retention (Torquebiau and Kwesiga 1996). Similarly, Chirwa et al. (2003) observed a high infiltration rate and cumulative water intake in improved fallows of sesbania and pigeon pea due to improved soil physical properties in Zambia.

Litter fall from fallows provides C as an energy source for soil microbes to enhance nutrient cycling (Palm et al. 1997) and soil C sequestration (Sanchez et al. 1999). Farmers interviewed in a formal survey also mentioned soil erosion control as another ecological benefit of improved fallows (De Wolf and Rommelse 2000). On a number of occasions, farmers had modified the improved fallow technology. One common case was adopting fallows of mixed species, for example, crotalaria and tephrosia; the former for its high biomass and ground cover and the latter for its pest control.

Minimum inputs

First, the most appropriate improved fallow species needs to be identified and sources of the germplasm identified. Second, improved fallows technology is knowledge intensive technology, and farmers need to be trained before they can adopt it. Third, improved fallow technology requires additional labour for sowing the tree seeds, cutting the fallows, and preparing the land following the fallow period. However, a fallow of 1000 m^2 implies additional labour of one day for cutting, one additional day person-day labour for land preparation, and a couple of hours for direct sowing of tree seeds. The labour is then freed up during the season in which the fallow is allowed to grow in the field (Place et al. 2004).

While the tree can provide large amounts of nitrogen through biological fixation, it cannot manufacture phosphorus and potassium and only recycles modest amounts from the subsoil (Jama et al. 1998). Thus for soils that are depleted of these two elements, it will be necessary to apply these nutrients. Farmers in western Kenya have been testing and using a rock phosphate that comes from northern Tanzania that is cheaper than the imported mineral fertilizers.

Agroclimatic zones

In western Kenya, research and dissemination efforts of improved fallow technology have focused on medium to high rainfall areas, covering the districts of Siaya, Vihiga and Kisumu, where rainfall is good. Rainfall ranges from 1200 to 2000 mm per year with two cropping seasons annually: the long rains from March to July, and the short rains from August to November. The short rainy season is traditionally less reliable in terms of total rainfall and length of growing season. The altitude is between 1250 to 1700 m with rather moderate slopes (wet lowland).

Main soil types are Ferrasols, Acrisols and Nitisols with pH of 4 to 6, and moderate to high base status and are of generally good physical structure. In many parts of the region, phosphorus is the major limiting nutrient, but nitrogen and potassium limitations are also prevalent (Shepherd et al. 1996; Jama et al. 1998).

Major factors that make the innovation successful

Owing to low soil fertility, most households in western Kenya produce maize enough to last for only 3 to 5 months of the year, forcing families to either buy maize from the market or endure hunger on a poor diet (Rommelse 2001b). Use of organic fertilizer such as animal or plant manure is limited and use of commercial inorganic fertilizers is constrained by both the lack of money to purchase them and the unreliable returns to packages recommended with hybrid crop seeds. Traditionally farmers would restore soil fertility by leaving part of their land uncultivated for many years but due to population pressure fallow period have reduced, lasting one to two seasons only (Rommelse 2001a). A survey carried out before introduction of improved fallows to farmers showed that about half of the farmers left their land fallow for at least one season, mainly for soil fertility restoration (Ohlsson and Swinkels 1994), but since the fallow periods did not last long enough to improve soil fertility sufficiently, the yields of subsequent crops remained low. Because farmers were already aware of the soil fertility and food security problems facing them, they easily adopted improved fallows.

In addition research identified many leguminous plants that were suitable for use in establishing short-duration fallows in western Kenya, giving farmers a range of species to choose from. These included both woody species such as *Sesbania sesban*, crotalaria and tephrosia and herbaceous legumes

(*Canavalia ensiformis*, *Dolichos lablab* and *Mucuna pruriens*). However in western Kenya the key species being used are *Crotalaria grahamiana* and *Tephrosia vogelii*.

Direct and indirect beneficiaries

Farmers derive many benefits from the improved fallows technology. Farmers' evaluation of the benefits they obtained indicated that improved soils and crop yields were the most important, followed by fuelwood and reduced growth of weeds (Rommelse 2001a). However, women rated improved fallows significantly higher than men did on improving soils and on reducing weeds. This finding reflects that women spend much more time in cropping activities than men and would thus be more likely to ascertain and appreciate the effects of improved fallows on soils and weeds. Also, improved fallows appear to be a gender- and wealth-neutral technology (Place et al. 2004).

The break-even maize yield increase following improved fallow depends on the amount and opportunity cost of the saved labour and the amount and value of the crop forgone. The lower the base maize yield is and the higher the opportunity cost of the household labour, the more attractive improved fallows become (Swinkels et al. 1997). When labour is scarcer than land, improved fallow requires only a low amount of yield increase to become more profitable than continuous cropping. Therefore, improved fallows may be of greatest benefit to poor households that have little labour available per unit of land (Swinkels et al. 1997).

Fuelwood is the main energy source for cooking in western Kenya and gathering it is the woman's responsibility (Swinkels et al. 1997). Women thus benefit from fuelwood harvested from improved fallows.

Upscaling strategies

Initial efforts at disseminating information on the improved fallows focused at the beginning of 1997 on a pilot area that involved 17 villages mainly in the districts of Vihiga and Siaya (Place et al. 2004). According to Franzel (1999), strong institutional support appears to be the most important factor affecting farmers' ability to establish and maintain fallows. Therefore a successful scaling-up strategy had to have a technical aspect of improved fallow technology and germplasm supply. In western Kenya, the research and extension partners' scaling-up strategy mainly concentrated on making information and germplasm available. Activities included

- Establishing village committees that facilitated information flow between community and research staff

- Training field technicians, who were made available to many villages for a period of 2 years
- Procuring germplasm for distribution to farmers
- Training extension and development organizations
- Organizing field days that were first conducted at researcher-managed sites and then later on farmers' own fields
- Developing extension materials for use by extension and development agents

Partnerships were developed with the Ministry of Agriculture, many NGOs such as CARE-Kenya and VI-Agroforestry Project–Kitale, church groups, and many community-based organizations (Place et al. 2004). These partnerships were effective because they catalysed other organizations to develop interest in this work, most of whom integrated improved fallow technology options into their existing programs. They therefore assisted in disseminating improved fallow technology using their existing approaches to development, including training primary contact farmers, holding field days and arranging exchange tours.

Although thousands of farmers in western Kenya are now practising improved fallows, resulting in important increases in their crop yields, a number of factors still hinder large-scale adoption of this technology (Sanchez 1999; Franzel 1999; Place et al. 2004). These include 1) households that are landless or nearly landless so are unlikely to leave even modest areas uncultivated, 2) situations with intensive livestock production systems where non-cropped land may be put under fodder production, 3) perennial cropping systems, such as coffee-growing areas, 4) farmers who do not recognize soil fertility as an important problem to give it the priority it deserves, and 5) inadequate supply of germplasm of improved fallow species and accessions.

Institutions promoting the innovation

Many institutions have been involved in developing and successfully disseminating improved fallow technology in western Kenya. Initial research was conducted by three institutions: Kenya Forestry Research Institute (KEFRI), Kenya Agricultural Research Institute (KARI) and the World Agroforestry Centre (ICRAF). based at KEFRI's Maseno Regional Research Centre. These institutions worked closely together, and their different disciplinary orientations complemented each other. Initial trials (on-station and on-farm) were established in 1991 and in 1999. Following promising results from these trials and results from Zambia, the directors of KEFRI, KARI and ICRAF decided to intensify efforts in research and dissemination of improved fallows.

In the dissemination phase many partners were involved: the Ministry of Agriculture, NGOs such as CARE-Kenya, Kenya Woodfuel Agroforestry Project in Busia, Hortiquip in Vihiga, Siaya community development project in Siaya, VI-Agroforestry Project in Kitale, Africa 2000 in Vihiga, church groups and many community-based organizations.

Research questions and knowledge gaps

Though dissemination of improved fallows using a multiple of partners was successful, it is not fully known which extension methods will work best under local conditions. Research must therefore be conducted on the appropriate strategies for disseminating improved fallow technologies.

The effects of scale in both time and space must be better taken into account in both on-station and on-farm research. This means fallows must be treated as systems rather than plots, and sampling schemes should include border effects and the influence of fallows on neighbouring systems that are monitored through time.

The actual income that farmers will obtain from their farms depends on where their produce is sold. Thus the distribution and sale of farm produce should be carefully studied in new areas before the technology targeted towards greater yields is disseminated.

The land-tenure status of farmers is an important factor in determining whether farmers will adopt agroforestry technologies such as improved fallows. At present, it is not known how land-tenure status will affect improved fallow adoption, and this is extremely important, especially in areas where land is controlled by the state.

With regard to extrapolation of improved fallows in other regions, further work is needed to identify more species for improved fallows. Also, greater attention should be devoted to understanding farmers' expectations from and management of fallows. There is a need also to understand how the fallow system will respond to the needs and the constraints in high population density areas, for example, incorporation of research on soil conservation.

Professional reflections and recommendations

Depletion of soils through loss of soil nutrients is a worldwide problem affecting 135 million hectares, mostly in Africa. This is particularly so for the eastern African highlands where soil depletion is a common feature of small-scale farms oriented towards food crops and has led to low labour and land productivity. Organic inputs like manure are limited in availability and the use of inorganic fertilizers is constrained by the high cost. Technologies are required that are not only able to recover depleted soils of small-scale farms but also offer attractive returns per day of labour.

The improved fallow technology, developed and in use by farmers in western Kenya, is a profitable way of replenishing soil fertility. At the plot level, its main benefits are improved maize crop performance, increased soil organic matter, improved tilth and colour of the soil, soil conservation and elimination of serious weeds. Although farmers immediately see the increased yields, they may not so quickly recognize the improved soil fertility. However, when farmers using improved fallow technology were monitored, they reported realizing tangible benefits.

Improved fallows appear to be a technically effective and financially profitable technology that is attractive to poor households with little cash available for investment. This conclusion is made from the fact that a significant proportion of households in areas of western Kenya have adopted the improved fallow technology since its dissemination in the late 1990s. Widespread expansion of improved fallows and use can increase food security, help alleviate poverty, and increase agroecosytem resilience.

However, it is best to view improved fallows as a component of a broader integrated strategy to manage soil fertility rather than a sole solution to soil fertility problems. Farmers will also use manure, compost, other organic materials and to some degree, commercial fertilizers. Improved fallows in this case have a comparative advantage in that they are relatively labour saving, they have a low risk of failure in supplying nutrients on the farm (because of extensive rooting systems), and they offer some by-products.

There is potential for scaling out improved fallows to other areas but there are certain challenges. It is not a traditional practice and therefore must be learned, especially because it is a knowledge-intensive technology. For example, there are several stages in managing fallows effectively such as choosing the species, establishing the fallow, and cutting and incorporating the biomass into the soil. Technical backup may be important for each of these stages, as well supplying the germplasm.

Chapter 8 Agroforestry innovations suitable for Dry Mid-highlands

8.1 Tef and acacia integrated agroforestry system, Ethiopia

Nature of the innovation

An agroforestry system based on a cereal and a leguminous tree is one of the agroforestry systems practised in the Rift Valley region of Ethiopia. *Acacia albida* scattered on farmland is believed to have ecological and economic interaction with cereal crops. Major crops associated with trees in this system are tef (*Eragristos tef*), haricot bean, wheat and maize. This system has been developed with farmers' innovation without intervention of government or non-governmental institutions.

Acacia albida trees leaf and fix nitrogen in dry seasons when the crops in the fields are harvested. They shed their leaves to reduce shading the crop during its growing season.

Farmers mostly do not plant the tree but retain and protect naturally grown wildings from livestock, particularly from goats. They lop the trees at summer periods so as to minimize shading to agricultural crops grown underneath. This is done once every 2 years. The lopping removes the entire canopy structure, which initiates sprouting from meristematic tissues. In a few cases, farmers fell the tree completely for charcoal and construction. They do this only after they have ensured that there are regenerated wildings. Farmers lop the branches heavily by axe, unmindful of damage to regeneration potential.

Farmers also collect pods from the trees. During winter seasons the trees produce pods that serve as fodder, mainly for goats. The lopped material is also used for firewood and fencing posts for households. Farmers use substantial amounts of the agricultural crops for household consumption and little amounts for sale.

Justification of profitability

An agrosilvipastural system is the major interface in an acacia–cereal-based agroforestry system. *Acacia albida* sheds its litter and improves the nutrient status of the soil. It also fixes nitrogen, enriching the site and thus improving productivity of agricultural crops grown beneath it. Moreover, the tree has a deep root system that uplifts underground water to the upper soil surface, thereby improving the moisture status of the site. Research has shown an increase of 56% in crop yield under an *Acacia. albidia* tree canopy in the eastern highlands of Ethiopia. However, key informants in the present survey said that yield under the tree was about the same as that beyond the tree canopy. Acacia trees also provide nutrient-rich pods, which can feed goats, especially during the dry season when fodder is in short supply, thus producing more milk and meat. Goats also browse the leaves and thorny twigs to satisfy their feed needs. The tree provides good shade for livestock that graze under it when there is no crop.

Each component in this positive synergetic interaction of trees with livestock and cereals can increase the income of households, mainly from the sale of agricultural and tree products. There are local criteria to evaluate quality and grading of tef and maize crops to fetch a good price. For instance, the colour and purity of tef and the purity of maize the consumers take as measures of quality. White tef with no soil or sand will get a better price, as will clean maize. However, transportation costs, unfair prices given by intermediaries, and lack of market information are some of the problems farmers mention.

Farmers also earn good income by selling charcoal and firewood. Local by-laws are formulated to require a permit to produce charcoal. When farmers intend to uproot their trees to make charcoal, they must apply to the local administration (peasant association) for a permit. Then the development agent will ensure that at least two wildings are grown on their fields. If not, they are told to plant two seedlings as a replacement. However, they do not need a permit to lop trees for firewood or fencing posts.

Once farmers get permission they select mature trees that are best suited for charcoal production. They prefer to make charcoal from *Acacia tortilis*, as they say it has higher caloric value than charcoal from *A. albida,* although the latter is found in larger quantity on their farms. They uproot the tree, bury it completely and set a fire. They attentively observe the change in smoke colour to ensure that the wood is fully burned. When the smoke turns blue, the charcoal is ready. Farmers sell the charcoal in sacks to passers by at the roadside or transport it by donkey cart to nearby markets where it fetches a better price. The selling price of a 50-kg sack of charcoal is about ETB 25–32 (USD 2.87–3.67), depending on the season. The price rises in the rain season, when people need more for heating the house. Charcoal from fully burned wood, high in caloric value and burning with less smoke, is sold at a better price. Income from charcoal and firewood sales serves during the annual risk period before crops are harvested.

Agroforestry components and interfaces

Interactions among components in this system are shown in table 8.1.

Minimum inputs

The district Office of Agriculture provides improved varieties of maize, tef, wheat and fertilizers on credit, with 25% down payment and the remainder to be paid post-harvest. Farmers provide local varieties of haricot bean and livestock. Also, they use their family labour for planting and weeding. They also pool their labour with colleagues and neighbours to harvest and transport produce from the field to the home. In a few cases, hired labour is used for mowing and processing the cereal crops. Farmers manage *Acacia albida* with their own techniques. Recently, the office has started delivering *Schinus molle, Acacia saligna* and *Sesbania sesban* seedlings to diversify the tree species in the area.

Furthermore, the Office of Agriculture provides technical advice on how to apply fertilizers, sow seeds in various patterns, and fence regenerated tree seedlings. However, it gives no technical advice on how to lop trees to hasten growth and produce high biomass. No technical advice is given on how to produce good-quality charcoal for better income.

Table 8.1. Interface among components in tef and acacia agroforestry system

	Acacia albida	Tef	Maize	Wheat	Haricot bean	Livestock
Acacia albida	No interaction since they are found sparsely apart	Less fruiting of tef crop sown underneath Shading effect Competition for nutrients Soil fertility maintained and nitrogen fixed	Soil nutrients maintained and crop productivity improved	Shading effect Soil fertility maintained and nitrogen fixed	Nutrient status of organic matter maintained	Leaves and pods serve as feed for goats in dry period when feed is scarce Shading effect
Tef	Competition for moisture and nutrients with surface roots	Competition for moisture and nutrients with surface roots	No interaction since they are planted in relay cropping (first maize then tef)	No interaction since they are not planted together	No interaction since they are not planted together	Tef straw after postharvest used for livestock feed
Maize	Competition for moisture and nutrients with surface roots	Residual effect on productivity of tef—provides nutrients through roots left over after harvest	Competition for nutrients and moisture	Residual effect of nutrient release from leftover maize roots	Competition for moisture and nutrients if the haricot is intercropped	Stalks as well as leaves used for feed
Wheat	Competition for moisture and nutrients with surface roots	No interaction since they are planted separately	No interaction since they are planted separately	Intraspecific competition	No interaction since they are planted separately	Straw used for livestock feed during dry period
Haricot bean	Competition for moisture and nutrients with surface roots	Residual effect of nitrogen fixation	Root competition if intercropped; otherwise no interaction	No interaction	Intraspecific competition	Feed for livestock
Livestock	Promotion of regeneration by seed passed through digestive tract Browsing of seedlings	Provision of cow dung, which serves as organic fertilizer	Provision of cow dung, which serves as organic fertilizer	Provision of cow dung, which serves as organic fertilizer	Provision of cow dung, which serves as organic fertilizer	Competition for grazing or browsing resources

Agroclimatic zones

Located in the Rift Valley, the area is characterized by moisture stress that affects crop production. It falls in dry mid-highland agroclimatic category. It is 88 km south-east of Addis Ababa, the capital city of Ethiopia. Rainfall ranges between 500 mm and 600 mm per annum with altitude 1600–1630 m and temperature 25–28 °C.

The soil type is sandy loam with low water-holding and high infiltration capacity. *Acacia albida, Balanites aegyptiaca* and *Acacia tortilis* grow in the area, with *A. albida* dominant. Fruit trees scarcely exist. The farming system is rainfed and intensive. Farmers use inorganic fertilizers to improve crop production. Major crops grown, for consumption and sale, are tef, maize, wheat and haricot bean.

Major factors that make the innovation successful

The system has worked effectively because it is easy to implement. *Acacia albida* grows naturally on the site. It tolerates moisture stress and the temperature of this semi-arid area. No monetary or labour cost needs be expended for extracting seed, planting or raising the wildings of this species. Labour is needed for fencing, lopping and complete harvesting of trees for charcoal production. Farmers explained that agricultural crops like tef, wheat and maize production need at least 5 times more labour than tree crops. For instance, for tef production the land must be cultivated at least 3 times before sowing. Then labour is needed for weeding, mowing and threshing.

Farmers need improved varieties and inorganic fertilizers for agricultural crops. They have indigenous knowledge for managing trees but need more technical advice on the pattern of improved seed sowing as well as the rate and time of application of fertilizers and insecticides or herbicides. Farmers in the area strongly believe that trees on the farm provide household income when the need arises. Thus, they consider acacia trees a living bank.

Farmers pool (cooperate) their labour only to transport cereal products from the farm. Otherwise, they use family or hired labour to prepare the land, tend the crop, mow, lop and thresh. There are three extension agents per peasant association, who provide technical advice and deliver technological inputs with respect to natural resource management, crop agronomy and livestock husbandry. This, as well as the role of acacia, has helped maintain soil fertility and improve production.Farmers are also given credit for purchasing inorganic fertilizers and improved varieties.

Farmers mostly sell their products individually directly to consumers or wholesalers. They transport and sell wood and crop products at the roadside, which is on the highway to Addis Ababa. They get market information from their colleagues and neighbours.

Direct and indirect beneficiaries

Men and women both benefit from the innovation. Both can sell the crop and tree products, except for firewood, which is women's responsibility since the income from its sale is considered low. Men (household head) have the power to decide about how to sell most products and what to do with the money generated.

All age groups benefit directly or indirectly from the income that the sale of charcoal and cereal crops generates. The youth are deeply involved in charcoal production. As most have no land of their own to cultivate crops, they fell trees on their parents' farm to prepare charcoal and sell it to cover school fees and to buy clothes.

Although the innovation benefits most farmers, they do believe that rich households benefit more than middle-class and poor farmers. The rich farmers get large amounts of income from the sale of charcoal and cereal crops. They also rent with cash the farms of others for 2–3 years to cultivate the land. Middle-income farmers benefit through the sale of cereals and charcoal. The poor mainly benefit from firewood and charcoal sales and by working for others as day labourers. According to local criteria for wealth, the rich farmer has at least 5 hectares on which he pays tax. He also rents farms from other farmers and has at least 8 pairs of oxen. Farmers in the middle category have 1 hectare with 2–3 pairs of oxen and do not rent land. Farmers in the poor category have less than a hectare of land, no oxen and work for others as day labourers. This implies that rich farmers have more trees per unit of farm than do the middle and poor categories. However, the poor farmer benefits from the innovation as it subsidises family consumption and averts the risk that would come were crops to fail.

Upscaling strategies

The innovation has been widely replicated among farmers in the area. Farmers stated that retaining scattered acacia and acacia trees on the farm with cereal crops has long been practised. It seems that the innovation is being perpetuated. Farmers are well acquainted with techniques for managing trees on the farm. They lop the tree every 2 years to reduce the negative effect of trees on the crops because of shading. The trees are well spaced (on average 15–20 m), giving crops good exposure to solar radiation and minimizing competition.

Population increase is one factor contributing to continuation of the innovation. Currently human population in the woodland is increasing at an alarming rate and agricultural land is expanding into the woodland. It is now unusual to find dense woods; only a few scattered trees are left on farms. Easy availability of market for charcoal now encourages farmers to adopt the innovation. They fetch good income from its sale, particularly in the rain season, when urban dwellers need more fuel to heat the house. The area is located near the highway, and population of the nearby town is increasing; thus the demand for energy for cooking and heating will rise. This in turn will result in an increase in the price of charcoal—implying that more farmers will develop a good attitude towards retaining more *A. albida* trees on their farms.

Multiple use of the innovation also attracts farmers. So long as they get firewood, fencing and construction materials, fodder (mainly during the dry season), maintain soil fertility and get income, there is no way that they will abandon the innovation. Moreover, once the trees mature there is less competition for nutrients and moisture between the trees and the cereal crops grown under them. This is because the trees use the subhorizon whereas the crop uses the upper horizon of soil. The trees also bear leaves and pods (fruit) during the dry period, indicating a potential agroforestry species for fodder at that time. It has a good seed bank for regeneration and dormant buds for sprouting that become active if the aboveground biomass is harvested or consumed by fire.

Regulation by the peasant association on harvesting tree products also ensures replacing the cut trees. The peasant association has formulated a regulation that states, 'Anyone who wants to cut a tree from the farm shall plant or retain at least two seedlings or wildings.' This will help to perpetuate the innovation on a wider scale.

Institutions promoting the innovation

Farmers are the main actors of the innovation. They began the practice and have maintained it for several years. Farmers contribute labour, land and capital for the purchase of inputs. The Office of Agriculture through its development agent is acting as a facilitator. It provides technical advice and material inputs to facilitate the activities. Each peasant association is expected to assign one development agent (DA) for crops, livestock and natural resource management each. The peasant association acts as a collaborator. This is one of the administration units at grassroot level in the government structure. The role and level of participation of each institution is described in table 8.2.

Table 8.2. Institutional role and level of participation

Institution	Roles and functions	Type of participation
Development agent (Office of Agriculture)	Provide improved crop varieties and inorganic fertilizers on a credit basis as well as technical advice Provide a few exotic species like S*chinus molle* Regulate forest movement of products	Facilitation
Peasant association	Formulate by-law to regulate cutting trees on farm Provide-tree cutting permit	Collaboration

Research questions and knowledge gaps

Farmers have knowledge gaps and need research on production. They do not know efficient techniques for producing charcoal. They have not been provided with sufficient material and technical assistance to know how to cope with moisture stress. In other words, alternative moisture retention measures have not yet been practised to boost productivity. Information is inadequate on yield analysis with and without shade, and on the effect of the tree on adjacent cereal crops at different radii from the tree. Nor has research been done on how many trees should be retained per hectare or farm and what the optimum spacing is between trees to get sustainable tree biomass and income per unit of time.

Farmers have knowledge gaps and need research on adding value to tree as well as crop products. There is inadequate intervention with improved high-value tree species like fruit trees that could be compatible with the area. Farmers do not pay due concern to improving the quality of tree products like charcoal and firewood. The value of cereal crops is also affected by different factors. For instance, farmers store maize and tef crops in the traditional way, indicating lack of post-harvest technology.

The price of crops and tree products fluctuates. This necessitates market assessment on where to sell products to get a good price. Farmers in the remote areas have transportation problems to transport trees as well as crop products. For instance, they are obliged to pay a minimum of ETB 2 for a donkey cart to transport one sack of charcoal from their home to the highway roadside, or they have to carry it by themselves. Yet up to now, no cooperative has been established that organizes farmers to get a better price for their crop and tree products. The Office of Agriculture has given more focus to improved varieties of cereal crops and fertilizers. Less attention has been paid to optimizing and diversifying the product and income from tree products.

Professional reflections and recommendations

Farmers intentionally retain trees on farm to diversify sources of income and satisfy needs for firewood and feed for livestock. As a result farmers have a positive attitude towards scattered trees on the farm and do not completely remove all the trees. Besides, the agroclimatic zone is located in a moisture-stressed area, and crop failures are frequent. Therefore, farmers keep a few trees for emergency use. This implies that trees in the system have potential as a risk-aversion crop that can earn farmers an income to buy food and escape hardship. Moreover, *Acacia albida* has a positive synergistic effect with crops grown underneath. It maintains soil fertility by fixing nitrogen and adding litter fall. This will ensure the sustainability of the innovation.

However, success of the innovation can be enforced by providing good technical advice and material inputs. Farmers lop trees with local axes without giving much attention to where and how to cut the branches so as to promote sprouting within a shorter time. They use traditional methods for making charcoal, which may reduce the quality and quantity that could be obtained per tree. Integration is low of alternative timber or fruit tree species that would support the households. To better this situation professional inputs are needed.

Farmers have already understood the benefits of the innovation and taken advantage of the multiple uses derived from it, encouraging them to continue using it. Moreover, the Office of Agriculture has been structured up to peasant association level. This will enable the farmers to have good access to extension services so as to maximize the diversified outputs and income from each component. Farmers escape the harsh times by selling tree products if crop production fails. Thus, it is more promising that they will retain trees on the farm.

Farmers are not allowed to cut their own trees unless they get permission from the peasant association. This might discourage them from giving newly regenerated seedlings adequate care. Furthermore, they should be allowed to sell their charcoal officially because it is considered as illegal unless permission is given to make it. This might force farmers to sell the charcoal at an unfair price. Thus the income that could have been generated from charcoal sales might be reduced. On the other hand, the increasing demand for charcoal and firewood might tempt farmers to cut a large number of trees. This might affect the sustainability of the innovation.

8.2 Boundary eucalyptus and cereal crops in agroforestry farming systems of Ethiopia

Nature of the innovation

The practice of planting financially lucrative tree and shrub species in Ethiopia has a long history. This practice has also been adopted in several other countries. The Indian experience, where farmers converted most farmlands including irrigated and fertilized plots into eucalypt plantations, stands conspicuously. Farmers in many regions of Ethiopia have taken up managing eucalypt woodlots mainly on available marginal lands. The Guraghe farmers are said to be the latest pioneers in this practice and draw substantial proportion of their livelihoods from the innovation. Eucalypt plantations are mainly established on lands potentially less suitable for other uses. Farmers fully perceive the strong competitive nature and exceedingly fast growth rate of eucalyptus species. Eucalypt woodlots are thus often confined to marginal lands and plots farthest away from home gardens. In readily accessible mid-highland and highland areas with developed pole markets, woodlots are also established on grazing lands and along boundaries separating grazing lands.

Farmers in the highlands often face severe land scarcity and thus concentrate eucalypt planting on moderately to highly degraded lands that

Typical boundary planting of eucalyptus in croplands in the Ethiopian highlands.

are unsuitable for crop cultivation. These are mostly sloping, gullied and severely eroded sites. Farmers have extensive knowledge about establishing and tending eucalypt woodlots. They raise seedlings in relatively fertile spots close to perennial watercourses or produce them in a small seedbed within the house compound, giving them regular watering and adequate shading. Lifting the soil around the root system with a local plough prunes the roots. Root pruning is done about one month before field planting to initiate new root development. Plantings sites are prepared first by manual digging, later by breaking earth lumps, and finally by digging pits. Breaking earth lumps can be ignored on fertile soils.

Seedlings are planted at an angle to maximize survival rates. Spacing between seedlings varies with site quality. Woodlots on degraded and sloping sites are often managed for small-sized poles and thus are grown at close spacing. On relatively more fertile sites, big poles and trees are grown at a relatively wider spacing. Successive tending operations include straightening slanting seedlings about one month after planting, weeding and manual ploughing in October, and fencing against animal interference. Harvesting is done 3 to 5 years after planting, depending on site quality, urgency of need for cash, and type of product needed. Existing plantations are usually generated by coppicing. Trees regenerated from stumps can be inherited by the next generation. Farmers often face the dilemma between clear felling for adequate coppice regeneration and gradual harvesting to minimize risks and cope with unforeseen contingencies.

Justification for profitability

The practice of eucalypt woodlot or boundary plantation management meets various household needs. Wood products from these plantations provide the critically needed household fuelwood and construction materials. On-farm production of both materials saves a substantial amount of cash that otherwise would have been invested for their procurement. Provision of fuelwood from eucalypt plantations saves animal dung for soil fertilization, which makes enset cultivation particularly possible in the region. Using animal dung for crop cultivation in turn saves the expense of acquiring chemical fertilizers and ensures sustainable agricultural production. Moreover, using high-energy crops like eucalypt plantations on small plots of farmland for household fuelwood production has substantial economic advantage. Diversion of animal dung from fuel to soil fertility maintenance adds many more macronutrients to the soil than an equivalent size of eucalypt plantation removes from the ecosystem. The combined effects of eucalypt plantation establishment and exclusion of chemical fertilizers from home gardens significantly improve local environmental conditions.

Financial viability of eucalypt woodlots has been confirmed by several studies. Eucalypt poles are harvested for various products 3–5 years after planting. Poles are often sold to local brokers appointed by major traders. Farmers sell one big pole (5-year-old) at the farm-gate price of ETB 4 to brokers. The intermedairy brokers sell to the main traders at a unit price of ETB 5. Main traders pay the local tax and transportation fees and pass the product on to retailer traders in Addis Ababa. The final consumer price of individual poles in Addis Ababa is ETB 16 or more.

Big trees 10 to 20 years of age are mostly sold to local consumers for house construction. Farmers rarely possess big-sized trees in commercial quantity. Standards in coppice stands are allowed to grow to big sizes for contingency purposes and for house construction. Big-sized trees often serve as a saving account that can be liquidated any time an important demand for cash arises. When there is no market demand for construction wood, they can also be split and sold for fuelwood. In most cases, eucalypt woodlots are grown on land plots that are least suited to crop cultivation or grazing. There is thus little competition between the plantations and other productive farm practices. Eucalypt woodlot management represents an effective technique to use the productive potential of marginal lands. There will thus be guaranteed continuity of the woodlots since no other land-use system makes better combined economic and ecological use of such marginalized lands.

The rising demand for eucalypt poles proves that for the near future the practice is sustainable. The current rate of urban expansion is expected to increase the demand for eucalypt poles. This will also involve a gradual increase in market price and the benefits that farmers accrue from the innovation. Eucalypt plantations, both woodlots and linear configurations, require relatively less labour and financial investment than other tree plantations. Initial site preparation and planting of seedlings make up the major investment in establishing and maintaining a eucalypt plantation. One or two weedings and soil cultivation operations are required during the first year. Subsequent management work includes harvesting, coppicing, protecting against animal damage, and infrequently, handling stumps. Most silvicultural operations other than preparing the seedbed can be performed by family members, even young children.

Most of the federal regions of Ethiopia have now formally or informally banned on-farm eucalypt planting. The bans have mainly emanated from worry that the species severely depletes soil nutrients and moisture and thus threatens the long-term productivity of grazing and farmlands. Another major concern appears to be worry over the gradual expansion of eucalypt woodlots, which, according to regional officials at various levels, would invade rural landscapes and thus deprive farmers of their productive agricultural lands. It would, however, be naive to fully accept these assumptions unless they are founded on scientific research findings. Farmers growing eucalypts know well its economic and ecological effects and how to abate and mitigate the undesirable effects. Farmers grow eucalypts because the benefits they accrue outweigh the disadvantages and no alternative species with better economic and ecological values is available.

Agroforestry components and interfaces

Eucalypt woodlots are usually established at the far side of the homegarden to reduce competition with food and cash crops. Synergistic interactions of eucalypt plantations are thus often confined to grazing lands (grasslands) and grazing animals. Eucalypt woodlots are known to reduce the growth of grass along the boundary. Reduction in grass yield is pronounced in the narrow strips surrounding the plantations. However, overall productivity of the land significantly increases from fast growth and high biomass productivity of the woodlots.

Linear eucalypt plantations are more popular in the highlands where land scarcity is more serious. Under these conditions, some degree of disturbance to food crops is commonly tolerated in anticipation of higher overall plantation productivity. Farmers confirm that eucalypts compete strongly with most agricultural crops. Eucalypt plantations also reduce the productivity of adjacent grazing lands and fallow lands.

Thus planting along the farm boundary requires intensive negotiation and agreement with neighbouring landowners. If crops are cultivated on adjacent fields, the law prohibits planting eucalypt seedlings on the boundaries between them. A farmer who wants to plant eucalypts along uncultivable land boundary needs to persuade neighbouring farmers to plant eucalypts on the adjacent boundary. Otherwise, a resulting complaint could legally incriminate the farmer who planted along the common boundary. An alternative is to leave an open area of about 10 m from the border. However, even this practice does not totally exclude competition from big trees as they cast shade on areas several times their height during the morning and afternoon hours. Hence, there is no legally fixed distance within which farmers can safely plant trees near crop fields of neighbouring farmers. It is thus highly dependent on mutual agreements and understandings.

Farmers rarely plant eucalypt seedlings on the borders of crop fields. Such linear plantations must be intensively managed to minimize competition for solar radiation, soil nutrients and moisture, and growing space. Management operations aimed at reducing competition from eucalypts include regular harvesting and pruning or lopping of branches. Farmers also dig a shallow trench about 1 m deep between tree lines and crop fields to restrict lateral root extensions. Another alternative could be to leave an open strip of about 2–5 m between the tree lines and crop fields.

Table 8.3 summarizes the most significant interactions between major components of the system.

Table 8.3. Significant interactions between major components of the eucalyptus–field crop system

	Eucalyptus	Enset	Barley	Potato	Horse bean	Field pea	Wheat
Eucalyptus	Competes for space	Roots compete for soil moisture	Suppresses crops along eucalypt lines	Suppresses crops along eucalypt lines	Suppresses crops along eucalypt lines	Suppresses crops along eucalypt lines	Suppresses crops along eucalypt lines
Enset	Shades out young seedlings	Competes for growing space	Shades out the crop	Reduces growth and yield	Shade reduces yield	Shade reduces yield	Shade reduces yield
Barley	Little impact	No impact	Optimum spacing	Competes for space	Competes for space	Competes for space	Difficult to harvest
Potato	Little impact	No impact	Not grown together	Optimum spacing	Not grown together	Not grown together	Not grown together
Horse bean	No impact	No impact	Not grown together	Not grown together	Optimum spacing	Not grown together	Not grown together
Field pea	No impact	No impact	Not grown together	Not grown together	Not grown together	Optimum spacing	Not grown together
Wheat	Little impact	No impact	Not grown together	Not grown together	Not grown together	Not grown together	Optimum spacing

Minimum inputs

The practice of eucalypt boundary planting requires land plot(s) and a few of the commonly employed hand tools. Site preparation for planting and ploughing in young stands is done with a traditional two-pronged hand tool locally known as the *maresha*. Weed clearing and grass cutting are done with sickles. Harvesting of matured trees is carried out by different types of axes. Land ploughing by oxen is practised by only a few farmers. Farmers own all these tools for regular farm activities. Household labour is an additional but indispensable input for innovation.

Currently, no external government agency or NGO is providing material or technical support towards promoting or improving eucalypt planting by farmers. As stated earlier, most of the regional states have placed a strong ban on expanding eucalypt plantations. Government nurseries that were once producing millions of eucalypt seedlings have since completely abandoned production. The recent strong discouragement of farmers from planting eucalypts is also in sheer contrast to some 15 years ago, when eucalypt planters were rewarded. Nonetheless, farmers in most regions with good access to road networks to pole markets are currently intensifying their eucalypt plantations. In all of these areas, one can easily observe how farmers are cautiously expanding their plantations, on one hand cautioned by current government policy, and on the other, alarmed by the need to avoid complete reliance on one commodity, practising the phenomenon termed 'risk aversion'. Hence, all efforts to expand eucalypt plantations are limited to marginal and degraded sites and to low-producing grazing lands.

Regional government policies concerning the complete banning of eucalypt planting seem to be based on unfounded claims regarding the extent of its ecological impact. Scientifically proven studies indicate successful and massive regeneration of indigenous species under coppiced eucalyptus. Recent studies also indicated that *Eucalyptus* species are efficient water users (750 litres kg^{-1} of produced biomass) when compared with other agricultural and tree crops, which use water in the range of 1000–3200 litres kg^{-1} of produced biomass. Moreover, farmers already well know most of the allegations proclaimed by local administrators. Farmers possess an accumulated wealth of knowledge and wisdom on the negative and positive effects of eucalypt plantations. Local policies thus need to recognize and acknowledge local indigenous knowledge and adjust their recommendations. Any ban imposed by local authorities on tree-planting activities by rural people will either remain unheeded or trigger strong resistance from farmer communities. It is thus important to make major changes to the current policy to help farmers make the best economic use of eucalypt plantations while maintaining environmental sustainability. There is a strong need to precisely quantify both the economic and the ecological benefits of eucalypt plantations in contrast to measuring only its negative ecological effects. Research experiments need to be directed towards identifying means of optimizing yields of adjacent grazing and croplands. Alternative means of mitigating the negative impacts of eucalypt plantations need to be explored and ascertained.

Agroclimatic zones

Eucalypt plantations can be established in almost all agroecological zones (except Alpine) where the mean annual rainfall is about 500 mm or more. This innovation performs best in the Highlands, Mid-highlands, and Lowlands with adequate rainfall amount and distribution. The different species of eucalypts perfectly overlap and fit into various agroecological zones inhabited by humans. However, current marketing demands favour only a few of the many possible species for pole production. The most traded species in rural Ethiopia include *Eucalyptus camaldulensis, E. globulus*, and a few others.

Major commercial eucalypt species grow where all major indigenous tree species and food crops grow. Some eucalypt species grow well even under conditions where indigenous tree or crop species cannot survive. This makes the innovation beneficial to rural people in most agroecological zones, either to gain additional cash income or to meet basic household needs for wood. Eucalypt species grow well on all soil types and land features. Most rural plantations, in fact, are limited to highly degraded and waterlogged areas, to make productive use of otherwise unproductive land and to minimize competition with other farm components.

Major factors that make the innovation successful

Eucalypt plantation management is currently surviving in spite of strong local government sanctions, due mainly to its simplicity and farmers' good knowledge and experience in producing seedlings and in establishing and managing plantations. Neither total exclusion of eucalypt seedlings from government nurseries nor strong agitation by government agents to persuade farmers not to plant eucalypt trees has significantly decelerated the pace of eucalypt plantation expansion. The simplicity of regenerating and managing eucalypts and the lucrative market price of poles are motivating farmers to plant more and more marginal lands with eucalypt seedlings. In areas with good access to the pole market, eucalypt planting is still gradually expanding into marginal lands.

Farmers know well how to raise eucalypt seedlings on farms. Seed-laden twigs are lightly spread on well-prepared plantation sites at the beginning of the rainy season. After the seeds germinate, excess seedlings are thinned out and planted on empty spots. Similarly, small seedbeds are prepared near perennial watercourses 6 to 8 months before the main rainy season. Moist seedbeds are covered with seed-laden twigs and maintained moist either through capillary movement of moisture or through regular watering. Such seedbeds can also be established under shade within the home compound and watered less regularly by fetching water from distant water sources. In addition, eucalypt seedlings are abundantly available in local markets during the planting season, and in fact, at a much cheaper price than any other tree seedlings. The prolific regenerative capacity of eucalypt stumps for several generations is an added advantage.

The most single difficult task in establishing a eucalypt plantation is to prepare the planting site thoroughly. Eucalypts require well-prepared weed-free seedbeds for adequate survival and early growth. One or two weeding operations are carried out to avoid seedling suppression and to minimize competition for moisture and nutrients. Once established, subsequent management tasks are to protect against animal damage and to harvest small poles regular as the need arises. The latter operation often amounts to thinning to open up space for the remaining trees. Post establishment tasks are quite simple and can also be undertaken by young children.

One other important aspect of eucalypt plantations is their propensity to establish under tough physical and biological circumstances. Eucalypt seedlings can be planted and will survive on shallow, rocky sites where even indigenous species may fail to thrive. Eucalypt seedlings can also be planted in waterlogged and marshy areas, where they grow fast after the end of the rainy season and help drain excess water. Eucalypts are thus often used to pump away excess water, making difficult sites productive. Eucalypt plantations are relatively free from any major pest and disease infestations that would call for additional investment. In general, eucalypt plantations have numerous ecological benefits including imporving of the local climate (see next section).

Market demand for eucalypt poles is constantly rising. Many new major marketing and loading stations are being established along major rural roads. Farmers get a market easily either by contacting local brokers or directly with the main traders. Farmers often prefer to sell to the local brokers since they play an influential role and can advertise or malign the product. In accessible areas with relatively widespread eucalypt woodlots, farmers enjoy uninterrupted demand for various pole products and thus they sell any time they need cash. This fact plays an important role in promoting small-scale eucalypt plantations as a vital means of overcoming contingencies and unforeseen shocks.

Direct and indirect beneficiaries

Harvesting and selling eucalypt products is entirely the responsibility of male household heads. Female heads can sell pole products only if the husband is absent for an extended period. All household members may collect and use eucalypt products for the house. In the Guraghe area, gathering fuelwood is entirely the responsibility of men and young children.

That only men harvest and sell eucalypt products does not necessarily mean that only they benefit. A large part of the sales income is set aside to cover major household needs. It covers expenses for children's education, family clothing, and purchase of farm inputs; it contributes towards social obligations, pays taxes, buys supplemental food, and covers other minor expenses.

Eucalypt poles also cover most household wood requirements. Eucalypt poles and wood are preferred for house construction over those from any other species potentially available. In many highland and mid-highland areas that are devoid of natural vegetation, eucalypt wood constitutes the major source of fuelwood and fence posts. Various household utensils and farm implements are also carved from eucalypt wood. All household members and community groups benefit from these products.

Farmers in the highlands of Guraghe witness strong positive ecological effects of eucalypt plantations. They attribute the widespread planting of enset to the favourable microclimate created by eucalypt plantations. In support of their claim, farmers assert that enset cultivation was possible only after the introduction and widespread planting of eucalypts. Eucalypt plantations moderate the chilly weather of the highlands that hindered enset cultivation. Enset is believed to be a hardy plant that provides staple food unfailingly to the people of the Guraghe highlands. Eucalypt plantations, from this point of view, thus benefit all community members regardless of ethnicity, gender, age group, wealth group, etc. Windbreak and shelterbelt functions of the plantations benefit all households and members and enhance cultivation of various cash and food crops.

Upscaling strategies

As stated in the preceding sections, the practice of eucalypt planting by farmers has in recent years come under intense criticism and open resistance from administrators of various regional offices. During the 1980s, farmers were not only receiving a large number of eucalypt seedlings for both private and communal plantations free of charge but also rewarded for planting and raising a greater number of eucalypt seedlings. The practice of encouraging farmers to promote on-farm tree and shrub planting, which started during the last decade of the 19th century, has gradually decelerated and reached a low point at the turn of the present century. Government agents were profoundly preoccupied with the adage of 'food security' by bringing all cultivable lands under production of food crops. Consequently, during recent years extension personnel deliberately discouraged on-farm tree and shrub planting to minimize competition with croplands.

Despite recent government efforts to decelerate the rate of eucalypt planting, farmers continued to expand their planting both for household use and for cash generation. Eucalypt planting is also conceived as the most viable means of bringing degraded and difficult sites under productive use. Both in rural and urban areas eucalypt woods are preferred for all kinds of construction work. Slender and straight eucalypt poles have no equal for roof construction of all sorts of rural residence houses. The tree's rapid growth and short rotation as well as its coppicing ability have prompted most farmers to initiate and slowly expand eucalypt plantations. In tree-deficient areas eucalypt planting is the quickest way of helping households meet their basic wood demands for fuelwood and house construction. On-farm eucalypt plantations are thus expanding without any promotional efforts from external agencies. This is mainly because of their multiple economic and ecological benefits as well as ease of regeneration and maintenance for the farmers.

Institutions promoting the innovation

At present, no external institution is involved in promoting on-farm planting of eucalypt seedlings. Rather, the Board of Agriculture (BoA) is advising farmers not to plant them, particularly on or nearby farmlands. Farmers take this advice positively as in fact it is in accord with their long-standing practice of distancing eucalypts from crop fields. Farmers also do not plant eucalypts on fertile lands that could be used for crop cultivation or grazing.

Farmers particularly appreciate BoA advice regarding the need to widely separate eucalypt trees from water bodies like springs, lakes, and ponds. A dense stand of vigorously growing eucalypt trees could completely dry up small water bodies, particularly during the dry season when moisture absorption by eucalypt trees exceeds that of most other tree species. Local institutions and marketing groups play some roles in promoting eucalypt plantations. Farmers exchange eucalypt seedlings free of charge or at fairly negotiable prices. This helps them obtain seedlings easily and expand eucalypt plantations, mainly on degraded or marginal and less productive grazing lands.

Research questions and knowledge gaps

Farmers still regenerate and establish eucalypt plantations in very traditional ways. No significant improvements in seedling production and plantation management regimes have been introduced into the existing traditional practices. Local seedling production methods involve collecting seeds from any mother plants regardless of their genetic and phenotypic qualities. Careful selection of mother trees greatly improves the yield and quality of wood products.

Other silvicultural operations that are still based on traditional methods and now require further research investigation include intensity of site preparation, planting time, spacing, juxtaposition with other components, thinning intensities and frequencies, rotation age for different products, and harvesting methods. Farmers require innovative information that complements the traditional techniques to maximize the yield of wood and non-wood products and their qualities. This helps eucalypt tree growers minimize financial and labour investments and maximize the economic benefits they drive from the practice.

The improvement most in demand in managing a eucalypt plantation is to ameliorate the synergistic interactions between eucalypt plantations and other farm components. Farmers want to grow eucalypts and food crops side by side with minimum negative synergistic impact. Mixed species plantations of eucalypts that quickly rehabilitate degraded sites and provide food and shelter for wild animals are useful for regions with extensive degraded areas. Appropriate planting niches for various products need to be clearly identified to make more effective and economic use of the limited land resources.

Product marketing is another major difficulty that farmers often face. In general, farmers are forced by law to sell eucalypt products on-farm or in the nearest marketing centre. Farm-gate price is only about one-fourth of the consumer price in Addis Ababa. This exposes farmers to substantial economic exploitation by outsiders. Pole traders make much more financial profit in a matter of weeks than do the farmers who managed the plantation for 5 or 6 years. Farmers thus need marketing support of strong policy and technical professionals so they may derive better benefits from eucalypt plantations. They need to be able to transport their eucalypt products over long distances so they may acquire maximum financial benefits.

Professional reflections and recommendations

Eucalypt plantations provide rural communities with enormous economic and ecological advantages. They can be established with minimum investment and require little capital and labour during their growing time. The ability of eucalypts to grow well on highly degraded and gullied sites offers the best opportunity both to rehabilitate wastelands and unproductive grounds and to make productive use of such sites. Combining eucalypts with low-growing leguminous shrubs speeds up the rate of recovery and overall productivity of highly degraded sites.

The present restrictions aimed at keeping farmers from expanding eucalypt plantations need to be reversed and replaced with positive thinking that will maximize farmers' overall economic benefits without compromising long-term environmental sustainability. In this process, recognition and acknowledgement of farmers' indigenous technical knowledge and thus developing future recommendations from the existing practice is critical.

Eucalypt-growing farmers are exposed to unethical and excessive exploitation by brokers and traders. Farmers receive only about one-fourth of the total consumer price in Addis Ababa. Government taxes imposed on eucalypt products are also too high. Farmers are forced to pay double taxes, once on the land they possess and second on the commercial products they produce. On the other hand, farmers are legally forced to sell tree products at the farm gate. These multiple injustices will continue to threaten the livelihoods of the farmers and their families if no policy and technological interventions are applied.

Government policies need to rectify these deficiencies and direct more of the benefits to the rural poor rather than rewarding urban traders at the expense of farmers' efforts. Genuine policies that are committed to promoting rural livelihoods are urgently needed to help farmers gain more benefits from their work. Farmers should be allowed, and in fact be supported with materials and technical advice, to transport their products to marketing centres that will benefit them with higher cash income. This will help farmers restrict the size of their eucalypt plantations and thus minimize officials' worries over their gradual expansion.

Competent experimental investigations need to be conducted on all possible means of maximizing both the economic and the ecological benefits of eucalypt plantations and on their compatibility with other farm components. Technical experts and extension personnel need to identify alternative means of growing eucalypt trees and food crops without significantly compromising the product of the other components and harming the environment. Appropriate eucalypt planting arrangements for better and sustainable productivity and long-term land resource management should be explored and disseminated.

In the absence of technical and policy support eucalypt plantations will continue to expand at an even slightly faster pace. Farmers will tolerate the minimum reduction of grazing and farmland productivity caused by the strong competitive nature of eucalypts. Without positive adjustments in marketing procedures, farmers will continue to be exploited by urban-based brokers and traders. The contribution of eucalypt plantations will not, in most cases, go beyond complementing subsistence household needs. Farmers with large landholdings and good access to marketing infrastructures will generate substantial cash incomes and thus totally change their livelihood.

8.3 *Ngitiri* farming system of Tanzania

Nature of the innovation

Ngitiri is an indigenous system of managing natural resources that conserves fallow and rangelands by encouraging vegetation to regenerate through controlled livestock grazing during the wet season for use during the dry season (Brandstorm 1985; Otsyina et al. 1997). It is a traditional practice among the Sukuma agropastoral community. The ngitiri practice in agroforestry systems has been identified as a silvipasture technology used to conserve and protect soils and reclaim degraded land. Studies indicate that ngitiri can improve the ecology of a site, where trees enrich the soil surface through decomposition and mineralization of their litter (leaves, flowers, twigs and branches). The extensive ground cover of shrubs, grasses, herbs and forbs also helps prevent soil erosion and facilitates water infiltration and percolation by reducing surface runoff and increasing soil water storage.

The type of soil varies characteristically in different localities within the same agroclimatic zone. Crop rooting depth and usable moisture reserves may be restricted by impervious and poorly drained subsoils.

As suggested by Kusekwa and Otsyina (2002), the ngitiri strategy aims to conserve forage and fodder plants for use far into the future, as natural grasslands for grazing under pastoral and agropastoral systems. Cut-and-carry will include both natural and sown forages under zero-grazing dairy production systems. Zero-grazing will entail development of appropriate forages for inclusion in the various farming systems to supply feeding materials and other uses while at the same time conserving the forage resources.

Justification of profitability

Ngitiri, regarded as keeping traditional dry season fodder reserves, encompasses farmer-led initiatives that evolved out of the traditional strategies in grazing. It means retaining an area of standing hay until the rain season ends. The area remains closed to livestock at the onset of rain season and opens up at the peak of the dry season to allow the livestock get fodder (Mugasha et al. 2006). Grazing under ngitiri normally starts in July–August of the year after crop residues and forage in fallow areas have been depleted. Animals are removed from ngitiri after all the fodder is exhausted or when fodder becomes available outside the ngitiri.

There are two types of ngitiri: private and communal; they differ in size, location and management. Depending on availability of land the size of private ngitiri varies from 0.2 to 20 ha. Communal ngitiri are established with mutual consent of village members and they consist of areas with an average of 50 ha.

Individual or private ngitiri are located around homesteads along lowland riverways and non-farm lands away from the homestead (Brandstrom 1985). Homestead locations are preferred for grazing calves, oxen and lactating cows during the wet season (Brandstrom 1985). Ngitiri on farmland serve several purposes including providing fodder during the dry season, restoring soil through fallowing and nutrient cycling, and protecting land ownership rights (Otsyina et al. 1997). The individual ownership pattern of ngitiri proved to have very positive implications for management, improvement and development, as farmers were more willing to undertake development work on their own land.

Ngitiri are also traditionally established on degraded croplands and rangelands, mainly for fodder supply. The sites are demarcated during the wet season and regularly protected from grazing animals until the most critical fodder shortage period in the dry season. Although ngitiri boundaries are not rigidly demarcated, the ownership right is highly respected and protected by the local community by-laws.

Ngitiri grazing minimizes weight loss, improves condition of oxen just before the onset of the cultivation season, increases animal survival, and possibly increases milk yield among lactating cows (Otsyina et al. 1997). Farmers prefer to graze on communal ngitiri or rangelands first and save private ngitiri for later use when feed sources are exhausted (Otsyina et al. 1997). To ensure prolonged availability of fodder in ngitiri during the dry season and minimize land degradation, the Wasukuma also develop various rotational grazing management strategies. The most common system presently used can be described as progressive deferred grazing, which involves demarcating the paddock for specific periods. Upon finishing the fodder on a particular paddock, the animals are moved to a fresh paddock. How long they graze on a paddock depends on its size, availability of fodder and the number of animals. In communal ngitiri, paddocks and movements of animals between paddocks are controlled by well-informed and experienced elders, who apparently make management decisions based on specific indicators such as level of utilization and availability of fodder.

The ngitiri by virtue of their composition mainly of trees, shrubs and grasses, and their interaction with livestock constitute an ideal agroforestry system capable of eliminating most of the fodder shortages, fuelwood and pole scarcity and soil degradation constraints. The traditional ngitiri system together with the underlying ecological and management concepts, therefore, provide a valuable opportunity and a basis for developing a sustainable silvopastoral agroforestry system in Sukumaland (Mugasha et al. 2006). The extensive indigenous knowledge that farmers and animal keeper have about the value of trees and grasses, the ecological basis for ngitiri location, and management and general acceptance of the system provide potential tools for developing parallel agroforestry technologies such as fodder banks and improved fallow systems. In addition to the development of sustainable silvopastoral systems, it is also possible that the ngitiri system analogy could be valuable for developing other agroforestry technologies on croplands, which could combine fodder production as well as soil fertility restoration in space and time (Mugasha et al. 2006). Ngitiri is an important innovation for conserving the soil and protecting the extinction of important plant species. It may help improve community livelihood, especially if its practice can be developed to the extent of changing the nomadic behaviour of pastoralists, and provide fuelwood and poles for domestic use and income generation. Table 8.4 outlines system productivity.

According to the present survey, farmers do not keep records for the costs invested on the farm. Family labour is normally used and communal work is organized during weeding and harvesting periods. People move from one household to another to assist each other in weeding or harvesting and the owner of the farm prepares food and local brew to be taken during and after the day's work.

Agroforestry components and interfaces

In agroforestry land-use systems there are three basic sets of elements or components that are human-managed: the tree (woody perennials), the herb (agricultural crops including pasture species) and the animal (Nair 1989). Table 8.5 lists the agroforestry components and gives the major initial objective of each component as identified in the ngitiri practice.

Table 8.4. Productivity in ngitiri innovation

Item	Input		Output		
	Description	Cost (ha^{-1})	Kg or m^3 ($ha\ yr^{-1}$)	Revenue $ha^{-1}\ yr^{-1}$ (USD)	
Trees					
Poles	Land and labour	NA	15 poles	15 poles × TZS 2000 = USD 23 $ha^{-1}\ yr^{-1}$	USD 23 $ha^{-1}\ yr^{-1}$
Fuelwood	Family labour for felling and transportation	NA	60 m^3	6 m^3 × TZS 5000 = USD 23 $ha^{-1}\ yr^{-1}$	23 USD/ha/yr
Fodder	Land and fallowing period	NA	NA	NA	Healthy animals, counted indirectly through milk, meat and better prizes
Seeds	Family labour for seed collection; work done during grazing	NA	10 kg	TZS 1000 = per kg: USD 80 $ha^{-1}\ yr^{-1}$	USD 80 ha yr^{-1} (idle labour used)
Crops					
Sorghum	Family labour	NA	800 kg	TZS 800 × 150 = USD 92 $ha^{-1}\ yr^{-1}$	USD 92 $ha^{-1}\ yr^{-1}$
Cotton	Family labour with oxen although farm tractors are used by a few large-scale farmers	NA	700 kg	700 kg × TZS 450 = USD 242 $ha^{-1}\ yr^{-1}$	USD 242 $ha^{-1}\ yr^{-1}$
Sweetpotato	Family labour	NA	2000 kg	TZS 10,000 per 100 kg = USD 154 $ha^{-1}\ yr^{-1}$	USD 154
Livestock					
Cows	Fodder	NA	1 cow	USD 62 $ha^{-1}\ yr^{-1}$	USD 62 $ha^{-1}\ yr^{-1}$
Sheep	Fodder	NA	1 sheep	USD 12 $ha^{-1}\ yr^{-1}$	USD 12 $ha^{-1}\ yr^{-1}$
Goats	Fodder	NA	1 goat	USD 8 $ha^{-1}\ yr^{-1}$	USD 8 $ha^{-1}\ yr^{-1}$
Poultry	NA	NA	1 chick	USD 08 / chick	08 / chick

Table 8.5. Components and interfaces

	Multipurpose trees	Livestock	Fodder banks	Agricultural crops	Soil conservation	Live fencing
Multipurpose trees	Poles, fuelwood; soil & water conservation; fruits; cash income	Fodder, shade, cow manure	Fodder, conservation, fuelwood	Nitrogen-fixing, shade, improved soil texture, increased crop yields	Less soil and water runoff, fuelwood, poles, medicinal plants	Security, conservation, fuelwood, traditional medicine
Livestock	Fodder, shade	Maintained improved breed	Cow manure, fodder	Cow manure, improved soil texture	Traditional medicine	Security, fodder, traditional medicine
Fodder banks	Conservation, fodder, fuelwood, building poles, timber	Fodder, cow manure	Fodder, conservation, fuelwood	Food, fodder	Fodder, reduced runoff, fuelwood	Fodder, security, traditional medicine
Agricultural crops	Shade, improved soil fertility through nitrogen-fixing	Fodder, cow manure	Conservation, shade, improved soil fertility	Rotational cropping, intercropping	Increased crop yields, reduced runoff	Shade, improved soil fertility
Soil conservation	Less runoff, increased vegetative cover, improved biodiversity	Organic farming	Less runoff, improved soil fertility	Improved vegetation cover, development of contour bunds	Improved vegetative cover	Less runoff, biodiversity, conservation
Live fencing	Building poles, fuelwood, security, conservation	Security, fodder, organic farming	Fodder, poles, fuelwood	Security, fruits, bioenergy, fuelwood, fodder	Less runoff, gene bank, improved soil fertility	Gene bank, increased diversity of species

The indigenous Sukuma people traditionally are pastoralists, introduced to agriculture due to change of lifestyle and increased population. Intensive livestock grazing resulted in land degradation. Soil erosion and more seriously, gully erosion became a national disaster. Strategies to conserve the land started within the community land, thence the ngitiri practice. This practice improved vegetation cover, serving both to control soil erosion and to provide fodder for the animals. Introduction of agroforestry technology has intensified the initiatives of the indigenous communities to the point that it has become possible for people to get several benefits and develop other income-generating activities to improve their livelihood. Building poles, fodder, medicinal plants from increased biodiversity, and improved food quality (availability of fruits and vegetables) are among the human needs the system provides. In addition, the land it has restored has made households aware of the importance of using organic manure on their farms to increase crop productivity.

A few families were practising zero grazing. The availability of fodder from the conserved ngitiri coupled with the improved fodder produced from fodder trees within the agroforestry systems have motivated these people to make a step forward towards dairy farming. It is believed that if these initiatives are encourage land degradation in such areas will become history.

Through this practice, soil and water are conserved. If this conservation is intensified, it might positively influence the climatic condition of the area. With the myriad number of overlapping outcomes that originate just from practising the ngitiri system, the practice is viewed as being very sustainable in the long run.

Minimum inputs

The agropastoralists of Shinyanga in the dry mid-highlands have been identified as efficient in their land conservation practice, increasing the availability of high-quality dry season fodder and wood-based products; however, ngitiri systems can be improved both administratively and technically. This may be achieved as suggested by Otsyina et al. (1997) as follows:

- introduce improved fodder grasses
- plant fodder trees
- practise rotational grazing and destocking
- thin existing trees to encourage grass growth
- expand ngitiri coverage areas

Although the Wasukuma have good knowledge on uses of trees and browse species, studies by Kamwenda (1999) as cited by Chamshama

(2006) showed a number of technical issues that need to be addressed to improve ngitiri management:

- lack of knowledge by farmers about propagation, planting and management of trees
- absence of tree seedlings
- lack of proper treatment or care at early stages of tree establishment
- inadequate knowledge of the site requirements of the tree needs
- conflicting primary objectives of land management

During this survey it was noted that in some ngitiri areas, trees have grown to size for harvesting building poles. A resource inventory is needed to show what can be removed and what should be left so as not to degrade the environment again. The Natural Forest Research Management and Agroforestry Centre (NAFRAC) has started inventorying tree stock in some ngitiri plots, but a lot of work is yet to be done to get adequate and reliable information for the zone.

Agroclimatic zones

- Dry lowlands
- Dry mid-highlands
- Moist and hot lowlands
- Moist lowlands

Major factors that make the innovation successful

The success of the traditional ngitiri fodder reserves in Shinyanga Region can be attributed to the fact that this system is established traditionally and managed by farmers themselves, implying that any land rehabilitation project (e.g. HASHI/ICRAF project) based on this valuable indigenous knowledge is also likely to succeed. This can be testified by the results from Kamwenda's (1999) studies (as cited by Chamshama 2006) demonstrating that 95% of the respondents (farmers) supported the use of ngitiri to supply dry season fodder and reclaim degraded lands.

The Tanzania National Forest Policy (MNRT 1998) specifies clearly in policy statement no. 5 that the government of Tanzania declares,

> to enable sustainable management of forest on public lands, clear ownership for all forests and trees on those lands will be defined. The allocation of forests and their management responsibility to villages, private individuals or to the governments will be promoted. Central, local and village governments may demarcate and establish new forest reserves.

This policy statement motivates individuals and communities to manage the ngitiris with confidence that the government will not take them away from them in future. In addition, the government of Tanzania, in this same forest policy states in policy statement 7,

> Private and community forestry activities will be supported through harmonized extension service and financial incentives. The extension package and incentives will be designed in a gender-sensitive manner.

These statements ensure the people practising the ngitiri system that education and training on land ownership rights to remove the inherited doubts of land security will reach them and fears of their land being taken away removed. This is expected to greatly influence efficiency and thence sustainable management of the forest resource base.

Direct and indirect beneficiaries

In this practice, animal feed during the dry season ensures communities of the survival of their cattle and of a sustainable supply of animal products, thus increasing the food support system. The land ownership pattern influences land security and value. Land tenure is a great motivation for increased land protection and conservation. It provides motive for traditional pastoralists to reduce migration and become settled.

Community satisfaction derived from assurance of the life support system, although not measurable in monetary terms, makes the practice seen favourably among the communities because everybody within the society benefits in one way or another. There are clear indications that at this stage of ngitiri development, women benefit the most, getting fuelwood for domestic use within short distances. They have time to do other work at home instead of walking the whole day looking for a headload of firewood to burn in preparing food for the family.

Middle-aged men (35–50 years old) with a medium income also benefit from this innovation. Firstly, this group of people was found to be the most sensitive. They are eager to embrace change that indicates future prosperity. They need to have well-constructed houses, and in this case, building poles were found to be an important product. These people also have children who depend on them for school fees, so most of the income they obtain from the sale of agricultural crops and fuelwood is used for taking care of the family. However, most men did not divulge to the other members of the family the money they obtained from the sale of livestock. Men said livestock were rarely sold and were their property; cows had nothing to do with women.

Upscaling strategies

A number of documents on managing semi-arid areas have been produced. Agroforestry has been introduced in some primary and secondary schools to ensure wide adoption of tree and crop planting including the development of ngitiri practices. This has increased the level of conservation in this semi-arid area. Government policies given under the Ministry of Natural Resources and Tourism, and the Ministry of Environment will continue to safeguard the rights and ownership of the ngitiri system.

Although practices developed elsewhere are not named ngitiri, they are similar. For example, in the dry lowland and within the overexploited areas of catchment forests within the moist and hot lowlands, the practice is used to encourage natural regeneration and restore the vegetation cover, both for biodiversity and for soil and water conservation.

Institutions promoting the innovation

NAFRAC is a centre that was established through recommendations on scaling up HASHI (Hifadhi Ardhi Shinyanga) and HASHI/ICRAF projects to make its experiences available nationally. Its goal is to manage natural forests and agroforestry, scaling up the lessons learned from HASHI for sustainable livelihood. Its purpose is to increase benefits to rural communities and households derived from managing natural resources sustainably. It aims to develop and document technologies in semi-arid zones, to scale up best natural resources management practices, and to strengthen mechanisms that will involve other stakeholders in effectively managing natural resources. Emphasis is placed on improving the management information system and documentation.

The centre focuses mainly on enhancing power relations among stakeholders and on strengthening stakeholder capacity at various levels, with emphasis on sustainable livelihood and natural resources management. Its functions are research and development, documentation and dissemination, and capacity building and empowerment. The Ministry of Natural Resources and Tourism works as the major stakeholder.

Research questions and knowledge gaps

It is encouraging to see that NAFRAC and ICRAF have worked a lot in this semi-arid area. However, extensive studies need to be done on a wider area, taking into consideration that most of the areas in the western and central zones are semi-arid, where strategies to eradicate poverty are greatly needed. These can only come up through research on several aspects in large areas. Research on tree species for enrichment planting in the ngitiri is important. Grasses suitable for planting to enrich fodder is another prerequisite for development of improved fodder production.

Destocking of livestock is a serious issue. This is both a policy and a technological issue. Introduction of the improved heifer is important, but this should go together with intensive training on the relationship between wealth, income, resources, culture, inputs/outputs, and environmental conservation education and marketing of livestock products.

Professional reflections and recommendations

Ngitiri has proved a successful practice among the Sukuma in Shinyanga Region. Such technology should be spread to other areas in Tanzania, especially in heavily degraded areas and exploited catchments. If this happens, the country could turn green in a short time. Both agricultural and natural resources extension staff should be trained in following up and using indigenous knowledge and in community involvement in natural resources management.

Intensive training and education are required to change the Sukuma cultural attitude of pastoralism towards accepting zero-grazing. Field visits, and determining proper tree species for enrichment and for live fence planting can be important strategies for improving the ngitiri innovation.

Chapter 9 Agroforestry innovations suitable foro Moist Mid-highlands

9.1 Conservation-based agroforestry innovation in Ethiopia

Nature of the innovation

This innovation is the outcome of participatory research; 12 innovative farmers and an agroforestry PhD student worked hand in hand in an iterative approach. The farmers identified the research questions; and the agroforestry researcher defined the method and the approach for implementing it, but always seeking approval from the farming community. The researcher followed a 6-step participatory approach:

1. Trust building between the expert and the community
2. Participatory socio-economic diagnosis
3. Farmer-driven land resource assessment
4. Participatory solution search and research planning
5. Participatory implementation and putting hypothesis to test
6. Farmer participatory conformity testing and evaluation

Therefore, the nature of this profitable agroforestry innovation may be characterized partly as a practice, partly as a method, and also as an approach.

Trees planted at the lower side of the terrace support and help it not to colapse. They also contribute to additional income eraning.

The overarching problems of the farmers in this area were soil erosion and fertility depletion due to steep slope topography, which necessitated terrace construction that in turn has four problems. It is the agroforestry solutions to these problems that make this initiative innovative. The four problems were:

- Prevalence of rodents harboured among the terrace stones
- Occasional collapse of terraces when constructed on steep slopes
- Space taken up by terraces from which there was no productive output
- Obstruction in farming operations caused by the narrowly spaced terraces

Justification of profitability

The research result at plot level shows that the system was able to seize 163–243 tonnes of eroding soil depending on different slope categories. This is a lot of saving in terms of continued productivity of the land. Visual assessment of the farmers recorded on the productivity of the system ranged from good to very high. On average, the cost–benefit assessment computed from the 12 innovative farmers who participated in developing the innovation showed a net average profit of USD 115 for the initial year. This was after paying back (in total in the initial year) all the investment cost incurred on the costly physical structures and planting agroforestry trees and shrubs that will serve for many years in the future. After 4 years, comparative assessment between those who adopted the innovation and those who did not has shown a yield difference of USD 253 (Bekele-Tesemma 1997).

Agroforestry components and interfaces

The major components of the system are stone terraces, *Grevillea robusta* and *Ehretia cymosa* trees, *Eragrostis tef* (cereal crop), and *Rhamnus prenoides* (a commercial shrub used in local breweries).

The terraces and trees jointly serve as a physical barrier to the soil and its nutrients that would otherwise have moved downhill along the slope gradient. Without the support of the physical barrier provided by the stone terrace, the trees alone could not have retained the soils and its nutrients. The nutrients and moisture conserved are made available for the trees and shrubs. At the same time, the terraces could have collapsed due to gravitational push from uphill if trees had not been planted along the underside of the terraces. This combined service of trees and terraces has played an important role in making the land productive.

Along the upperside of the terrace, *Rhamnus prenoides* shrubs or *Citrus medica* seedlings are planted. This serves as a physical barrier against the oxen-drawn iron spike that farmers use as a farming implement. Hence the collapse of terraces that human error could have caused is avoided.

The trees, shrubs and terraces protect the soil and make its moisture and nutrients available to field crops (*Eragrostis tef, Sorghum vulgare* and *Zea mays*) that farmers grow between terraces. Often, farmers weed and also apply fertilizer to the field crops, which also benefit the trees and shrubs that are grown with it.

The shading effect of trees and shrubs on the adjoining field crops is significantly minimized by orienting the line of trees and shrubs that grow alongside the terraces east to west. Where this is not possible because the contour runs north to south, the grevillea is extensively pollarded or replaced by *Ehretia cymosa,* which is frequently harvested for livestock feed. The rhamnus is coppiced frequently for sale and no shading effect occurs on the field crops. Instead, the litterfall improves the soil quality of the plots that are laid out between the terraces and lines of shrubs and trees. Overall, the interface between terraces, trees and shrubs as well as the field crops is positive, often reflected in increased cumulative income.

Minimum inputs

A major strength of this innovation is that most of its inputs are within farmers' reach. The A-frame farmers use to lay out the terraces and the lines of trees and shrubs can be prepared and graduated by development agents locally. Farmers need only a few days of training on how to use it. Stones for terrace construction are locally available. Where stones are not available, coarse aloe-like plants or meshed pegs can be used. The few external inputs are improved seeds and polyethylene tubes for producing *Rhamnus, Grevillea, Citrus medica* and *Ehretia* seedlings. The other vitally important input is human labour for constructing the terraces. Of course, this is available within households, especially when they come together in a self-help group.

Agroclimatic zones

This innovation has been developed at Tikurso subcatchment in the moist mid-highland agroclimatic zone. However, it can work in almost all of the agroclimatic zones where agricultural lands are sloping, although the type of shrubs and trees to be used will differ. Under such conditions, it is necessary to consult the book *Useful trees and shrubs of Ethiopia: identification, propagation and management in 17 agroclimatic zones* (Bekele-Tesemma

2007a) along with the preferences of farmers for options on the species. The arrangement remains the same.

Major factors that make the innovation successful

The major factor that make the innovation work successfully is its acceptance by farmers. Farmers, rational as they are, have accepted the innovation for its ability to solve the four basic problems initially stated.

- Repelling rodents. The foundation of the terrace is excavated to a depth of 7–10 cm. After leveling it, the foundation is laid with thorny or spiny shrubs such as *Carissa edulis*. On this foundation, the terrace is built to the required height by filling between the stones with cut branches of the spiny or thorny shrubs. As rodents try to enter and hide, the thorns and spines protruding from all openings repel them.
- Avoiding terrace collapse. The physical support to the terrace of thorny shrubs within the foundation stabilizes it. Trees or shrubs are planted with 50-cm spacing at the underside and along the length of the terraces. Farmers enjoy cash benefits from the trees and shrubs, and also discover that they limit plough interference.
- Making the space occupied by the terrace productive. At the upperside and along the length of the terrace, shrubs such as *Rhamnus* and *Citrus medica* that reproduce by layering are planted. When their branches attain a diameter of 1–2 cm, some of the branches are coppiced while a few are laid at the top of the terrace for layering. A longitudinal slit is made by a razor blade at the contact point where soil is placed over the branch to be layered. Often this is done during the rainy season so that watering is not required. The branch sends out roots from the contact point. Soon the non-productive stone terrace becomes productive and no land is wasted due to stone terracing.
- Avoiding farming obstruction caused by the terrace. On steep slopes, the terrace needs to be spaced narrowly. If spaced widely, the height of the lower terrace will have to be very tall so that the toe of the upper terrace is at equal level with the head of the lower terrace. If the lower terrace is shorter, the plot between the upper and the lower terrace cannot be level. This is why terraces get spaced narrowly and cause farming obstruction. To space the terraces widely

and avoid obstruction, the height of the lower terrace will have to be increased every season after the rain has caused soil deposition at the upper side of the lower terrace. This is a tedious and laborious job, and farmers often do not keep it up. This is where this innovation becomes important.

- The *Rhamnus* shrubs that have been layered and are growing on top of the terrace are coppiced every 6 months, and the harvested twigs sold. Every other season they are coppiced, the cut being made at least 2 inches higher than the previous cutting height. Hence, the height of the rhamnus stool that has replaced the stone terrace and that is now growing on stone terrace is increasing by at least 2 inches every season. When layering is done in multiple rows, the stone terrace becomes a living rhamnus stool terrace that adds height by itself. By doing so, the terraces are spaced widely and farming obstruction is avoided.

An additional quality of this innovation that makes work effective is because it is simple to implement and inputs are within farmers' reach. The innovation has been implemented in a place where communities were to be evacuated because land productivity was exhausted. Currently the farmers are economically at par with any average farming household in Ethiopia.

Direct and indirect beneficiaries

The direct beneficiaries of this profitable agroforestry innovation are the farmers who have adopted the technology. Initially, only 12 households were willing to participate in the experimentation work. Later many farmers replicated the innovation, in part and in whole. By the third year, adopters of the innovation within the mini-catchment alone numbered 35. The place has now become a teaching and demonstration site, where many development NGOs have taken their staff to share the experience. Many farmers elsewhere in the country have thus indirectly benefited because their development facilitators have been exposed to such innovation.

Upscaling strategies

The innovation has been developed by farmers who were willing to participate with an individual student doing his PhD studies. Normally, in Ethiopia, innovations individuals develop face difficulties in becoming part of national programs. Since development extension work is almost fully by government, with private involvement very limited, it is difficult to say that this innovation has been put into the mainstream of the national development upscaling strategy.

However, on this occasion, government authorities have witnessed international appreciation of the innovation and national mass media personnel were deployed to document and broadcast the innovation. This has helped in upscaling it.

Farmers in the Tikurso subwatershed have an association with its own office and bank account. To promote and upscale the innovation, the association rewards farmers in the watershed who have demonstrated better performance in land protection and development efforts.

Institutions promoting the innovation

The innovation is not institutionalized per se, but, communities in the watershed have now established a market-focused land management association, devoted to maintaining and improving the productivity of the watershed. Elsewhere, many NGOs are promoting the innovation.

Research questions and knowledge gaps

A number of research questions have not yet been answered. Land health and productivity effects of the innovation have been tested on-farm but not more widely within the watershed. The same is true of the socio-economic impact: assessment has been made at household level but not yet in the community. Such assessments could give vital information for upscaling at watershed and community levels.

The innovation was found productive and successful 10 years ago. Basic information is available on to livestock and human population and on biophysical factors such as soil fertility, soil depth, and slope parameters at watershed scale. The situation must have changed within these 10 years. Therefore, comparative assessment could provide useful information about the compliance of the innovation to the changing circumstances.

This innovation is exceptional in that the problems were defined by farmers and a researcher and solutions sought in a field-based experiment by the same parties. Similarly, use and upscaling of the innovation is still uniquely private, often shouldered by small-scale farmers who have organized themselves to keep up productivity of their land. Yet they are not officially registered because farmers can be organized only under the Service Cooperative Association and organizing to keep land productive is not recognized in its portfolio. This is another gap that needs to be looked at in terms of its merits and demerits.

Professional reflections and recommendations

Farmers of the sub-watershed have become strongly committed to improving land health and productivity. With minor support, such as a supply of improved seed and polyethylene tubes for seedlings, their efforts will be at a level at which they can play a successful exemplary role.

They are denied official registration of their association for the reason that land health maintenance is not part of Service Cooperative Association portfolio. Land productivity is eroding significantly in the country; policymakers should be alerted to the fact that they need to make it possible for farmers who devote their concerted efforts and resources to land productivity to be officially registered and supported.

9.2 Agroforestry innovation that involves high-value perennials in Uganda

Nature of the innovation

An agroforestry practice with *Vanilla planifolia* and *Jatropha curcas* is found in the banana–coffee system in the lakeshore region and foothills of Ruwenzori and Elgon Mountains. It occurs in several districts in the country, an estimated 60,000 farmers are practising it (MAAIF 2000), while the area under it is estimated to be 45,000 acres (New Vision 2005). The practice fits well in banana–coffee farming systems as the vanilla crop is usually intercropped with bananas and coffee.

Vanilla (*Vanilla fragran*s) was introduced to Uganda from Ceylon in 1912 and its commercial production started in the 1930s. However, production by small-scale farmers drastically declined during the civil strife in the 1970s but was revived in the 1990s, largely because of increased promotion efforts by agricultural extension services and NGOs. This was spurred mainly by the then prevailing high market prices (Oluka-Akileng et al. 2000).

Vanilla, being a perennial creeping vine, requires trees for support, particularly when it is under fruit. Trees that are usually used as support are established from cuttings, grow slowly, can be pruned easily and produce many low branches onto which the vanilla crop can hang. *Jatropha curcas* is the most common support tree used by farmers in Uganda but other trees used are *Gliricidia sepium, Albizia* species and *Ficus* species (Bisco 2001). The vanilla crop also needs shade for proper growth and must grow under it for about half the year (MAAIF 2000; IDEA Project 2000).

Jatropha is often integrated with vanilla, which needs its support or it can be used as fencing for croplands.

Justification of profitability

Vanilla is a high-value export crop, which has proved profitable to smallholder farmers, processors and exporters in Uganda (NAADS News 2003). The active ingredient (vanillin) extracted from its pods is used to flavour foods and beverages and in perfume production. For local use, the mature pod is harvested, dried and used to flavour water, tea and cakes. It is a companion crop for main crops such as banana and coffee, hence income from it supplements income from these crops.

The positive association between the vanilla crop, jatropha trees and shade trees greatly leads to the profitability of the practice in terms of the quantity and quality of the vanilla beans produced. The support trees greatly contribute to the quantity of vanilla produced as they enable the crop to produce many pods that are suspended from the ground and hence are not affected by pests and diseases. The shade trees, on the other hand, greatly contribute to the quantity as well as the quality of vanilla beans produced as both depend on the amount of shade provided.

Two attributes make Ugandan vanilla meet the preferred quality standards demanded by world markets. The first is the high content of vanillin it has compared with that from other countries (IDEA Project 2000; New Vision 2005). Extractors are, therefore, prepared to pay extra for Uganda vanilla. Secondly, there is a gourmet market in the US that pays premium prices for top-quality beans, especially those certified as organically grown (IDEA Project 2000). Since farmers in Uganda do not use fertilizers or pesticides in vanilla production, Uganda vanilla qualifies as organically grown.

The aggregate global demand for vanilla is estimated at 2500–3000 tonnes per year. The US is the leading importer of vanilla, absorbing 50–60% of global demand. Other major buyers are France and Germany (Ferris et al. 2000). By 1998, Uganda was the second largest supplier of fresh vanilla beans to the US, behind Madagascar. In 2000, vanilla production in the country was estimated at 300–400 tonnes of green beans or 70 tonnes of cured beans. This is significantly more than the 7 tonnes of green beans produced in 1990. Projected production of cured beans for 2005 was about 170 tones (New Vision 2005). At current export levels, Uganda is supplying only 1% of world import demand. Despite increased production by other countries (Indonesia, Comoros), it seems certain that Uganda can increase its export share to at least 200 tonnes of cured beans annually, which is about 6% of current world demand.

Currently farmers are forming vanilla growing and marketing associations. Some have attracted support from advisory services and development partners. This has greatly enhanced production of the vanilla crop in the country. However, these associations are still weak and therefore require more support to enable them to enter into contracts with importers.

There are several credible processors and exporters of vanilla in Uganda including Magellan Worldwide Inc., Uganda Crop Industries Ltd, Esco Ltd, Buiga Farm Industries Ltd, Landways Agencies Ltd, Uvan Ltd and the Uganda National Vanilla Association. These operate under the Association of Vanilla Exporters of Uganda (VANEX), an umbrella organization that brings together vanilla exporters in the country. With these in place, exporting vanilla produced in the country can be assured.

Farmers, processors and exporters in the country rate this practice as one of the most profitable enterprises. However, the recent drop in world market prices for vanilla has affected expansion. Despite this scenario most farmers in the country are continuing with the practice.

Agroforestry components and interfaces

The synergistic interfaces are between the vanilla crop, the *Jatropha curcas* trees and the shade trees (table 9.1). Jatropha trees support the vanilla crop, by letting it get sunlight and keeping the pods suspended from the

Table 9.1. Major components in the vanilla and jatropha agroforestry practice in Uganda

Components	Vanilla crop	Jatropha trees	Shade trees
Vanilla crop	Vanilla crop can be better managed when grown intensively as supervision is more efficient. With higher yields per stool, farmers can intensify production, enhance quality of the crop, and increase income	Vanilla being a creeping plant requires support to reach sunlight. Jatropha provides strong support for the heavy vines, without which the pods would rot on the ground, causing yield loss	Vanilla being a succulent plant requires cool conditions that shade trees provide
Jatropha trees	Jatropha benefits from management practices targeted for the vanilla, such as weeding and mulching	Propagation is much easier as the number of plantings on farms has increased drastically since the species started being used as support for the vanilla crop	Jatropha is shade tolerant. It can even grow with a few leaves as succulent green stems also contribute to photosynthesis
Shade trees	Vanilla performs best under limited shade but cannot grow in full sunshine	Shade trees permit the necessary amount of light for jatropha trees to grow	Number of shade trees on farms has drastically increased with the practice

ground, resulting in high vanilla yields and hence higher income for the farmers. Jatropha benefits from the vanilla crop in that farmers give it good attention by weeding and mulching. Being used as a support tree, it is planted large scale on farms.

Minimum inputs

The major material requirements for this agroforestry practice include vanilla vines, jatropha stem cuttings (support tree) and shade trees. Technical skills needed for establishing the vanilla crop include planting, mulching, lopping, stimulating of flowering, pollination and harvesting. Vanilla is propagated using mature vines 1.5–2.5 m long. Planting is done when the rainy season starts along the support trees at a spacing of 2.5 x 2.5 m in a pure stand or 3 x 3 m if intercropped.

Mulching is essential for good growth of vanilla; it keeps the soil light and moist, especially during dry seasons. Lopping allows the vines to be within reach and renews and increases the root system. During the dry season, reducing shade and removing shoots growing on hanging vines stimulates flowering, which usually starts 2–3 months later. Skill in timing and carrying out pollination is vital. Flowers are fertile for one day only and pollination has to be done timely and in the morning. Good knowledge is required to identify mature flowers and to locate male and female parts and know how to handle them during pollination.

Beans are ready for harvesting 7–9 months after pollination. Immature beans should not be harvested as they are low in vanillin content. Late harvesting of beans leads to loss due to splitting pods. Support trees are planted 3 months before planting vanilla and the height of the cuttings is 1.5 to 2.0 m. Once shade trees have established, shade management becomes important. Shade levels are adjusted as the plant grows but generally it requires light shade (34–50%).

Financial requirements include purchasing of vine and jatropha cuttings, labour costs for pollination and security. Pollination is done by family labour although highly skilled labour is hired at times. During periods of high prices, farmers invest in security when the pods almost are ready for harvesting to minimize theft (NAADS News 2003). Production costs involved in establishing one hectare of the vanilla crop is estimated at UGS 2 million (USD 1110) (IDEA Project 2000).

Vanilla loses quality if stored for more than 4 days after harvest without curing. Mature raw vanilla beans are processed or cured into the highly aromatic, dark brown beans required for export. In the process, moisture content is reduced to 22–30%, and vanillin production and colour changes take place. It requires skill, experience and specialized facilities. The cost of establishing a traditional processing plant for 50 tonnes of fresh vanilla beans is Uganda shillings 42.4 million (USD 25,000) (IDEA Project 2000). Transportation to the processing plant should be prearranged as storage after harvest should not exceed 4 days.

Most vanilla buyers demand whole processed beans and impose strict specifications for size and colour. It is graded into four classes, based on flavour, bean size, length, and appearance of the pods (table 9.2). Vanillin content of 2% and moisture content of 20–22% are normally preferred. Infrastructure necessary for the innovation to succeed includes efficient transportation facilities, sound storage and an efficient marketing system.

Table 9.2. Classification of vanilla in the market

Class	Description
1st	Good flavour, length > 14 cm, supple, full, no spots, no scratches, tannish-brown uniform colour, moisture content less than 25%
2nd	Good flavour, length > 14 cm, supple, some spots and scratches, moisture content 25–28%
3rd	Good flavour, length > 14 cm, supple, some dry spots and scratches, red blemishes, moisture content more than 30%
4th	Broken or cut, length < 14 cm, red blemishes, moisture content more than 30%

Source: IDEA Project 2000

Agroclimatic zones

The vanilla–jatropha agroforestry practice is found in areas around Lake Victoria and in the foothills of Mt Ruwenzori and Mt Elgon. These areas receive bimodal rainfall with the first rains received between March–May and the second from August–November. Mean annual rainfall ranges from 1000 to 2250 mm. Average annual maximum temperatures range from 22.5 °C to 27 °C; average minimum temperatures vary from 18 °C to 23 °C. These regions are generally warm and humid.

Vanilla needs a warm, moist climate, with high humidity and high rainfall. It cannot grow in dry areas but needs a dry season of 2–4 months to stimulate flowering. Where there is more than one dry season, two flowerings will occur. Suitable temperatures for vanilla growing are 20–30 °C. It performs best on loamy soils but also grows on a wide variety of other soils, which must have good drainage and be rich in organic matter. In the harmonized agroclimatic zones of eastern and central Africa, the practice can work in the moist lowlands and moist mid-highlands.

Major factors that make the innovation successful

Vanilla does not affect the production of associated crops. It can be grown as an additional crop on the same piece of land. It is a high-value crop with a high potential to generate income for farmers. It is easy to maintain, and tending activities are restricted to lopping and cutting off the apical shoots to improve flowering. The jatropha tree is easy to propagate using stem cuttings and can be integrated easily on cropland as it does not grow tall.

Under good management the crop takes 18 months to mature. Maximum yields are reached at 7–8 years after planting; economic yields are obtained for 10–20 years. This implies that the crop gives quick returns to investments and ensures continued productivity for a long period. The crop also has few pests and diseases. Occasionally, distorted leaf shape and shoot rot may occur, but these require only minimal inputs to control and can be contained by proper agronomic practices. Jatropha is also resistant to termites and provides durable support.

Overall, the cost of inputs incurred in establishing, superving and harvesting are low relative to the returns. The ratio of expenditure to income is 1 : 2.8. This is based on Uganda vanilla farm production costs of UGS 2,000,000 (USD 1110) per hectare and revenues of UGS 7,500,000 (USD 4170) per hectare with a margin of UGS 5,500,000 (USD 3060) per hectare. The National Agricultural Advisory Services (NAADS) provides the institutional infrastructure for promoting vanilla growing as it stresses market orientation and natural resource management during enterprise selection.

For local use, vanilla pods are harvested, dried and used to flavour water, tea, yogurt and cakes. About 10 multinational companies dominate buying of processed vanilla beans from producing countries and two trading companies (McCormick and Zink & Triest) are already buying from Uganda through various agents. They sell whole vanilla and extracts to many secondary processors as well as to food processors such as high-quality ice cream manufacturers.

Direct and indirect beneficiaries

Major direct beneficiaries of the practice are vanilla growers, processors and exporters who get economic returns from the practice. For vanilla growing, men, women, the youth and other interest groups such as persons with disabilities actively participate. This, therefore, means that employment is created in the communities where vanilla is being grown. Vanilla growing is also affordable for even the less-wealthy farming households, like those with small landholdings. However, in the processing and export sectors, males tend to dominate while the wealthy tend to dominate the processing and export business.

The indirect beneficiaries are the communities where the vanilla growers live and the government, which benefits from taxes generated from sale of the vanilla crop. Others include local beverage dealers, extension service providers, input dealers and transporters. Farmers in dry areas where jatropha naturally grows also benefit from selling cuttings to vanilla growers. The practice has contributed to increased household incomes leading to increased economic access to food. It has also contributed to an improved way of life for the communities through creating employment, better housing and acquisition of assets such as purchase of vehicles and land.

Upscaling strategies

Current production figures show that between 2000 and 2002, vanilla farm acreage increased by 22% from 10,000 to 45,000 acres. This is attributed to increase in market prices as a result of the world's leading producer (Madagascar) experiencing severe damage due to cyclones and floods (IDEA Project 2000). Efforts to promote vanilla as a high-value crop were in response to this. Because of this, the practice, which was limited to the central region, has been replicated in 28 districts in the country in a period of 4 years (MAAIF 2000).

Strategies used for scaling up vanilla growing by the agricultural extension services and NGOs were mainly through radio programs and the print media, training workshops, exchange visits and policy briefs. Instituting a service delivery framework such as district production coordinators and mobilizing farmers into vanilla growers groups enhanced the scaling-up process. NAADS facilitated farmer groups through training and acquiring quality planting material.

Major factors that have contributed to upscaling of the practice included the then attractive world market prices, wide publicity given to the practice, the short gestation period of the crop, ease of establishing and maintaining it, and its ability to fit into existing farming systems. The revival of the practice in country also coincided with the outbreak of major diseases of coffee and banana, which are the major sources of income for most households in these areas (NAADS News 2003).

Institutions promoting the innovation

The major institutions that promote the practice in the country range through those involved in production, processing, marketing and policy, as shown in table 9.3. The roles and the contributions of each institution in promoting the vanilla–jatropha agroforestry practice are also highlighted.

Research questions and knowledge gaps

In vanilla production, little information and knowledge exists in areas of vanillin content, shade levels, support trees, pests and diseases. It is important to establish what factors contribute to Uganda vanilla having a higher vanillin content compared with that of other countries as this will enable its growing to be targeted to locations or conditions that enhance this at-

Table 9.3. Major institutions involved in promoting the vanilla–jatropha agroforestry practice in Uganda

Institutions	Role / function
Extension and advisory services	Create awareness of the potential of vanilla enterprise Provide technical advice (information, knowledge, skills) Build capacity of farmers and farmer groups
NGOs	Upscale production by providing planting material and technical advice Organize farmers into groups for better production and marketing Facilitate exchange visits Set up demonstration plots
Farmer groups and organizations	Access training and link farmers with advisory services Acquire planting materials Provide better environment for marketing of crop Ensure quality products
Input dealers	Provide easy access to the necessary inputs for the production and marketing of crop
Local vanilla trader groups	Determine prevailing farm-gate price Search for market outlets
Local governments (district and subcounties)	Access and multiply planting materials Support farmer organizations through building capacity and forming groups Facilitate exchange visits
Policymakers	Provide conducive policy environment for producing and marketing crop Create awareness
Association of Vanilla Exporters (VANEX)	Process the raw vanilla Export the processed vanilla Standardize prices and streamline marketing procedures
Multinational vanilla traders (e.g. McCormick, Zink & Triest)	Procure vanilla from producer countries such as Uganda Ensure quality of products

tribute. Given that vanilla thrives well under limited shade, a range of suitable tree species and their associated management need to be identified. There is also need to evaluate a wide range of tree species that can be used as support trees. In some areas, jatropha trees have died; research needs to be done to ascertain the cause. Similarly, control measures for pests on vanilla such as caterpillars and diseases such as wilt and root rot need to be developed and widely promoted to farmers.

In processing, the capacity of farmers to cure vanilla is limited mainly due to lack of knowledge. The local process currently being used is cumbersome and time consuming. More effective methods need to be explored. Strategies for regulating the vanilla market also need to be explored and developed. Currently, instituting price ceilings to stabilize vanilla prices has largely been futile. For Uganda to benefit from vanilla growing, it needs to undertake market research to determine what the market demands and how best to fulfil these requirements. In general, documentation of the practice in Uganda is limited. A communication and knowledge management strategy needs to be developed if the practice is to be upscaled countrywide.

Professional reflections and recommendations

The biggest problem currently facing vanilla production and promotion in the country is the weak farmer organization at the production level. It is therefore important to strengthen existing organizations so that they are able to produce commercial quantities and required qualities demanded by the market. This is the role of government and the private sector.

Currently some farmers use the local method of curing vanilla. This is cumbersome and produces vanilla beans of varied quality, hence low profits for farmers. Farmers will need to invest in new equipment for curing vanilla be able to cure economic quantities. This will enable them to link directly or enter into contracts with importers, hence increase their profits. Farmer association or cooperatives would be the best avenues for doing this.

The risks and threats to the practice in Uganda include synthetic vanillin, low market prices and bad weather. The presence of synthetic vanillin in the world markets provides a cheap alternative, thus reducing demand. Current low market prices as a result of recovery of the major producer have slowed down the upscaling of the practice. Because most of Ugandan agriculture is rainfed, occurrence of drought spells can also greatly affect the production and quality of the vanilla beans, as can the occurrence of hailstorms.

The institutional and organizational set-up for vanilla production, processing and marketing does not clearly point out the roles of different actors. There is need to strengthen institutional links to streamline roles of all actors towards an assigned contribution. Uganda vanilla needs to be internationally certified under ISO (International Standards Organization) to attract better prices in the world market. Currently, despite being of high value, Uganda's vanilla does not fetch high prices on the world market because it does not meet ISO certification requirements. In addition, the Uganda vanilla that is currently being produced organically needs to be certified, and the capacity to do this should be built locally. It is also recommended that to boost the consumption of local vanilla products, there is need to diversify these products and improve their processing and packaging. In conclusion, it can be said that the major stakeholders of vanilla in the country need to come together and develop a strategy to upscale the practice.

9.3 Vertically and horizontally packaged agroforestry farming in Ethiopia

Nature of the innovation

The innovation is an agroforestry system based on enset–coffee–tree–herbaceous crops, locally termed *nibrete,* which means property. Research findings have shown that the system has been practised for 5000 years. The innovation includes food crops such as enset (*Ensete ventricosum*), the tuber crops boyna (*Dioscorea abyssinica*) and godere (*Colocasia esculenta*), leafy vegetables, green pepper, duba (pumpkin) and maize. Cash crops include coffee (fresh and dry), enset (in small quantity), avocado, banana, boyna and godere. Multipurpose tree species are integrated within the system. Enset is spaced within the farm at 1.5–2 m; coffee is scattered within the enset; godere between coffee trees; boyna along the fence; avocado at the front yard and fence; a few maize plants within gaps of enset, only for household consumption.

Farmers have a method of establishing different components of the innovation. First, they clear and cultivate the land by retaining naturally regenerated tree species. If there are no trees in the field, trees with high value for improving soil fertility like *Millettia ferruginea, Albizia gummifera and Erythrina abyssinica* are planted at wider spacing. Second, the site is cultivated for the second time. Enset and coffee are planted in February–April and the tree seedlings tended in May. Third, suckers of enset corms are transplanted from May to June. Finally, godere is planted between coffee stands.

Once the system is established and some of the components have matured, the next step is to manage and harvest the products. Farmers slash the undergrowth (weeds), harvest and plant godere and sell fresh coffee simultaneously in January–February. They harvest honey March–June. From

September to December they sell sun-dried coffee and tend beehives. They tend plantations, cut matured enset, and slash weeds from October to December. Farmers use crop residues, household refuse and farmyard manure for maintaining the soil fertility.

In southern Ethiopia as many as 32 spices are found packed in a multiple-canopy hierarchy.

Justification of profitability

The characteristic of the innovation is agrisilviculture. There is a synergetic interface among the different components that add up to high productivity and maintain the quality of the products. Tree species like *Millettia ferruginea* and *Albizia gummifera* typically serve as coffee shade trees. They also add organic matter to the soil since they are deciduous and the leaves easily decompose. *Erythrina abyssinica* is also deciduous; its litterfall maintains soil fertility and its roots fix nitrogen. Enset also conserves soil moisture and maintains soil fertility. More than 70% of enset parts are by-products, left on the area after processing. Thus, farmers rotate enset-processing sites within the field, because exudates from fermenting enset biomass have a soil-enriching quality. This creates fertile ground for coffee since both are planted within the farmyard. As a consequence, farmers in the area do not use inorganic fertilizers.

Farmers fetch a good income from coffee and hence attempt to keep its quality high to add value. They clear herbaceous vegetation from under the coffee at the beginning of the dry season. Maximum care is given at the time of picking the coffee berries not to damage the branches and leaves.

Farmers pick selectively ripened (deep red) berries, leaving the greenish ones behind. Secondly, farmers expend intensive labour to collect the leftover dried coffee berries. Emphasis is also given to maintaining the quality of coffee in storage. Coffee berries collected are dried on a bed set 0.5–1 m high from the ground and covered by bamboo mats. Dried coffee berries are stored in large bamboo baskets, which are placed 30–50 cm above the floor to allow good ventilation. They can be stored in this way for up to a year to fetch the best market price.

Farmers sell coffee berries to traders, the fresh coffee-processing industry, and cooperatives or directly to the consumer at nearby Dilla town (especially dried coffee beans). In the current market, the price of fresh coffee berries is ETB 2.50 (USD 0.29) and dried ETB 7 (USD 0.81) per kilogram. According to key informants, there would be 70% weight reduction when the fresh coffee gets sun dried as a result of moisture loss. For instance, to produce 1 kg of dried coffee berries, about 3.3 kg of fresh coffee are needed. Nevertheless, farmers prefer to sell dried coffee. They justify that the sale of dried coffee can be saved until late September when the income is needed to cover land taxation, school, household and wedding expenses. Farmers said that most marriages in the area take place when farmers sell dry coffee. Cash obtained from fresh coffee from January to March would not have been saved until September.

Farmers also manage firewood and fruit trees to optimize the benefits. Crooked trees will be cut and used to satisfy household energy demands as well as to sell; trees with straight boles will be retained for future timber and the hanging of beehives. Farmers also emphasize storage of firewood, placing it above the fireplace to dry in the smoke. This generates additional income, as farmers can sell one bundle of wood (three pieces of split wood, 0.25 m length) for ETB 0.50 (USD 0.06). One horseload of firewood costs ETB 25 (USD 2.87).

Farmers grow herbaceous plants like godere, boyna and cabbage mainly for household consumption and a small quantity for cash. They also aim to improve quality to add value. For example, for godere and boyna, varieties that produce larger tubers, and more than one, are selected to fetch a better price. For leafy vegetables like cabbage, varieties that sucker abundantly and tolerate continuous harvest are selected. Vegetables for the market are harvested piecemeal, so as to avoid spoilage and to adjust the quantity harvested to prices of the day.

Enset is mainly for consumption but small amounts of it are sold if there is a surplus product. One fermented and wrapped enset product (locally termed *kocho*) costs ETB 50–60 (USD 5.73–6.88). Kocho that is well fermented, pure white in colour, and with less impurity fetches a better price.

One kilogram of fibre by-product of enset is sold at ETB 8–10 (USD 0.92–1.15). Leaves of enset are also used for wrapping traditional bread (*defo*) while baking. Farmers collect the leaves and each sells for ETB 1 (USD 0.15). Other social and cultural benefits include leaves for thatching roofs, bedding, and seating at a wedding ceremony.

Agroforestry components and interfaces

See table 9.4 for synergistic interfaces.

Table 9.4. System components and interfaces

	Enset	Coffee	Tree (*Millettia, Albizia, Erythrina,* avocado)	Herbaceous (godere, boyna, cabbage)
Enset	Compete for moisture and nutrients once the canopy is intermingled	Serve as shade for coffee, add organic matter, conserve moisture through mulching; but fruiting is not good because of heavy shading	Conserve moisture and add organic matter	Interact only with cabbage Conserve moisture
Coffee	Neither harm nor benefit	Compete for moisture and nutrient once the canopy is closed	Neither harm nor benefit	Only godere is planted with coffee Neither harm nor benefit
Tree (*Millettia, Albizia, Erythrina,* avocado)	Serve as shade to reduce evapotranspiration losses, except avocado	Use as shade and fix nitrogen, except avocado	Compete strongly for resources at narrow spacing Avocado tree is planted alone	Suppress the root crops planted underneath
Herbaceous (godere, boyna, cabbage)	No interaction except cabbage	Godere is planted between coffee	Do not interact	Compete for moisture and nutrients because of crowded spacing

Minimum inputs

Farmers have locally made tools for managing and processing different components in the innovation. A slashing knife is used for slashing herbaceous vegetation like weeds. African hoes are used for planting trees, and for planting and uprooting enset and root crops. Small axes are used for pruning, pollarding and lopping trees, a large axe for felling trees. Handles of hoes and axes are made from branches of mature *Pygeum africanum* trees. Baskets are used for coffee harvesting and bamboo mats for drying. Enset-processing materials include a small knife to chop the enset leaf sheath, a large knife to cut the pseudo-stem, a wooden plank on which enset leaf sheaths are scraped, and a wooden table to prepare enset food.

Farmers have indigenous knowledge for managing and sustaining the innovation. The local coffee variety performs better than improved varieties in the area, as reported by key informants. They also indicated that only about 50% survived. However, farmers are eager to improve their coffee and enset-processing technologies. For instance, they dry coffee in the traditional way but use modern drying methods to improve quality. They also need improved varieties of fruit trees to produce more and fetch a better income.

Farmers need to learn how to use wisely the money they earn from the innovation. For instance, they sell sun-dried coffee even though fresh coffee fetches a better price. Also, farmers need improved varieties of leafy vegetables and root crops. There is limited extension support on supplying fodder seeds, though the innovation can accommodate livestock feed as one of the components. Farmers also need support in poultry production, such as introducing an improved variety of hybrid chicken. Farmers prefer the traditional beehives to the modern ones, indicating that bees would not inhabit the modern beehives. At the moment, most of the modern beehives that the Office of Agriculture distributed have been abandoned.

Agroclimatic zones

The agroclimatic zone of the area is moist highland. The innovation is located in Wonago District, Gedo Zone, Southern Region, at 6°20′N latitude and 38°19′E longitude. Altitude ranges from 1750 to 2000 m. The area has bimodal rainfall of 900–1000 mm with temperature range of 9–26 °C. The soil types are Ferrasols and Nitosols, with great depth. These constitutes 83% of the total area of the zone.

Farmers practise intensive farming of subsistence and cash crops with rainfed agriculture. Major agricultural crops include enset, coffee and herbaceous annual crops. Major woody species in the area are *Millettia ferruginea*, *Erythrina abyssinica*, *Vernonia amygdalina*, *Albizia gummifera* and *Polyscias fluva*, with *Millettia ferruginea* dominant.

Major factors that make the innovation successful

Mostly farmers use naturally grown tree seedlings and plant exotic fruit tree species like avocado in the farmyard. They also use local varieties of enset, godere, boyna, etc., implying that they do not spend much to purchase technological and material inputs. There are a number of processing industries for both fresh and dry coffee, presenting a good market opportunity to sell coffee. Also, the cooperative purchases and processes coffee berries and sells them to the international market. Farmers also get technical assistance on preventing coffee berry disease and on aspects of management.

Population pressure is a major driving force that makes the innovation most effective. Population density is estimated to be 500 persons per km^2; 60% of the households have an average farm size of 4.5 ha with family size of 7 persons per household. This implies that farmers intensively manage their small landholdings with agroforestry systems from which they reap food, income, firewood, construction wood, medicinal plants, etc.

Slope of the land is more than 30%. This also urges the farmers to practise the innovation as a strategy to conserve and use the land sustainably. Also, the amount of rainfall per annum and the temperature are suitable for effective implementation of the innovation. This is because most of the components in the innovation need sufficient amounts of water for better productivity.

Direct and indirect beneficiaries

Both men and women in the household play a significant role in sustainable management of the innovation and benefit from it. It is the responsibility of men to cut enset for sucker production. Men are also responsible for transferring suckers to the nursery and tending them, slashing back the herbaceous vegetation (twice a year), pruning and pollarding or selling trees, harvesting coffee, planting enset out in the field, and preparing and hanging beehives on the trees. Women are mainly accountable for processing the enset and fetching water and wood. In marketing, men sell the dried coffee and firewood, the products that fetch more. Women sell enset products, avocado fruit, godere, boyna and fresh coffee berries (very small quantities). However, if the quantity is good, men also sell fresh coffee.

Children are indirect beneficiaries of the innovation. They are not allowed to sell any type of products without permission from the head of the household. However, adolescent children do assist their parents, particularly in pollarding trees, slashing and weeding, and harvesting fruit and coffee berries.

Both rich and poor farmers benefit. However, there is a difference, exhibited particularly at enset harvesting. For instance, rich farmers harvest the enset crop after it has matured (average 6–7 years), whereas poor farmers harvest within 3–4 years to satisfy family food needs. Moreover, the poor farmers usually collect greenish, unripe coffee berries and sell them at the local market. They also cut immature trees for firewood for household use and for sale. Root crops help the poor fill the gap in feeding the family, serving as risk aversion crops if enset fails because of frost damage.

Upscaling strategies

Almost all the farmers adopted the innovation. They became well skilled in selecting the right site for a given species. This enables them to apply the innovation on a wider scale more easily. Farmers surveyed believed strongly that the system had benefited them in terms of income, food, firewood, construction wood, etc. Local food preferences contribute a lot to perpetuating the innovation. Enset dishes need to bake a long time and hence they need firewood, for which millettia is the major species. Coffee within the system entails shade trees, which farmers use.

The physical features of the area also have contributed a lot towards replicating the innovation. The topography too has led farmers to upscale the innovation, because most of the area slopes more than 30%—too steep to practise monocropping. Multiple-layer arrangements of different components are needed to conserve water and soil, and to drive maximum benefits from the system. Farmers have confirmed that if they had not practised the innovation, they would have lost a large amount of soil. Scarcity of land has also motivated them to adopt and replicate the innovation so as to get diversified products from the available small plots. Population pressure has also obliged farmers to adopt the innovation on a wider scale. The density of population forces farmers to adopt and maintain the innovation widely.

Institutions promoting the innovation

Farmers are the main participants in this innovation. They contribute labour, land, materials and capital inputs. They have indigenous knowledge to manage each component of the innovation. They also store and plant local varieties of enset and coffee as sources of seed. The peasant associations, cooperatives and the Office of Agriculture play facilitative and collaborative roles. The Office of Agriculture organizes a safety net program in which a farmer is allowed to work for 5 days per month with a payment rate of ETB 6 (USD 0.69) per day. For instance, if all in a household of six mature persons work for one month, they will earn ETB 180 (USD 20.64). Only households categorized as poor villagers can participate in this program.

Table 9.5 shows the role and level of participation of institution.

Table 9.5. Role and level of participation of institution

Institution	Role and function	Level of participation
Cooperative	Buys fresh coffee, processes and presents it to the international market	Facilitates coffee marketing
	Shares out the dividends to its members	
Office of Agriculture	Provides technical advice on pollarding coffee; provides papaya seedlings, vegetable seed, hybrid chickens, modern beehives, fodder seed	Facilitates and collaborates
	Organizes farmers in safety net program to maintain and construct roads, develop springs, construct bridges, etc.	

Research questions and knowledge gaps

Although the innovation provides multiple benefits, it faces serious problems from coffee berry disease, which causes premature shedding of coffee berries. This decreases coffee productivity and reduces income. Enset crops suffer from the mealybug insect, which damages the rootstock and dries standing plants. However, farmers are striving to protect the system from this pest with the cultural practice of planting enset in the shade.

There has also been inadequate research on the ecological role and productivity of each of the components in the innovation. Little investigation has been done on spacing within and between system components to increase productivity and add value to the system.

Farmers complain about the incompatibility of modern beehives in producing honey, preferring the traditional beehives. They say that bees will not stay more than a week in a modern beehive. A thorough study is needed on the limitations of the modern beehive, and the problem should be addressed to raise productivity.

Farmers could be given more technical advice on how to improve quality of harvesting and storage of enset and coffee berries to add value. They do not have adequate training on modern processing and storage methods or input of materials for them. Most farmers use local varieties and have little interest in adopting improved coffee varieties. The key informants stated that improved varieties were not successful in terms of production, because they could be easily attacked by disease. Therefore, they mainly stick to local varieties.

Coffee price fluctuates greatly, mainly due to the declining price of coffee on the international market. Farmers in distant areas do not have access to market information. Therefore, they sell their coffee to intermediaries who are often perceived as deceitful. Nor is there an institution that shows farmers how to save and manage money obtained from coffee sales. Access to credit facilities is low. These and other issues deserve high research attention.

Professional reflections and recommendations

Farmers have already widely adopted the technology. They need less technical and material inputs, which implies less intervention from outsiders. Population pressure also contributes a lot to expanding the innovation since it provides a wide range of benefits for sustaining household livelihoods. Extension and investment strategies of the country have also contributed to the success of the innovation. For instance, a number of coffee-processing industries and cooperatives for both fresh and dry coffee have been established in the area, creating good access to coffee markets and enabling farmers to get better prices. Currently, a coffee exporting union has been established that may increase the benefits for farmers from the sector.

However, basic improvement is required on the processing and storage of coffee to improve coffee quality. Spacing between components should also be examined since most farmers plant enset, coffee, tree and root crops randomly. Rationalized spacing might reduce intra- and interspecific competition among components and increase productivity and hence income too. Farmers still process enset with traditional tools. Modern technology could improve product quality and reduce the amount of labour needed.

Farmers well understand the benefits of the innovation so the likelihood is high that it will be pursued. The innovation includes coffee as one of the components. It is known that coffee needs shade and hence its existence necessitates retaining and planting trees within the system. This implies that, so long as coffee is within the system, the existence of trees is inevitable. Additionally, enset is a perennial and drought-tolerant crop in the system. It is also compatible with tree, coffee and root crops. This will attract good attention from policymakers as a strategy to maintain food security.

The inconsistent market price of coffee may discourage farmers from implementing the innovation. Coffee berry disease and mealybugs on enset may cause great damage on the two crops and reduce crop quality and quantity. This may threaten the livelihood of the people who are fully dependent on the innovation.

To increase the productivity and add value in the system, research is needed on synergetic interfaces among components: the need for improved varieties of coffee and root crops, and the problems with modern beehives being addressed. Furthermore, training should be given on poultry production, apiculture, compost preparation, modern enset and coffee-processing technologies, management of money, and family planning.

9.4 Calliandra-based fodder production systems in Kenya

Nature of the innovation

The greatest constraint to improving the productivity of the livestock sector in sub-Saharan Africa is the low quality and quantity of feed resources (Franzel et al. 1998). The main feed source in Uganda for livestock is the perennial Napier grass, which is supplemented during the dry season by crop residues. However, milk production from this practice is low due its low protein content. Many farmers are increasingly planting high-value multipurpose tree species on farm to provide high-protein feed. *Calliandra calothyrsus* is one of the species most commonly planted as hedges along farm boundaries or along contours to provide fodder for livestock.

Calliandra is a native of Central America and Mexico. It was introduced in Uganda where it has been grown by farmers for more than 15 years

Calliandra and other fodder crops that are integrated in agroforestry systems are major sources of cut-and-carry based cattle keeping.

(AFRENA Project Uganda 2000; ICRAF 2001). It is the main fodder shrub grown to provide an inexpensive and high-protein livestock feed (Franzel et al. 1998; ICRAF 2001). Due to limited sources of fodder, farmers realize limited milk yields. In addition they spend money to purchase livestock feed supplements that are expensive, difficult to transport, and at times not available.

Its fast growth, excellent quality as supplement fodder for livestock and ability to regrow after cutting has made livestock farmers appreciate and integrate it in intensive livestock production systems (Franzel et al. 1998). On many farms where it is grown, calliandra cuttings are used as fodder for improved dairy cows and other livestock, resulting in increased quality and quantity of milk produced. This system is better than the old system in which animals were fed low-quality roughage or fodder grasses.

In hilly areas, calliandra hedges are deliberately planted on steep slopes to provide stability and prevent soil erosion, while at the same time providing a continuous source of stakes and fuelwood (AFRENA Project Uganda 2000; ICRAF 2001).

Justification of profitability

For dairy farmers to obtain high economic returns from their dairy enterprise, lactating cows need to be fed with a protein-rich supplement like tree fodder. Often calliandra is used as a protein supplement, in addition to the basic diet that normally consists of Napier and other grasses, weeds and crop residues. It has been found that 3 kg of fresh calliandra fodder can replace 1 kg of dairy meal without affecting milk production, while an additional 3 kg of fresh calliandra fodder increases milk production by 0.6 litres daily, an increment equivalent to that obtained from an additional 1 kg of dairy meal. Therefore, 6 kg of fresh calliandra replaces 2 kg of dairy meal, if the farmer does not have money to buy dairy meal. In addition, dairy animals fed with calliandra produce milk high in butter fat content, which improves the nutritional value of the milk (AFRENA Project Uganda 2000, ICRAF 2001).

The benefits of feeding livestock with calliandra compared with commercial dairy meal can be assessed in terms of savings in money, time and effort, and in increased milk production. It is easier and cheaper for farmers to meet the protein requirements of dairy animals from plants grown on farm than through buying commercial dairy meal. When used as a substitute for dairy meal, the costs and benefits of feeding a cow on 6 kg of fresh calliandra a day are comparable to the costs and benefits of feeding the cow on 2 kg of meal, which has the same quantity of digestible protein and in some cases gives the same milk output.

Another benefit of using calliandra is the amount of money saved by not purchasing and transporting the equivalent quantity of dairy meal for protein. After the initial costs incurred during establishment, farmers' net income increases by about UGS 110,000 per annum by using calliandra as a substitute for dairy meal. The investment costs and returns per year of 500 shrubs for feeding one cow are presented in table 9.6.

Table 9.6. Investment costs and returns per year of 500 shrubs for feeding one cow

Item	Amount (UGS)	Equivalent in USD
Investment costs		
Seedlings—500 at UGS 50	25,000	14
Labour for planting—2 days at UGS 1500	3,000	2
Total investment costs	28,000	16
Returns per year		
Extra milk—450 litres at UGS 300	135,000	75
Labour cost for feeding and cutting—per day for 300 days	–25,000	–14
Net returns	110,000	61

Source: AFRENA Project Uganda (2000)

In Uganda, about 34% of the present cattle population is dairy cattle, from which most milk and milk products are obtained. In 2001, up to 900 million litres of milk were produced, of which 156 million were processed. Over half of the annual national milk production was offered for marketing and over 70% was sold unprocessed. About 10% of the processed milk was exported to neighbouring countries, earning the country over USD 3 million. Per capita milk consumption for Uganda has also increased from 16 litres in 1985 to 40 litres by end of 2001(Uganda Bureau of Statistics 2003).

There has been an increase in the cattle population in Uganda from 5.5 million in 1996 to 6.15 million in 2001. This has been mainly as a result of general improvement in animal health, improved breeding programs, and better management practices (Dairy Development Authority 2003). Exotic and cross-breed cattle account for 5% (0.3 million). Due to the high productivity associated with intensive dairy farming methods such as zero-grazing of improved breeds, many farmers have adopted modern farming techniques at various levels of production.

The liberalization of the dairy industry in the mid-1990s removed the monopoly of the Dairy Corporation and opened up opportunities for private investors to join the business. These included Jesa Dairy Farm, GBK, Country Taste and Alpha Milk. As a result, nationwide the proportion of milk production that is processed before marketing increased to about 156 million litres in 2001 (Dairy Development Authority 2003).

Several cooperative societies are involved in collecting and marketing milk, and some of these have recently gone into milk processing. In addition, involvement of regulatory institutions like the Uganda Dairy Industry Stakeholders' Association (UDISA), the Uganda National Dairy Traders Association (UNDATA) and the Uganda National Bureau of Standards (UNBS) contribute to ensuring high quality of milk produced by formulating a code of practice for handling and marketing raw milk. This contributes to quality assurance. Despite this, the majority of farmers are not organized into associations to process and market their milk and its products.

Agroforestry components and interfaces

The major components in the practice are calliandra, livestock and interplanted crops. The production of calliandra on farms assures livestock farmers of a reliable and easily accessible source of fodder. The shrubs provide quality fodder for the livestock, improve livestock health and enhance milk production. Animals fed on calliandra fodder also produce high-quality manure, because calliandra leaves are high in nitrogen. This manure is used as organic fertilizer for the interplanted crops. Calliandra hedges planted along soil-conservation structures provide the additional benefit of stabilizing these structures, thereby reducing soil erosion (ICRAF 2002). This improves on the productivity of the farm. Table 9.7 summarizes the synergistic interfaces between the components in the system.

Minimum inputs

The success of the practice depends on careful consideration of the minimum requirements in materials, technical inputs and financial capability to be able to facilitate the complete chain from production to marketing.

In production, material requirements include calliandra planting materials (seeds or seedlings), labour, improved livestock and land. About 500 seedlings are required to sustain one dairy cow for a year. When planted at a spacing of 50 cm, a single-line hedge will be about 250 m long. If planted as double lines, the hedge will be 125 m long and spacing between lines should be 90 cm (ICRAF 2001, 2002). The other major requirements in managing calliandra are to harvest at the right height and time so it regrows well, and

Table 9.7. Synergistic interfaces between the components in the system

Component	Calliandra	Livestock	Interplanted crops
Calliandra	With more calliandra trees planted on farm, some can be left for seed production; ready availability of seed enables farmers to expand the practice	Improved fodder availability on a sustainable basis on the farm results in increased milk yield	Crops benefit from the nitrogen fixed by the shrub in addition to the soil and water conserved; mulch from the shrub also suppresses weeds and retains soil moisture
Livestock	Manure from the livestock is applied to the associated crops but benefits calliandra trees as well, thereby enhancing biomass production	Increased milk production results in improved incomes	Organic manure from the livestock is applied to crops, increasing their productivity
Interplanted crops	Good management applied to the crop leads to better growth and productivity of the calliandra shrub	Crop residues are fed to livestock as feed supplements	Increased crop yield improves household food security; surplus produce is marketed to generate income

to control pests and diseases.

Financial inputs required for establishing and managing calliandra shrubs mainly cover costs of acquiring planting materials (seeds or seedlings), and labour for planting, weeding and harvesting. It also includes the costs of procuring specialized tools such as pruning knives. Purchase and proper management of improved livestock is the other financial requirement.

The necessary infrastructure for the success of the practice is an efficient marketing system for milk, which is the main product from the practice. Good prices for milk are also a precondition for success of the practice. Cooling facilities are necessary to reduce milk losses. However, such facilities are costly and therefore require that milk producers or traders pool resources to purchase them. This is possible only if cooperative societies exist.

Agroclimatic zones

Calliandra performs well at altitudes ranging from sea level to 1900 m and where annual rainfall is above 1000 mm. The shrub can withstand dry seasons of 2–4 months with less than 50 mm of rainfall per month (AFRENA-Project 2000; ICRAF 2001). It can grow on a wide range of soils, including Humic Nitosols, Humic Andosols and Ferrasols with a minimum pH of 4.5. It does not do well on soil that is heavily saturated with aluminium, neither does it tolerate frost or soils with poor drainage that flood regularly.

In Uganda, this practice is common in various parts of the country. It is, however, more pronounced in the eastern highlands, the lakeshore region, and the southern highlands of the country. According to the harmonized agroclimatic zones for east and central Africa, the practice can work in the moist mid-highlands and moist lowlands.

Major factors that make the innovation successful

The practice has gained popularity as the cattle population in the country has steadily increased at a rate of 3.1% over the last 10 years. This growth has been attributed to increasing demand for milk by consumers and milk processing plants, better herd management, adoption of improved breeds, and improved animal health and support services. However, due to increased pressure on the land, areas for grazing are rapidly diminishing. The practice, therefore, fits well into the current shift to the use of more intensive production methods. This fits well into the country's Plan for the Modernization of Agriculture (PMA).

Dairy farming provides smallholder farmers with a pathway out of poverty, boosting household incomes, improving nutrition, and providing a source of animal manure for crop production (Franzel et al. 1998). The main concern is that the animals need to be fed well. With good grazing land increasingly in short supply, raising animals in most areas of Uganda is becoming a risky business that can easily defeat even the most skilful farmers. But using calliandra in intensive livestock production systems reduces the risks by providing farmers with a reliable form of high-protein fodder that is available throughout the year (ICRAF 2005).

This practice fits easily into intensive production systems as it does not require farmers to divert land from other crops to fodder production. An average farmer needs about 500 shrubs to feed a cow for a year and can easily find space for planting these shrubs along the outer boundaries of a typical 1-acre (0.4 ha) farm. Also, the shrub withstands repeated harvesting and when maintained at a height of 1 metre it does not shade companion crops.

Generally, the practice is easy to implement right from establishment through to management as it requires minimal labour and material inputs. Most of the workload involved is at the establishment stage and thereafter, the shrub normally grows vigorously and coppices well.

The practice improves upon both the quantity and the quality of the milk produced. The milk has a market both locally within villages and in nearby urban centres. It is in high demand in households as well as in commercial units like restaurants and institutions. Milk can also be processed into a wide range of dairy products such as ghee and yogurt that are also consumed locally.

Direct and indirect beneficiaries

The main beneficiaries are farming households, milk processors, milk transporters, nursery operators and milk product vendors. They benefit in terms of improved nutrition (especially children) and income, and hence better education, housing and medical care.

Specifically the practice saves time for women and children by reducing the labour and time required to look for fodder from off-farm sources. Traditionally, women manage the livestock enterprise in the farm household. Thus, integrating calliandra into livestock production systems eases women's farm management tasks. The children commonly graze the livestock or look for fodder for feed. Increased availability of fodder on farm will reduce the time and drudgery involved in carrying out these tasks, thus reducing their workload.

The practice fits into intensive agroforestry systems that are characterized by poor households who normally experience land shortages. It enables smallholder farmers in such systems to sustainably integrate livestock (that is, dairy cattle and goats) and trees or shrubs (calliandra) on small pieces of land. Given that calliandra shrubs are also good for feeding dairy goats makes the practice especially useful for households that can seldom afford dairy cattle.

The indirect beneficiaries of the practice are the local governments that generate revenues from taxes imposed on trade in milk and its products. From the environmental perspective, the practice creates a cumulative effect on the entire landscape and its catchments, which in the long run translates into improved land productivity. This is an indirect spin-off that benefits all communities in the catchment.

Upscaling strategies

This practice is widespread in areas where intensive livestock production is prominent. Currently, it is practised in about 10 districts in the country. There has been a lot of promotion of generating household income by raising improved livestock breeds. Most of this promotion has been through government programs such as the National Agricultural Advisory Services (NAADS) and various NGOs and community-based organizations. Several of them promote zero-grazing and have made it conditional that for farmers to receive heifers or improved goats, they must have a good supply of improved fodder.

One of the approaches has been to use group nurseries to produce calliandra planting materials, which are passed on to other group members. Another scaling-up approach has been to establish seed stands to ensure a sustainable supply of seeds. Study visits or tours have also been a scaling-up approach.

Several factors have contributed to the success of upscaling. Top among these is the need to improve household income for farming communities. Ready availability of market for milk and its products and the availability of planting materials and technical information on calliandra management also greatly contributed to this process. In addition, decreasing landholdings and the introduction of improved breeds of goats and cattle have led to intensive livestock production systems. This meant that households had to purchase livestock feed, which unfortunately is expensive and not readily available.

Institutions promoting the innovation

There are many actors involved in milk production, processing and marketing in Uganda. These are summarized in table 9.8. Production mainly involves farmers and transporters who link them to the markets. The farmers are aided by many secondary actors for example the extension departments, researchers, and NGOs and community-based organizations.

At the processing and marketing stages, until 1994, the Dairy Corporation (a public company) monopolized the formal marketing for pasteurized milk and milk products and dominated the dairy industry (ILRI 2004). Since then, however, the dairy sector has undergone substantial transformation and shifted towards more private sector participation. As a result the role of the government is now primarily to create an enabling environment for the private investors to develop and promote the dairy industry (Dairy Development Authority 2003).

Table 9.8. Institutions actively involved in promoting the practice and their respective roles

Institutions	Roles
Research institutions (Forestry Resources Research Institute, ICRAF, Kawanda Agricultural Research Institute, NAAR)	Develop and promote improved fodder technologies to farmers and provide technical backup
Farmers and farmer groups	Access training and link farmers with advisory services Acquire improved planting materials Provide better environment for marketing of milk Implement the practice and evaluate performance of the shrubs
NGOs (e.g. IUCN, HPI, Send-A-Cow, Farm Africa)	Provide improved livestock breeds Provide planting material and extension services to farmers
National Agricultural Advisory Services (NAADS)	Facilitate formation of groups Provide technical advice Build capacity of farmer groups
Uganda National Traders Association	Purchase milk from farmers and sell it to urban centres and towns Promote marketing of high-quality milk and its products
Veterinary services	Provide veterinary services to dairy farmers
Land 'o Lakes	Research on processing aimed at improving the dairy sector Support institutions linked with farmers
Dairy Development Authority	Oversee activities of the dairy sector (regulatory body)
Worldwide Sires Inc.	Breed livestock for dairy and beef
Dairy Processors (e.g. Dairy Corporation Ltd, Country Taste (U) Ltd, GBK Dairy Products, Teso Dairies, Jesa Dairy Farm Ltd)	Process raw milk into various milk products Sell these products to consumers
Uganda Dairy Industry Stakeholders' Association (UDISA)	Regulate quality in handling and marketing milk
Uganda National Bureau of Standards (UNBS)	Regulate quality in handling and marketing milk

Research questions and knowledge gaps

Despite the fact that the practice is widespread, there are still research issues that are limiting its upscaling. Currently there is insufficient information on calliandra pests and diseases and so further research in this area is necessary. Profitability of the practice in cases where there are more than 10 livestock numbers is not well studied and documented. The practice has also not been evaluated outside the zero-grazing system and therefore there is need to do research on its suitability for other livestock systems. For example, there is need to find ways of integrating fodder shrubs into open grazing systems that are common in the country.

Other issues relate to preserving extra calliandra produced in the wet season for use during dry seasons. Some research has been done in this area, especially on silage production; however, there is need for more work on product development and promotion.

Another problem is to identify, evaluate and promote indigenous fodder species. There is need to determine suitable propagation methods, palatability and nutritional value of these species, and their effect on livestock health. Exotic fodder species are currently being developed and promoted at the expense of the indigenous ones, which have advantage in terms adaptability and availability of planting materials.

Uganda consumes less milk than the other East African countries. There is need to better understand the reasons for this low consumption and develop ways and means of increasing consumption of milk in the country.

Professional reflections and recommendations

Currently the practice relies heavily on the calliandra shrub. This is risky as any outbreak of pests or diseases of the shrub will greatly affect the practice. It is therefore recommended that other shrubs (*Leuceana, Acacia* spp., *Mimosa,* mulberry) that have been found to be good fodder species should be promoted.

Calliandra requires proper timing and spacing and the seedlings planted should be of good quality. For the innovation to benefit all components there is need to maintain the cycle by returning the manure from the livestock to the gardens.

The marketing and pricing system for milk and its products is not regulated. Farm-gate prices are low and disadvantageous to the farmers as a result of the poor marketing structure. For farmers to get better prices from the sale of milk and its products, it is recommended that farmers form producer and marketing associations in their communities. These associations should also be strongly linked to the markets and oversee the activities of smaller farmer groups.

9.5 Multistrata perennial crop agroforestry system in Ethiopia

Nature of the innovation

Multistrata perennial crop agroforestry is a system that combines a large number of perennial crops including plantation trees and shrubs. It consists of complex horizontal and vertical arrangements of perennial species, which in most cases and with careful management practices, complement each other. The upper layer is dominated by timber, shade and fruit tree species. The middle layer is occupied by medium-sized plantation species and medium-sized agricultural crop species. The lowest layer is occupied by vegetable and spice species as well as young plantation species. Species mixture dynamics is subject to continuous alteration to fit into the emerging biophysical, socioeconomic, and soil condition realities.

The system is managed by regular weeding and cultivating as well as by applying animal manure and mulch to selected plantation species. Fodder species are regularly lopped and fed to animals (cattle and sheep). Bee nectar and fuelwood are additional by-products. Hanging branches of shade trees are pruned to avoid damage to crops underneath and to reduce excessive shading of sensitive species. Animal dung is the only external input applied for soil fertility. The multistorey gardens effectively recycle soil nutrients

Banana–coffee–maize in a multi-canopy agroforestry system.

on a sustainable basis and provide harvestable products throughout the year. Neither the decline of soil fertility or soil erosion is evident in the system.

Soil fertility is maintained by animal manure, compost, and leafy decomposition of various species. Species like leucaena and herbaceous vegetation are fed to animals, which in turn provide manure to fertilize the plots. Many of the fruit species require regular application of manure to bear well. Mulching is essential to avoid soil desiccation.

Plantation species are largely managed for meeting household food requirements and cash generation. Women and young children shoulder the major part of the work in planting, weeding, manuring and watering. Male household heads make most of the management and utilization decisions. Nevertheless, women possess full access to fruit and vegetable products from the system for household use. Harvesting mature indigenous tree species is allowed only with permission from a local committee, approved by the district Board of Agriculture). Permission is granted only after five seedlings of the same species have been planted on farm, as confirmed by the committee. The system created a brilliant opportunity for local communities to experiment with various species and component arrangement patterns to back up and expand existing indigenous knowledge.

Justification of profitability

The system is continuously altered to adjust to contemporary biophysical, socio-economic and ecological requirements. Farmers replace local coffee varieties to meet specifically demanded product quality and yield. Fruit species are constantly being selected for higher fruiting intensity and for size and juiciness of fruits. A farmer in the area claims to have identified an avocado variety that takes only three fruits to weigh a kilogram. Similarly, sugarcane varieties were screened for stem breadth and height as well as early-maturing qualities. Traditionally in selecting varieties, farmers not only pick better-performing candidates but also eliminate inferior ones from their farmlands. Therefore, opportunity to upgrade both the productivity and the product quality of the system is unending.

Farmers also promote the quality of their agroforestry products through timely tending of the system. Timely suppression of weeds and regular maintenance of optimum distance between trees and shrubs, as well as proper adjustment of the density of upper crowns, help maintain and promote product quality and quantity. For example, the flowering and early fruiting stage of coffee greatly enhances fruit development and health, resulting in bigger and full berries. Farmers understand very well the importance of strictly maintaining irrigation frequencies during the dry season.

They regularly apply manure and mulch. The system relies entirely on litter fall, compost, and animal manure and thus there is no need for inorganic fertilizer. Leguminous woody perennials provide nutritious leaves and twigs to supplement animal feed, particularly during the dry season.

The Board of Agriculture provides seeds and seedlings of improved crop varieties as a means of upgrading the genetic potential of traditionally popular varieties. Farmers are quite judicious in selectively adopting the best-performing varieties and reject varieties that they have determined would not perform well under their ecological and socioeconomic conditions. New fruit varieties are screened for quality of produce, amount of yield, disease resistance, and pleasant taste.

All crop and fruit products are marketed in the town of Finote Selam, about 7 km away. Sugarcane is sold on farm to brokers who in turn sell to intermediate traders. Searching for a better market price elsewhere is either unknown to the farmers of the area or discouraged by current government policies. Farmers attribute this to the small-scale production system, making the limited amount of produce from the area financially unprofitable to transport long distances. The reality is that it is not feasible for the farmers to transport their products over long distances because they would have to cross many intermittently located checkpoints. Thus farmers sell their fruits in the town at a mutually negotiated price, which often is the price offered by town traders. They also take avocado fruits to the next nearest town, Debre Markos, for a slightly better price.

There were occasions when farmers had to dispose of avocado fruits for lack of market demand, since the fruit was new to the area. It took some time even for household members to gradually get used to eating avocado fruits and juice. Its popularity now is gradually growing, and thus its market demand increasing. Now it is not only an important and nutritionally rich dietary supplement, but it is also a readily accessible 'breadbasket' that can be resorted to at will.

Major fruit products are quickly perishable, an additional consideration in marketing. Coffee is non-perishable and thus can be sold any time of the year when market prices are relatively attractive. *Rhamnus Prenoides* can be sold in the market. It is mostly planted on steep slopes where continuous vegetation cover is essential. For household use, only the leaves are stripped off and used while the branches are largely retained intact for further regeneration. Farmers also raise seedlings of various fruit and tree species including coffee and sell them to neighbouring farmers.

Another positive aspect of the system is its low requirement for male household labour. Once the system is established, it is mainly managed by women and children, thereby releasing the male household head to produce field crops and carry out other basic activities.

In general, current product quality is said to be low. Farmers of the area do not know well the harvesting time of various fruit species. Likewise, farmers are not aware of how to store and transport perishable farm products, which thus deteriorate after harvest. The avocado market is still limited to a few juice shops in Finote Selam. Mango has better market demand than avocado. Coffee has a good market in all the shops.

Transportation infrastructure to deliver products to market are poor. The distance between farm and town is a serious disincentive when transport is by animal-drawn cart. There is, however, an increasingly growing demand and market for new fruit products. Their popularity among both urban and rural populations is gaining ground. The economic and ecological future of the system in the area thus look promising.

Agroforestry components and interfaces

The system is composed of a wide range of species that proficiently fit into its complex vertical and horizontal strata. All components exhibit synergistic interactions with each other, the outcomes of which may be either positive or negative depending on their competitive potentials. Trees that grow tall with a dense crown usually outcompete lower-canopy plants, unless they are specifically shade tolerant. Trees that occupy upper-canopy strata need to be spaced more widely apart so that their crowns, under no circumstances, interlock. Intermediate trees and shrubs need to be spaced relatively closer together to maximize biomass and crop production. These are mostly composed of shade-tolerant species like coffee and sesbania.

The uppermost layers are inhabited by tree species: *Cordia africana, Persea americana, Mangifera indica, Albizia gummifera*, and *Acacia lahai*. The middle layer is occupied by *Sesbania sesban, Coffea arabica, Rhamnus Prenoides, Citrus sinensis, Citrus reticulata, Leucaena leucocephala, Prunus persica, Musa x paradisiaca, Carica papaya, Arundo donax*, and *Saccharum officinarum*. The ground layer is dominated by various herbaceous weeds and annual and biannual crops such as *Capsicum annuum* and a few spices as well as young plantation species. The system also involves honey production using both traditional and modern beehives.

To guarantee access to the minimum required growth factors, all plants in the system continuously interact biologically and physically with their neighbours. Farmers easily identify the major outputs from continuous synergistic interactions between system components. In most cases, however, they only describe the outputs qualitatively as ‘good’, ‘moderate’, or ‘undesirable’. In describing the outputs of component interactions, farmers largely count on accumulated experience and long-term observations. Accordingly, they adjust both vertical and horizontal placements of the system components to efficiently use available growing space and to optimize the overall economic and ecological benefits. Table 9.9 summarizes outcomes of the most significant interactions between major components of the system.

Minimum inputs

The system requires about a quarter of a hectare of land or more to maintain adequate quantity of each component. The system is entirely managed by family labour, predominantly by women and children. It is also claimed to be one of the least labour-intensive systems, once established. The male household head takes the leading decisionmaking role with regard to both horizontal and vertical arrangements of the components. Hired labour is used only in rare cases where heavy work such as pit sawing of the timber tree species is required. No commercial fertilizer is employed in the system. Various species require different levels of cultural practices. Cordia and sesbania, for instance, require the least attention once established. In contrast, coffee, papaya, avocado and mango require regular mulching, manuring, weeding, harrowing, irrigation, and maintenance of adequate shading intensity.

A continuous supply of high-yielding crop and fruit varieties is crucial to intensify the system and to improve productivity per unit area. Once farmers accept a promising variety, they can multiply the species from either seed or vegetative parts. At the time of the survey, farmers were constrained by lack of polythene tubes for raising seedlings of rhamnus, cordia and acacia. They collect plenty of seeds from their own farms.

Technical experts provide infrequent and unsatisfactory support in promoting the system, but such support is needed to supplement farmers’ indigenous knowledge with new scientific innovations. Farmers strongly protested that they lacked technical support and replies from technical experts to their questions. Innovative farmers also require frequent follow-up, encouragements, and new technologies that coincide with their felt needs.

Particularly needed is competent training on when and how to harvest fruit, post-harvest treatment, product transportation and marketing methods. Farmers have complained that in the past the avocado harvest was a complete disaster; fruits were dumped, mainly due to lack of market demand in the area and lack of know-how on post-harvest management tech-

Table 9.9. Outcomes of the most significant interactions between major components of the system

	Avocado	Mango	Cordia	Coffee	Orange	Albizia	Papaya
Avocado	Compete for space	Need wider spacing	Grow well side by side	Growth rate and yield low	Reduce fruiting under shade	Compete for space	Shade reduces yield
Mango	Compete for space	Need wide spacing			Cast heavy shade, low yield	If overlap, serious competition	Casts shade, low yield
Cordia	Need wide spacing	Need wide spacing	Needs wider spacing	Shade favours growth and yield	Heavy shade reduces fruiting	OK at wider spacing	Shade reduce fruiting
Coffee	Seedlings need open space	Seedlings need open space	OK	Need not overlap	Can grow side by side		Grow well side by side
Orange	Seedlings need open space	OK, once established	OK	Need proper spacing	Compete for space	OK, once established	OK at wide spacing
Albizia	Compete for space	If overlap, serious competition	Grow well at wide spacing	OK for coffee growth and yield	Shade reduces fruiting	At wider spacing, OK	Need not cast heavy shade
Papaya	OK, once established	OK, once established	OK	OK	OK	OK	Slight distance

niques. Similarly, demand for pepper, maize, and honey has fallen sharply in recent months (pepper is still in store). Training is also critically needed on site selection and preparation, component selection, vertical and horizontal arrangements of components, and management practices for better profitability of the system. Farmers seek training on effective use of irrigation water and water conservation procedures.

Development of marketing infrastructure and arrangement of reasonable and non-exploitive product prices are among the major promotional measure of the innovation. Assisting farmers in transporting their products to high-demand areas is an essential requirement. This calls for a major shift in farm product marketing policies, developing those dedicated to enhancing free product marketing and higher profitability of the system. Adjustment of corrupt local extension policies, which trapped many farmers in debt and landlessness, are badly needed to adjust to local realities. Placing farmers on the track of primary losers and victims of such unfounded policies needs to be rectified.

Current provision of technical and material inputs on the basis of farmers' political affiliations will decelerate the pace of disseminating the technology. Proper on-farm verification and establishment of demonstration plots should precede diffusion of innovative farm practices. Farmers are bitterly disappointed, for instance, with the adoption of modern beehives, which failed to retain bee colonies.

Agroclimatic zones

The innovationis practised in Jebe Tahnan District, Menkusa Abdegoma PA; Amhara Regional State (10°40′N, 37°11′E; 1890 m). This practice performs well in moist mid-highland agroclimatic region of Ethiopia where altitude range is 1500–2300 m and mean annual rainfall 900–1400 mm. For better economic benefit, the site should have access to irrigation facilities during the dry season. Mean annual temperature should be around 18 °C. Red and brown colours generally characterize soils.

Major crop species include tef, maize, millet, barley, wheat, horse bean, noug, pepper and fruits. Such vegetable species as tomato, cabbage, pepper and carrot are also commonly grown in homegardens. Whereas maize, pepper and fruit species are grown in or close to homegardens, other crop species are grown in the field. Naturally grown tree and shrub species include *Croton macrostachyus, Cordia africana, Ficus vasta, Acacia lahai* and *Albizia gummifera*.

Major factors that make the innovation successful

Farmers claim that their interest in promoting the practice is the primary factor responsible for effectiveness of the innovation. The technology significantly increased recognition of farmers' indigenous innovative practices and knowledge as well as their self-confidence. Many practitioners as well as senior government officials visited the homegarden plots. The innovation is considered as a notably successful activity in securing the food self-sufficiency target of the government.

Effectiveness of the innovation is mainly attributed to the multiple products obtained from a small plot of land. There always will be something to harvest year-round and a higher overall yield. Thus farmers use the homegarden plots primarily as a means of risk aversion by placing reliance on multiple crops. Moreover, fruit species like avocado represent readily available food stock that can be picked and consumed at will. A farmer can pick and eat one or a few avocado or papaya fruits before going off for fieldwork rather than waiting for long cooking procedures. These two fruits can also be used as a readily available sauce for other dishes.

An added advantage of the innovation is that it can be largely managed with family labour. Once the system is established women and children can perform all the management tasks including weeding, cultivation, manuring, irrigation, and harvesting. The practice does not involve cultivation by oxen and thus frees the male household labour for field-crop production.

Monocropping mostly exacerbates the problem of soil erosion and gulley formation, particularly on hilly slopes. Soils under a combination of perennial crops are under continuous vegetation and litter cover and thus are little exposed to water and wind erosion. Continuous application of leafy biomass and animal manure to the plots improves water percolation, which in turn greatly reduces soil erosion and promotes constant and regular water flows from the catchment. Moreover, continuous addition of admixtures of leafy biomass and animal manure maintains or even improves soil fertility on a sustainable basis, resulting in no need for chemical fertilizers, frequent crop rotation, or fallowing as with monocropping systems.

As the use of irrigation expands, water scarcity increases, particularly during the dry season. Perennial crop combinations reduce evaporation loss from the soil because of ground cover with leafy biomass and tree crowns. Farmers are introducing drought-tolerant species into the lower and middle canopy layers as a coping strategy. This helps adjust the system to changing production conditions (reduced amount of irrigation water) and maintains overall productivity of the system.

Direct and indirect beneficiaries

Any household with an adequate homegarden and adequate amount of family labour available can adopt and benefit from the practice of combining perennial crops. Benefit from the system is equally shared between men and women household members as well as various religious groups. Women have full access and control, particularly over food crops after harvest. Men in most cases have full control over income from sale of fruits and over products produced in relatively large quantities. Children benefit indirectly through better nutrition and availability of cash for education and clothing.

The poorest sections of the community require financial and technical support to adopt the innovation. Cash is needed to purchase seeds or seedlings of non-local components and their improved varieties as well as a few basic farm implements. Households with no or little household labour may also need some financial support to cover the ensuing labour wages. Access to irrigation facilities and water during the dry season is also necessary for maximum and ensured continuity of the production year-round. Under these provisions all members of the households and community groups can make maximum use of the system to improve their livelihood conditions and living environments.

Upscaling strategies

Innovative farmers are rapidly taking up and expanding the innovation. Frontiers of the practice are expanding, particularly in irrigated areas. The system is visibly dominating irrigated areas and expanding as perennial tree combinations give the landscape the appearance of natural forests rather than fragmented croplands. Adopting farmers vigorously confirm the significant economic benefit of the system over conventional mono-cropping practice and thus are winning keen interest of the adjoining farmers in adopting the innovation.

Multiple benefits that flow throughout the year from the system are said to be the primary motivation for adopting farmers. In addition, farmers with large landholding sizes are particularly benefiting and changing their living standards with increased cash incomes from the system. With gradual familiarity of both urban and rural communities and the taste and dietary values, as well as with the exploration of alternative marketing channels for fruit products, the economic values farmers accrue from the innovation and the diffusion of the innovation to new areas are expected to rise.

The fact that the practice is less labour intensive and less destructive to the local soil and biodiversity resources, as well as climatic conditions than conventional monocropping systems prompted innovative farmers to adopt on a large scale. The land under this practice can be kept in sustainable production indefinitely without any need to apply commercial fertilizer. Whereas the leafy biomass is used for animal fodder, mulching, and maintaining soil fertility, the woody biomass is largely used for construction, fencing and fuelwood. On-farm availability of fodder diverts the use of animal manure for fuel to use for soil fertility maintenance. Similarly, easy access to fuelwood from the garden saves family labour employed in fetching fuelwood for use in productive farm activities in home gardens.

Institutions promoting the innovation

This practice has largely evolved through the curious and dedicated search to improve agricultural production and conserve resources. In evolving the innovation, farmers used their indigenous knowledge and experience, combining it with the scanty information available from external sources on integrated farming and sustainable resource management practices. An innovative farmer confidently illustrates the way to discriminate between pioneer and poor crop varieties as well as the method of screening more productive and disease-tolerant varieties. The farmer still continuously modifies the homegarden, searching for better productivity of the most desired components of the system. Less innovative farmers supplement their own experimentations with findings of more innovative farmers and technical advice from development agents. Occasional provision of technical support and sporadic distribution of seedlings by the Board of Agriculture are said to be the only external inputs to the practice. The board disseminates farmers' own innovations more than it injects promotional inputs into the practice. In fact, adopting farmers regularly receive advice and encouragement from visiting regional and federal government officials as well. Farmers also use the local transport infrastructure to deliver their farm products to nearby consumer centres.

Research questions and knowledge gaps

No systematic study has been undertaken to characterize and fully understand the existing component admixtures and their synergistic interactions. Although the general features and patterns of component arrangements look very much alike, tremendous variation exists in the number and arrangements of the components in each homegarden. Individual farmers pursue their own way of species selection and arrangements. This results in slight variation, particularly in the size and placement of specific component with regard to the other. The productivity and economic values of individual components have not yet been ascertained. It is also not possible to clearly establish the overall ecological benefits of the practice and the contribution of individual components to the overall wellbeing of the system. Both vertical and horizontal arrangements have resulted from a long history of farmer trial and error rather than being supported by scientific and empirical evidence.

The current evolutionary climax of the practice emanates from traditional and indigenous knowledge of the farmers. Many of the components have not been tested for their productive potential or disease resistance. Nor have tree and shrub species been exhaustively screened for their multiple benefits. The possibility of integrating additional local and exotic multipurpose tree and shrub species for improved output and new product lines is thus still promising. With competent on-station and on-farm experimentation, it is possible to achieve more efficient component arrangements and better economic and ecological benefits.

Marketing prices and infrastructure are too poor to encourage farmers to intensify the practice. Present marketing possibilities are either too exploitative or too exhaustive to satisfactorily benefit the farmers. Local market demand for some homegarden products is pathetically small, and farmers' capacity to deliver the products to distant demand centres is quite weak. Farmers have not yet received the technical advice from Board of Agriculture experts that they have anticipated.

Current policy arrangements strip farmers of their right to harvest and transport some homegarden products over long distances. Farmers need to acquire legal permission to harvest *Cordia africana* timber from their homegardens and are totally banned from hauling timber to major marketing centres. Farmers have bitterly contested this legality as it is a serious disincentive to on-farm timber production. Policy statements and improved marketing prices and infrastructure urgently need to be adjusted to effectively promote this multipurpose, multistrata practice.

Professional reflections and recommendations

Perennial crop combination practice proves one of the most viable and sustainable systems for managing land resources and agricultural production. It ensures sustainable soil fertility management without the need to apply costly and polluting chemical fertilizers. Likewise, it is best suited to hilly slopes that are subject to severe soil erosion and gully problems. In regions with virtually no natural forest cover and high population density, this practice provides not only vitally needed food, fuelwood and construction poles but also the cash income needed to purchase basic necessities.

Current policy support for promoting the system is too weak. Farmers need means to improve both the economic and the ecological roles of the practice. This is what local development agents need to offer. Local and regional policies are required to create an enabling condition for profitable marketing of farm products. Development of a good marketing infrastructure facilitates easy access to major market centres. Creating unrestricted access to possible marketing centres would not only strengthen farmers' bargaining powers but would also help them reap better rewards for their efforts. There is a need to introduce new components such as beekeeping, fish and other animal production as well as high-value crop species into the system.

The practice is undergoing continuous evolutionary metamorphosis through farmers' traditional trials and experimentation. Complementing farmers' efforts with scientific investigation on components and their arrangements, regeneration techniques, minimum management regimes, harvesting and post-harvest maintenance, product marketing, and so on, are imperative. Poor farmers need to be supported with effective credit facilities, subsidized material provisions, and free seedlings of proven species. Farmers' indigenous knowledge needs to be fortified with regular training on innovative technologies pertaining to more efficient system management. Under these conditions the economic and ecological benefits that farmers reap from the innovation as well as its sustainable survival will flourish.

9.6 Apple tree cum annual crop farming in the Kigezi highlands of Uganda

Nature of the innovation

Developing and promoting temperate fruits in Uganda was initiated in late 1990s by the World Agroforestry Centre (ICRAF) in collaboration with the Forestry Resources Research Institute and Kawanda Agricultural Research Institute of the National Agricultural Research Organisation (NARO). These efforts resulted in the identification of four suitable apple varieties that included Anna, Golden Dorset, Rome Beauty, and Winter Banana. After a series of on-station and on-farm trials, two varieties (Anna and Golden Dorset) were released to farmers in the Kigezi highlands (Turyomurugyendo et al. 2004).

Since then farmers and local governments in the area are promoting the integration of apple growing into the farming system. Apple growing is a new initiative aimed at improving incomes for households in south-west Uganda. With its temperate-like climate, the Kigezi highlands (1500–2400 m) are favourable for growing apples and other temperate fruits for income generation (AFRENA Project 2001). Many farmers have therefore planted apple trees mainly near their homesteads for easy management. Intercropping of apples with traditional crops like beans and irish potato is common in light of prevailing land shortages. They are grown either scattered in annual crop plots or planted along contours bunds. The intercrops


Experts observing the nature and quality of apples in the fruiting season.

provide ground cover and encourage weeding of the apple orchards. Farmers are thus able to benefit from both the annual crops and the perennial apple crop.

Justification for profitability of the practice

Temperate fruits are not currently grown in Uganda on a commercial scale. High-value crops such as apples can help modernize agriculture in the Ugandan highlands (AFRENA Project 2001; Raussen 2003). Rural development in the country requires food and nutritional security and income generation. Temperate fruits such as apples meet these requirements in an exemplary way. Integrating apple trees into the annual cropping system of the Kigezi highlands can lead to profitability of the system in several ways. Their introduction has increased productivity per unit area of land, and the apple trees use niches that would not otherwise be used for annual crops.

The quality of apples grown in the Kigezi highlands meets the local market requirements as far as taste is concerned. They are preferred over imported apples as they are said to be fresher and crisper. Their size, however, is only small to medium, and consumers and traders are used to apples that are large and uniform in size. For these locally produced apples to compete with the imported ones, not only does their taste have to be 'right' but also their size has to appeal to the buyer (Chemining'wa et al. 2005). Variability in size remains a challenge to the innovation if it is to increase household incomes. Therefore, these apples must be graded to meet market requirements. Apple varieties should consider market demands. Currently, Granny Smith and Golden Delicious from South Africa are the most popular in the country. The cultivars that are being promoted to farmers in Kabale have good characteristics and seem to fit well into the current local market demands.

Apple growing was introduced as a strategy with the main aim of assisting farmers to eradicate poverty by transforming subsistence farming to commercial production of high-value crops (AFRENA Project 2001). Major market outlets for apples are in the major urban areas such as Kampala, Kabale, Mbarara and Masaka, mainly in supermarkets and key open markets and with street vendors (Turyomurugyendo et al. 2004; Chemining'wa et al. 2005). Most local consumers buy apples from open markets like Nakasero and street vendors, while well-to-do locals and expatriates buy from the major supermarkets such Shoprite, Metro and Uchumi. All apples sold in these markets are imported from South Africa, either directly or indirectly through importers in Kenya. Supermarket operators in these urban centres are becoming familiar with local apples and express willingness to stock them.

Currently the production of apples in the Kigezi highlands is limited and therefore cannot satisfy domestic market requirements. It will take some time before local production can do so. However, local apple production is being fronted as a profitable import substitution option, aimed at capturing part of the apple market being dominated by imports from outside the country. Locally produced apples have a high potential to compete on the domestic market based on their ability to command a stable market share and even substitute for imports in the national markets.

Due to the fact that the innovation is at the early stages, not a lot of effort has gone into organizing the production and marketing of the apple crop. Some efforts are being done through the National Agricultural Advisory Services (NAADS) and local government programs aimed at increasing production and marketing of the crop through producer and marketing groups.

Agroforestry components and interfaces

Intercropping apples with other annual crops like beans, potato and sweetpotato is becoming common in the farming system. In this innovation, the intercrops provide ground cover and encourage weeding of the apple trees. Table 9.10 shows the outcomes of the positive interactions between the components of the innovation.

Table 9.10. Components of the innovation and their interactions in the Kigezi highlands

Components	Apple trees	Annual crops
Apple trees	Presence of several apple trees enhances effective cross-pollination and results in economies of scale	Where apples are planted along contour lines, they contribute to soil and water conservation, improving crop productivity
Annual crops	Apple trees benefit from good crop management such as regular weeding, mulching and manure application	—

Minimum inputs

For apples to do well, they need to be planted on slightly acidic (pH 6.0–6.5) and well-drained soils. Soils with pH values below 5 will require liming before planting. Sites that are waterlogged during rains are not suitable as the trees planted there tend to succumb to root rot (Andersen and Crocker 2000).

Materials required for the innovation include apple seedlings, manure, pruning shears, and basic farm implements like hoes and pangas. The variety and quality of seedlings used determines characteristics of apples produced—taste, (aroma, sweetness, acidity), texture, appearance (colour, shape) and time needed to ripen. Pruning shears and knives are necessary for cutting the fruits off the branches during harvesting to enhance shelf life.

Apples require cross-pollination with compatible cultivars. It is therefore advisable to have more than one cultivar of each tree species on farm or at least within 200 m. Pegs and durable strings are required for training the apple trees to develop lateral branches. Other important practices necessary are annual pruning and defoliation, weed management, mulching and fertilizing. At harvest, fruits must be picked only when they have attained sufficient size, attractive colour and internal maturity. They should be placed immediately in picking bags or baskets and not allowed to drop on the ground (AFRENA Project Uganda 2001).

The costs for establishing and maintaining a hectare of apple orchard for the first 4 years in Uganda highlands have been calculated (Chemining'wa et al. 2005) and are summarized in table 9.11. Most initial investment expenditure will be incurred on land and acquisition of farm inputs. During subsequent years (5th year onwards), feeding of the trees with fertilizer and manure becomes the main cost, representing about 31% of the total annual cost. The annual investment costs for maintaining the 1-ha apple orchard at this stage are summarized in table 9.11.

Table 9.11. Establishment and management costs for 1 hectare of apple orchard in Uganda

Item	Amount (Uganda shillings)	Equivalent in USD
First 4 years		
Land	6,280,000	3589
Farm inputs	6,274,950	3586
Labour	1,420,000	811
Total	13,974,950	7986
5th year onwards		
Farm inputs	747,670	427
Labour	566,000	323
Total	1,313,670	750

Source: Chemining'wa et al. 2005 adapted from Mbuga 2004

The financial cash flow using three price scenarios of UGS 300, 200 and 100 per fruit is summarized in table 9.12. The capital invested is assumed to be a bank loan with an interest rate of 21%. As indicated in the table, apple production will only be economically feasible if the sale price is UGS 200 per fruit or more.

Table 9.12. Financial cash flows using three scenarios for marketing of apples in Uganda

Price scenario (UGS)	Net profit (UGS ha^{-1})	Equivalent in USD
Price 300	71,506,253	40,861
Price 200	22,271,905	12,727
Price 100	–2,573,678	–1,471

Source: Chemining'wa et al. 2005 adapted from Mbuga 2004.

Like many other fruits, apples are perishable and therefore require efficient and reliable transport. For transportation to market, fruits should be packed in boxes (not in bags) and be stored in a cool dark room. When apple production scales up to commercial levels, it will be necessary to invest in cold storage facilities. It is crucial that the high quality of fruits be maintained to reduce losses. In addition, the ability to trace the origin of the product is important as it enables identification of pitfalls and helps identify sources of poor-quality products. There is also need for a good road network to minimize damage during transit.

Agroclimatic zones

Apples are adapted to various climates but are best suited to cool temperate zones (latitudes 35–55°N/S) (Bal 1997). However, the Kigezi highlands do not fall in this geographical zone but in a high elevation zone, ranging from 1500 m to 2400 m; it provides a climate similar to that of temperate climates although it lacks winter periods (AFRENA Project Uganda 2001; Turyomurugyendo et al. 2004).

These highlands have two distinct rainy seasons, one March–May and a second September–December. The mean annual rainfall varies in the range of 800–1000 mm; temperatures range at 8.3–27.2 °C with June and July being the coldest months. The relative humidity ranges at 90–100% in the mornings and decreases to 42–75% in the afternoons throughout the year (Kabale Meteorological Department 2000). Other potential apple-growing areas in the country include areas around Mt Ruwenzori (Kabarole, Bundibugyo, Kasese Districts), West Nile highlands (Nebbi District) and Mt Elgon (Sironko, Mbale, Kapchorwa Districts) (Raussen et al. 2002). In the harmonized agroecological zones of eastern and central Africa, this practice can work in moist mid-highlands and moist highlands.

Major factors that make the innovation successful

Under moderate management, the two varieties of apples being promoted produce on average 5 kg of apples per tree (a retail value of UGS 20,000) and highest yields are obtained from trees that have been grafted in the field (Turyomurugyendo et al. 2004). In the Kigezi highlands, two fruit harvests are possible, May–June and November–December.

Production of apples locally will be more reliable than those imported from external sources. The southern highlands do not experience the seasonal variations that external sources like South Africa face. Thus apple traders will be able to maintain a steady supply throughout the year. In Kabale, local apples are being sold at UGS 200 each. Kabale supermarkets buy Kabale apples at UGS 150–200 per fruit while Kampala supermarkets buy imported apples at UGS 300–400 each (Chemining'wa et al. 2005).

Local consumption of apples and other temperate fruits has increased, especially among the elite and the wealthy. Uganda imports about 190 tonnes of apples per year, worth up to USD 115,000, to satisfy this growing demand (Ssemwanga Centre 2003). Currently most apples on the market are imported from South Africa, Kenya and Egypt. However, they are expensive, selling for UGS 400–800 each or UGS 4400–6200 per kilogram, and most local people cannot afford them. Local people will therefore find locally produced apples more affordable due to low transportation costs and no storage costs involved.

Traditionally, Kabale District has a well-established vegetable and horticulture production and marketing system. From the 1960s to the 1990s, Kabale monopolized vegetable markets in most urban centres, especially Kampala. A wide range of temperate vegetable crops are grown and include cabbages, cauliflower and carrots. Apple production and marketing easily fits into this well-established system.

Local and national policies are geared towards eradicating poverty by increasing income at household level through the Plan for Modernization of Agriculture (PMA). Farmers are seeking to adopt enterprises that can generate high income. Growing temperate-climate fruit has been selected as a strategy to commercialize farming and raise farm incomes. Local governments have therefore embraced this innovation and are actively promoting it.

Direct and indirect beneficiaries

Major direct beneficiaries of the practice include the farming households, traders, transporters, market vendors and nursery operators, as the income status of all is improved by the practice. Local governments are the main indirect beneficiaries as they generate revenue by taxing apple products being sold in their areas. The government of Uganda also benefits as this innovation has the potential to save foreign exchange by as much as USD 115,000 per year, presently spent on apple imports. This can be ploughed back into the local economy through payments to farmers and transporters (Chemining'wa et al. 2005).

Mainly women and youths handle and multiply planting materials. Apple seedlings are also distributed through farmer groups, most of which comprise women (Bizimana pers. comm. quoted in Chemining'wa et al. 2005). Apple growing is thus introduced to most households by women, who perform most of the apple production activities. But men dominate the trading and transport of the produce, although women mainly vend produce at the market.

Generally the wealthy handle trading and transportation, as they are able to raise the necessary capital for investing in the business. Growing fruit greatly contributes to food security for households, improves nutrition, especially for the children because it contributes minerals and vitamins to their diet, and increases incomes. Improved household income translates into better health and improved education and housing. All beneficiaries rank the innovations highly in terms of profitability.

Upscaling strategies

The National Agricultural Research Organisation (NARO) and the World Agroforestry Centre (ICRAF) have a central tree seedling nursery at the NARO field station in Bugongi. The station has been training and supporting commercial nursery operators to enable them to produce quality planting material. The trained commercial nursery operators are certified to produce seedling materials. NARO and ICRAF have plans to select and train farmers to produce clean scions (Chemining'wa et al. 2005).

Farmers have been receiving ungrafted rootstock for planting, and some are selected to produce scions to be used. Grafting is done by trained farmers and NARO-ICRAF project staff. This dissemination strategy was adopted because mobile community grafters are able to supply more farmers with rootstocks. Also, rootstock planted and grafted in situ is more likely to survive, thus reducing farmers' loss. This approach, however, does not assure quality as it is doubtful that community grafters are able to obtain consistently high-quality scions for grafting.

Other institutions like the local governments, NAADS, NGOs (for instance, Africare and Africa 2000 Network) and community-based organizations have been instrumental in promoting the practice to farmers by making free apple seedlings available. This agroforestry innovation has in the past 2 years rapidly spread through the districts of Rukungiri, Kasese, Bundibugyo, Sironko and Kapchorwa. This has been made possible through the active participation of local governments, NGOs, NAADS and farmer groups in these districts.

The main factor that has contributed to scaling up the innovation is the fact that apples are a high-value crop that commands a good market. This has created vast interest in various circles. As a result, promotion of the innovation has been aggressive in the highland areas of the country.

Other factors have included the availability of clean planting materials. This has further enabled the widespread replication of the innovation to various highland areas. Lack of alternative perennial crops in the farming system has contributed to the wide replication of the innovation, as producing annual crops is quite costly and in most cases income returns from them are low.

Institutions promoting the innovation

Most farmers growing apple trees obtain seedlings from the NARO-ICRAF seedling nursery or through NAADS and NGOs promoting temperate fruit production such as Africa 2000 Network and Africare. Other stakeholders in producing and marketing apples are the central and local governments, farmer groups, private extension service providers and apple traders. The institutions involved in the innovation and their respective roles are summarized in table 9.13.

Research questions and knowledge gaps

According to Turyomurugyendo et al. (2004), there are several knowledge gaps for this innovation and they include determining which annual crops to integrate with apple growing, which growing season fits which apple cultivar, how to synchronize bud breaking for various periods and varieties, and options for managing various pests and diseases.

Kabale apples must compete with those from South Africa, not only in taste but also their size must appeal to buyers. Kabale apples suit the current market in terms of taste and colour. However, their small and varying size is a major drawback. The challenge for researchers, therefore, is to produce large-sized, uniform fruits, and hence reduce the amounts of non-marketable fruits.

Tree nutrition is another area where little concrete information is available. Farmers use manure to plant their apple tree seedlings as recommended. Apples being a new crop, the optimum manure and fertilizer application rates in the southern highland region are largely unknown. Questions remain on the optimum rates of inorganic and organic fertilizers, the appropriate fertilizer types and whether there are any micronutrients necessary for apple nutrition in Kabale.

The synchronization of flowering and fruiting so as to obtain one crop per year has been identified as a major challenge and one likely to remain so in the near future. The main problem seems to be uniformity of bud burst after breaking dormancy. Flower buds within the same trees seem to take longer to open, causing a prolonged tree flowering and fruiting period. This can have a negative effect on fruit quality as development of the late flower buds may not fall within favourable weather for fruit development. More

Table 9.13. Institutions involved in the innovation and their roles

Institution	Roles and functions
Farmers	Produce and sell quality apples
Research (e.g. NARO)	Conduct research and develop and promote appropriate fruit varieties Conduct market research on apple production (e.g. market chain analysis) Build capacity of staff in fruit research
Farmer groups	Organize farmers to access funds (e.g. through NAADS) Access training and link farmers with advisory services Acquire improved planting materials Provide better environment for apple marketing Implement and evaluate the practice
National Agricultural Advisory Services (NAADS)	Develop and disseminate appropriate apple production technologies and marketing strategies Ensure that extension service providers are equipped with appropriate extension packages on apple production and marketing
Private extension service providers	Provide quality planting materials Provide extension services for apple production and marketing Build capacity of farmers
NGOs (e.g. Africa 2000 Network, Africare)	Provide agricultural services through links with farmer groups, associations and donors Disseminate apple technologies to farmers Organize exchange visits Build capacity of farmers in apple production and marketing
Central government	Fund the promotion of apple growing and product development of the enterprise Provide an enabling policy environment for producing and marketing apples
Local government	Fund apple growing in their areas Facilitate the acquisition of clean planting materials Facilitate capacity building of farmer groups Facilitate exchange visits for farmers
ICRAF	Provide technical backup of collaborating NARS institutions Acquire new materials for evaluation from other regions Build capacity of technical staff in NARS Facilitate acquisition of funds for temperate fruit research
NARO Bugongi substation	Conduct research in fruit production and marketing Produce elite fruit seedlings Build capacity of service providers and NGOs
Open markets	Provide major market outlets for apples
Supermarkets	Provide a formal market outlet for apples
Development partners (e.g. USAID, EU)	Fund research in fruit production and marketing Provide the necessary infrastructure for fruit research

investigation in this area is necessary if harmony between fruiting and climatic seasons is to be attained.

Professional reflections and recommendations

Ecologically, the Kigezi highlands do not have the real temperate climate necessary for producing apples. Still, it is intended that all farmers across the agroecological zone adopt apple growing as an income-generating enterprise. Also, the crop is new with no in-depth experience on its variety characteristics, management practices, and marketing aspects. Efforts need to be directed towards gaining more technical expertise and a better understanding in these areas.

Quality consistency is a major factor that determines marketability of fresh apples. Quality, however, cannot be guaranteed if the quality of rootstock and scion is not guaranteed. Acquiring seedlings through a technically sound institution is often critical for maintaining high-quality, disease-free seedlings.

Seedling loss in nurseries is reported to be quite high (up to 40%), mainly due to powdery mildew. Whether commercial seedling nurseries will be able to absorb such high levels of losses is not certain. Disease-infected seedlings and scions are likely to be distributed to systems that are not closely monitored by qualified specialists (Chemining'wa et al. 2005). Thus without compromising quality, development of an effective system for certifying commercial nurseries and selecting host scion centres is critical.

Apple varieties grown in Kabale are Anna (red) and Golden Dorset; the main varieties seen in the market were Golden Delicious (yellow), Fuji (red), and Granny Smith (green). This gives a message that Kabale-grown apples may need special promotional campaigns to compete with established varieties in the current market.

About 90% of fresh apples are imports from South Africa, which like most traditional producer countries has the right climate and soils for apples. Also, their apple industries have well-developed market chains and production is cost effective and responds to market demand. Given the prevailing market prices, local apples will have to be produced at low cost and meet quantity and quality requirements to be able to penetrate the formal market.

The PMA is a strategy for commercializing agriculture in Uganda. For Kabale District, it involves a shift towards perennial crop enterprises, from a system that has been predominantly based on annual crops. This is an important advancement towards both improving farmers' income and contributing to natural resource conservation.

9.7 Shade tree-based coffee–banana farming systems of Uganda

Nature of the innovation

Coffee is a bushlike tree that grows to up to 2 m. The most important coffee varieties are *Coffea arabica* commonly referred to as 'arabica' and *Coffea canephora,* also called 'robusta'. Arabica originates from the Ethiopian highlands while robusta is indigenous to the equatorial rainforests of Africa. Traditionally, it is grown under the shade of a variety of trees. Today the crop is cultivated predominantly by small-scale and medium-sized farmers, mainly in Africa and South America. Coffee production is quite varied, adapted to suit different conditions. In most developing countries, coffee is grown using the extensive system that has essentially closed nutrient cycles and is predominantly cultivated by smallholder farmers, often on small land holdings (Okech et al. 2004).

In Uganda, coffee is a major cash crop in the central region and has been grown by farmers since the beginning of the 20th century (Sayer 2002). Arabica coffee thrives well in highlands areas like Mt Elgon, while the robusta

Coffee, banana, and timber trees can be an economically useful agroforstry system. Shade-demanding herbacious species such as *Amomum subulatum* are integrated in the system.

coffee is more common in the low-lying areas of the country, especially the lakeshore region. It is common practice for farmers to retain trees like *Ficus natalensis, Cordia africana* and *Maesopsis eminii* on coffee plantations to provide shade to the coffee plants (Hoekstra et al. 1991). Fruit trees such as mango and avocado are also interplanted with coffee and banana. In addition to providing shade to the crops, the trees also provide farmers with various products such as fuelwood, poles, fruits and timber.

Justification of profitability

Coffee is the most important raw material traded throughout the world, after crude oil. It has become the most important export article for countries that grow it. Robusta yields about 30% higher more than arabica, although its prices are 30% lower. It is used almost exclusively in the drinks industry and is sold to consumers as roasted beans, ground, and instant coffee. In consumer countries, roasted coffee is a blend of different origins and qualities.

An important constituent of the coffee bean is caffeine. The free caffeine content in a bean can be more than 25% but it varies according to coffee type, variety and site conditions where it was grown. International importers pay a premium for Ugandan robusta because its neutral taste allows it to blend with more expensive coffees, thus reducing manufacturing costs. Historically, Uganda has been considered a first-line suppler to the world's coffee industry (Sayer 2002). To maintain this status, efforts should be made to ensure sustained production of high-quality coffee.

It is estimated that 500,000 households, distributed over two-thirds of Uganda, depend on coffee as an important source of income. For many of these households, coffee is the only source of cash income. The current levels of production place Uganda about 8th among the world's largest coffee producers and third to Vietnam and Cote d'Ivoire in exporting robusta. By 2001, Uganda was producing an estimated 3.2 million 60-kg bags of coffee, of which about 96% was exported and 4% was consumed locally (UNCTAD 2001; SIPPO 2002). The per capita coffee consumption for Uganda is low (0.2 kg per annum), especially compared with Finland, which has a high per capita consumption rate of 11.0 kg, and Netherlands and Norway, each with a consumption rate of 9.2 kg per person.

Nationally, the industry is dominated by major exporters like UGACOF/Sucafina, Kyagalanyi/Volcafe, Ibero/Naumann, ECOM/Kawacom and Olam International. They buy from independent traders but also set up branches around the country during the harvesting seasons. They mill dried robusta coffee, known in Uganda as *kiboko,* and transport the green coffee to their factories in Kampala for grading and export. The Uganda Coffee Development Authority (UCDA), charged with regulating the sector, has links with the International Coffee Organization. Uganda's Ministry of Tourism Trade and Industry is also actively involved in promoting Uganda coffee to outside markets.

Agroforestry components and interfaces

The most important function of shade trees in coffee plantations is to produce large amounts of organic matter and humus, especially by pumping up nutrients from the lower soil horizons. The trees also protect the coffee plants against excessive sunshine, which regulates the intensity and rhythm of the plant's photosynthesis. As a result, coffee yields are stabilized and the life span of the coffee plantation increased. Shade also has an immense influence on the quality of the coffee, maximizing it if maintained at optimum density. It also reduces weeds in the plantation. The trees benefit from the good management that is accorded the coffee crop, like weeding and mulching (table 9.14).

Minimum inputs

Technical requirements for this practice include proper spacing, and managing both coffee trees and shade trees. Density of the coffee trees should not exceed 1000–2500 plants per hectare, to allow enough standing room for the shading trees. As a rule of thumb, the shade trees should be trimmed

Table 9.14 Major components in the coffee–shade trees agroforestry practice

Components	Coffee	Shade trees
Coffee	Coffee trees produce leaf litter that provides mulch in the plantation, thus reducing erosion and water loss; replication of the practice is easier when there are many coffee trees on farm	Shade trees generate large amounts of organic matter and humus for the coffee and they also protect coffee plants from excessive sunshine resulting in steady yields and longer life span of the coffee plantation; shade also has an immense influence on the quality of the coffee and leads to reduction of weeds, while leguminous shade trees fix nitrogen, which benefits the coffee crop
Shade trees	Shade trees receive good management alongside the coffee crop—e.g. weeding and mulching	Shade trees are grown widely, thus increasing their numbers on farms and protecting the species from extinction; having many shade trees on the farm increases income generated from sale of tree products such as poles and timber

to maintain the shade at around 50%. Annual labour required to maintain 1 hectare of established robusta coffee and to process and market the crop is estimated to be 200 person-days. The average yield per hectare is estimated at 1200 kg of hulled coffee beans. Arabica coffee requires 220 person days.

Material requirements necessary for this practice include coffee seedlings, shade tree seedlings, manure, land and basic tools—pangas and hoes, fertilizers and sprays. In addition, labour costs are involved in planting or replanting the coffee plants and shade trees.

High requirements for quality are placed on organic coffee, focusing mainly on time of harvesting and post-harvest handling (in addition to site conditions and cultivation procedures). Strictly, only the ripe fruits (red) should be harvested and processed. Two different methods are used—the dry and the wet method. Almost all of Uganda's robusta coffee is 'dry processed'—sun dried by farmers immediately after picking with the cherry left intact around the beans. Once dried, the beans can be stored without loss of quality to accumulate with later pickings as the season progresses. This kiboko is milled locally, usually at small factories, to minimize transport costs. Milling removes the dried berry and the seed hull, producing 'clean' or 'green' coffee. Kiboko yields 50–56% of its weight as green coffee, with the required moisture content of less than 12.5%. At this stage the exporter sorts it into different grades.

The general requirements for coffee processing are a floating chamber, a rack and rakes. The wet processing is mainly done for arabica and must commence on the day of harvest. When a wet stage of processing is involved, there is need for adequate drying surfaces for the coffee beans, preferably concrete. Insufficient drying encourages growth of fungus, which adversely affects the quality of the coffee.

Coffee-producing countries are responsible for establishing the characteristics for each coffee grade. Exporters must specify processing method (wet or dry), bean colour (green or blue green), growing site (district, altitude), style (outward appearance) and number of defects (foreign particles, broken beans, etc.) of the coffee being sold. It is also important that preparing raw coffee due for export is carried out under clean, hygienic and ideal conditions (COMPETE 2001; Sayer 2002).

Buyers on the world market critically consider cup quality, bean shape and water content to determine quality of the coffee. In terms of cup quality, the preferred beans should be clean, aromatic and free from foreign taste and smell. The beans should also be homogeneous in shape with a water content not exceeding 13%. They should also be free of residue like pesticides and contain minimal levels of mycotoxins (COMPETE 2001). Coffee is a bulky product, and transporting it requires a good road network for easy access to the farmers by traders or buyers. There is also need to revive and strengthen farmer cooperatives to enable bulking of their product and ease buyers' accessibility to their products.

Agroclimatic zones

Coffee thrives best on well-drained and aerated soils; it can grow in shallow soils, due to its network of surface roots. Lightly acidic soils that are rich in humus are beneficial to the crop, which means that virgin soils of volcanic origin are the best conditions for it. The ideal temperatures for arabica coffee range are 18–24 °C. At lower temperatures, coffee is susceptible to frost, which inhibits growth, while in hot areas; arabica coffee succumbs to various pests and diseases that reduce its quality. Robusta coffee can withstand high temperatures and is more resistant to pest and disease attack. The ideal amount of annual rainfall is 1500–1900 mm. It should be evenly distributed throughout the year as uneven rainfall causes uneven blossoms and fruit maturity.

In Uganda, coffee generally grows in the highlands and the central region. Arabica coffee thrives on mountain fringes such as on Mt Elgon in the east, in the Ruwenzori Mountains in the south-west and in the highlands of West Nile on the Congo border. Robusta coffee grows in the Lake Victoria Crescent at an altitude of about 1200 m. In the harmonized agroclimatic zones, the practice fits in the moist mid-highland and the moist lowland.

Major factors that make the innovation successful

Coffee has been grown in some parts of Uganda for close to a century (since 1912 around Mt Elgon), making it almost a traditional practice. Farmers are familiar with most of the management practices involved, which have been traditionally passed on from one generation to the next. The practice integrates other crops grown as understorey and shade trees on the upperstorey, while the coffee forms the middle storey. This system allows intense production, thus increasing overall farm productivity.

The practice addresses farmers' needs for tree products such as firewood, poles and timber. Whereas there is great need for tree products in the coffee-growing areas, the land shortage in these areas does not permit allocation of land specifically for tree growing. The practice therefore presents an excellent opportunity to integrate trees on coffee farms.

Coffee has long been one of the main cash crops for Uganda. It has a ready market with well-established marketing systems. Liberalization of the coffee subsector has brought on board many private agencies, thus improving the efficiency of production and marketing of coffee and its products.

Direct and indirect beneficiaries

The practice benefits many resource-constrained rural households that rely on coffee production as their major source of income. Proceeds from coffee sales provide households with basic needs like clothing, medical care and education. Trees also provide much-needed wood products as these areas have no big forests that provide tree products. In addition the sale of these products increases household incomes that can be used to add value to the farm estate.

The integration of shade trees provides women with fuelwood that they otherwise would have to gather from off-farm sources. This saves them time and energy, which they can then put into other productive activities. Where fruit trees are used for shade, they also provide fruits that improve household nutrition, benefiting women and children in particular.

Rural business people thrive to a large extent on the income from coffee farmers. During periods of coffee boom, the demands of rural people increase, and this boosts businesses as well. The practice, therefore, has a big spin-off in terms of generating income, not only for farmers, but also for rural business people. Traders and transporters also benefit from the sale of coffee, thereby realizing a better livelihood and paving the way to expand their businesses. Local governments generate revenue from coffee farmers, transporters, traders and processors.

Upscaling strategies

Coffee is a traditional cash crop that many farmers have grown for decades. Most of the promotional campaigns date as far back as colonial times, when local leaders imposed mandatory requirements for households to plant coffee trees. Though initially unpopular among many farming communities, this approach enabled many farmers to realize the benefits of growing the crop. Subsequent plantings have to a large extent been out of farmers' own initiatives.

In Uganda today, the practice is carried out by up to 500,000 households, distributed over two-thirds of the country (COMPETE 2001; Bigirwa 2005). One of the major factors that have contributed to expanding the practice is the liberalization of trade in the coffee sector. In addition, the development of new varieties has enabled the growing of coffee in non-traditional regions of the country, which has increased the national acreage of the crop. Coffee is a perennial crop that farmers have adopted to generate sustained incomes over generations.

The wide publicity by UCDA has facilitated upscaling of coffee growing in Uganda, especially through radio programs and print media. UCDA has facilitated the production of improved varieties of coffee by engaging certified organizations and individuals to produce seedlings and sell them to farmers at subsidized prices. It has also put strong advisory teams in the coffee-growing districts to provide advice to farmers on the best practices.

Institutions promoting the innovation

The main participants in the practice are coffee farmers, traders, researchers, coffee exporters, UCDA, and the Uganda Export Promotions Board. The institutions involved in the practice and their respective roles are summarized in table 9.15.

Research questions and knowledge gaps

Coffee wilt disease has spread to most of the coffee-growing areas; it poses a major challenge to coffee production and calls for research interventions. The disease is killing about 5% of the robusta population annually. Research has developed some varieties that are tolerant to the wilt but more efforts are needed to address this threat. Farmers also need to be trained on how to manage the disease.

Knowledge on biophysical interactions between coffee and shade trees is still limited. There is need to establish the number of different kinds of shade trees that can be grown in one hectare of coffee plantation and their associated management. There is also need to understand the use of resources (light, nutrients and water) by the tree and coffee components.

Professional reflections and recommendations

The coffee sector in Uganda is currently being challenged by low prices, aging trees and coffee wilt disease. The average age of the country's coffee plant population is 40 years, and productivity of the older trees is declining; thus they need to be replaced.

In terms of export value, Uganda currently relies heavily on robusta (85%) and less on arabica (15%). Yet the arabica specialty market (premium quality) segment is realizing a much greater growth rate—20% relative to the overall growth rate in the world coffee market of 1.6% per year, and the market appears to be far from saturated (New Agriculturist 2005). Uganda

Table 9.15. Major institutions involved in promoting coffee growing in Uganda

Institutions	Roles and functions
Farmers	Grow coffee and maintain the quality of beans collected
Traders	Purchase coffee from farmers and bulk it to enable easy accessibility for exporters
Uganda Coffee Development Authority (UCDA)	Regulate activities of the coffee subsector and ensure that Ugandan coffee satisfies international market requirements
Researchers	Develop new coffee varieties Identify appropriate trees for shade and their management Develop pest and disease control measures, especially coffee wilt disease Carry out market studies on demand and supply dynamics
Coffee exporters	Purchase coffee from farmers, carry out processing and seek external markets
Uganda Export Promotion Board	Carry out advocacy on market for Ugandan coffee
Uganda National Bureau of Standards (UNBS)	Certify products derived from coffee according to set standards
Uganda Investment Authority (URA)	Attract potential investors to invest in the coffee subsector
Central government	Fund the promotion of coffee growing and product development of the enterprise Provide an enabling policy environment for production and marketing of coffee
Local government	Fund coffee growing in their areas Facilitate the acquisition of clean planting materials Facilitate capacity building of farmer groups Facilitate exchange visits for farmers

can expand its current production of specialty coffee, both in the main arabica specialty market and in value-added washed robusta. This will significantly benefit thousands of Ugandan households relying on the sector for their livelihoods.

To take advantage of these market opportunities, Uganda needs to focus resources on developing farmer associations that can act as conduits for delivering services and capital to producers.

The coffee sector also needs to create a better link between quality and price. The large exporters that currently dominate the sector focus on volume rather than quality. In the current local market structure, there is no price incentive to produce quality product. By creating a private voluntary auction for Uganda's premium coffee segment, the sector will put in place the vehicle that will provide a link between price and quality, which will give businesses and associations a platform from which they can sell their quality coffee at a premium price.

9.8 Temperate fruits and fodder farming in Kiambu District of Kenya

Nature of the innovation

The temperate fruits agroforestry system in Limuru is found in the moist mid-highland agroclimatic zone. This is a highly integrated and organized agrisilvipastoral system that has developed mainly because of the availability of the large market of Nairobi. The temperate fruits are pear, peach, apple and plum, but avocado is now also being introduced. The fruit trees are grown in association with a wide range of fodder and horticultural crops. The fruits and horticultural crops are sold while the fodder serves the dairy enterprise that is also priority in the area.

Horticulture is becoming an increasingly important sector of Kenya's economy, contributing significantly to foreign exchange earnings, human nutrition, employment, industrialization and soil conservation activities (Griesbach 1992). Attempts to grow temperate (deciduous) fruits in Kenya can be traced back over a long period when many cultivars and rootstock were introduced, observed and evaluated. In Kenya, temperature is the most important factor, affecting the growth of temperate fruits, and therefore restricting the extent to which these crops can be grown. This is because they require a sufficiently cold period to break bud dormancy. Limuru, a division within Kiambu District, is cold due to its high altitude (> 1800 m) and therefore suitable for growing temperate fruits. Other divisions where temperate fruits are grown include Tigoni, Rironi, Lari and Ngecha—all in Kiambu District.

Temperate fruits in Limuru cover approximately 5000 hectares (MoA 2002). The main fruit species include pear (*Pyrus communis*), plum (*Prunus salicina*), peach (*Prunus persica*) and apple (*Malus sylvestris*). Lately, avocado (*Persea americana*) has become an important fruit and is being grown together with the temperate fruits. According to the farmers, these fruits have been grown for a long time, some farmers indicating that they planted their fruits during the 1960s. The fruits are grown in a highly integrated agroforestry system, combining the various fruit types with many types of fodder and horticultural crops. The fodder crops are prominent and occupy a relatively large area to serve dairy production, which is also an important enterprise in the area. Due to the interrelationship of the different components (fruit trees–crops–livestock), this agroforestry system can be described as agrisilvipastoral.

With appropriate agroforestry managerment, growing high-value temperate fruit trees such as pears with a staple food crop diversifies both income and nutrition sources.

Justification of profitability

Intercropping the temperate fruit species in Limuru area is intensive and highly organized, with farmers adopting spacing and arrangements that favour production of both fruits and crops. The main purpose of intercropping is to maximize productivity of small farms. The average farm size is 0.2 ha (MoA 2002). Main intercropping practices involve two production systems: horticultural crops and fodder crops. Horticultural crops comprise vegetables (kales, spinach) and spices (parsley, onion, leek, celery, red cabbage, beetroot), mainly grown for commercial purposes. The city of Nairobi provides a ready market for these products. To boost and maintain production of these horticultural crops year-round, irrigation is common. The fodder crops serve dairy production, which farmers in the region have adopted as another major source of cash. The varied fodder crops include various types of grass, banana (ornamental), fodder legumes such as lucerne, and maize. The fodder crops are usually cut and carried to livestock confined in zero-grazing units. Fodder production is intensively managed within fruit fields. Livestock production contributes to the profitability of the system by generating cash throughout the year. Farmers therefore rate it highly, indicating that it complements cash earnings from the fruits that are seasonal and harvested once in a year.

Maximizing profits has been the major objective of farmers in developing the current agroforestry system. Farmers have adopted growing of these fruit species in mixtures (different types are grown together on the same field) so as to guard against risks of pests and diseases and also to prolong the marketing period. The fruits mature at different times and therefore farmers are able to sell fruits and earn cash continuously over a long period. In addition to combining different fruit types, different varieties of the same fruit are grown together for the same reason. For example, there is a January peach and a November peach. A critical assessment showed that fruit production and marketing go on throughout the year since avocado has been introduced.

Marketing both fruits and crops is local. Traders, who mainly go to sell in Nairobi, collect the produce at the household and pay farm-gate prices. Some farmers indicated that they like this system because these intermediaries save them the time of having to take the produce to market. This system of fruits, milk and vegetables can potentially improve performance and profitability by adding value to the wide range of produce it generates. One way would be for the government to establish appropriate cooling plants to preserve the produce before it is transported to market.

Tree nurseries, mainly propagating fruit trees, have been developed as another source of income and also for the farmers' own planting. Propagation is mainly from cuttings harvested during pruning from selected old trees. The main source of market is neighbours although some buyers come from neighbouring divisions. According to farmers, these nurseries are highly profitable because the cuttings are obtained from old plants on the farm and need little tending once the cuttings develop roots. Also, a small area can propagate many seedlings. One farmer, who has about 1000 mature trees of different fruit species, has established a nursery as an alternative source of income. Prices for his seedlings vary according to type, selling peach and apple at KES 150 (USD 2) per seedling.

Pear is the most common and important fruit in the market. Farmers say that they have widely planted it because it produces well and fetches good prices locally. Apple also markets well, but getting good cultivars is a problem. Planting of avocado has increased because it is becoming an important export crop for Kenya and is also increasingly being consumed locally, perhaps because of its nutritive value (Magana-Mugambi 2001).

Pruning the fruit trees is a major management practice, done to obtain a desired shape and to maintain a balance between fruiting and vegetative growth (HCDA 2001). Regular pruning is done every year at the end of the fruiting period; rejuvenation pruning, that is, cutting back all the branches to promote the sprouting of dormant buds, is carried out on old trees that have declined in production. The prunings yield firewood, which can create additional income, although most farmers prefer to use it at home rather than sell it. Fuelwood is a highly valued product from the trees, especially for keeping warm during the cold weather in July–August. Fuelwood yields are substantial, as 600 trees of pears can produce enough firewood to last a family of six for a year.

Agroforestry components and interfaces

Grasses deliberately planted under the fruit trees for use in feeding livestock animals also help control soil erosion, especially on steep slopes, which are a common feature in Limuru. The grasses are fed to cattle under the cut-and-carry system but sheep are usually let in to graze in the pastures, because they do not destroy the trees but instead fertilize them with their droppings. Also the fruit trees shade the fodder crops, and farmers say that grasses do well, probably due to moisture conservation.

Temperate fruits drop all their leaves during the dormancy period, which is around June–August in this region. The litterfall at this time is enormous, providing a thick mulch that helps conserve the soil and improves its fertility. Sometimes it is collected and taken to the cowshed to improve manure quantity and quality. Information on leaf quality was not available although farmers indicated that they decomposed at a medium rate.

The fruit trees are not normally manured or fertilized. However, manure is applied to the fodder and horticultural crops, especially the vegetables, and the trees benefit by sharing this manure. Farmers mentioned that the fruit trees perform better when they use a lot of manure and fertilizer on the crops growing beneath them. Through sharing nutrients, a closed nutrient cycling system is created as the deep-rooted fruit trees trap leached nutrients that would otherwise be lost. Also, fodder crops and horticultural crops are normally irrigated and the trees benefit from this water. Another positive interaction is observed when animals are fed on fruits that are not marketable.

The temperate fruits are intercropped with tea, Napier grass and a wide range of vegetables, such as leek, cabbage and onion.

Different types of fruit species are interplanted in lines and intercropped with fodder grasses. Beekeeping is also possible as the flowering fruits provide bee forage.

Minimum inputs

A major input of these systems is high-quality seedlings. Currently farmers obtain planting materials from a wide range of sources. These include individual farmers who own nurseries, Genetic Technology Limited, which is a private company, KARI's Horticultural Research Station at Thika, and Kamiti Prison.

As these temperate fruit species were introduced into Kenya, new fruit cultivars must continue to be imported and must be maintained in selected centres to conserve genetic material for future use. Policy support is needed to facilitate the process. Because of specialized pruning and management techniques required to break bud dormancy when natural chilling is not adequate, policy support is needed to organize appropriate training and to supply the materials required.

Agroecological zones

Temperate fruits require high altitude, above 1800 m, where it is cold. Mean annual rainfall in the Limuru area is 1000 mm and the altitude range is 1800–2300 m (moist mid-highland). The soils are mainly Nitisols. Soil pH ranges from 5.5 to 6.5. Temperature is the most important factor affecting the growth of temperate (deciduous) fruits and may therefore limit the extent to which these crops can be grown. This is because the trees need a sufficiently cold period to break the bud dormancy.

Major factors that make the innovation successful

Farmers greatly appreciate the role temperate fruits in the agroforestry system play in their livelihood. The diverse crop types (horticultural crops, fodder crops, cereals) intercropped with fruit trees provide opportunities to earn cash as well as boost the nutritional status of the family. A major factor contributing to the success of this highly integrated and commercialized system is the ready market for all products in Nairobi, about 30 km away. The profitability of the system motivates farmers to intensify it (Kabiru, pers. comm.).

Farmers rarely control pests and diseases by spraying chemicals although they mention that there are pests and diseases such as powdery mildew that attack the fruits. Only plums are sometimes sprayed. Minimal spraying is beneficial; it saves cost and it results in premium fruits that are not exposed to chemicals.

Firewood obtained from the trees prunings is greatly appreciated by farmers and is considered a major output from the system. Demand for firewood in the area is high because land sizes are small (0.2 ha), limiting the planting of trees in woodlots. Firewood is needed for both cooking and keeping warm, especially because of the cold climate. Farmers indicated that they preferred the marketing system adopted by the traders who collected produce at the farms and had labour for harvesting organized. This is because farmers felt that they saved the time required to search for labour and supervise the harvesting.

Livestock such as sheep benefit from positive interactions with the trees by getting shade and fodder. Manure from the livestock is applied to vegetables planted in association with the fruit trees. The fruit trees share nutrients from the manure applied.

Fodder crops under the fruit trees are also mixed, for example, ornamental banana and fodder grasses.

Direct and indirect beneficiaries

This is one system that clearly benefits families and farmers in this area in general. There is a high complementarly of activities by the different sexes. Roles are clearly shared in managing the system. The fruit trees are mainly a man's crop, and men are usually in charge of all management practices carried out including selling the fruits. Women take full responsibility for the crops that are grown under the fruit trees, including marketing them.

Children get good nutrition from eating the fruits, and farmers reported that during fruit season, there is less cooking in the household because the fruits supplement the diet. The fruits are nutrient rich ; for example, avocado has dietary fibre, vitamins B6, C and E, potassium and folic acid (Magana-Mugambi 2001), containing vitamins and minerals.

Women operating small businesses in towns can afford to buy the rejected fruits, which they transport in small baskets and sell to passengers travelling in public transport vehicles. Women also benefit from the prunings as they are a source of firewood. Cooking is usually a women's responsibility and so is searching for firewood.

Young men and women also benefit from employment the traders offer during harvesting. Again, roles are shared; the young men climb the trees and pick the fruits, and hand them over to the young women, who gather them and deliver them to the packing area. During this time, farmers mentioned that crime rates are minimal because the youth are not idle.

People living with HIV and AIDS stand a chance of benefiting from this system, because fruits in their diet improve and strengthen their immune system.

Upscaling strategies

Temperate fruits are exotics and initial introductions involved evaluation of their adaptability in the region to identify superior cultivars (Griesbach 1992). Because most of the evaluations were done at the research stations, efforts to introduce them to farmers involved sensitization meetings, provision of germplasm at subsidized prices, and advisory messages on their management. This was done by research organizations in collaboration with the Ministry of Agriculture (MoA). During training, both formative and routine pruning practices were emphasized as pruning affects productivity of the fruit trees.

Other development agencies such as the Genetic Technology Institute and the Horticultural Crops Development Authority (HCDA) have also been working in partnerships with MoA to empower farmers to propagate their own planting materials. Approaches used include training farmers on various propagation techniques, like grafting, soil preparation and use of rooting powder to enhance root development in cuttings. A major strategy adopted by the various stakeholders especially MoA in collaboration with HCDA is that of providing assistance to farmers in marketing, through linking farmers with markets.

Institutions promoting the innovation

A number of organizations have been involved in the successful performance of the temperate fruits agroforestry system. Ministry of Agriculture personnel assist farmers by providing technical advice, linking them with sources of superior germplasm and markets. The horticultural division within the ministry also collates statistics on local production of various horticultural produce and explains production patterns (Magana-Mugambi 2001). HCDA is a national body mandated to address issues in the horticultural industry. It has assisted farmers mainly by providing superior germplasm and by marketing. It has installed a cooling plant in Limuru, mainly to serve farmers in the area.

The Kenya Agricultural Research Institute has a National Horticultural Research Centre at Thika; one of its mandates is to carry out research on temperate fruits. The centre has been the main source of planting materials for farmers in Limuru. The Genetic Technology Institute has provided farmers with improved planting materials, especially for apple.

Research questions and knowledge gaps

The system is highly integrated and highly commercial, and research should aim at evaluating and documenting the profitability of this system in tangible terms such assessing gross margins. There is scanty documented information of this important agroforestry system, and the need is urgent to carry out an intensive study to document the current system and possibly offer guidelines to improve productivity of this system.

Increased standards of living, greater purchasing power and increased communications have made these exotic temperate fruits part of the way of life for both producer and consumer. Crop diversification and further research on the improvement of potential fruit species are needed to supply these lucrative markets and earn more profits.

There is a need to continue importing and evaluating adaptability of new fruit species to increase productivity. The apple has potential for generating more cash but there is a big problem with availability of good cultivars. Research should therefore work with farmers to develop ways of getting quality cultivars for the region. Market research is also needed to analyse various channels and links.

Farmers mentioned susceptibility of the fruit species to the fungus *Armillaria mellea,* especially peaches and pears. Once attacked, the trees dry up and die. Currently, an effective treatment of this fungus does not exist, and research should evaluate and develop an effective mechanism for controlling it.

Professional reflections and recommendations

The agrisilvipastoral agroforestry system involving combinations of different types of fruit species with fodder and horticultural crops in Limuru area is a highly integrated and organized system that clearly maximizes use of the land. All components on the farm are a source of income for farmers, and this is the single most important reason why farmers have adopted this highly integrated system. Availability of a ready market has enhanced its development and sustainability.

There is scope for improving marketing and potential for farmers to increase their profits through selling the fruits and other commercial crops at prices higher than current ones. Some farmers are already aware of the low prices being offered by traders and they desire an opportunity to sell their produce at a better price. For example, a farmer in Limuru Location plans to sell his next crop to traders from Uganda whom he identified last season and who offer better prices than the Kenyan traders.

A more sustainable alternative is to form marketing groups that would allow farmers to negotiate prices. Farmers have the potential to organize themselves into marketing groups; they already have local milk marketing organizations, which have helped them market their milk easily and at good prices. The Ministry of Agriculture in collaboration with HCDA, which is already working in the area, should spearhead formation of the proposed marketing groups through sensitization meetings and workshops. In doing this they should consider forming partnerships with other stakeholders and also include all other commercial crops. Farmers will also need to be sensitized on managing farming operations as a business so as to maximize profits.

Policy support is also needed to develop good marketing mechanisms and to process produce, to assist farmers earn more income. The government should provide basic infrastructure in the form of better roads and create an enabling environment for the private sector to engage in processing activities for agricultural produce. A policy that specifically favours investors on agricultural produce would go a long way in enhancing the potential for investing in processing.

Another way of making the system more profitable and beneficial to farmers is if the government would make deliberate efforts to encourage farmers to invest in processing. The government could use the already existing network of staff in the Ministry of Agriculture to encourage farmers to engage in processing by providing training and the basic infrastructure, which could be in form of small processing factories, such as for making soap or processing oil from avocado or making jam from plums. To achieve this, the government should also consider providing microfinancing to stimulate farmer groups to form cottage industries for processing primary produce.

9.9 Calliandra-based agroforestry farming in the central highlands of Kenya

Nature of the innovation

Dairy farming is a major farm enterprise in the central highlands of Kenya with animals managed under zero- or semi-zero-grazing conditions. Most farmers (> 90%) own cattle and some keep up to three head. Gross margin analysis (Franzel et al. 1996) showed that dairy cattle production was the most important livestock activity in terms of generating household income, contributing 37% of the total household cash income. The sale of milk is the main source of income from the animals. Shortage of high-quality fodder for feeding dairy cattle during the dry season is a major constraint to milk production among these smallholder farmers in the central highlands of Kenya. Whereas the extension service recommends 4 kg dairy meal be fed per day, depending on the level of milk production, farmers' feeding rates were found to be considerably low (Murithi 1998). Farmers also complained that the price ratio between dairy meal and milk was not fa-

Gliricidia is grown as an agroforesty crop either in hedges or as a boundary crop for improving soil fertility and as a supplemental livestock feed in improved dairy farming.

vourable, and that it was difficult for them to transport dairy meal from the market to the homestead (Paterson et al. 1996a,b,c).

The aforementioned constraints to dairy production led to initiation of research into the use of fodder trees as a protein supplement. Over the years, *Calliandra calothyrsus* was tested for fodder production and planting materials of it disseminated to farmers in this region. Consequently, many have adopted planting calliandra and currently the practice of using calliandra as a protein supplement to dairy animals is widespread in the area. The edible fraction of calliandra has a crude protein level of 20–25% of the dry matter depending on the cutting interval and the leaf-to-stem ratio. This crude protein content is much higher than that of Napier grass, which has an average of 8.5%. Farmers are using calliandra either as a supplement to their base diet or as a substitute for commercially purchased dairy meal Paterson et al. 1996a,b,c). They say their income from dairy farming has increased (Franzel et al. 2002).

Justification of profitability

Calliandra has been widely planted by smallholder farmers in the central highlands of Kenya, where it is used primarily as fodder for dairy animals but also to conserve the soil and improve its fertility. Recently farmers have started planting *Leucaena trichandra*, also a leguminous shrub that serves the same purpose. The fodder trees are attractive compared with the expensive protein concentrates that farmers feed their dairy cows and goats (Franzel et al. 2003). Adoption of calliandra trees by farmers in the central highlands of Kenya has been due to successful collaborative research, which has shown that growing these leguminous trees for fodder is profitable (Franzel et al. 1996, 2003). One kilogram of calliandra (24% crude protein and 60% digestibility when fed fresh) has about the same amount of digestible protein as 1 kg of dairy meal (16% crude protein and 80% digestibility) (Paterson et al. 1996a,b,c). Under on-farm conditions, each increases milk production by about 0.75 kg (from 10.0 to 10.75 kg day^{-1}) but the response is variable, depending on such factors as health of the cow and the quantity and quality of basal feed (Paterson et al. 1996a,b,c).

Partial budgets for calliandra as a supplement or substitute show the profitability (Franzel et al. 2002). In scenario one, calliandra is fed at a rate of 2 kg dry calliandra a day as a supplement throughout the lactation period. Incremental benefits per year after the first year were found to be over 12 times higher than incremental costs. This resulted in annual net benefits per cow after year 1 of USD 120 (Franzel et al. 2002). In scenario two, calliandra is used as a substitute for dairy meal. The farmer saves the money that would have been spent buying and transporting 730 kg dairy meal during the year. Incremental benefits per year after the first year were found to be over 14 times higher than incremental costs and the annual net benefits per cow was USD 142. Therefore using calliandra was found to increase farmers' annual income by about USD 120 to 142 per cow, depending on whether the farmer is supplementing or substituting. The average farmer owns 1.7 cows. Calliandra therefore increases farmers' income by about USD 204 to 241 per year, representing an increase of about 10% in the total household income (Murithi 1998).

Calliandra increases the butter fat content of milk, giving it a richer taste and creamier texture. Farmers note that calliandra has important advantages over dairy meal: it is available on the farm, they do not need cash to obtain it, and its nutritional content is more reliable than that of dairy meal (Franzel et al. 2003). They also feed calliandra to a range of animals, including goats and heifers, improving their health (Franzel et al. 2003). Calliandra accrues additional intangible benefits: firewood, soil erosion control, boundary marking, fencing, and ornamentation of the homestead.

Some farmers have reported calliandra produces excessive amounts of leafy material during the rainy period and less during dry periods. Excess pruning during the rainy period could be harvested, dried, and stored for use during the dry period. A few farmers, especially those with more than 500 trees, have tried drying the prunings and making leaf meal. This indicates that processing calliandra has great potential because of the great importance of dairy production in the region. This potential could be developed, such as producing a dairy meal with a known protein content that could even be packed and graded like a commercial concentrate.

Agroforestry components and interfaces

Farmers commonly plant calliandra in many niches and its interactions in these different niches is here considered:

- *Planted along contours:* Calliandra trees hold the soil together and help control soil erosion on steep slopes. Due to their deep root system, they are able to recycle leached nutrients, especially nitrogen. The recycled nutrients benefit the livestock if used for fodder but they may also be used to improve soil fertility by incorporating the prunings directly into the soil (Mugendi et al. 1999; Mugwe et al. 2002)

- *Intercropped with Napier grass:* Results from intercropping experiments suggest that introducing calliandra into Napier grass plots has little effect on Napier yields and sometimes presence of calliandra prolongs productive life of the grass (Nyaata et al. 1998)

- *Between upperstorey trees commonly planted along boundaries:* The most common upperstorey tree is *Grevillea robusta*. The growth of fodder is hardly affected by taller trees, planted on the same line (NAFRP 1993).
- *Around the homestead:* Calliandra provides animal fodder and creates a hedge that protects the homestead.
- *Seed production:* Flowers provide bee forage.
- *Tree–animal–soil interactions:* Dairy cattle fed on high-quality calliandra fodder produce more milk. The manure from animals fed on these leguminous shrubs is of high quality, and when applied to the soil improves its fertility, resulting in higher crop production.

Minimum inputs

Since calliandra is propagated through seedlings that are raised from seeds, it is important to provide the right germplasm and give farmers technical support. Training is necessary on appropriate propagation, planting and management practices. The training should also give farmers the know-how to ensure continued production and sustainability. Institutional support is needed for establishing seed stands at central points that are easily accessible to farmers. Alternatively, farmers should be encouraged to establish their own seed production units.

Agroclimatic zones

Calliandra occurs naturally in some parts of tropical Central America at altitudes ranging from sea level to 2000 m. It however grows well in the tropics at altitudes ranging from sea level to 1900 m and where the average rainfall is above 1000 mm. In Kenya, the tree grows well in altitudes above 1000 m with an annual rainfall of 1000 to 1500 mm (moist lowland). Agronomically, calliandra tolerates soils that are heavily compacted, acidic and poorly aerated, including those that are poorly drained (Roothaert et al. 1998).

In the coffee-based land-use system of the central highlands of Kenya, where use of calliandra for fodder is widespread, the altitude range is 1300–1500 m and rainfall 1200–1500 mm per annum. Farmers in the tea zone at altitudes of 1700–2000 m and rainfall of 1500–2000 mm per annum have also started incorporating calliandra into their farming systems.

Major factors that make the innovation successful

The importance of dairy production in the region is a major reason for farmers' fast adoption of the fodder shrub. The demand among farmers for fodder shrubs is huge, mainly because the shrubs save cash, farmers' scarcest resource, and require only small amounts of land and labour. Also, the central highlands are noted for the dynamism of its farmers, and access to markets is good, enhancing the adoption of new practices.

That this fodder shrub can be planted in a range of niches within the farm has greatly contributed to its adoption. Niches most commonly adopted are along contours, intercropping with food crops, and on homestead boundaries. Farm sizes in central highlands of Kenya are small, averaging 1.2 ha, and it is unrealistic for farmers to have fodder shrubs in separate plots.

Calliandra is planted on-farm as seedlings that are raised first in nurseries. Research has shown that they can be grown in raised seedbeds rather than by the more expensive and laborious method of planting the seeds in polythene bags (Mugwe et al. 1998).

Prunings harvested from calliandra contain substantial amounts of nutrients in the leaves, averaging 3.5% nitrogen, 1.6% potassium, 0.2% phosphorus, 0.6% calcium, and 0.2% magnesium. The shrubs are first pruned for fodder 9–12 months after planting, and pruning continues at the rate of 4 or 5 times per year. Leafy biomass yields per year rise as pruning frequency decreases and cutting height increases. The most productive compromise is in the range of 4–6 prunings per year at 0.6–1 m cutting height. Trees planted under farmers' conditions in hedges at a spacing of 2 per metre yield 1.5 kg dry matter per tree per year (Franzel et al. 2002). A farmer in this case needs 500 trees to feed a cow throughout the year at a rate of 2 kg dry matter per day (6 kg fresh material), providing about 0.6 kg crude protein (Roothaert et al. 1998). A typical farm of 1.5 hectares can easily fit 500 shrubs along internal and external boundaries and other niches (ICRAF 2003).

Direct and indirect beneficiaries

Due to their greater involvement in managing cattle, women in Embu were reported to appreciate technologies that improved feed supply, and hence to have benefited more from the calliandra technology than men (Kiruiro et al. 2002). More women (71%) than men (62%) indicated that diminishing the burden of searching for feed was one of the greatest benefits of using fodder harvested from the farm. Using calliandra to substitute for or replace dairy meal, however, saves money and thus raises the income of all farmers.

Increased milk production contributes to increased nutrition, especially for women and children. Women also benefit by using the firewood harvested from the fodder trees. Firewood from calliandra is friendly because it does not need to be split, it dries fast and it burns well.

Using calliandra as an agroforestry system is suitable for families with small grazing areas and for beekeeping and honey production, which are technologies that are not labour intensive. It is thus appropriate for those affected by HIV or AIDS, for whom also milk is a source of protein that can boost their nutrition.

Upscaling strategies

With the initial trials having been set up in 1991 by the National Agroforestry Research Project (NAFRP), test farmers adopted calliandra, mainly facilitated by a farmer-to-farmer dissemination approach. This is because initial on-farm trials were farmer designed and farmer managed, thus permitting farmers to plant trees in the farm niches of their choice and to manage them as they saw fit. There was evidence of increased establishment and expansion of calliandra planting by the test farmers. By 1995, the average number of trees per farmer had increased from 84 in their first planting to 218, an increase of over 2.5 times (Franzel et al. 1999).

During 1999–2000, a project implemented through the Systemwide Livestock Programme through a dissemination specialist helped about 3000 farmers plant calliandra across seven districts of central Kenya. The program was implemented by the World Agroforestry Centre (ICRAF) The Kenya Agricultural Research Institute (KARI) and the International Livestock Research Institute (ILRI) also introduced two other fodder shrubs to farmers, *Leucaena trichandra* and *Morus alba*.

The success, as registered by the dissemination specialist, was due to using the following strategies: building partnerships with a range of stakeholders in new areas, assisting farmers' groups and communities to effectively mobilize local and external resources, and promoting effective participation of farmers' groups and stakeholders in testing, disseminating, monitoring and evaluating the practice. These strategies were considered vital to ensure that scaling up would be sustainable once the project was implemented.

From 2000 to 2003, NAFRP continued its dissemination efforts in collaboration with Kenyatta University through an integrated soil fertility management project supported through the Rockefeller Foundation. Currently another collaborative integrated soil fertility management and upscaling project is being implemented by Kenyatta University, the Kenya Forestry Research Institute (KEFRI), KARI and the Tropical Soil Biology and Fertility Pogramme, and supported by the Belgium government and FARM Africa

Technology Transfer Initiative. It continues to promote growing calliandra and leucaena for fodder production and soil management. It is estimated that through this project a further 2000 farmers have planted these tree legumes on their farms to meet their needs.

A major factor that contributed to achievements in developing and disseminating the fodder tree technology was collaboration among research partners, farmers and extensionists. Because researchers and extensionists worked through partner organizations, they were able to build on local organizational skills and knowledge and reach more farmers than would otherwise have been possible. Also, the strong partnership facilitated the flow of information among all those involved.

Institutions promoting the innovation

Research on fodder shrubs began in Kenya in the 1980s by ILRI and the KARI.

The first on-farm trials in the Embu area were initiated by the National Agroforestry Research Project (NAFRP), a project that was jointly implemented by KARI, the KEFRI and ICRAF in 1991. The on-farm work incorporated farmers as research partners by having on-farm trials that were mainly farmer designed and farmer managed. Researchers, farmers and extension staff jointly managed these trials, and this facilitated strong partnerships that were indispensable in successfully developing the technology.

During the dissemination phase in 1999–2000,when a scaling-up project was funded through Systemwide Livestock programme participating partners included government departments, NGOs, churches and community-based organizations. Ministry of Agriculture extension agents and other collaborators were crucial in identifying interested groups. A large number of groups was involved. For example during this time the dissemination specialist assisted by staff from the collaborating partners worked with 10 community-based organizations, 150 farmers' groups, and 10 schools and churches. By the end of 2000, the 150 groups had developed 250 tree nurseries involving over 2600 farmers. Most (76%) of the groups included both men and women, 15% were women's groups and 9% were men's groups (Wambugu et al. 2001).

After 2000, an integrated soil fertility management that is collaborating between Kenyatta University, KARI, KEFRI, and the Tropical Soil Biology and Fertility Program have been promoting planting calliandra and *L. trichandra* for soil conservation and fodder production.

Research questions and knowledge gaps

More research should be carried out to expand small-scale dairy production. Fodder trees can help reduce costs and improve the productivity and profitability of smallholder dairy farming. Among the main research areas:

- Greater diversification of fodder shrubs is needed to reduce the risk of pest and disease attack and improve feed quality. This could be achieved by evaluating more fodder trees that should also include indigenous species.
- Many farmers now have 5–10 years of experience feeding calliandra to their cows; the knowledge that these farmers have gained on feeding calliandra should be captured and shared.
- More research is needed on the constraints and incentives affecting the adoption of calliandra and other fodder shrubs. This information could be useful for identifying the problems farmers face in testing and adopting calliandra.
- More research is needed to compare the effectiveness and efficiency of different mechanisms for producing and distributing planting material.
- More research is needed on integrating fodder trees for feeding animals and managing soil fertility to be able to come up with a situation that optimizes utility of these shrubs by farmers.

Professional reflections and recommendations

Calliandra calothyrsus grows fast and has characteristics that are favourable for fodder production; it rebounds from coppicing and is palatable to livestock. Farmers in the central highlands of Kenya have therefore adopted it widely, using it primarily to produce fodder. Smallholder farmers will continue to use this sustainable practice because of the benefits it accrues by providing fodder and conserving soil.

Producing and using calliandra as a fodder tree is evidence of spontaneous diffusion of a high-performing agroforestry practice. However this technology is complex, and farmers need information, training and assistance with planting materials if they are to achieve potentials in production and income. Its success highlights several key elements for agroforestry extension: tailoring recommendations to farmer and regional socio-economic conditions, providing information on agroforestry management, and involving farmers strategically in developing and disseminating the technology. Involving a large number of partners in the dissemination phase was critical for the success that was recorded.

Efforts to disseminate calliandra have mainly concentrated around Embu and Meru South Districts, but the demand for planting calliandra and leucaena is still high in the whole of the central highlands of Kenya and areas with similar conditions. There is therefore a need to reach more farmers. Doing this requires considerable training, information and amounts of germplasm. Further scaling up should focus on collaborating with institutions working in areas of the country where dairy farmers predominate. To increase availability of germplasm, community-based seed production and distribution must be promoted through a range of partners: farmer groups, individual seed producers and private nurseries.

Research should spearhead development of calliandra processing, which should involve developing a simple processing technology that small-scale farmers can afford. This should go hand in hand with research to determine the ratio for mixing calliandra with other animal diets, and feeding rations. Using farmers' experience with drying calliandra could be a starting point, to be followed up by research to determine other materials that could be mixed with it to make a ration whose nutritional status is known.

Currently milk marketing is a constraint to many farmers. A government policy favouring marketing of milk and milk products is needed to spur dairy development. Such a policy is likely to create demand for animal fodder and probably make calliandra fodder technology more profitable by creating demand for processed calliandra.

The fodder trees calliandra and leucaena appear to be appropriate for smallholder dairy farmers throughout eastern Africa since they can grow at altitudes between sea level and 2000 m and are suitable for cut-and-carry feeding systems or for grazing systems. Dissemination potential is high considering that there are approximately 625,000 smallholder farmers in Kenya with improved cows, each having about 1.7 cows per farm (Omore et al. 1999). Calliandra also has potential in the large-scale sector, which supplies 30% of Kenya's milk, and in the dairy goat sector, which is growing rapidly and is particularly suited to resource-poor farmers.

9.10 Homegarden farming system of Tanzania

Nature of the innovation

Most homegardens in Tanzania are characteristically found within the northern Rift and volcanic highlands agroecological zones and in the southern highlands. Homegardens have a long tradition in many tropical countries (Nair 1989). Tropical homegardens consist of an assemblage of plants, which may include trees, shrubs, vines and herbaceous plants growing in or adjacent to a homestead or home compound. These gardens are planted and maintained by members of the household; their products are intended primarily for household consumption. The gardens also have considerable aesthetic value, and they provide shade for people and animals. The word 'homegarden' has been used rather loosely to describe diverse practices, from growing vegetables behind houses to complex multistoried systems (Nair 1989). It has been used to refer to the intimate association of trees and shrubs with annual and perennial crops and, invariably livestock within the homestead compound, with the whole crop–tree–animal unit being managed with family labour.

Lopping and mulching vegetable croplands with leaves and twigs from adjoining tree farming is one form of a productive agroforestry system.

In spite of the small size of the average management unit, homegardens are characterized by high species diversity and usually 3–4 vertical canopy strata, which results in intimate plant associations. The layered canopy configurations and combinations of compatible species are the most conspicuous characteristics of all homegardens. Contrary to the appearance of random arrangement, the gardens are usually carefully structured systems with every component having a specific place and function.

In general terms, all homegardens consist of a layer near the ground, a tree layer at upper level, and intermediate layers in between. This layered structure is never static; the pool of replacement species results in a dynamic, productive system whose overall function is maintained.

Justification of profitability

In recent years, homegardens have shown great potential to enhance food security, reduce deforestation, increase diversity of food crops, and maintain ecosystems for small-scale farmers, providing them with goods and services. However, food production is the primary function of most, if not all, homegardens. An aspect of homegardens is the almost continuous production of food that occurs throughout the year. The combination of crops with different production cycles and rhythms results in a relatively uninterrupted supply of food products. Depending upon the climate and other environmental characteristics, there may be peak and slack seasons between harvests of crops such as coffee and maize. Then harvesting of tuber crops such as taro, yam, irish potato and sweetpotato, and of banana can be staggered over several weeks depending upon household needs.

Trees such a *Grevillea robusta*, *Olea capensis*, *Croton megalocarpus*, *Albizia schimperiana*, *Markhamia lutea* are among the tree species planted and found along the boundaries and scattered in the middle of the farms as shade trees and for producing wood products. Various leguminous tree species are planted to provide protein and improve animal feed: *Sesbania sesban*, *Calliandra calothyrsus* and *Leucaena diversifolia.* Dairy cattle, goats and pigs are kept. Poultry faming is also an important component. Animal fodder is collected from the maize–beans lowlands. Napier grass is also managed as an energy-giving feed. The intent of this system is to encourage communities to practise zero-grazing where a few breed animals are domesticated for high milk and meat production. The zero-grazing prevents haphazard grazing and reduces social and environmental conflicts.

The Chagga tribe in the northen agroecological zone has an intimate knowledge of the various crops and plants and their ecological requirements. This knowledge is handed down from one generation to the next, becoming improved and refined with time.

Traditionally, irrigation furrows were used to water the crops; thus weather changes did not strongly influence farm productivity or greatly influence agricultural patterns. Now, drought, little farm irrigation due to shortage of water and no maintenance of the traditional furrows, coupled with migration of youths to urban areas have stricken the communities with poverty.

Agroforestry components and interfaces

The agroforestry component in this system is a combination of tree, livestock and crops around the homestead. Consequently, the system has several outcomes: alley farming; trees and hedgerows for browse, green manure, soil and water conservation; integrated production of trees, pasture and livestock (table 9.16).

Table 9.16. Components of the homegarden system and their interactions

	Subsistence agriculture	Livestock	Multipurpose trees	Poultry farming	Cash crops mainly coffee	Fish farming	Beekeeping
Subsistence agriculture	Production of a variety of food crops, intensifying production of indigenous food	Improved food security, increased soil fertility, zero grazing	Fruits, traditional medicine, shade, soil fertility, soil and water conservation, shade for coffee, wood products, fuelwood	Organic manure, improved poultry farming technology	Intercropping technology, credit facility, marketing and formation of community cooperative societies	Fish farming technology, improved food quality	Income generation, food production, pollination activity
Livestock	Fodder reserves, improved food quality, zero grazing	Soil and water conservation strategy, rotational grazing technology	Fodder trees, rotational grazing technology, soil and water conservation strategy	Soil and water conservation strategy, zero-grazing technology for livestock and poultry	Use of organic manure on-farm, zero-grazing practice and technology	Organic manure as source of food for fish	Livestock and beekeeping technologies
Multipurpose trees	Shade-tolerant crops	Fodder trees, shade trees	Wood and non-wood forest products utilization, marketing, regeneration and conservation	Medicinal plants and shade trees	Nitrogen-fixing and shade trees	Fish fodder, shade and conservation trees	Bee fodder (plants), timber tree species

Poultry farming	Cereal production and processing of poultry feed technology, organic farming technology	Controlled grazing for poultry and livestock	Knowledge on shade trees, fruit trees to produce fruits for poultry feed	Poultry-keeping technology including breeding, infrastructure such as marketing	Organic farming	Fish farming with chick droppings technology	Stingless bees technology
Cash crops, mainly coffee	Land-use and planning techniques and practices	Land-use and planning techniques, conservation strategies	Value-addition of tree and agricultural crops technologies, including processing, packaging and marketing	Improved poultry farming practices	Intercropping technology	Processing technologies and infrastructure development	Crop pollination, integrated pest management programs
Fish farming	Cereal processing technology, efficient use of water resource	Live fencing practices and technologies	Knowledge of fish fodder trees and shade trees	Processing of poultry feed with fish as one ingredient	Integrated pest management	Infrastructural development on efficient fishing techniques, processing and marketing	Development of vegetative cover including soil and water conservation technologies
Beekeeping (stinging and stingless bees)	Small-scale food and bee products processing industries	Development of natural resources conservation technologies intensified	Beekeeping practice intensified under apiary management	Development of zero-grazing in poultry farming	Efficient pollination of crops, integrated pest management program	Soil and water conservation technologies and practices	Infrastructure development on efficient beekeeping techniques, processing, quality control and marketing

Growing mixed types of food crops is normally followed with rotational cropping and intercropping of leguminous crops such as beans with maize. Yam, vegetables, banana and potato are also among the agricultural crops grown under subsistence farming to provide food all year round for the households.

These areas are densely populated and therefore zero-grazing has long been practised. With zero-grazing, it has been possible to collect manure; consequently, people use animal manure to fertilize their farms. Increased soil fertility with cow manure results in improved farm productivity with organic manure that is environmentally friendly and cost effective. The system is quite sustainable for hardworking and innovative farmers.

Minimum inputs

The low prices given in the world market for coffee demoralized coffee farmers both in northern and southern agroecological zones, where this crop has been commercially planted. Farmers felled coffee trees and replaced them with vegetables such as tomato and carrot. Since 2005 farmers have been promised better prices in the world market and are advised to grow improved coffee species and intensify the management of their cooperative unions to consolidate the market.

Extension activities need to be strongly supported to reach as many farmers as possible. Strategies to produce improved coffee trees should be in place. The cooperatives need to be staffed with honest and capable professionals to handle market transactions and finance.

Timber business from the farm trees also replaced agricultural practices in most of the households until June 2005. Felling trees on-farm was considered an alternative for generating income. The trees were cross-cut and sold as fuelwood to timber dealers, who sold the wood to textile industries, who in turn used the wood in incinerators and boilers instead of electricity due to high electricity tariffs. To change this attitude the government of Tanzania has given guidelines to industrial wood users to plant their own trees for this purpose. In areas that have already been deforested the following strategies are suggested:

- Extension services that will concentrate on sensitization, advising, and facilitating farmers to start both individual and group tree nurseries to supply seedlings
- Training of professionals on Natural resources management, with specific emphasis on teamwork, to ensure trees are planted, tended and used sustainably
- Intensification of research on propagating indigenous tree species

Farmers are good in crop production (especially vegetables and fruits) and in animal products. But production costs and market prices do not let them break even. Also, the distance from the farm to the prominent markets causes farmers to sell their produce to intermediaries, who give them low prices. Suggested strategies for improvement:

- Education on how to add value to vegetables and fruits
- Development of cooperative societies through building staff capacity and maintaining existing infrastructure
- Credit facilities and training in managing small but profitable enterprises for individuals and organized groups, to reduce the idleness of youths that leads to increased illegal activities and spread of HIV/AIDS in these densely populated areas

Agroclimatic zones

- Moist highlands
- Moist lowlands
- Moist mid-highlands

Major factors that make the innovation successful

The homegarden is an indigenous technology among most of the communities in the mountain humid highlands of Tanzania. This system has many aspects—food, medicines, building materials, fuelwood, as well as social, aesthetic and cultural values, so the communities appreciate these goods and services.

Peasants, households and small local communities based upon traditional knowledge and practices have developed ecologically sustainable sound resource management techniques, providing them with a wide range of basic human needs.

The inherent attributes of crops, integrated livestock and self-sustaining agroecosytems motivates the communities to continue living with the system. Productivity increased by using livestock manure has also increased overall efficiency of the innovation.

Direct and indirect beneficiaries

Homegardens exemplify many agroforestry characteristics—the intimate mix of diversified agricultural crops and multipurpose trees fulfils most of the basic needs of the local population while the multistoried configuration and large species diversity of the homegardens help reduce environmental deterioration commonly associated with monocultural production systems. Moreover, they have been producing sustained yields for centuries in a most resource-efficient way.

These lands are characteristically located in the highlands recognized as watershed areas. Most of the rivers and streams start from the mountains and mountain ranges of Kilimanjaro, Meru, and the Eastern Arc (Usambara, Pare, Udzungwa and Uluguru Mountains). The Water Development Authority taps this water supply and distributes it to the urban centres. It collects revenue from the water users, and this activity creates employment. In addition, the Tanzania National Electric Supply Company holds this water in dams where they generate electricity for the whole country. Foremost, the government benefits from the revenue collected and jobs created.

Upscaling strategies

Currently the village leadership in collaboration with environmental groups have set stringent rules on tree cutting from farms. One has to plant 20 trees to cut one mature tree. This has been set as a village by-law in most villages around Kilimanjaro Region and it has been effective.

When the price of coffee fell, most farmers cut all of their coffee trees or left their coffee farms unattended. Currently village leaders and agricultural extension staff (both under government guidelines) and environmental groups, are working to persuade coffee farmers to revive coffee planting. This includes intensified research with the intent of producing improved coffee strains. In some areas, a strong link exists between the village environmental groups and research institutions. The groups act as a bridge between farmers and researchers, facilitating distribution and development of improved coffee plants from the neighbouring agricultural coffee research stations. One coffee seedling is currently being sold at TZS 100 (USD 0.8), making seedlings affordable for most farmers.

Most farmers use cow manure to increase fertility in their farms. This saves them from having to buy inorganic fertilizers, which are expensive and environmentally unfriendly.

Improved cooking stoves have been developed that reduce the amount of wood required. Some farmers have started using biogas as a source of energy. Cultural ecotourism is now being seen as a successful effort in integrated management, aimed at rural community development.

Institutions promoting the innovation

Promoting homegardens are government extension staff in the districts, agricultural and natural resources training institutions and their government ministries, Habari Maalum Media in Arusha, Himo Environmental Trust Fund in Moshi, and Lyamungo Coffee Research Centre. COMPACT was established by UNDP in collaboration with the United Nations Foundation with the main objective of involving communities in conserving the World Heritage site of Mt Kilimanjaro.

Programs and projects involved include HIMA (Hifadhi Mazingira Mkoa wa Iringa, or Environmental Conservation Program), and MEMA (Matumizi Endelevu ya Misitu Asilia) in Iringa in the Southern Highlands. There are also SCAPA (Soil Conservation Programme in Arusha Region, under RELMA/Sida, Northern Highlands), and Heifer Project International in the Meru East area of the northern highlands.

The Himo Environmental Trust Fund in Moshi, Kilimanjaro Region, has the goal of improving living standards in communities by reducing environmental degradation resulting from the increased use of firewood. Its objectives include:

- Protect and manage natural resources (emphasis on land, vegetation and water resources)
- Improve farms of small-scale farmers
- Initiate income-generating activities

To achieve these objectives, the trust emphasizes:

- Educating the community surrounding the forest on conservation of forests
- Giving environmental conservation education in schools

Under the SCAPA program some prominent farmers have constructed *fanya juu* and *fanya chini* terraces on their farms as conservation structures. They plant trees along contours and boundaries for timber, nitrogen fixing, fodder and fruit.

The Heifer Project advocates upgrading to improved dairy cattle. This has consequently resulted in the development of biogas plants as an alternative energy source for the early adopters of the SCAPA extension program in the northern highlands, specifically villages on the slopes of Mt Meru in Arusha Region where the program had been conducted.

DAKIKA (Dawa Kikatiti, or traditional medicine in Kikatiti) in the northern highlands is involved in adding value to honey, mixing it with relevant herbs and medicinal tree products to get traditional medicines for treating a number of human and animal diseases.

Research questions and knowledge gaps

Access good markets for animal products, especially milk, has been a big problem in these areas. Little or no knowledge among farmers about how to add value to agricultural products, especially to seasonal crops such as vegetables and fruits, means that much of the harvest is wasted during peak season.

Education and training in handling, processing, controlling quality, packaging, and storing and marketing procedures of agricultural products is greatly needed. Special initiatives through extension services and research should be undertaken to intensify development of cash crops such as coffee and tea, for farmers to generate enough income to help them to pay for school fees for their children, build better houses, and pay their medical bills. Otherwise rural people will remain poor and rural youth increasingly will migrate to urban centres, in all likelihood becoming jobless.

Professional reflections and recommendations

The mountain highlands in these zones produce the water that is the source of electric power, as tapped by TANESCO, that serves urban centres and lowland irrigation schemes. Watershed management and distribution involves all beneficiaries. An example is the Pangani Water Basin Authority, which initiated control of water flow in the forest reserve. This control was said to have reduced the water available in the natural water furrows traditionally used for irrigation in agroforestry farms. These furrows need to be revived to provide water for irrigating homegardens.

Organic farming should be emphasized for all the crops that need improved soil fertility. Inorganic fertilizers are both environmentally unfriendly and exorbitantly expensive. Their availability is also limited. Extension services should intensify work to educate resource-poor farmers on alternatives and possible ways to improve their livelihood.

9.11 Taungya cultivation in an agroforestry system of Tanzania

Nature of the innovation

Communities dependent on natural resources have been a primary focus of community studies and social impact assessment because in them, development for economic gain or other purposes had a demonstrable and sometimes dramatic history of effect on locals (Rickson et al. 1995). Efficient development and conservation of forests has in the recent years been a major concern to the world, nations and local communities due to their influence on global climatic change and the fact that communities around these forests depend on these natural resources for their wellbeing. Consequently, proper management for development of these forest resources requires efficient use by the communities and proper environmental conservation. Taungya cultivation is a common practice in Tanzania for establishing a forest plantation.

The competence of indigenous communities in developing and managing forest plantations has been observed in the taungya cultivation of a squatter system in the Mt Meru forest reserve in the northern highlands agroecological zone. Mt Meru forest is situated in northern Tanzania between latitude 3°12′S to 3°25′S and longitude 36°32′E to 36°38′E within Arumeru District of Arusha Region. It is a tropical montane rainforest, with an area of approximately 44,445 hectares. It contains a natural catchment forest reserve, a national exotic monoculture forest plantation (6000 ha) and a national park.

Taungya is a Burmese name that describes a kind of shifting cultivation, in which a farmer is given a part of forest land to clear and plant annual crops among the forest trees. In principle, the taungya system consists of planting plantation trees with annual crops (Hamilton 1988; Gomez-Pompa and Burley 1991). The system has been used in establishing plantation forests in Tanzania as a source of income and food to alleviate hunger and as a way to cut down on the cost of establishing a forest.

In a study on this system conducted by Lema (1998) in Mt Meru Forest reserve on the social implications of taungya cultivation, a participatory approach was adopted. Quantitative and qualitative methods of collecting and assessing data were used, including a review of secondary data sources, semi-structured interviews, group discussions, direct observations, and ranking and scoring.

Both interview schedules prepared before the interview and open-ended questions were used. The researcher who administered the interview schedule followed up if unexpected but relevant issues were raised with further questions or probing and recorded all on a data collection form. The 152 people interviewed included individual squatter families who were living inside the forest plantations and 20 key informants from each of the five selected wards of the villages surrounding Mt Meru forest plantations. The sample population included both men and women. Also interviewed were 10 forestry specialists working with Meru forest plantations and other forest Institutions around the forest reserve and 2 representatives from district and regional authorities. Group discussions were conducted with homogeneous groups of people to verify the individual interviews.

One form of agroforestry is planting cereals and legumes in open forests or young plantations untill the canopy closes and interferes with the productivity of such crops.

Justification of profitability

The taungya system was designed primarily to establish permanent timber crops. It was most successful in areas where there was a shortage of good agricultural land although there has been concern that the peasant labour involved is exploited because the forest services benefit from their efforts but pay no remuneration. However, it is noteworthy that despite dilution with the tree crop, per hectare yields to the farmers are higher than on land available to them outside the reserves. In fact, it has been calculated that in north-eastern Tanzania the value of the food crops grown under the taungya system far outweighs the discounted value of the subsequent tree crops. This is in keeping with the study done by Lema (1998) that is presented here to justify the significance and contribution of taungya cultivation for the wellbeing of the communities in forest plantations.

The forest plantation area of 6000 ha is managed on a sustained-yield basis. The crops grown include potato, beans, maize, cabbage, peas, carrots and amaranthus, cultivated for both subsistence and sale.

The forest plantation is situated on the hill slopes of Mt Meru where the slopes range between 0° and 30°. Efforts to reduce soil erosion on steep slopes were made both by the cultivator's own initiatives and through forest management initiatives. However, soil erosion problems still persist due to the nature of the topographical features of the area coupled with cultivation and timber harvesting with its consequences. Food products from the forest are produced both for home consumption and for sale. Major consumers of these products are people from the Arusha municipality, Mwanza Region, Shinyanga Region, neighbouring Kenya, Zanzibar Island, and the indigenous communities.

The estimated amount and value of these products from the forest plantation is as shown in table 9.17. The estimated total revenue that could accrue from the forest plantation through taungya cultivation of these crops is equivalent to USD 214,579.

Table 9.17. Estimated income from food crops in Mt Meru forest plantations, 1998

Name of crop	Amount (kg)	Cost per unit (USD)	Total income (USD)
Maize	550,000	0.13	71,500
Beans	200,000	0.44	88,000
Potato	360,000	0.13	46,800
Pea	2,500	0.15	375
Carrot	36,000	0.13	4,680
Cabbage	12,400	0.26	3,224
Total			214,579

Major crops grown are beans, maize and potato; minor crops include cabbage, carrot and pea. Maize constituted 48% of the crops grown. Maize is highly cultivated because it is a staple food for all people living in this area. In addition, maize can be preserved for future use during the periods of hunger. Potato ranks second in production, its contribution being 31% of the crops. Although few people from the indigenous community cultivate this crop, the squatters are highly specialized in its production, mainly produced to generate income. Arusha municipality, being a tourist town, consumes most of this product, making it fetch a good market most of the year.

Agroforestry components and interfaces

Interaction among components of the system are shown in table 9.18.

If the intent for the forest is only timber production, then an alternative means of establishing the forest is needed, to replace taungya cultivation in government forest plantations. Thus far, alternatives increase tremendously the costs of establishing the forest and increase mortality of newly planted trees because of poor tending operations. With taungya cultivation, trees are tended from the land is prepared for their operation, through weeding and pruning until the canopy closes. With proper forest operations and management taungya cultivation sustains forest management and food productivity for areas with land hunger.

Adherence to forest management practices includes ensuring that forest management under sustained yield basis is followed. Supervision of the squatters during cultivation to ensure proper handling of the seedlings and survival assessment of the planted trees should be done. To intensify soil and water conservation, the farmers should have the knowledge and technological know-how to construct conservation structures including terraces and contour bunds. This will prevent soil erosion on steep slopes, which is the situation found in most of the highlands.

Table 9.18. Component interface in the taungya agroforestry system

Components	Timber trees	Agricultural crops	Soil and water conservation
Timber trees	Forest establishment technologies; efficient use of wood products	Forest management practices	Diversification of tree species; biodiversity conservation; forest management practices
Agricultural crops	Selection of the types of crops for intercropping with trees	Infrastructure development including marketing and value-adding technologies	Improved agricultural practices and technologies
Soil and water conservation	Development and adaptation of several technologies and practice to prevent accelerated soil erosion	Construction of conservation structures, especially terraces and contour bands	Biodiversity conservation; diversification of tree species

Diversification of tree species will also be necessary where conservation is required with trees. This is because most of the timber trees are grown as exotics in monoculture; such development has negative implications for the environment. To make the practice sustainable a commercial forest plantation should contain several species that have been scientifically recommended for the purpose and location.

Minimum inputs

Soil degradation intensifies in all monoculture forest plantations. However, the present scheme of licensing farmers who cultivate in the forest plantation gives farmers responsibility for assigned plots to cultivate, a step that will ensure proper protection and survival of the planted tree crop. Farmers are assured of a market for the crops due to population increase and the drought, which has adversely affected crops grown on public land.

Agroclimatic zones

Agroclimatic zones suitable for this taungya cultivation innovation:

- Moist mid-highland
- Wet lowland
- Moist and hot lowland
- Moist lowland

Major factors that make the innovation successful

Through the Ministry of Natural Resources and Tourism, the forest policy gives a clear policy statement on the involvement of communities in national forests including forest plantations. Policy statement 3 of 1998 states:

> To enable participation of all stakeholders in forest management and conservation, joint management agreements, with appropriate user rights and benefits, will be established. The agreement will be between the central government, specialized executive agencies, private sector or local governments, as appropriate in each case, and organized local communities or other organizations of people living adjacent to the forest.

The allocation of cultivation plots in forest plantation is believed to be a great incentive for communities to safeguard the forest and participate in forest work effectively.

Direct and indirect beneficiaries

The indigenous people of this area are the Waarusha on the western and southern slopes and the Wameru on the eastern side of the Mt Meru Forest reserve. These people are a mix of agriculturists and pastoralists. The value to their society of the forest reserve can be measured and expressed in terms of economic, cultural and social benefits that include water supply, fuelwood, employment, seasonal farms, traditional medicine, sacred areas, and minor forest products such as honey and ropes. There are also a myriad of intangible benefits that include provision of research and educational opportunities, conservation of biodiversity, and aesthetic values.

The areas surrounding the forest reserve are densely populated, making land hunger the main issue among the communities. Furthermore, low fertility in public land due to poor land use and management has led people to believe that they can get more harvest when they cultivate in forest land than in their homegarden.

The Forest Industries Training Institute under the Ministry of Natural Resources and Tourism trains people to work in wood industries, learning furniture making, sawmilling, and processing of sawmill waste into briquettes. Institute graduates find employment in private and public wood-processing industries.

Timber produced from these taungya forests benefits the timber dealers and sawmillers. Sawdust briquettes produced are another value-added product, developed by the Kilimanjaro Industrial Development Trust.

Upscaling strategies

The taungya system has had a wide positive influence, both to the communities around the forests and to the government. However, its management has had to develop strategies in dealing with stakeholders to balance food crop production, quality tree crop production and soil conservation (Lema 1997). It was found that:

- farmers kept land under cultivation for longer than the desired period
- there has been a continuous loss of biodiversity due to farmers killing wild animals for food
- tree stocking was being reduced by farmers who purposely uprooted the planted tree seedlings to avoid tree canopy closure in order to get more time and space for food crop production
- poor cultivation practices in some steep areas were found to intensify soil erosion, degrading forest land

Government Notice No. 160 under the Forest Act No. 14 of 2002 (MNRT 2002) gives regulations that govern taungya cultivation in national forest plantations. To get land for cultivation, a farmer must obtain a licence and adhere to its conditions. In recent years squatter conflicts with management in Meru forest plantations have been a major problem for the Forest Division. Although there is a well-stated policy on managing squatters, implementing it has not been successful enough to ensure efficient use and management of this forest resource.

Institutions promoting the innovation

The government of Tanzania through Ministry of Natural Resources and Tourism is the sole owner of the national forest plantations in Tanzania, including the Mt Meru Forest Plantation. The surrounding communities have recently been involved through the participatory forest management approach adopted in the country.

Research questions and knowledge gaps

There should be strategies to develop socio-economic research to examine the implications of the taungya cultivation on forest management and to study the impact of the participatory approach in managing forest plantations. Quantitative to determine the influence of taungya cultivation on tree quality is also required.

Professional reflections and recommendations

The squatter system requires proper management to ensure that plantation forest management objectives of soil conservation and production of high-quality timber are attained. It is suggested that the Forest Department employ an environment specialist in all the plantations in the country who will advise management on cross-cutting issues such as conserving soil and water in timber-harvesting sites and involving communities in forest management. Environmental impact assessments should be made to determine new policies, programs and actions taken to manage forest plantations.

Forest management should consider taking action on the following issues:

- Introduce contour bunds on sloping areas
- Plant new trees Immediately after clearfelling
- Stop burning farm debris and instead put it on contour bunds
- Stop cultivating hilly and steep slopes
- Stop grazing in the forest area to reduce gully erosion and runoff

Chapter 10 Agroforestry Innovations suitable for Wet Mid-highlands

10.1 Grewia-based agroforestry farming systems of India

Nature of the innovation

Fragmented and undulating tracts in the western Himalayan region support tree-based farming practices. Fodder trees are generally planted or retained on the bunds and terraces of agricultural lands and around the homestead for meeting fodder needs during lean periods, whereas fruit trees are generally planted as commercial orchards. The major agricultural crops are maize, paddy, wheat, barley and potato with off-season crops like beans, tomato, cabbage and ginger.

Grewia optiva is the most important fodder tree species of this region. It acts as a reserve fodder supply, exploited in case of scarcity and lean periods. *Grewia* has wide adaptability to edaphic conditions, ability to withstand drought and frost, pollarding and coppicing, and has multiple uses. Its timber is used for axe handles, shoulder poles, cot frames, etc. ; its bark yields a fibre suitable for basket making, and fruits are also edible. The leaves provide nutritious fodder; leaves and edible green twigs are palatable, nutritious and easily digestible. The leaf fodder, when fed with straw or other inferior dry roughage can profitably substitute for concentrates. Nutritious young leaves are converted into a protein-rich meal after drying in the sun.

It is artificially propagated by seedlings or stumps. Seedlings are planted on farm boundaries or terrace risers at spacing of 8 m as a single row or in clumps around homesteads. The number of trees per household varies widely (12 to 129) depending on landholding size. The general trend is that farmers with smaller landholdings plant or retain a larger number of trees than those of larger landholdings, the latter opting for commercial-scale fruit orchards or monocropping cash crops. The trees are lopped during winter when no other fodder or grass is available.

Justification of profitability

Growing grewia and fruit trees, based the traditional agrihortisilvicultural model in mid-elevations of the western Himalayas was found to be ecologically sounder than either agricultural monoculture or agrihorticultural systems (Toky et al. 1989). The agrihortisilvicultural system is remarkably efficient in producing biomass for fuel, fodder and fruits; it also helps compensate for nutrients lost through harvest.

Although no systematic studies have been conducted regarding the economics of grewia and other fodder species grown in agrisilvicultural models under rainfed conditions, centuries-old use of these models justifies their profitability. As more than two-thirds of the annual rainfall of this region occurs during 4 months (June to September), the probability of drought is quite high; every alternate *rabi* crop (winter) and one in three *kharif* crops (summer) fails. Shade and root competition reduce crop yield in most situations. However, keeping in mind that crop failures are common under rainfed farming of the region, the tree-based models ensure fodder and fuel supply even during drought seasons. Moreover the fruit and timber trees also supplement income.

Khybri et al. (1992) worked out the economics of an agrisilvicultural system under well-managed irrigated conditions. The yield of wheat for 13 years, paddy for 8 years, yield of trees at harvest, and yield from lopping trees were treated as income. Cultivating crops and planting and managing trees were treated as costs. Growing crops alone was most economical; it requires less investment and provides maximum income. *Eucalyptus* hybrid was the most economical among tree-based systems. Although the *Grewia optiva* and *Morus alba* practices were the least economical, their economic value could be higher because for 8 to 9 years they provide leaf fodder for cattle, and feed for silkworms, leading to value-added products. The return from native species was found to be quite low (INR 23,581 to 25,146 ha^{-1}) compared with that under sole cropping (wheat–paddy) (INR 53,775 ha^{-1}) and INR 43,089 ha^{-1} with eucalyptus hybrid. However, such irrigated facilities are available only in a limited region (flatlands on lower altitudes) where deep local government institutions have installed irrigation tube wells.

Grewal et al. (1992) compared various agroforestry models in the lower hills of western Himalaya on different categories of sites and found that the agrisilvihorticultural system integrating leucaena, lemon, papaya and turmeric on irrigated land provided sustainable mean net returns of INR 17,066 against INR 7852 ha^{-1} yr^{-1} from a double-cropped agricultural system. Intercropping cluster beans with leucaena gave the highest net returns of INR 3540 ha^{-1} yr^{-1} in an agrisilvicultural system. A model based on *Eucalyptus tereticornis* with bhabbar grass (*Eulaliopsis binata*) in the understorey on a sandy loam gave a 4-year (1985–1988) mean yield of 4.2 t ha^{-1} yr^{-1} for air-dried grass (used for paper pulp) from the October cut and 1.19 t ha^{-1} yr^{-1} from the June cut (used for fodder). Bhabbar grass raised under acacia on a 25–30% sloping gravelly land provided yield varying from 2.18 t ha^{-1} yr^{-1} to 4.31 t ha^{-1} yr^{-1} from the October cut and 0.50–1.1 t ha^{-1} yr^{-1} from the June cut, with a 6-year mean of 3.9 t ha^{-1} yr^{-1}, which at 1988 prices provided net returns of INR 2402 ha^{-1}. These agroforestry models proved superior to traditional farming in each land-capability class.

Agroforestry components and interfaces

Agroforestry practices of fodder and fruit trees mostly involve three components—annual crops, fodder and fruit perennials, and animals on the same unit of land. Common domestic animals are sheep, goat, buffalo, cattle with average herd size of four per family, and some ponies. In some areas silkworms are also reared. Singh (1991) reported 28 tree species growing in agricultural fields and boundaries in Sirmaur District of Himachal Pradesh. Four species (*Grewia optiva*, *Celtis australis*, *Toona ciliata* and *Bauhinia variegata*) constituted 79.1% of tree area. Fodder trees occurred most frequently (61–72%) and timber species 13–28%.

Integrating trees has invariably caused reduction in yield of companion crops; however, the protective services of trees outweigh the losses.

Studies on tree crop interaction under rainfed condition in Dehra Dun valley were conducted for 13 years, from 1977 to 1990 (Khybri et al. 1992). *Grewia optiva*, *Morus alba* (mulberry) and *Eucalyptus* hybrid were tried along with a rice–wheat rotation. The trees were harvested in 1990. All tree species had depressed crop yields. Eucalyptus had depressed crop yield most until the first harvest and least thereafter. From 1987 onwards, *Morus alba* most affected rice, and *Grewia optiva* most affected wheat. The depressing effect varied from 28% to 34%, depending upon the species. The distance of tree line from the crop significantly affected crop yield to a distance of up to 5 m. Decrease in crop yield when the tree line was 1 m away was 39%; from 1–2 m distance, 33%; from 2–3 m, 25%; and from 3–5 m, 12%. Annual lopping and topping trees partly compensated for the deficit. Grewia could produce 1.08 t ha^{-1} yr^{-1} of branches and 0.26 t ha^{-1} yr^{-1} of leaves (air dried) and 1.28 t ha^{-1} yr^{-1} of branches; *Morus alba* produced 0.28 t ha^{-1} yr^{-1} of leaves. Wood produced by the trees was 33.6 t ha^{-1} from *Eucalyptus*, 9.5 t ha^{-1} from *Grewia optiva* and 11.6 t ha^{-1} from *Morus alba*.

Tree-based land-use systems, mainly silvipastoral, considerably reduce surface runoff and soil loss (Grewal 1993; Narain et al. 1998), thus improving fertility and physical properties of soil (Dadhwal and Tomar 1999) and higher productivity (Saxena et al. 1996). Agroforestry models on mined and degraded lands in Uttranchal resulted in decreased soil pH, and bulk density, along with improving organic matter and water-holding capacity

(Dadhwal and Tomar 1999). The nitrogen-fixing tree species increased N and P cycling through production of more aboveground litter and enhancing the release of these nutrients (Sharma et al 1997).

Thakur and Dutt (2003) found that *Morus alba* grown as alleys caused the maximum negative effect on adjoining wheat growth, yield, root and physiological parameters at 1 m distance from the crop; depressing influence was least at 3 m distance.

Minimum inputs

Traditional agroforestry systems based on native tree species are being pratised in this region for ages and seem to be in harmony with nature if provided some protection from grazing. The private farms of this region maintain a wide variety of trees, shrubs and herbs on the same unit of land, whereas common lands and government forests have been exploited mercilessly and have very poor productivity. Farmers protect their crops, shrubs, fodder and fruit trees from cattle and wildlife by raising live fences and couple them with barbed wire.

In general, grewia and other fodder tree models seem to be sustainable with low application of inputs. Although some foliage and branches of trees are used for fodder and fuelwood and thus not recycled into the system, the trees add more to soil fertility than do agricultural crops. Tree roots, bark and leaf litter add to soil fertility by changing its physical, chemical and biological properties; they enhance percolation and water-holding capacity of soils. Trees also act as nutrient pumps, bringing nutrients up from deeper layers. Cow dung is recycled into the system. Thus the agroforestry systems farmers with smaller landholdings have adopted generally require little inputs.

Agroclimatic zones

Fodder and fruit tree-based agroforestry models are followed in the northern part of the country and distributed in states of Jammu and Kashmir, Himachal Pradesh, and parts of Punjab, Haryana and Uttranchal at elevations of 550–2300 m. The climate varies from subtropical to temperate and alpine with mild summers and severe winters. The mean annual rainfall varies from 1000 to 2500 mm, mostly from the south-west monsoon during June to September. Rains also occur during winters, mostly from western disturbances, December to February. The temperature varies widely with location, altitude, topography, etc., with maximum temperature up to 40°C at lower altitudes and minimum below freezing at higher altitudes.

The topography is hilly, undulating, sometimes rugged; higher mountains are steep to precipitous. Some of the valleys are broad and flat, for example Kangra in Himachal Pradesh and Kashmir Valley in Jammu and Kashmir. The soils also vary widely, depending on parent material of rocks, topography, location, extent of surface runoff and soil erosion. The sites with undulating topography mostly have shallow soils and are less suitable for cultivation with shrubs and small trees as natural vegetation. The valleys have relatively fertile lands and are food baskets for the region, growing cereals, pulses, vegetables and cash crops. The Shiwalik foothills situated on lower altitudes along Himalayan Mountains have mostly loose sandy soils, frequently subject to flash floods.

The agriculture in this region is mainly subsistence, because of restricted irrigation facilities and small, fragmented landholdings. Annual crops frequently fail owing to long drought spells; fodder and fuelwood obtained from perennial components are more assured. Severe soil erosion, heavy surface runoff and frequent flash floods are the major obstacles to crop production. Trees for ages have been the integral part of the land-use system in this region. Farmers retain the trees growing naturally on farms and around homesteads, and they plant saplings around farm boundaries, to meet the needs of fodder, fuelwood, fibre, small timber and other minor forest products (Singh 1991). Average farm size is 1–1.6 ha, often fragmented and located in many sites, making farming more difficult (Tejwani 1994).

Major factors that make the innovation successful

Grewia optiva and other fodder tree species are native species that have been grown for centuries in many pockets of this region. Farmers thus have no hesitation in adopting this innovation. Many studies have confirmed that *G. optiva* has two distinct periods of leaf flush, higher leaf production, and significantly higher protein content than do other fodder species found in natural forests.

G. optiva serves many functions of the rural population. In addition to nutritious and palatable fodder, it yields small timber, fuelwood and fibre for basket making.

Though many studies have proved the higher productivity of some exotic tree species like *Leucaena leucocephala*, few farmers have adopted that model because it has drawbacks: toxic chemicals present in the foliage (high mimosine content causing health problem for animals) and its weedy nature because of prolific flowering and seeding.

Direct and indirect beneficiaries

Most farmers of the western Himalayan region have small landholdings and practise subsistence farming. Agriculture has been a subsidairy occupation because of the low productivity from rainfed cultivation. Women farmers and landless poor must travel several kilometres daily to nearby forests to bring the fodder and fuelwood, and they have to toil hard during lean periods. Productivity and carrying capacity of forests have diminished; thus adopting grewia and other agroforestry-based systems will supply fodder and fuelwood, at least during lean periods. Small-scale farmers will benefit from it.

The supply of timber, fibre and minor forest products will encourage setting up cottage industries in the rural areas —charcoal making, pencil making, rope spinning and basket making—will provide employment to landless labourers. Higher economic returns from agroforestry models and decreased risk of total failure (as in sole cropping) will enhance the socio-economic system. Rearing animals will also boost their economy by higher yields of milk and other dairy products.

Adopting agroforestry will enhance the total vegetative cover, resulting in climate amelioration, carbon sequestration, enhanced fertility status of soils, and reduced soil erosion. Reduced dependence on natural forests will result in decreased exploitation, preservation of flora and fauna, and conservation of biotic diversity.

Upscaling strategies

Saxena et al. (1996), while studying productivity of para grass (*Brachiaria mutica*), found that its total net primary production was about 15% higher under a mixed tree stand than in the open. The economic returns from *Eucalyptus* hybrid + *Eulaliopsis binata* on degraded lands of the Shiwalik foothills was 3 to 4 times more than agricultural crops (sesame, rapeseed) grown on similar soils (Grewal 2002). In a silvipasture system, comparative performance of different grasses under trees showed higher biomass production from *Eulaliopsis binata* than from *Chrysopogon fulvus.* Total biomass production was the highest in association with *Bauhinia purpurea* followed by *Grewia optiva* (Samra et al. 1999).

Various studies conducted in the region have proved that lopping, thinning and digging root trenches may modify competition between various plant components. Under silvipastoral systems, the enhanced lopping (75% intensity) of tree species resulted in significantly higher productivity of companion grasses because of increased light intensity (Samra et al. 1999). Another study in central Himalayas compared the effect of various lopping intensities (0, 25, 50, 75, 100%) of mixed stands on the light penetration, temperature and understorey crop yield (Semwal et al. 2002). Crop yields under control (no lopping) were severely reduced while significantly higher yields were noticed with 75% and 100% lopping. Similarly, Thakur and Singh (2002) opined that canopy management treatments (0, 25, 50, 75% crown removal) on 5-year-old *Morus alba* trees significantly influenced growth and yield potential of urd (*Phaseolus mungo*) and pea (*Pisum sativum*) with maximum value in control (without trees) followed by plants under least shade (75% crown removal).

Rapid vegetative propagation of promising multipurpose trees is an important need for enhancing the productivity of agroforestry models. Swamy et al. (2002) observed that the rooting ability of stem cuttings harvested from juvenile (2-year-old) and mature hardwood (15-year-old) trees of *Robinia pseudoacacia* and *Grewia optiva* was significantly influenced by the period or season when cuttings were harvested. The auxin treatments also significantly enhanced the number of roots (23.8 in *R. pseudoacacia* and 17.6 in *G. optiva*) and their mean length (14.3 cm in *R. pseudoacacia* and 16.1 cm in *G. optiva*). The results of the study suggested that it is possible to develop clones of genetically superior trees of *R. pseudoacacia* and *G. optiva* for use in agroforestry or afforestation programs.

Institutions promoting the innovation

The Central Soil and Water Conservation Research and Training Institute, Dehra Dun, has developed good technologies for rejuvenating degraded ecological balance of this region. The major thrust area of the centre was to develop agroforestry systems for enhancing tree cover on agricultural lands.

The state agricultural universities of Punjab, Himachal Pradesh, Jammu and Kashmir, Uttranchal have been undertaking research on various aspects of agroforestry. Potential tree and shrub species have been shortlisted for each agroclimatic region and agroforestry practices are being developed. Punjab Agricultural University, Ludhiana, has evaluated various fodder tree species for the Shiwalik foothills and found that the growth rate of grewia was medium but that it was the ideal fodder. Work on genetic improvement, vegetative propagation and silvicultural practices for grewia has been given priority. These universities are also working to develop tree–crop systems that involve various trees.

The state forest departments of Himachal Pradesh, Jammu and Kashmir, Uttarnchal. Haryana and Punjab and various non-government organizations have stressed undertaking afforestation drives and extension approaches for transferring technology. Other institutions like schools and municipal corporations have been involved in creating awareness among masses for planting trees and adopting agroforestry models.

Research questions and knowledge gaps

The agroforestry practices are mostly based on naturally growing trees that are retained in the fields. Scientific studies that work out optimum density of trees and planting geometry for maximizing production are lacking. The ideal tree crop combinations should be worked out for the whole rotation age and for different locations of this region. Studies on genetic improvement and standardization of silvicultural practices of trees should be given priority. Superior planting stock raised from clonal orchards and hedge orchards from genetically elite trees will further enhance the economic viability of such agroforestry models. Marketing of wood should be regulated to ensure optimum prices for the growers. Efforts need to be concentrated on studying how major wood products of the system are used. Adding value to minor forest products will result in more revenue for growers.

Financial institutions should be encouraged to ensure cash credits for farmers adopting agroforestry, especially during initial years until perennial trees start yielding products.

Professional reflections and recommendations

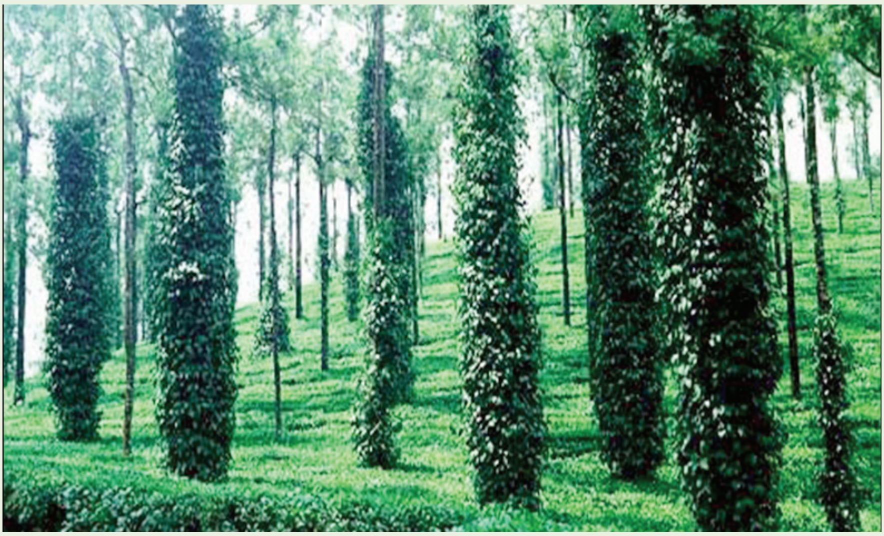
The western Himalayan region of India has traditionally adopted fodder trees agroforestry practices. As most of the farming in this region is rainfed and subsistence level, the scope of commercial-based agroforestry systems is limited. Cropping systems combined with grewia are sustainable and economical in these situations of small and fragmented landholdings, rainfed, and on sloping lands. Such models may be replicated with some refinements in understorey crops, depending on climatic features, soil types, etc.

This system is not economic for fertile flat lands where evn irrigation facilities are available. Under such situations, other agroforestry models based on fruit trees, eucalyptus, etc., or even sole crops will yield more income.

10.2 Multipurpose tree-based agroforestry systems in the eastern Himalayan region, India

Nature of the innovation

This region is characterized by difficult terrain, with wide variation in slopes and altitude, and diverse land-tenure systems and cultivation practices. Most of the population, predominantly tribal, is dependent on agriculture and land-based activities. Agroforestry in the form of shifting cultivation has long been practised in the north-eastern hill region, but recently many scientific studies have innovated some successful agrisilvicultural models. Based on experimental results at the Indian Council for Agricultural Research (ICAR) research complex for the north-eastern hill region, Barapani, Meghalaya, various agroforestry systems were found suitable for different areas (Dhyani et al. 1996; Dhyani and Tripathi 2000).



Spices growing under and up the trunks of alder yeild a number of high-value crops and at the same time keep the ground covered, preventing erosion

Alder (*Alnus nepalensis*) is grown in the eastern Himalayas to enhance soil fertility for growing cardamom, maize, millet, potato, chilli, barley, pumpkin, etc. Tribal people have exploited the nitrogen-fixing capacity of alder to retain soil fertility. It is the main component of coffee and cardamom systems at both lower and higher altitudes as a shade tree. At 6–8 years of its growth the tree is pollarded at a height of 2–2.5 m, its leaves and twigs are heaped on the ground and burned, and the ashes are spread to enrich the soil. Domestication of cardamom plantations under *A. nepalensis* from the earlier practice of its collection from the natural forests by indigenous Lepcha and Limbu tribes is an age-old agroforestry practice in eastern

Himalayas. Besides the prevalent *A. nepalensis,* there are 29 other tree species (*Albizia lebeck, Ananas comosus, Morus alba*, etc.) supporting this plantation crop. Farmers' tree management practices involve harvesting trees larger than 16 cm basal diameter to assist natural regeneration of younger tree seedlings and open the canopy to regulate light at the ground. This tree management system provides a continuous supply of fodder and fuelwood. The nitrogen-fixing trees help improve the site and the growth and production of cardamom. Lopping fodder trees during November after the cardamom matures and not allowing twigs to fall on it does not interfere with its production, and makes the system economically viable.

Justification of profitability

As the people of the eastern Himalayan region have been closely associated with such natural resources of forests as wildlife and herbal wealth, their livelihood requirements also depend on them. Hence, through experience over generations, local farmers have developed several indigenous practices involving domestication of tree species. They also have techniques for rotating crops and recycling kitchen wastes for maintaining soil fertility. Agroforestry systems provide different services that include nutrient cycling, soil formation and primary production. These supporting services also provide products such as food, water, fibre and fuel; regulatory services such as climate, flood, and disease control and water purification; and cultural services with aesthetic, spiritual, educational, and recreational values. These ecosystem services can be either direct or indirect, depending on the consumptive or non-consumptive use of the resources. Direct use is consumptive use by local communities and visitors. An example of indirect use is use of downstream water; optional value is potential value, such as medicinal and aromatic plants being used for pharmaceuticals or local gene pools being used for human benefit. Non-use value is the greenery that has aesthetic, spiritual or religious, and recreational values.

Promising agroforestry practices in Meghalya are areca nut + black pepper + pineapple (INR 42,750 ha^{-1}), areca nut + black pepper (INR 36,500 ha^{-1}) and pineapple + mandarin (INR 29,000 ha^{-1}). Accumulation of 2.91% organic matter was observed under areca nut + jackfruit + black pepper + tejpatra followed by 1.85% under areca nut + betevline + miscellaneous trees as against 0.78% in a degraded land with 10–15 years of this practice (Singh et al. 1994). The cost–benefit ratio for sole mulberry was 1.58, for mulberry intercrop 1.54, sole crop (improved practices) 1.31, and sole crop (farmer's practice) 1.13 (Dhyani et al. 1996). This indicates the potential for agroforestry systems in the region. Moreover, the adoption of this system, especially in shifting cultivation areas, will conserve natural resources.

The net income from large cardamom is still higher than from other cash crops. Two systems were studied in Sikkim: 1) large cardamom dominated and 2) maize–potato dominated. Gross incomes from different livelihood options from these systems were compared and results showed that the household income and per person per day was almost double for large cardamom over the maize–potato dominated system. The income from large cardamoms has been substantially higher than for other livelihood options from either system.

When the socio-economic benefits of the cardamom-dominated system were compared with maize–potato-dominated systems, Sharma and Sharma (1997) found that livelihood quality, livestock and service sector of the cardamom system was far superior, the per capita and household income derived being nearly double. One of the advantages that make it especially suitable for mountain conditions where accessibility is restricted is that it is a low-volume crop that nevertheless has high economic value. Apart from its high-income value and the fact that it is not labour intensive, large cardamom is a non-perishable crop (Sharma et al. 2000).

Multipurpose tree agroforestry systems also provide an opportunity to increase the income of poor mountain farmers who can draw in forest products from it. Thus they are provided with basic household requirements while minimizing pressure on forests and biodiversity. It potentially can contribute to environmental stability in terms of soil and water conservation, carbon sequestration and biodiversity conservation (Sharma et al. 2001).

By comparison with sole agriculture or shifting cultivation, agroforestry interventions are less nutrient-exhaustive, organic, ecologically sound, secure and they fit well in fragile ecosystems. They have scope for household enterprise development and for enhancing the quality of life of the rural population.

Agroforestry components and interfaces

Multipurpose tree-based agroforestry systems usually involved all three components of trees, crops and animals. Multipurpose trees such as *Alnus nepalensis* and *Morus alba* planted on terraces and as the block plantation form the upper canopy. Various crops such as cardamom, maize, millet and potato are grown beneath the trees. Grasses such as *Panicum maximum, Setaria sphacelata* coupled with *Stylosanthes guianensis* are grown for livestock forage.

Comparative productivity of large cardamom grown under N_2-fixing Himalayan alder and natural forest was investigated by Sharma et al. (2002)

and found that the agronomic yield in the alder–cardamom agroforestry system was 2.24 times higher than the natural forest–cardamom system. Higher cash returns make this system ecologically and economically viable for the mountain regions.

In a long-term agrisilvicultural trial, a positive effect of intercropping on height and diameter growth, crown width and timber volume was observed in alder and *Albizia* but no significant differences were observed for these traits in *Citrus reticulata* (Dhyani and Tripathi 1998). The higher growth of tree species was mainly attributed to weeding and applying fertilizers to intercrops. The better performance of *Albizia* could be attributed to its well-developed and extensive rooting with profuse fine roots well distributed within the rhizosphere (Dhyani et al. 1994).

The silvihortipastoral system comprising *Alnus nepalensis, Ananas comosus* (pineapple), and forage crops *Panicum maximum, Setaria sphacelata* coupled with *Stylosanthes guianensis* provided sustained agroforestry system in lands with 30–60% slope (Chauhan et al. 1993).

Minimum inputs

In general, this agroforestry practice is a closed system that does not depend on external inputs. The firewood produced is sufficient for both domestic consumption and curing cardamom capsules. Soil loss as sheet erosion and nutrient loss in the large cardamom system are low when compared with other cropping systems in Sikkim. Cardamom agroforestry systems under Himalayan alder are more productive as their nutrient cycling rate is fast. The poor nutrient conservation and low efficiency of nutrient use of alder and the malleability of nutrient cycling under its influence make it an excellent associate for cardamom by making nutrients rapidly available. Biodiversity is another indicator of sustainability, and biologically diversified systems have a capacity for resilience and more sustenance than other systems. Agroforestry practice supports diverse tree species, and the tree diversity index in a cardamom agroforestry is higher than in other agroforestry practices in the region. The trees also support birds and other wildlife, and this influences the ecological structure and functioning of the agroforestry system.

The quick decomposing leaf litter of *A. nepalensis* also fertilizes the cardamom plants. The nitrogen added to the soil in this way has been found to be as high as 249 kg ha^{-1} (Singh et al. 1989). Large cardamom thrives well in a moist soil, which is maintained by water diverted from seasonal springs on the upper slopes. The system is well suited to conserve soil, water and tree cover of the characteristically steep slopes of the region. Moreover, inputs required for growing cardamom are low but the crop gives a higher financial return than rice or maize. The shade trees used in the system are also a major source of fuel, fodder and timber, especially as access to state-owned forests is restricted by legislation.

Agroclimatic zones

This region covers the upper mountainous hilly areas in West Bengal and seven north-eastern states. Bounded by China and Tibet in the north, Mynamar in the east and Bangladesh in the south, it occupies 5.6% of the total geographic area of India. Demographically, more than 120 diverse ethnic groups, who maintain their own cultural heritage, inhabit this region. The region encompasses a wide variation in altitude, climate, soil and rainfall. Cropping systems, cropping patterns, cultivation and storage practice differ from state to state. Overall, about 70% of the land area is cultivated at one time or other in the region.

This region receives the highest rainfall in India. The climate varies from subtropical to temperate, and mostly there have been thick natural forests. This region is also important floristically and accounts for 43% of the total species in India, 48% of them endemic. It has been recognized as the primary or secondary centre of origin of many cultivated plants. Within the Indian gene centre, the region represents a primary centre of diversity for rice, minor millets, tree cotton, banana, cucurbits and canes, and a secondary centre of diversity for maize, chillies, tea and areca nut. It also harbours at least 138 herbaceous and 59 tree species of medicinal and aromatic importance.

About 53% of the geographic area is classified as forest land although there are large variations from a minimum of 8% in Meghalaya to 91% in Arunchal Pradesh. The land under the forest apart, about 60% of the land is classified as not available for cultivation. The net area sown is scarcely 7% of the total reported area in the region. Under in situ conservation, about 25,400 km^2 of the forest area has been declared as reserve forests. Many biosphere reserves, national parks and sanctuaries are located in this region. The *Citrus* gene sanctuary of Garo Hills and the *Nepalensis khasiana* habitat of Jaintia Hills are a few examples of in situ conservation of plant genetic resources.

The cropping pattern in the region, with the exception of Sikkim, is characterized by the predominance of rice. In Sikkim, maize is the dominant crop. Food crops account for more than 80% of the gross cropped area, which is suggestive of prevalence of subsistence agriculture and lack of crop diversification. Cereals alone account for about 70% of the gross cropped area. Within the region, however, there are exceptions. Sikkim records 9.3%, and Tripura 6.2% of the gross cropped area under oilseeds. A remarkable feature of shifting cultivation is that a wide variety of crops is grown in shifting cultivation fields. Paddy in shifting cultivation is the dominant crop and is mixed with maize, millet, beans, tapioca, sweetpotato, ginger, cotton, tobacco, chillies, sesamum and vegetables.

Major factors that make the innovation successful

Local people have long practised agroforestry in one form or another. Traditional homegardens, shifting cultivation, and the *taungya* system have all been followed in this region. *Alnus*-based agroforestry systems in the mountains are similar to natural ecosystems, and they provide similar ecosystem services. These systems with a combination of forestry and agricultural components are excellent practices through which environmental services are obtained in a sustained manner for both upland communities and downstream users. Natural nutrient cycling and maintenance of soil fertility, serial growth of a forestry component and related carbon sequestration, improved water quality for downstream users, and biodiversity conservation are examples of the regulatory functions of traditional agroforestry systems.

These agroforestry systems are accepted as one of the good practices adopted by mountain communities in the Hindu Kush-Himalayan region. They conserve soils by improving fertility levels; control erosion; and provide good quality water for local consumption, fodder for livestock, fuel and wood for use as energy and construction materials, and traditional crops for food security. Integration of cash crops in the practice gives good economic returns that help alleviate poverty. These attributes have a positive effect in terms of improving human health. One good example of such a traditional agroforestry practice is the cultivation of large cardamom as a cash crop in the eastern Himalayas. This type of agroforestry is a unique example of providing ecological sustenance and economic viability for mountain people while providing goods and services to downstream users.

The large cardamom is a perennial cash crop grown beneath the forest cover on marginal lands. Large cardamom agroforestry has been a boon to the peoples of Sikkim for a long time. It is widely cultivated under the nitrogen-fixing Himalayan alder *(Alnus nepalensis)*, a practice modified to maintain soil fertility and increase productivity. Its cultivation is an example of how a mountain niche can be exploited in a sustainable way. The capsules (fruit) produced are used widely as a spice and condiment; they contain about 3% of an essential oil rich in cineole. Over the past three decades, this traditional agroforestry system has become so popular that the practice has been scaled up through community exchange in the neighbouring countries of Nepal and Bhutan (Sharma 2006).

Direct and indirect beneficiaries

The adoption of agroforestry in this region will be beneficial to local populations, farmers, landless people, industry and society as a whole. Present farming practices in most states of the eastern Himalayas are neither ecofriendly nor sustainable. Agroforestry innovations based on local bushes and trees, if practised with local involvement, will contribute towards economic upliftment. Continuous higher productivity will boost the local economy. Adopting high-value crops such as cardamom, rubber or sericulture, or a high-value occupation such as dairy farming will generate other small-scale industries. The raw materials from farmer's fields will spur wood-based industries, as the Supreme Court of India has put a blanket ban on felling natural forests from ecologically sensitive regions.

The MPT agroforestry models will substitute for the shifting cultivation practice and check the exploitation of natural forests. It will be also helpful for conservation of biotic diversity.

Upscaling strategies

Research efforts have been made to realize the potential of micro-watershed land-use systems as an alternative to shifting cultivation. Suitable alternate land-use systems involving agriculture, horticulture, forestry and agroforestry have been designed. Agroforestry was identified as one of the major methods for tackling problems of land degradation and for restorating ecological balance (Dhyani and Chauhan 1995). Dhyani et al. (1996) found that a silvihortipastoral system with mulberry, guava, pineapple (in paired rows), and grasses on bunds was ideal on hill slopes (30–45%). Contour hedgerow intercropping and sloping agriculture land technology (SALT) have been advocated for degraded lands of shifting cultivation (Kothyari et al. 1996). Contour hedgerow intercropping technology is based on modifying agroforestry systems in which nitrogen-fixing plants are planted along the contour with desired food crops and other useful plants in the alleys. The space between two rows of contour hedgerows is called a strip. Similarly for SALT, alternate strips are selected for cultivation during the year and the strips left uncultivated are planted with permanent crops of horticulture and wood value.

Tree growth, survival and crop yield under agrisilvicultural practices based on mandarin (*Citrus reticulata*), alder (*Alnus nepalensis*), cherry (*Prunus cerasoides*) and siris, or East Indian walnut (*Albizia lebbeck*), with understorey crops of soybean (*Glycine max*), linseed (*Linum usitatissimum*), groundnut (*Arachis hypogea*) and mustard (*Brassica campestris*) were investigated for 7 years under rainfed conditions of Meghalaya (Dhyani and Tripathi 1998).

A positive effect of intercropping on height and diameter growth, crown width and timber volume was observed in alder, albizia and cherry but no appreciable differences for these parameters were observed in mandarin between the two situations. Alder and albizia attained maximum growth and woody biomass followed by cherry and the minimum growth was recorded by mandarin.

Institutions promoting the innovation

The Indian Council of Agricultural Research (ICAR) has given attention for this region, as it is an important zone for biodiversity and has a fragile ecosystem. The ICAR Research Complex for North Eastern Hill Region was established at Umiam (Barapani) in Meghalya. It has several regional centres.

The Central Agricultural University, Imphal, is the first such university of the country, established by the ICAR at Imphal, Manipur, in 1993. The university envisaged establishing seven major campuses in six states of the region: Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Sikkim and Tripura, with provision for establishing other smaller institutions at different sites in these states. Agricultural education in the region is imparted through the College of Agriculture at Imphal, and Colleges of Agriculture, Medziphema, Nagaland; College of Veterinary Science at Aizawl, Mizoram. Other institutes in this region include Assam Agriculture University, Jorhat. The G.B. Pant Institute of Himalayan Environment and Development, Tadong, Gangtok (Sikkim) has also studied the agroforestry systems of large cardamom grown under the N_2-fixing Himalayan alder (alder–cardamom) and natural forest (forest–cardamom) and found this practice ecologically and economically viable for the mountain regions. Several NGOs have played significant roles in creating awareness among local people regarding the ill effects of shifting cultivation and suggesting alternative agroforestry models.

Research questions and knowledge gaps

- Greater intervention through agroforestry and horticulture is necessary to remove the unbalanced and unsustainable short cycle of shifting cultivation and its limited opportunity to expand arable lands and their mechanization on the slopes. Traditional agro-forestry practices existing in the north-east region need in-depth understanding for agronomic improvement.
- There is need to encourage product diversification in a unit of land through agroforestry to increase the land's capacity to produce and bring the land to its full potential, linking it to assured marketing channels by identifying demands and outlets or outputs.

- Research on cardamom cultivation, mushroom cultivation, sericulture and processing of the produce needs to be encouraged.
- Implementation of appropriate soil conservation practices should be mandatory for any cultivation program in the hills, where soil and water losses are beyond the permissible limits.

Professional reflections and recommendations

The multitiered innovation of *Alnus* and similar trees is a modification of traditional agroforestry systems being followed in the eastern Himalaya region of India. Such agroforestry models have vast potential for being adopted in this high rainfall region. With persuasion through NGOs or other social welfare organizations, local farmers can be convinced to abandon existing cultivation practices (mostly shifting cultivation), which are not sustainable. Local populations should be involved in developing agroforestry models that will need but little site-specific modification to include local herbs, bushes and perennials.

In general *Alnus*-based models combined with high-value crops are economical, ecologically sound and productive. Such a system will generate employment and enhance local socio-economic conditions. With government support in the form of marketing and credit facilities it can be replicated in most areas. Value addition of herbs, cash crops and minor forest products will ensure a further boost to economic returns.

10.3 Enset–coffee–tree–spice-based agroforestry system in Ethiopia

Nature of the innovation

The innovation is the enset–coffee–tree–spice agroforestry system; locally it is termed *welkessa*, which means integrating trees with agricultural crops. The system has been developed with the aid of the Office of Agriculture. The office had introduced *Sesbania sesban* for temporary coffee shade and maintaining soil fertility. Farmers have also planted or retained different types of indigenous and exotic tree species within the system. Food crops like *Ensete ventricosum*, and root crops are part of the system. Fruit crops papaya, *Persea americana* (avocado) and *Annona senegalensis* (geshta, or wild custard apple) are part of the components. Coffee is planted as a cash crop as well as for consumption. Spices like cardamom are also found in the system.

In establishing the innovation farmers first cultivate the soil and plant coffee under shade trees. If the site already has naturally growing indigenous trees (mainly trees with light shade), they will serve for shade. Otherwise, farmers will plant temporary shade species like *Sesbania sesban.* In the survey it was observed that farmers in marshy areas have drained excess water by constructing ditches and have made the site more fertile with compost. They kept the area under improved fallow with *Sesbania sesban* for a year. Then they chopped down the herbs and shrubs for maintaining soil fertility. Finally they planted coffee. The sesbania tree would be harvested in 2 years for firewood. Farmers also raise fruit trees seedlings on their own homesteads. Most manage and use naturally growing coffee seedlings to expand their coffee plantation. They justify this by stating that coffee grown naturally will best adapt to the site and tolerate diseases.

Thus the innovation shows the skills and methods of farmers in integrating woody species and crops within a given farmyard. This is a result of the Office of Agriculture, which has enabled the farmers to use sesbania as temporary shade trees. However, one farmer said that experts from the Office of Agriculture had originally opposed establishing coffee on wet soil. Later, they were convinced that if wet soil is drained and well composted it can be used for integrating coffee in the system.

Typical nature of enset–coffee–tree–spice-based agroforestry system in Ethiopia.

Justification of profitability

The agrislivipasture is a main feature of the innovation. The agricultural crops and trees species have a positive synergetic interface. For instance, *Sesbania sesban* and *Acacia decurrens,* used as temporary shade, improve soil fertility, conserve the soil and fix nitrogen. It therefore improves the growth and fruiting habit of coffee. This in turn brings farmers a better price for their coffee since organic coffee has a higher value than inorganic coffee in the international market. *Acacia decurrens* serves as bee forage and its pods are fodder for livestock. Farmers chop the leaves of acacia and feed them to cattle, thus supplying scarce fodder and promoting zero-grazing. Beehives are hung in fig trees.

Coffee, spice and root crops (taro and boyna) planted under woody species can serve as sources of income as well as for household consumption. Moreover, they serve as risk-reducing crops. For instance, if coffee productivity fails because of disease, mainly from coffee berry disdease or some other unidentified disease, farmers can earn income by selling taro, boyna and avocado. During the survey one farmer said that an unknown disease, which dried the whole of the plant, had infected coffee. Currently the disease has been spreading and becoming a more serious problem. Then the pointed out that they would have starved if they had not had taro and fruit trees. The agroforestry innovation has thus served as the means to escape harsh times and has provided sustainable supplies of food and income for households.

Most farmers sell their coffee in nearby markets. However, they say the price they get is unfair. Lack of access to transport, lack of a wet coffee-processing industry in the locality, lack of good drying and processing method, problems of theft all cause them to sell locally despite the price. Most farmers dry and extract coffee berries in a traditional way. They simply spread the berries in the sun to dry not giving attention to the extent of drying for better quality. They smash the berries on a stone or in a mortar, which also tends to reduce the quality. Thus, farmers need material and technical advice to improve the quality and fetch a fair price.

Root crops taro and boyna are planted for sale and household consumption. They can be transported freely from one area to another where farmers can get a better price. To improve quality and maximize productivity, the roots crops are planted in rows. The distance within rows is estimated to be 0.25 m and between rows 0.5. Between rows they plant haricot beans, which helps fix nitrogen in the soil and supply a balanced diet for the households.

Farmers also get a good income from selling tree products like timber (cordia) and firewood (*Acacia decurrens* and sesbania). They cut trees when

Agroforestry components and interfaces

	Fruit trees (avocado, geshta)	Sesbania, cordia	Coffee	Root crops (taro, boyna)	Enset
Fruit trees (avocado, geshta)	Compete strongly for resources after canopy closure	Compete for nutrients and moisture	Avocado has negative interaction because of heavy shade; it also depletes soil nutrients and moisture Geshta could be shade for coffee with pruning at 2.5 m height. It sheds its leaves in dry season	Less impact at the time of establishment Root crops will be harvested by the time fruit trees mature	No interaction since they are not placed together with enset
Sesbania, cordia	Compete for nutrients and moisture	Compete strongly after canopy closure	Sesbania gives temporary shade, maintains soil fertility and fixes nitrogen Cordia permanent shade for coffee but needs be lopped if it casts heavy shade	No interaction since they are planted separately	Cordia could occupy the upper canopy and act as shade in intensive solar radiation Little interaction with sesbania since they are planted widely apart
Coffee	Compete for nutrient and moisture	Compete for nutrients and moisture	Compete for moisture and nutrients	Neither harm nor benefit if the root crops are planted before coffee	Compete for moisture and nutrients
Root crops (taro, boyna)	Compete little for moisture and nutrients in surface soil horizon at the establishment stage	Compete for surface water and nutrients	Conserve moisture for coffee through mulching	Compete for moisture and nutrient if they are not well spaced	Compete little for moisture and nutrients since root crops need a gap
Enset	Conserve moisture and supply organic matter	Conserve moisture and supply organic matter	Conserve moisture and supply organic matter	Shading effect	Compete for moisture and nutrients after canopy closure

they attain approximately 40 cm diameter at breast height to get quality timber. s They are not officially allowed to sell cordia timber, since cutting this indigenous species for sale, considered endangered, is illegal. Farmers need to get permission to cut if for personal use from the Office of Agriculture. This prohibition has discouraged farmers from planting more cordia trees. One of the key informants stated that if one does not have the right to cut and sell his own trees, he might not retain cordia trees for 6–7 years on the land. He added that it would be better to plant agricultural crops, for which transport is not restricted, and sell them wherever the price is better.

Farmers have not paid much attention to improving the quality of timber since it is sold locally. Moreover, they are not allowed to transport the product to the nearby town to fetch a better price. If they try, the product will be confiscated at a checkpoint. This reduces the price farmers would have fetched from timber sales.

In marketing, coffee is judged on amount of impurity and bean weight. Solid, uninfested, heavy beans fetch a better price. Timber with straight boles, free from defect, get the best price. Root crops like taro and boyna are valued by taste and size; root crops that are sweet and large fetch the good price. Likewise, fruits like avocado and geshta need to be big and black in colour to fetch top price.

Minimum inputs

Farmers contribute land and labour for implementing the innovation. They also use their own equipment, such as spade, panga and sickle. They have their own local varieties of trees such as avocado and coffee. Farmers use mostly family labour including children above age 7 for weeding, harvesting, and managing fruit trees like avocado and geshta. Rarely, they use labour hired at a daily wage of ETB 5 or USD 0.57 per person per day. Hired labour is mainly for land preparation, weeding and picking of coffee berries. Farmers use cow dung and slashed materials instead of inorganic fertilizers to maintain soil fertility.

Farmers also use irrigation water during the dry season. To construct irrigation channels they need a shovel, line level, stones, metal sheet and cement. They mentioned that lack of the above materials hindered their effort to maximize the values of the innovation. During the survey it was observed that some farmers had established their own nursery to raise aocado and coffee seedlings for sale as well as to plant on their own homestead. At the moment, they are looking for improved varieties of avocado and vegetable seeds from the Office of Agriculture.

Farmers in the area also require technical advice on protection from an unidentified disease on coffee. This disease has already damaged about 15% of their coffee. Thus, researchers need to identify the disease and develop adequate treatment as soon as possible. Farmers also appeal that controls on natural products be lifted at checkpoints, to allow them to transport timber and coffee products freely to the main market centres to earn better prices.

Agroclimatic zones

The agroclimatic zone of the area is wet mid-highland. It is located in Sekka Chkorsa District, Jimma Zone, Oromiya Region, at 7°33′N latitude and 36°37′E longitude. Annual rainfall is estimated to be 1400–1800 mm and altitude 1700–2000 m. Temperature range iss 15–25 °C. The soil is mainly red or brown. It is deep soil, good for producing agricultural crops and trees.

Farmers in the area mostly depend on rainfed agriculture with extensive farming. A few farmers irrigate to produce root and fruit crops. Since the rainfall is reliable, farmers produce a diversity of crops. Major types of agricultural crops are enset, maize, taro and boyna. Enset is a staple food. Cash crops produced are coffee and chat (*Catha edulis*). Fruit trees are avocado, papaya and geshta.

Major woody species in the system include *Millettia ferruginea, Grevillea robusta, Acacia decurrens, Cordia africana, Ficus* species, *Prunus africana* and *Arundo donax* (planted or retained within the farm), *Cupressus lusitanica, Rhamnus staddo* and *Eucalyptus camaldulensis* are planted as boundary and live fences.

Major factors that make the innovation successful

Farmers perceive that the innovation is easy to put into practice. They are able to sustain household livelihood throughout the year since they have practised the innovation for a long time. The innovation assures that they get alternative food products and income to escape harsh times. For instance, if enset should fail to produce, taro and boyna would fill the gap. Farmers have good indigenous knowledge on raising fruit and coffee seedlings in their own nurseries. Moreover, cultivating and harvesting enset has long been a tradition in the area.

The innovation saves cash and labour. It takes more labour to establish the system, then less labour is needed for weeding and harvesting. Cultivation and weeding conducted for one crop also serve all the other crops. This means farmers can care for all components within the system at the same time. The innovation does not incur much cost for purchase of enset suckers and fruit and coffee seeds since farmers use local varieties. However, they use hired labour for weeding and for harvesting coffee berries. In general farmers estimated that the innovation reduces the cost and labour by half as compared with monocrops.

The innovation is also effective because it needs a minimum of material and technical inputs. Farmers use only the spade and sickle to cultivate the land and weed the crops. They do, however, need more technical advice on how to prevent coffee disease and they need improved varieties of fruit crops, like avocado.

Farmers in the area sell their products directly to the consumer or to traders at the local market. This may reduce the number of brokers; hence farmers will get a better income. They also get market information like price from their neighbours when they sell their coffee and root crops. The extension agent assists by delivering tree seedlings like sesbania and *Acacia decurrens* to provide temporary shade for coffee and maintain soil fertility. Soil type, altitude and rainfall pattern of the area have also all contributed to the effectiveness of the innovation.

Direct and indirect beneficiaries

Men and children are actively engaged in cultivating, weeding and harvesting the crops within the innovation. Women, however, are usually not directly engaged in managing the innovation since they are extensively occupied with housework. Moreover, managing the innovation is assumed to be men's work. Women's contribution is indirect, through preparing food while the man is at work. Yet she gets much benefit through easier collection of firewood, fruit and food crops for household consumption. Men (heads of household) decide on issues pertaining to the innovation. A woman is responsible only for selling geshta, coffee in small quantity, and avocado, although the male head of household may give her permission to sell other produce as well.

Children above 7 years age contribute labour mainly through weeding and through harvesting fruit and coffee berries. They can eat fruit (avocado and geshta). However, they are not allowed to sell either fruit or other crops unless they get permission from the head of the household. One of the key informants stated that if children were allowed to harvest and sell fruit crops, they might abuse the resource.

Generally speaking, the innovation benefits all wealth groups. This is because they can get food and income from a diversity of sources, thereby improving their lives. Even so, rich farmers may benefit more than poor farmers, since rich farmers likely have more land on which they could plant more trees and food and cash crops. These farmers benefit mainly from coffee sales. Poor farmers may not have enough land to allocate to different types of perennial and annual crops. They benefit mainly from avocado sales, firewood and root crops to avert risk at the time of drought.

Upscaling strategies

The innovation is widely replicated. It has long been practised, showing that farmers have a positive attitude towards it. Farmers mostly use local varieties of enset, coffee, trees and spice crops for planting, with minimum extension support. They do not depend on improved crop varieties or inorganic fertilizers. Farmers promote the innovation themselves. For instance, one key informant said that he has given seeds and at least five seedlings from different varieties to day labourers whom he had hired to weed and harvest coffee berries, to plant in their own gardens. In this way, he is diffusing the innovation to different farm units.

Moreover, farmers believe that the innovation is ecologically and economically sound. This makes the sustainability of the innovation certain. For example, cordia, sesbania and *A. decurrens* maintain soil fertility through litterfall, and by fixing nitrogen and providing shade for coffee. Enset plants provide food for the household, and it is drought tolerant; enabling the household to survive harsh times. The root crops of taro and boyna supplement household food demand. They also are drought-tolerant crops that satisfy the demand for food if main crops fail at any time of the year. Fruit from avocado and geshta satisfy food needs and supply vitamins, as well as earning income for emergency use. The household also gains income from coffee, spice and chat sales.

There is continuous follow-up and material and technical support from the agricultural office. Its experts are ready to help farmers at any time. The physical features in the area also contribute to upscaling. Rainfall is reliable, which is fortunate, as few farmers have access to irrigation during dry periods.

Institutions promoting the innovation

Farmers are main participants in this innovation. They contribute labour, capital, land, trees, and local varieties of coffee, enset, spice and root crops. The district agricultural office has assigned a development agent to assist farmers by providing materials, technological inputs and technical advice on managing coffee. The development agent also facilitates the flow of information from the Office of Agriculture or research stations to farmers and vice versa. Farmers feel a strong need for the development agent to help protect their coffee from disease.

The agricultural office contribution is also immense. It deliveries technical advice on space of coffee plants. It provides fungicides to treat coffee disease. The office delivers planting materials like sesbania and *A. decurrens* to give the coffee temporary shade. It provides avocado seedlings. This institution also gives farmers selling permits products made from restricted indigenous tree species like *Cordia, Juniperus, Podocarpus* and *Olea*.

Research questions and knowledge gaps

Farmers do not efficiently measure the amount of yield that they should harvest per year or the period from each component. Spacing between components is too narrow and hence could reduce the amount of yield. Information is also inadequate as to the ecological interaction between different components and its effect on productivity. Farmers have given less emphasis to livestock production, which would have more fully exploited the innovation.

Farmers have a knowledge gap on value addition. They have given less emphasis to factors that might add value like better methods of drying and extracting coffee and of selecting improved coffee and fruit tree varieties. The nearby wet coffee-processing industries are inadequate. As a consequence, farmers have paid little attention on how to improve the quality of their products and hence fetch better prices. They have inadequate information about the potential economic contribution of each of the components, to maximize the income.

Marketing products is one gap in the area. Farmers in the remote areas have lacked access to market information to fetch better prices, particularly for coffee. The price depends on the overall production and international markets. There is also strict regulation at checkpoints on movement of coffee and timber to major towns, requiring permission from the Office of Agriculture.

Professional reflections and recommendations

There are several indicators for the potential success of the innovation. Farmers have long practised the innovation and have good indigenous knowledge on how to manage and sustain the system. Some farmers have also acquired skills in small-scale irrigation. This will enable them to get adequate production from components during the dry season. Diversified income and food sources from the innovation also contributes to household food security and hence ensures sustenance of the innovation. Structure of the Office of Agriculture extends to peasant associations, presenting a good opportunity for farmers to get technical and material assistance from the development agents.

Although the innovation has good potential to accommodate a livestock component, farmers have given less attention to this sector. Thus, emphasis should be given to integrate livestock in the components. Farmers are more focused on trees, coffee, fruit, enset and root crops. Farmers also integrate high-value crops like lentil, spice and other cereal crops within the system. Improvement is also required on spacing between different components, as currently farmers are crowding them. This density increases competition for resources and reduces net primary productivity. Therefore, consideration on adequate spacing is imperative.

Diverse benefits of the innovation in terms of income and food persuade farmers to retain the system. They have already begun to plant root crops like taro and boyna under coffee as a strategy to survive harsh times. Scarcity of land and extension support from the Office of Agriculture may also motivate more farmers to adopt the innovation.

The checkpoints that deter the movement of coffee and timber products may discourage farmers into discontinuing different components of the innovation. Furthermore, fluctuation of coffee prices and unfair prices offered by traders may dissuade farmers from pursuing the innovation. The newly emerged and as yet unidentified coffee disease may also cause great damage to the coffee yield. As mentioned above, farmers need to envision how to incorporate livestock into the system.

To sustain the innovation, farmers need technical advice on spacing between components, managing cordia like pollarding and lopping it to reduce its shading effect, and constructing irrigation channels. Further research should also be conducted on optimum spacing, the economic and ecological contribution of individual components, and marketing.

10.4 *Vitex keniensis* cum food crops in farmlands of Meru, Kenya

Nature of the innovation

In central Kenya, especially in Meru District, *Vitex keniensis*, an indigenous hardwood species known locally as Meru oak or muuru, is a popular timber species that farmers widely grow and used for multiple products. It is a source of high-quality timber with high market value. Initially farmers sold standing trees at prices that were generally low, but due to increased demand and campaigns to sensitize farmers, most are now selling processed timber, earning three times the amount they received for standing trees.

A fruiting *Vitex keniensis*.

Vitex produces an attractive high-quality wood that is termite and fungus resistant; it is widely used for furniture and joinery (Leegkeek and Carsan 2003). Farmers around Mt Kenya and Meru rank vitex as either the first or the second most important timber species (Betser et al. 1999; MoA 2000). It is a fairly fast-growing tree; indigenous to Kenya and Tanzania it has now been introduced in Uganda (ICRAF 1992).

Farmers in Meru and other districts surrounding Mt Kenya such as Embu and Kirinyaga have become increasingly interested in on-farm planting vitex for commercial sale of timber rather than for domestic use. The most common agroforestry system is planting it as on-farm boundaries or scattered in cropland in combination with common food crops (maize, beans, potato, banana) and cash crops (coffee and tea). The species is also important as a boundary marker and for fruit and firewood production (Ahenda 1999). Nurseries and farmers surrounding Meru and in proximate areas indicate that vitex has for a number of years been one of the most popular indigenous trees for planting. The demand for the wood exceeds the supply from both natural stands and commercial plantations (Ahenda 1999). As a result, some sawmillers in parts of central Kenya have shifted sourcing of its timber to on-farm stands (Holding and Carsan 2001).

Justification of profitability

Farmers value vitex for several uses: timber, poles, furniture, internal finishing in houses, firewood, boundary marking, mulch, bee forage, shade, ornamentation, ceremonial (Forester-Meru forest station, pers. comm.). It is intercropped with a variety of crops such as maize, beans, banana, coffee; due to land shortage, planting in lines and on boundaries are the methods most widely adopted. In coffee, vitex is mainly planted in lines and farmers indicate that the tree provides mulch and controls weeds on the coffee plots (Micheni and Karlsson 2000). Because of its ornamental characteristics, it is sometimes planted as a windbreak. The fruits are edible but in most areas eaten only in times of food shortage (Ahenda 1999).

Timber production is the major reason farmers plant vitex because it produces high-quality timber that can be marketed to generate cash (Mugwe et al. 1998). Vitex timber is hard and durable, pale coloured and similar to teak. It works easily and is used for cabinetwork, paneling, veneer, furniture and coffin boards (ICRAF 2005). The wood is coarse textured with well-marked growth zones, often with a wavy grain figure; it seasons well. The heartwood of trees over 60 cm in diameter is often dark and very decorative. Because of these characteristics, it is highly valued in the furniture and joinery industry (Omondi et al. 2004).

The market value for vitex timber is among the highest for timber species. For example, 6 x 1 boards of vitex sell for KES 18–25 per foot, that of grevillea KES 6–8. A bed 4 x 6 feet made of vitex sells for KES 4000 (USD 54), that of grevillea for KES 2000 (USD 27). Timber traders who buy vitex timber from Meru District come from all over the country, although most come from Nairobi. Traders from afar, such as from Nairobi, prefer to buy whole trees on-farm and cut them into thick timber sizes, called beams, for easy transportation.

Traditionally farmers have been selling standing trees (whole). According to Holding et al. (2001) prices offered to farmers have been low, especially because farmers do not have a way of valuing the tree and sometimes lack marketing information to guide them in fixing prices for their trees. However, recently, sensitization by the Forestry Department and other agencies working in the region such as the Forestry Action Network (FAN) has made some farmers change from selling whole trees to selling processed timber, substantially increasing their profits. By selling processed timber, profits may increase threefold. For example, a tree of about 25 years old when sold whole would earn a farmer KES 3000 (USD 41), but when sold as timber it would generate KES 6000 (USD 81), and firewood worth KES 2000 (USD 27), making a total of KES 8000 (USD 108).

Farmers also earn cash from firewood harvested from the trees. Following a logging ban in government forests, the demand of the Kenya Tea Development Agency (KTDA) for firewood has increased. The main tree species KTDA buys for firewood are eucalyptus and vitex. As a result, farmers are able to sell firewood at higher prices than before;k for example, a stack of wood that cost less than KES 1000 (USD 13.5) in 1999 is now being sold for KES 2000 (USD 27). According to the forester at Meru forest station, the increased price of firewood is one reason that is attracting farmers to sell processed timber, because after selling the timber, farmers can still earn more from the firewood.

It is evident that consumers of timber and timber products value vitex timber for its high quality. This indicates that there is great potential for increasing profits for farmers by increasing and improving the processing. For example, since vitex is highly valued for furniture farmers would earn more if instead of selling timber they set up workshops to make and sell furniture.

Growing yams has been a tradition since time immemorial in Meru. The yams need support mainly from trees and *Commiphora zimmerman* has traditionally been the tree species of choice. However, during the last 10 years, vitex has become popular with farmers who grow yams for the export market. The preference is because the tree can later be sold for timber and thus earn more profit than when a non-timber species is used.

Agroforestry components and interfaces

As mentioned earlier, vitex is grown in close association with food crops, either within the cropland or on boundaries. Farmers report that it combines well with crops, especially if it is pruned consistently. It drops its leaves during the dry season and these leaves act as mulch (Leegkeek and Carsan 2003). When the rainy season starts, the mulch controls soil erosion and as the season progresses it decomposes, releasing nutrients into the soil thus improving soil fertility. In addition, the mulch controls weeds, especially in coffee.

Another positive interaction is observed when vitex is used to support yams. Because it grows tall, it provides a good support, especially for varieties that grow long vines. Also the mulch and the canopy provided by the tree are beneficial to the yams in terms of improving soil fertility, providing shade and conserving moisture.

Other positive interactions on adjacent crops are when vitex is used as a windbreak, and the tree roots are important for controlling soil erosion, especially on steep slopes.

Minimum inputs

Seedlings are the ideal method of propagation. Seed germination is low and sporadic, up to 40% after 9 weeks. Pretreatment is not necessary but soaking in cold water for 24 hours may improve germination. In Meru increased planting has been through naturally regenerated seedlings that are transplanted within the farm (Muriuki and Jaenicke 2001). Vitex seedlings are delicate and should not be more than 4 months old. If possible root pruning should be avoided because it retards seedling growth. On-farm nurseries are therefore an effective way of raising vitex seedlings. Seedlings transported over a long distance are subject to shock, lowering their survival rate in the field. With on-farm nurseries, seedlings are exposed for a short time only, and thus survive better in the field.

Agroclimatic zones

Vitex occurs naturally in the moist evergreen forest at altitudes of 1300–2000 m; it prefers deep sandy-loam soils and a mean rainfall of 1400–1900 mm (Omondi et al. 2004). In Meru where it is very common and planted widely in plantations by the Forestry Department, it does well at altitudes of 1290–2100 m (wet mid-highland agroclimatic zone). Mean annual rainfall in the Meru area is 1600–1800 mm and bimodal: long rains from October to December and short rains from March to May. The soil is deep Nitisols of medium fertility. The oldest Meru oak, with a diameter of more than 2 m and estimated to be 500 years old, is found in this region.

Major factors that make the innovation successful

Small-scale farmers, when considering timber as an enterprise, seek a multipurpose tree that will complement other enterprises on the farm yet yield timber as a final product (Holding et al. 2001). The multipurpose nature of vitex has contributed to its high preference by farmers.

Wood from vitex is highly valued by businesses dealing with timber and timber products. These businesses include sawmillers, timber workshops, furniture-making yards, and mobile bench and power saw operators. Since the Kenya government declared a logging ban within gazetted forests in 1999, the main source of vitex timber for these businesses has been farms. This has given farmers an opportunity to sell their trees for cash (Akinga 1999). One advantage of vitex is that even without good silvicultural practices such as timely pruning, it still yields good timber because it is self-pruning (forester, Meru forest station, pers. comm.). Self-pruning helps produce a knot-free bole, which is a requirement of good timber.

Timber and timber products businesses in Meru operate at different scales, and about 70% of the timber used is vitex. In this region, some traders specialize in selling processed timber. They have developed a strategy of locating all their timber yards at one place so that they can easily access the market. These traders get their timber solely from the farms. To facilitate selling timber from the farms, the forester based at the Meru forest station in collaboration with other stakeholders have organized timber marketing days where farmers bring their timber for sale. Though presently they sell individually, this could be a starting point for organizing timber-marketing groups. Other businesses have developed a complete chain of using the timber sourced from farms. Instead of selling raw timber, they make finished products like furniture, and this way they are able to make more profits than if they sold raw timber.

Also, there is a strong tradition of agroforestry among Meru people and in the central Kenya highlands as a whole, with farmers planting and retaining a variety of multipurpose trees on farms (Betser et al. 1999). This may have contributed greatly to increased growing of vitex on farms.

Direct and indirect beneficiaries

Cash earned from timber sales generally benefits all members within the household because it is used to meet household needs such as paying school fees and health bills and buying food.

The timber business favours both men and women. In Embu District both men and women own and operate timber yards and timber product businesses (Lumumba and Ouma 2004).

Women also benefit from firewood obtained during tree pruning or after a tree is felled for timber. The firewood is of high quality and burns well, generating a lot of heat.

Upscaling strategies

The Forest Department in Meru has consistently promoted growing vitex on farms, mainly by providing seedlings and providing advice on planting niches and arrangements. The Meru forest station nursery currently has 260,000 vitex seedlings to sell to farmers during the next growing season, which starts in October. A seedling is sold at KES 10. At the same time, farmers are encouraged to raise their own seedlings in community nurseries or individually. For example, a farmer group that has been permitted to raise seedlings at the Forest Department's nursery in Meru forest station has raised some 420,000 vitex seedlings ready for planting. The group members will plant some of these seedlings while the rest will be sold.

Other varied approaches have been used to scale up on-farm vitex planting by other stakeholders. For example, Forestry Action Network approaches included recording radio programs and facilitating workshops to discuss forest policy related to farm-produced trees, timber felling and movement permits.

The Ministry of Agriculture through the National Agriculture and Livestock Project has mainly used the focal area approach, involving community-based activities such as participatory rural appraisals, field day demonstrations and common interest groups. They have used these approaches in scaling-up activities that have included training farmers in nursery management, evaluating and pricing trees, piloting the formation of farmers' timber-marketing groups, and developing improved market-oriented silvicultural tree practices. All these have helped raise awareness of the value of trees among farmers.

Institutions promoting the innovation

The Forestry Department in Meru is the key stakeholder in promoting vitex on farms. As earlier mentioned, they have been involved in raising and selling seedlings to farmers as well as encouraging farmers to start their own nurseries.

The National Agroforestry Research Project (NAFRP), which was collaborative between the Kenya Forestry Research Institute (KEFRI), the Kenya Agricultural Research Institute (KARI), and the World Agroforestry Centre (ICRAF), operated within the central highlands of Kenya from 1991 to 2004. Vitex was a major species in the NAFRP high-value tree-initiative program (Mugwe et al. 2000). Promotional activities included setting up demonstrations and holding workshops to sensitize farmers on proper tree management for various uses.

Another collaborative project involving the Forestry Action Network, the Ministry of Agriculture and ICRAF that operated in the Meru area from 2000 to 2004 combined research, extension and advocacy activities to address issues within the timber sector.

Recently, a project led by IRAF that started in 2003 has embarked on research to screen provenances of vitex and dissemination activities to promote on-farm based tree nurseries.

Research questions and knowledge gaps

There is currently great concern on the reduction in tree cover of this valuable indigenous species on farms. Data do not exist to show how vitex is being harvested and planted. A study is urgently needed to assess changes in tree cover of the most valuable timber tree species, especially from 1999 when intensive exploitation of the farms started.

There is currently no record of the number of mobile sawmills currently active in the region, but it is estimated to be in the hundreds (Holding and Carsan 2001). Though not effectively enforced, there was a system in place of licensing sawmills harvesting from the forest estate, so approximate records of volumes harvested were possible. Currently no mechanism monitors the activities of mobile sawmills, and no record is kept of the volume of timber being harvested from farms. There is therefore a need to conduct studies to monitor the activities of mobile sawmills with an objective to avert overexploitation.

There is potential to improve marketing, with an aim to increase profits for farmers. Market assessment skills would need to be developed to analyse opportunities and constraints of various market options available to farmers. Options should consider the technical, social, and economic aspects of market analysis and the sustainability of the resource.

Studies on tree–crop interactions are needed to identify combinations, arrangements, spacing and management practices that optimize productivity of a vitex–crops agroforestry system. In addition, more efficient ways need to be developed that will increase the timber recovery percentage.

A literature review did not reveal any study on assessing profitability or economy of growing vitex under the current agroforestry system. Studies should therefore be carried out to evaluate profitability of this system. Again, due to the high demand for vitex timber, farmers are cutting trees for timber production that are as young as 10–12 years. Studies on variation of timber quality with age should be carried out to assess and recommend the best timber rotation under the current scenario.

Professional reflections and recommendations

Vitex keniensis is a valuable agroforestry tree species, adapted to Meru and similar agroecological zones of Kenya. It is multipurpose, providing many products and services, some of which include high-quality timber, firewood, and windbreak. However, timber is the most profitable product. With the decline in commodity price of farmers' principal cash crops, coffee, farmers are increasingly viewing timber as an active cash-generating farm enterprise. For example, farmers planted vitex for their own use or for local markets, but rising demand for timber coupled with timber-marketing efforts by development agencies and firewood demands by tea companies have recently increased the options for vitex sales.

To maximize profits farmers can obtain, it is necessary to encourage formation of marketing groups to facilitate marketing, transportation and accessing of appropriate technical advice. Farmers in these marketing groups could be empowered to carry out participatory market research, which would give them access to good markets instead of relying on farm-gate buyers, who purchase their products at low prices. In addition, farmers should be encouraged to sell processed timber to maximize their profits. Government policy should play a leading role in promoting processing as one of the ways to alleviate rural poverty. One of the limiting factors to efficient timber processing at the farm level is lack of good sawing equipment. The government should consider providing organized marketing groups with good equipment such as circular saws through a loan system.

Farmers also need to know the potentials of timber sales to generate income and to know the right time to harvest quality timber, avoiding sale of timber from immature trees. Government and other stakeholders should also develop mensuration and valuation techniques that are farmer friendly to help farmers get value for their trees.

The Forest Department in collaboration with other stakeholders working in the region should continue focusing their efforts on encouraging farmers to plant more vitex to avert overexploitation and to meet the rising demand. Stakeholders should aim at analysing and documenting the structure of timber markets as linked to farms as well as identifying the range of potential market for farmers.

Chapter 11 Agroforestry innovations suitable for Moist Highlands

11.1 Pome fruit trees cum enset and vegetable farming in Ethiopia

Nature of the innovation

The type of innovation is pome–vegetable–enset–based agroforestry system (homegarden vegetables). Pome fruit trees (like pear, apple, plum) were initially introduced in the area 50 years ago by missionaries. However, their benefits have been recognized and propagated in farmers' fields during the past 10 years. The Office of Agriculture introduced vegetables like beetroot, carrot, cabbage and salad 3 years ago in a food security program. To promote the innovation, 50 farmers were selected as model farmers in highland fruit and vegetable production in the surveyed peasant association. Farmers have highly diversified farms with different types of plants. For instance, one surveyed farm (1000 m^2 area) had 17 woody and herbaceous annual plants such as cabbage, garlic, salad, wheat, pome (apple, pear, plum), bean, carrot, beetroot, mountain bamboo (*kerkeha*) (as live fence and boundary), reed grass (*shembeko*) (in patch form), *Erythrina* species, *Ramnus Prenoides*, tree lucerne (along the boundary), sugarcane and enset.

Farmers become well skilled in producing grafted seedlings for pome fruit trees. Currently farmers are producing three fruit trees: pear, apple and plum. Pear is grafted with Queen and apple with Apple 106/104. Farmers have been propagating and grafting seedlings in a bed. The propagation involves first preparation of nursery bed at the homestead. Next, the male part of the cutting (Queen or Apple) is planted in the bed. When it reaches at least 1 metre in length, it is layered horizontally to produce shoot suckers from the node. For example, a layered 1-m stem may have up to 50 nodes; the number varies depending on the length of the stem. Each node develops shoot suckers. The root suckers produce shoots. After 1 or 2 months the shoots are cut and transferred to a new bed. The remaining stump will give 3 to 4 coppice sprouts for at least 7 times per stump.

Once the male part of the pome has reached pencil size, it is transplanted to a new bed. If it survives, the grafting will commence. The pear will be grafted with Queen and the apple with a local variety Apple106 or 104. The grafted seedlings will be ready for sale and planting after they bear green leaves. The young rootstock bears fruit as long as it is grafted with the female plant. However, there is no need of grafting for the plum variety. Each kind of pome will mature to bear fruit at a different time. For instance, pears will bear fruitin 5–7 years, apple 4–5 years and plum 3–4 years depending on moisture availability. A continuous supply of water is vital. During dry periods farmers must water the plants. Watering also applies for vegetables.

Apples at fruiting season (lower right) and plum trees (at sheding season before flowering) are grown in commercial fruit-based agroforestry systems.

Justification of profitability

The innovation is agrisilvihorictultural. There is a synergetic interface between cereal crops, trees (including fruit trees) and horticultural crops. Woody species like bamboo, erythrina and rhamnus are planted as boundary demarcation and live fencing, serving as windbreaks and maintaining soil fertility underneath through litterfall. Tree litter is also used as animal fodder, mulch for vegetables and added organic matter. Pome trees scattered within the farm serve as a source of organic matter since they shed their leaves in the summer and sprout in the winter. This interaction will contribute to quality production of various components of the innovation.

The market for highland fruit has become a lucrative business in the survey area. Producing fruits and grafted seedlings has become a major source of income. The grafted seedlings are sold in the national market or to clients who come from different parts of the country. For instance, at the moment the farm-gate price of one grafted pear seedling when it is sold to the co-operative is ETB 52 (USD 5.96), apple ETB 42 (USD 4.82), and plum ETB 25 (USD 2.87). If the seedling is sold direct to an individual, the price for pear is ETB 30–35 (USD 3.44–4.02), apple ETB 25–30 (USD 2.87–3.44), and plum ETB 8–12 (USD 0.92–1.38). However, farmers need to get permission from the Office of Agriculture to sell grafted pome seedlings to individuals. This is meant to prevent theft. Farmers also sell fruits at ETB 12 (USD 1.38) per kilogram. Therefore, farmers pay more attention to producing grafted seedlings than fruit.

Thus, one farmer says that nowadays pome trees are considered 'Green Gold' that can be mined from the farmyard. He added that they had been asleep for the last 40 years without knowing the economic importance of the fruit, and they thanked the professionals who woke them. Not surprisingly, farmers are even staying out at night to guard their pome gardens and grafted seedlings from theft.

Farmers give maximum care to pome trees to improve fruit quality and fetch a better price. They select a site that is fertile and open, since pome is shade intolerant. Farmers regularly water, weed and compost. They keep the site clean in approximately a 3-m radius around the tree trunk to minimize intra- and inter-specific competition. Farmers also strive for improved varieties to propagate on a wider scale.

Farmers also get income and food from vegetable crops within the system. They sell vegetable products in the local market, providing them with additional income to cover unforeseen costs. For instance, when the woman needs to buy oil and salt for the table, she picks vegetables from the farmyard and sells them at the local market, even though the price is not as attractive as for pome fruits. Vegetable products also complement the family's dietary requirements, especially important for children to give them a balanced diet. To improve quality, farmers also take maximum care of vegetables, watering them continuously (particularly in the dry period), composting and weeding. Seed is mostly obtained from the Office of Agriculture. is mostly for household consumption.

The basic requirement for a pome tree is that it bears large and many fruits of marketable quality. Accordingly, farmers prefer pear to apple and plum. Two pears may weigh a kilogram; pear is sweeter than apple and plum and fetches a better price. For grafted seedlings, those with straight growth, free of fungus, command a better price. However, farmers do not pay serious concern to the quality of grafted seedlings.

Marketing criteria for vegetables products are mainly size and healthy appearance. Farmers have found some fungus on cabbage but not on the other vegetables. The vegetables are sold fresh, and farmers harvest them only when they want to sell them, because so far there is no cold storage in the area.

Agroforestry components and interfaces

Interaction of components in this innovation are shown in table 11.1.

Table 11.1. Interaction of innovation components

	Pome trees	Vegetables	Enset	Wheat
Pome trees	Strong competition once canopy closes because of heavy fruiting	Adds organic matter and casts little shade since it sheds its leaves in the dry period It might transmit fungus disease	No interaction since they are separately grown	No interaction since they are planted separately
Vegetables	Transmit fungus disease if they are planted adjacent to pome trees	Compete for resources because of narrow spacing within and between rows	Only local cabbage (*yeabsha gomen*) is planted in the gaps between enset plants; neither harms nor benefits the enset	No interaction
Enset	No interaction	No interaction	Less competition for resources since they are planted with spacing of 0.50 m	Farmers plant enset in a scattered pattern in wheat field at about 3 m spacing until it matures; protects wheat from intensive rainfall and frost, conserves moisture
Wheat	No interaction	No interaction	No interaction	—

Minimum inputs

Farmers put the innovation into practice on their land and with their own labour. They offer materials like spades and hoes to cultivate planting sites and prepare beds for producing grafted seedlings and vegetables. Enset, wheat, sugarcane, mountain bamboo and indigenous tree species are local varieties that farmers have contributed. The Office of Agriculture distributes vegetable seeds and improved varieties of pome.

Farmers need material support for grafting seedlings as well as managing the gardens such as watering cans, spades, shovels, scissors (for cutting root suckers), knives (for grafting), barrels, handcarts, dry cell batteries (to guard against theft at night) and rakes. They need credit to buy additional improved pome varieties and a variety of vegetable seeds.

Although farmers have already acquired some skill in producing pome fruits and vegetables, they require additional training on seedbed preparation, appropriate methods and time of grafting, watering timing and frequency, and protection against fungi. At present, farmers are basing their activities on their indigenous knowledge. They are conducting a farmer-to-farmer extension approach to share ideas and experiences. At present, the Office of Agriculture is focusing on distributing grafted pome seedlings and vegetable seeds.

Farmers also need improved road networks to transport their products to market. There is a shortage of post-harvest technologies that would help to transport and store products. Modern beehives are needed to maximize honey production. Farmers also need hybrid chickens so they canto engage in poultry production. The government should suggest a livestock-fattening program, because the innovation has the potential to produce fodder.

Agroclimatic zones

The agroclimatic zone of the area is categorized as moist highland. The area is located in Chench District, Gamo-Gofa Zone, Southern Region, at 6°15′N latitude and 37°33′E longitude. Altitude range is 2000–3200 m. Rainfall is bimodal, 900–1200 mm annually, and temperature range is 11–23°C. The area has different soil types: brown (60%), red (30%), black (4%) and grey (6%).

Farmers practice intensive farming for subsistence needs and cash crops. Major crops include wheat, barley, bean, vegetables and enset. Crops except vegetables and pome fruits are rainfed. Enset and vegetables crops are planted at the homestead to avoid theft. Other crops are planted either around the homesteads or out in the farmland. The major woody species are pome trees, mountain bamboo, *Erythrina abyssinica* and *Rhamnus Prenoides.*

Major factors that make the innovation successful

The innovation is simple to implement. Farmers have already acquired skills in grafting and managing pomes and in producing vegetables. They grow woody plants and let them propagate naturally. They use bamboo for house construction. A number of tourists visit these traditional houses every year.

Farmers are attracted by the income that pome and vegetable production generates. One informant compared the value of enset and pome. One matured enset would generate ETB 80–90 (USD 9.17–10.32) in 7 years, while one mature pome tree would give at least 100 kg of fruit over a 5–7-year period, earning ETB 1000–1500 (USD 144.68–172.02). This is based on the assumption of ETB 10–15 per kg (USD 1.15–1.72), depending on the market.

The physical characteristics of the site are conducive for fruit and vegetable production: rainfall bimodal, high altitude, low temperature range. There is also a perennial water source for small-scale irrigation schemes. Since pome fruits as well as vegetables need frequent watering, this has positive results. Farmers have a good marketing channel. Establishment of a highland fruit cooperative has paved the way for more farmers to engage in the innovation. Farmers also get good extension support from the Office of Agriculture and World Vision. A number of governmental and non-governmental institutions from all over the country come to the site to purchase fruit and grafted seedlings.

Strict regulation on the movement of grafted seedlings has also motivated farmers to enrol in the innovation. One farmer stated that if there were no such regulation, they would not gain the current fair price, and the regulation has enabled them control theft.

Direct and indirect beneficiaries

Men are direct beneficiaries from the high-value products of the innovation. They are responsible for selling the grafted seedlings, timber and cattle. Women are responsible for selling animal and enset products, with approval of men. Both men and women sell fruits and vegetables; both have access to produce from the innovation although men decide what to do with most of the products. Children are not explicitly allowed to sell produce unless they get permission from the head of the household (men). However, whether men or women make the sale, money earned from the innovation directly or indirectly goes into the household.

All family members benefit from the consumable items of the innovation: cabbage, carrot, beetroot, wheat, bean and enset. Income from the sale of fruit, grafted seedlings and vegetables covers the purchase of oil and salt, school expenses, etc. Firewood is another benefit. Both rich and poor farmers benefiting. For instance, one poor farmer with a small-sized holding could plant one or two pome trees in the backyard and graft seedlings, thus fetching an income that would improve household livelihood. At the moment, therefore, most farmers are striving to adopt the innovation despite their difference in resources.

Upscaling strategies

The innovation is widely replicated among farmers. Presently, 50 farmers have been trained and taken as a model for highland fruit production. Farmers perceive the relative advantages in terms of income of pome production over monocropping. The innovation can be tried on a small scale. Farmers may plant a single pome tree near the homestead and get an income within a limited period of time. As a consequence, the outcome of the innovation can be observed within a short time. The innovation is well suited for the rainfall, altitude, temperature and soil type of the area.

Farmer-to-farmer extension is one of the most effective strategies for scaling up the innovation. Most farmers have adopted it from either their neighbours or friends after observing its effectiveness and profitability. Complementary benefits have contributed a lot to adoptability. Farmers get food and timber products. They collect firewood and thus can use cow dung as organic fertilizer. This in turn reduces expense for artificial fertilizer and promotes sustenance of soil fertility.

Technical and material assistance from the Office of Agriculture and World Vision has also contributed to widespread adoption of the innovation. Currently, the two institutions are providing improved varieties of pome at discounted price. They sell one grafted seedling pome for ETB 6–8 (USD 0.69–0.92) while farmers propagate and sell it for ETB 25–52 (USD 2.67–5.96) per seedling. This will enable farmers to actively engage in the innovation and improve their livelihoods.

Institutions promoting the innovation

Farmers are the main participants in the innovation. They allocate land and contribute labour to implement it. The Office of Agriculture and World Vision act as facilitators and collaborators. For example, World Vision had given pome root suckers and nursery materials to 33 farmers. The district justice and police office are also collaborators, by deterring illegal movement of the pome plants, penalizing those found guilty of stealing grafted pome seedlings. Table 11.2 shows the role and level of participation of each institution.

Table 11.2. Role and level of participation of various institutions

Institution	Role/function	Level of participation
Office of Agriculture	Delivery of material inputs like spade, panga, watering can, shovel, pedal pump (for irrigation) Provision of vegetables, seed Distribution of improved varieties of pome at a discounted price Training in vegetable production, pome grafting and planting, compost preparation and apiculture Limited provision of construction materials for water harvesting	Facilitation and collaboration on material and technical inputs Creation of a link between farmers with different governmental and nongovernmental institutions of the innovation to build farmers skills and marketability of the products
World Vision	Training in compost preparation, pome grafting and planting Provision of improved varieties of pome suckers for selected farmers	Collaboration in training and provision of material inputs
Cooperative	Purchase of grafted seedlings of pome and fruit from farmers and paying them a fair price	Facilitation of marketability of the products

Research questions and knowledge gaps

Farmers focus on grafted seedling production, giving less attention to fruit production and other components of the innovation that would have brought the household additional income. No yield assessment has been made for each component. No research has been conducted on optimum spacing for planting, optimum length of the stem for developing root suckers or appropriate grafting methods. Farmers presently have only a limited number of pome varieties. Fungus is a problem for existing varieties. Such obstacles may reduce the overall output of the innovation.

Farmers have given little thought to improving the quality of their produce. For instance, there is no adequate storage and preservation technology for post-harvested products. This is believed to reduce the price of the products. This may be becaujse the innovation was developed only few years ago. Farmers have not been trained adequately on how to maximize outputs of the innovation. Moreover, no analysis has been done on the economic contribution of each of the components in the innovation. For instance, mountain bamboo is one component, but it is underutilized from the point of view of generating income. Farmers have less road access during the summer period. The road is an earth road and slippery so they are forced to pay additional transport costs to transport their produce to a nearby town. Farmers have little access to irrigation water in the dry period since most farmers do not have pedal pumps. The regulation on moving and marketing grafted seedlings is strong and strongly enforced. Farmers are not allowed to sell the grafts to anyone and whenever they need without first getting permission from the Office of Agriculture. This mean improving the regulation since farmers may need to sell the grafted seedlings to solve a particular problem. Farmers do not have access to a credit facility for buying improved varieties of pome and farm tools. This might discourage poor farmers from becoming fully involved in the innovation.

Professional reflections and recommendations

Farmers have already acquired the skills needed for the innovation. The Office of Agriculture and World vision have played major roles and have shown interest in providing material and technical support. This will contribute a lot to the success of the innovation. The district authority has already understood the benefit of the innovation for changing the livelihood of farmers in the district. There is also a great demand for pome fruits by governmental and non-governmental institutions within and out of the region. This will make farmers more enthusiastic and encourage them to perpetuate the innovation on a wider scale.

However, basic improvements are required on producing grafted seedlings and managing the fruit trees. For instance, once farmers plant the pome tree within the farm they do not prune it, nor do they use fully the space between trees. Therefore, farmers should be advised on how to manage and space the trees to maximize the biomass of foliage so as to produce more branches for fruit production.

The current price may attract more farmers to try the innovation. Farmers have already seen its positive effect in changing their livelihoods; thus it may attract more farmers. Farmer-to-farmer extension will also play a great role for continuity. The innovation can be tried out on a small scale so that farmers may want to pursue and retain it. Current government support for the innovation will also continue.

Since the current market of pome from the innovation is attractive and profitable, farmers may change their farm to monocropping fruit. This might reduce the multiple benefits of the innovation. The high demand for fruit may aggravate the conflict among individuals because of the problem of theft. The market for pome products may become saturated in the future since the grafted seedlings are being disseminated to different parts of the country. Or pest epidemics may destroy this valuable crop, discouraging farmers to diffuse the innovation.

It would be good for sustainable production to expand small-scale irrigation and water-harvesting technologies to supply water during the dry period. Also necessary are providing access to credit facilities, building capacity through training and experience sharing, and demonstrating the uses of bamboo. There is also need to research assessment of yield and economic contribution of each of the components.

Chapter 12 Agroforestry innovations suitable for Wet Highlands

12.1 Bamboo cum cereal farming system in Ethiopia

Nature of the innovation

Boundary planting with bamboo is a common land-use system in this area. All farmers with well to moderately drained soils adopt the innovation, mainly to earn cash. The practice, evolved through generations, is now nearing a climax with a gradually increasing demand for bamboo products. Farmers mainly employ indigenous knowledge in promoting bamboo planting and fine tune the processing of bamboo stems into different products. Distant households sell bamboo stems to those nearby main roads for processing mainly into mats.

Arundinaria alpine (bamboo shown here) is often used as boundary planting or in riverine/gueliied ecotones between farms.

Bamboo planting is carried out by carefully digging out a portion of the clump with one stem and digging a hole wide enough to accommodate the root system of the clump. The apical shoot of the main stem is removed by breaking the main stem at the top before planting. If planting is done in an open space, the main stem of the clump is supported by firmly tying it at about 1.5 m height to two stakes to prevent it from swaying and leaning. Newly planted clumps are manured and mulched with leafy debris. Adequate protection against browsing and trampling damage by animals during the first year guarantees the clump will survive and regenerate.

If the soil is impoverished, new stems will be stunted and will regenerate little. Farmers correct decline in soil fertility by applying leaf mulch and manure.

Bamboo planting in the area is confined to farm boundaries, on fence rows between cropland and grazing lands, and along farm plots. It casts shade on adjacent crops and rainwater accumulates on the canopy and drops in big droplets; these combined effects reduce crop growth and the yield up to 2 m distance from the bamboo line. Root competition is less serious and causes little impact on crop yields since lateral root extension is limited. Such crops as barley and potato, as well as thatching grass are commonly grown adjacent to bamboo lines.

Farmers generally distinguish bamboo varieties by colour and stem size. The black variety grows much thicker and taller than the red variety. Thicker and taller stems apart from accruing better cash income for the growers yield more bamboo products. Stem size generally declines with decreasing altitude. Harvesting matured stems is done by clean cutting 10 to 20 cm above the ground. If the stump splits during harvesting it rots easily and fails to produce new shoots.

Split bamboo stems make baskets, mats, brooms, beehives, covers for baking plates, walking sticks, chairs, tables, desks, fuelwood, granaries, etc. Unsplit and split stems are used to construct all except the pillar of rural *tukuls* and for internal divisions. Split stems are also used for doors and windows as well as for fencing.

Bamboo leaves and twigs are used for animal fodder. They make an important food supplement particularly during the dry season. Cattle, horses, mules, goats and sheep feed on bamboo leaves and twigs. Animals feed either on the leaves of harvested bamboo trees or on leaves of standing trees. In the latter case, farmers deliberately bend bamboo stems to allow animals to browse leaves and twigs.

Justification of profitability

Bamboo boundary plantations provide a lucrative financial opportunity for the highland farmers. A single bamboo stem of about average girth and height costs up to ETB 5. If the stem is processed it makes 2.5 mats. Individual mats of about 1.5 by 2 m sell at the farm gate for ETB 2–3. Mats are transported over long distances from the area. A single mat sells for ETB 7–10 in Gondar and ETB 11–15 in Shire and Metema towns. Bigger mats fetch higher prices: mats of 2 x 4 m cost ETB 7–8, mats 2 x 5 m cost ETB 9–10, and a 2 x 3 m mat costs ETB 5.

Other bamboo products such as benches and chairs produce a much better cash income. However, manufacturing chairs and benches, is not only tedious and time consuming, it requires special skills and costly materials. Relatively few skilled men with adequate experience are engaged in commercial manufacturing of chairs and benches. This is attributed to the low market demand for the products and the very specialized nature of the work. The mats, on the other hand, are used mainly for roofing, flooring and fencing; therefore, they attract many urban and rural consumers.

Apart from size and product assortments, the quality of various products greatly influences their respective market prices. Weaving mats with double strands improves strength and quality and thus increases market prices. The outer bamboo stem splits make hard and durable carpets in addition to other products. The strength and durability of the splits decrease from the outer exocarp to the central pith. Outer slices are commonly used for products such as doors and carpets where greater strength and durability are required. Products manufactured purely from exocarp slices are rarely available on the market and thus processed only by special order. For example, a 1.5 x 2 m mat weaved from external slices costs ETB 20.

One added factor contributing to the profitability of the system is that all family members can help manufacture products made from split bamboo stems. Whereas housewives may devote much less time to bamboo product processing due to tight schedules with other household activities, children of 7 years and older fully engage in splitting bamboo stems and weaving mats—the major bamboo product of farm households. Mats can also be woven at night when all family members are at home. An average -ized household weaves two to three mats per night.

Providing or facilitating the availability of expensive tools such as saw, axe, sickle, strings, screwdriver and hand drill enables farmers to manufacture chairs and desks from bamboo, resulting in a diversity of products and better cash income. Providing training in additional product manufacturing from bamboo and improving product quality improves the economic benefits farmers receive from the innovation. Preservative treatment and colouring of the splinters improve product durability and appearance and thus help increase cash income.

The innovation has an added economic advantage in that it demands few household resources to establish and subsequently to manage a bamboo plantation. Once a portion of the clump is separated from the mother clump, planted, and established, the major concerns are to exclude browsing animals and intermittently to apply leafy mulch. These management practices can be carried out as side activities of the major farm practices. Protection against grazing and trampling damage is commonly practised for adjacent crop fields and need not be separately organized for the bamboo plantation alone. Similarly, applying leafy biomass to maintain soil fertility can be part of the routine cleaning and weeding operations.

Bamboo can be harvested any time of the year and processed into various products by different household members, including young children. It thus serves as an important strategy for highland farmers to reduce risk and diversify income generation. The innovation can also enable farmers to survive the shocks of climatic upsets and seasonal food and cash shortage contingencies.

Agroforestry components and interfaces

The innovation essentially consists of a narrow strip of linear bamboo plantations and a few species of food crops. Food crops interspersed with dense linear bamboo plantations characterize the landscape in the area. Both food and plantation crops are grown side by side in a close intervening space because of serious land scarcity and high population densities in the highland regions.

There is a strong synergistic interaction in the system between the woody components and herbaceous crop plants. In contrast to intermittent eucalypt stands, bamboo strips have a much less aggressive effect on the adjacent crop plants. Bamboo outcompetes and suppresses eucalypt saplings if grown at the same time. Because bamboo trees grow much faster than eucalypt trees they are often planted under well-established eucalypt stands. Nevertheless, strong competition from eucalypts will reduce yield of the first bamboo crop.

Linear bamboo plantations reduce the yields of adjacent crops, mainly through shading and by the bigger rain droplets that fall from the leaves. Peripheral bamboo stems naturally lean away from the centre of the clump for better access to sunlight. This growth tendency affects wider crop areas on all directions of the plantation than is the case under normal growth condition.

Reduction of crop yield through root competition for nutrients and soil moisture is believed to be less serious. Farmers claim a yield reduction on an area of up to 2 m from plantation line. In general, bamboo clumps are strong competitors; they completely exclude other ground vegetation and form a monocultural stand.

Table 12.1 summarizes outcomes of the most significant interactions between major components of the system.

Minimum inputs

Bamboo boundary plantations can be established and maintained by households with any size of landholding. Land, traditional digging tools, axe, and sickles are the major inputs that the direct beneficiaries of the system need, to establish, manage, harvest and process bamboo. If the land size is extremely small, farmers can establish a single row of bamboo plantation along the home compound or homegarden fencing and boundaries. Labour required to plant bamboo is often limited to digging out a small portion of the existing clump and making a pit for the new planting. In most cases, strips of land that would otherwise remain either unutilized or underutilized are dedicated to bamboo plantations to effectively use the productive potential of the land.

Plantation management is also quite simple compared with that for many other tree plantations. The single most important silvicultural operation is to protect against grazing and trampling damage. Frequent intrusions by domestic animals cause serious damage to bamboo's regenerative capacity. Some wild animals feed on young shoots immediately after they emerge from the soil. However, in most highland areas damage from wild animals does not constitute a major threat.

Manufacturing and marketing an assortment of products requires strong policy support to maximize the benefits farmers accrue from the innovation. Range of products and manufacturing methods still rely heavily on traditional techniques. To date no quality improvement or product diversification through modern techniques has been attempted. In addition, government agencies have shown little concern for promoting the innovation or to maximize its economic and ecological benefits. There is a need to develop farmers' plantation management and product manufacturing capacities, using the experience of other major bamboo-growing countries like China.

Farmers also need enabling conditions and assistance for transporting their products to major marketing centres. This would enable them to generate higher financial incomes from the innovation. Facilitation in establishing

Agroforestry components and interfaces

Table 12.1. Interactions of components in the bamboo–cereal cropping system

	Bamboo	Eucalyptus	Barley	Potato	Tef	Wheat	Thatching grass
Bamboo	Competes for space	Suppresses young eucalypt stands	Suppresses crops along bamboo lines	Suppresses crops along bamboo lines	Suppresses crops along bamboo lines	Suppresses crops along bamboo lines	Suppresses grass along bamboo lines
Eucalyptus	Mature trees suppress young bamboo stands	Competes for growing space	Suppresses wider adjacent crop strips	Suppresses wider adjacent crop strips	Suppresses wider adjacent crop strips	Suppresses wider adjacent crop strips	Suppresses wider adjacent grass strips
Barley	No impact	No serious impact	Proper spacing	Not grown together	Not grown together	Not grown together	Not grown together
Potato	No impact	No serious impact	Not grown together	Proper spacing	Not grown together	Not grown together	Not grown together
Tef	No impact	No serious impact	Not grown together	Not grown together	Proper spacing	Not grown together	Not grown together
Wheat	No impact	No serious impact	Not grown together	Not grown together	Not grown together	Proper spacing	Not grown together
Thatching grass	No impact	No serious impact	Not grown together	Not grown together	Not grown together	Not grown together	Proper spacing

marketing cooperatives helps farmers organize and deliver bamboo-based products in quantity and of acceptable quality. Promoting bamboo plantations and improving the manufacturing process and quality would significantly reduce further depletion of genetically threatened valuable indigenous tree species.

Farmers critically need training and technical advice on product manufacturing and marketing opportunities. Bamboo plantations represent a very attractive supplementary source of household employment and cash income. In particular, they benefit rural youth and women, who are the most likely be be unemployed. Once the plantation is established, children can undertake product processing and marketing tasks. Rural development programs aimed at promoting rural employment for the youth need to provide pertinent training. Mature women are often so busy with other household duties and childcare that they have little time to engage in making bamboo products.

Agroclimatic zones

The innovation is recorded from Amhara Regional State (10°53′N, 36°59′E; altitude 2420 m). This agroforestry practice best performs in wet highland areas with altitudes over 2300 m. The mean annual rainfall range is 1500–1600 mm. Bamboo performs well on moderately to well-drained soil. Temperature extremes during a given year range 1626 °C.

The major food crops in the area include tef, barley, wheat, maize, millet, and noug. Such tree species as *Hagenia abyssinica, Acacia lahai, Croton macrostachys, Erythrina* spp., *Albizia* spp. and *Maytenus* spp., are dominant remnants of natural forest species. *Eucalyptus globulus*, *Cupressus lusitanica* and various *Acacia* species are the dominant plantation species.

The land features range from flat to moderately sloping.

Major factors that make the innovation successful

The high profitability of the innovation is the major reason for its successful development and dissemination to other areas. Farmers accrue uninterrupted cash income throughout the year without a major financial and labour investment. Substantial income can be generated on small land strips that otherwise often remain idle or underused. Apart from being highly labour saving, most management, harvesting, processing and marketing work involved in this innovation are carried out by household members such as women and children. The permanent lateral expansion and high density of bamboo regenerations make the need for weeding and cleaning totally unnecessary.

The cost of a single bamboo stem is ETB 5.0–5.50 (1 year after regeneration). Continuous and indefinite proliferation of new bamboo plants from the original mother clump, as well as the exceedingly fast growth rate of the tree, accrues great economic benefits of the innovation. This allows farmers to manage bamboo strips as a highly secured living bank—revenue that can be tapped any time of the year. The rising demand for bamboo products in both urban and rural settings helps assure the future economic benefits of the practice. The production of more sophisticated and refined products in big cities by well-trained and experienced artisans further brightens the future of on-farm bamboo plantations.

Weaving split bamboo stems into mats is considered to be a very simple task that can be performed even during non-working days and evenings. Unlike many other agroforestry products, both bamboo stems and manufactured products can be stored well for some time without significant deterioration in quality. This enables farmers to match product marketing with market demand and attractive prices.

Another economic advantage of the practice is that adopting it requires very little financial investment. A farmer needs only portions of a mother clump with single stems to establish the first plantation. The tools required tools to establish and manage a plantation are simple digging tools and sickles. This low investment makes both adoption and profitability of the system seem attractive.

Last, but not least, bamboo is a very hardy species that can tolerate extended droughts. This characteristic gives the innovation a special quality and value during drought years.

Direct and indirect beneficiaries

This innovation benefits all household members and community groups within the agroecological region. Product processing and marketing activities involve most household members, and it is expected that every participant draws at least some benefit from the cash generated. The practice is not associated with any cultural or religious beliefs, and thus all community groups engage in bamboo plantation management.

The benefit accrued from the innovation is largely influenced by the distance of the farm from the main road. Farmers near main roads sell both bamboo stems and processed bamboo products. Farmers farthest from the main road sell round stems to the farmers closer to the road at about half the roadside price. Roadside farmers mostly weave split bamboo stems into mats and sell them at a profit.

Round and split bamboo stems are also used for manufacturing various household utensils, for example, baskets, plate covers (*akenbalo*) for *enjera,* the Ethiopian *mosob* (a grass-woven plate with cover), house construction, fuelwood. Bamboo stems also provide durable and impenetrable fencing materials and internal house division frames. The leaves and twigs of bamboo provide an essential animal feed supplement, particularly during the dry season. Bamboo generally provides cheap construction and fencing materials for rural highland dwellers.

Upscaling strategies

Bamboo boundary planting is a typical land-use system in the wet highland regions of Ethiopia. In most of these areas, selling round bamboo stems and weaving split stems into various products is quite common. The use of bamboo products in rural and urban settings is increasing along with the number of local bamboo stem-processing artisans.

Transportation of bamboo products (mats, chairs, desks, etc.) over long distances and the high prices of these items indicate how their use has expanded, not only in the highlands, but also in midland and lowland urban and rural areas. This serves as an incentive and motivates farmers to scale up adoption of the innovation.

Simplicity of the entire work involved in the innovation and employment of young children and women into product manufacturing represent an important factor that has contributed to the expansion of the innovation. Adequate market demand and reasonable product price are additional incentives. Multiple uses of bamboo plants, low financial and labour requirements and high profitability of the innovation continue to induce many highland farmers to adopt and enhance the practice. These farmers claim to make enough income from selling bamboo products to pay for their household expenses, family clothing, children's schooling, tax payments, etc.

Institutions promoting the innovation

This practice was largely promoted through farmers' own motivation to meet various household needs. In many highland regions bamboo is the dominant source of wood for house construction, fencing, and greening the landscape. The recent increase in demand for bamboo products has also prompted highland farmers to expand bamboo boundary plantations to earn cash.

Bamboo can be grown on marginal lands between croplands, along fence lines, between crop and grazing lands, around house compounds, and around homegardens. This is a type of non-competitive planting in which crops are grown close to root lines, although some yield reduction is unavoidable.

Research questions and knowledge gaps

The major research issue to be addressed is the possibility of improving bamboo product assortments and quality. Possible means of improving product quality and quantity need to be investigated, not only to boost farmers' cash incomes but also to safeguard the extinction of valuable indigenous timber species. Several products now made of valuable timber species can be manufactured with bamboo: beds, shelves, doors, windows, ceilings, floorings, chairs, desks, tables, etc. With adequate policy support and competent research experimentation, it is possible to improve the quality and durability of bamboo products.

It is still undetermined how one can improve the width of the bamboo stem diameter without missing the required durability and quality of the outer stem shell. Apart from identified knowledge on improving bamboo wood, there is also a lack of information on non-competitive bamboo planting niches. Farmers traditionally grow bamboo as live hedges around home gardens and along farm boundaries, tolerating subsequent crop losses. Other alternative niches have not been identified. The level of crop loss from bamboo strip competition has not yet been ascertained to correctly determine the benefit–cost ratios.

There may still be possibilities of improving overall yields from adjacent crop fields and linear bamboo plantations. The economics of crop cultivation and bamboo plantations per unit area and future bamboo marketing scenarios have not been conclusively ascertained. This may particularly help roadside farmers to gradually increase the proportion of bamboo plantation area relative to that of their croplands. Professional research is needed on current economics concerning bamboo and on future demand patterns and possible market prices of various products. Farmers need counselling on the relative proportion of their land-use units they can devote to bamboo.

Professional reflections and recommendations

With competent rural development policy and judicious support there are ample opportunities to further promote both economic and ecological benefits of bamboo boundary plantations. Optimizing yields of the different system components is one possible means of improving its economic benefits. Although bamboo boundary planting in all directions provides an effective means of protection against wind and external intrusions, trials on other plantation configurations should be set up.

The basic required improvement on the practice is product diversification and quality improvement. Increasing product assortment and introducing modern bamboo wood-carving technologies help farmers improve product quality and thus meet consumer demands. This will likewise increase the economic benefits farmers derive.

The practice should greatly enhance farmers' cash incomes and livelihoods if supplemented with modern bamboo wood-processing technologies and adequate training to selected farmers. Unemployed youth groups can be provided with adequate training in modern bamboo wood-processing techniques and facilities credited to establish well-equipped woodwork plants. Organizing local youth groups in bamboo-processing cooperatives and introducing modern machinery would boost the economic benefits of bamboo to both youth groups and farmers. This should enable farmers to offer as many bamboo stems as they can to the factories at much better and guaranteed prices. The prices may also be regularly adjusted in response to changing market demand and price of the manufactured products.

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