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Chapter 5

Confronting land degradation in Africa: Challenges for the next decade

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Abstract

This chapter presents five challenges for integrated natural resource management research at the World Agroforestry Centre within the theme of Land and People:

1. What are the determinants of the adaptive and adoptive advantages of the available technological options for sustainable soil fertility management?
2. How can the functions of the soil community be optimized with respect to different ecosystem services?
3. What are the trade-offs between the storage of organic matter in the soil (to counter climate change effects of gaseous emissions) and its use to drive nutrient cycling, crop production and other ecosystem services?
4. What are the key questions arising from interactions in the chain linking resource management–system intensification–market access–policy?
5. What are the rules governing cross-scale transitions in natural resource management?

These issues will require both holistic and reductionist interdisciplinary methodologies working across a range of scales, but many of the necessary tools have been put in place during previous work.

Introduction: land degradation in Africa

The purpose of this chapter is to identify some of the major challenges facing the research community concerned with combating land degradation in Africa and its effects on human welfare. This purpose can be rephrased in the form of a question: What type of science, to do where, and for whom? There is no intent to review in detail the problem of land degradation and its multiple causes, or the scientific response in terms of methods and results. These have been documented in exhaustive detail elsewhere and reference is made to the key sources where appropriate. Five major challenges for future research have been identified, but the most central issue for the World Agroforestry Centre remains that of investigating the keystone roles of trees as regulators of landscape dynamics and providers of goods and services for human welfare.

Land degradation has many characteristics, including soil erosion and nutrient depletion, decreasing quality

and quantity of available water, and loss of vegetative cover and biological diversity. These have knock-on effects on the prevalence of disease – of plants, animals and humans – and, most importantly, on human welfare and well-being by the disruption of food production and other ecosystem services. The causes of land degradation are multiple and interactive. This complex chain of cause and effect has been analysed and documented in detail; most recently in the proposal by the Forum for Agricultural Research in Africa (FARA) for a Challenge Programme for sub-Saharan Africa and its many supporting documents (FARA 2003). The bottom line is that problems of this complexity require holistic solutions.

The challenge of scales and emergent properties

In proposing a holistic response to the problems of land degradation, one of the major structuring features must be a multi-scale approach, embracing both space and time. Learning to work across scales (plot, farm, land use type, landscape) with the associated human perspectives (farmer, farm family, community, district planner, forestry manager, etc.) is already one of the major concerns of the Consultative Group on International Agricultural Research (CGIAR). The World Agroforestry Centre has made major contributions in this respect and Chapters 7 and 10–13 illustrate many of the innovative and successful advances that have been made as well as addressing many of the most important methodological issues (see for instance the scalar approaches in the work of the Alternatives to Slash and Burn (ASB) Programme as described in Palm et al. 2000). Nonetheless, our facility in moving between scales, and in translating results learned on one scale into possible implications on scales above and below, remains limited.

At different scales in space the associated interests of different sectors of society become dominant and the issues of importance to these stakeholders also change (Figure 1). It is at the plot and farm scales that the natural resources of soil, water and biota are often most intensively managed and their dynamics altered by the interventions of humans. For the farmers, therefore, the availability, quantity and quality of resources at this scale, and the factors influencing their capacity to convert these resources into food and marketable products, is their major (but not their only) concern. At higher-level scales, moving through the hierarchy of catchments across the landscape to the aggregate of river basins, additional issues become the concern, not only of farmers and other direct land users, but also of urban society. These include ecosystem goods and services beyond food production, such as the impact of land management on water availability and quality. At a global level, the effects of land use on climate and biodiversity have become issues of significance. Resource

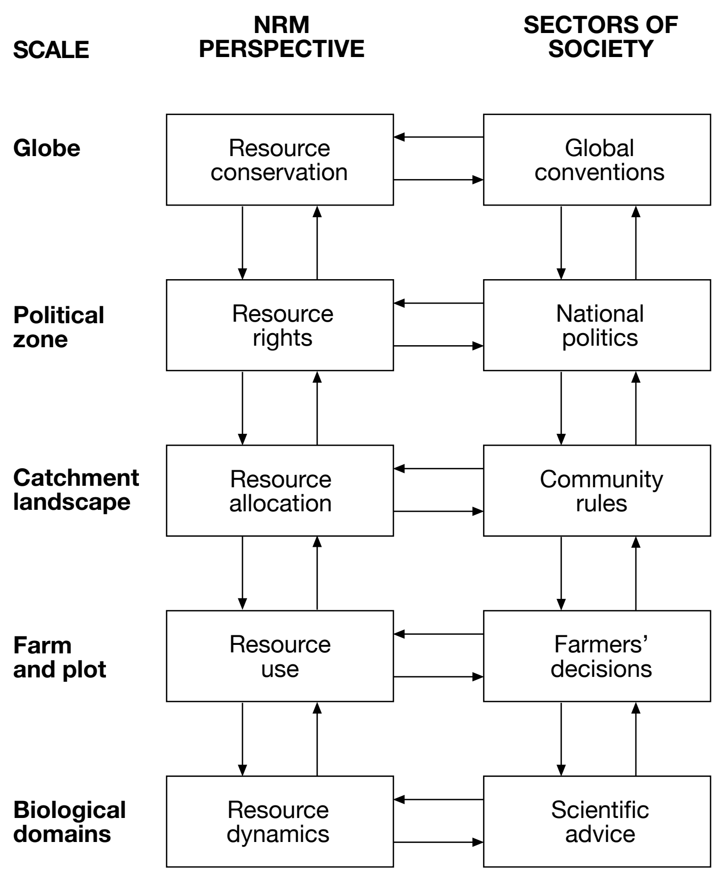

Figure 1. *Perspectives on natural resource management at different scales. The left-hand column provides a convenient classification of scales. The middle column indicates some of the major issues in resource management at each of these scales (although of course they overlap). The third column designates stakeholders with the dominant role in tropical land management at each of the given scales.*

protection becomes a feature of decision making at these higher scales, sometimes conflicting with the aspirations of the farm-level land users with respect to rights of allocation and use. Likewise, forests can be harvested by private enterprise or government, and the resultant land cover changes can influence the availability of water to local people.

In the following discussion we deal successively with challenges at the scales of plot and farm (the most common level of concurrence of agricultural practice and scientific exploration); the scales below the plot where biological dynamics in the soil influence agricultural productivity and other ecosystem services; and finally with the 'landscape', an aggregation of scales above the farm. It is perhaps necessary to note that this chapter is predominantly concerned with biological aspects of the management of natural resources. Those to do with the economic, social, cultural and institutional aspects are covered in Chapters 7: 'Scaling up the impact of agroforestry' by Franzel et al. and 8: 'Policies for improved land management in smallholder agriculture' by Place et al. in this volume. This is simply a matter of convenience and, hopefully, it does not need to be said that the biological problems associated with ecosystem service provision and those of the sociology of need and acceptability are inseparable and must be tackled holistically.

Plot and farm

The degradation of soil fertility, specifically the capacity of the soil to support agricultural production, has been identified as one of the main causes of Africa's agricultural failure (Buresh et al. 1997). It has been recognized that the problem of soil fertility degradation is a microcosm of that of land degradation as a whole. TSBF/ICRAF (2002) states: 'The soil fertility problem remains intractable largely because of the failure to deal with the issue in a sufficiently holistic way. Soil fertility decline is not a simple problem. In ecological parlance it is a slow variable, which interacts pervasively over time with a wide range of other biological and socioeconomic constraints to sustainable agroecosystem management. It is not just a problem of nutrient deficiency but also of inappropriate germplasm and cropping system design, of interactions with pests and diseases, of the linkage between poverty and land degradation, of often perverse national and global policies with respect to incentives, and of market and institutional failures such as lack of extension services, inputs or credit opportunities.' Tackling soil fertility issues thus requires a long-term perspective and a holistic approach that integrates biological and social elements (e.g. Swift and Palm 2000). As expressed in the African Highlands Initiative, integrated natural resource management embodies the following (Stroud and Khandelwal 2001:

- principles for improving livelihoods;
- inclusion of the perceptions, needs, opportunities and positions of multiple stakeholders;
- formulation and adoption of strategies to better balance the differing goals of those primarily concerned with environment, economic growth, equity or governance;
- facilitation of institutional arrangements and linkages within organizations and between various actors so as to achieve better coordination;
- fostering of synergies and information exchange between stakeholders to promote sustainable development;
- promotion of institutional and technological innovations and policies that contribute to local ownership and stewardship; and
- building upon local assets (financial, physical, knowledge and skills) to promote self-determinism and limit dependency.

For more than two decades, the Centre and its partners have focused on developing technological options for sustainable soil management that are biologically effective, economically viable and socially adoptable (Raintree 1987). This work has produced a substantial database of empirical knowledge, including a series of books, e.g. Young (1997), Buresh et al. (1997), Bergstrom and Kirchmann (1998), Tian et al. (2001), Vanlauwe et al. (2002), Gichuru et al. (2003), Schroth and Sinclair (2003) and Bationo (2004). From this work, a number of general lessons have emerged, with significant success in adoption and impact (see Jama et al. Chapter 6, this volume). Most of this success has been centred round the recognition that combined use of inorganic and organic sources of nutrients has greater benefit than either alone (Figure 2). As described in these publications, the menu of available technologies is broad and the potential for identifying the appropriate one under a given set of conditions is now high. The cropping designs that promote integrated nutrient management include integration of legumes as grain or cover crops, rotations and intercrops, improved fallows, integration with livestock (i.e. use of manure) and conservation tillage. Agroforestry has contributed successful options to many of these generic systems. A key feature of the success in soil fertility research in Africa over the last decade has been the integration of ecological and participatory social science research.

The focus on integrated nutrient management as the basis of soil fertility management is, of course, a relearning of an old lesson, but one that has been accompanied

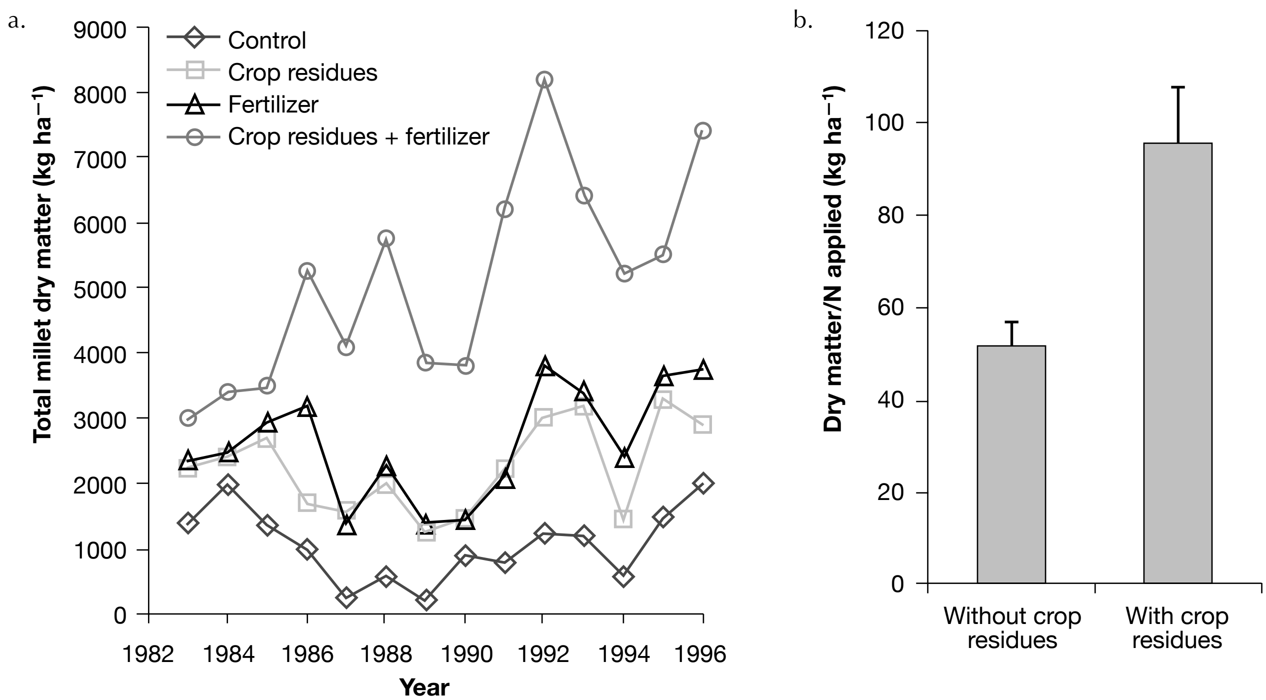

Figure 2. *The effects of crop residues and nitrogen fertilizer on (a) total millet dry matter yield and (b) nitrogen use efficiency at Sadoré, Niger (modified from Bationo et al. 1999).*

by significant advances in scientific understanding and practice. These include high-precision fertilizer management (e.g. Baidu-Forson and Bationo 1992) and the development of knowledge-based organic matter management practices (e.g. Palm et al. 2001 and 2002; Vanlauwe et al. 2003). The target of the these practices is, of course, not only to replenish soil nutrients and improve crop yields but also to (re)build soil fertility for long-term sustainable soil management. This has always been a target of soil fertility management but has gained additional impetus with realization of the wide range of ecosystem goods and services that stem from the maintenance of high levels of organic matter in the soil. In particular, the sequestration of carbon in soil as a means of alleviating the climatic impacts of excessive greenhouse gas emissions has become a global objective (Feller et al. 2001; Albrecht and Kandji 2003). Significant questions remain, however. It is still unclear how to predict the optimum quantitative mix of fertilizers and the various qualities of organic inputs. Such models must take into consideration the substantial site variability commonly found on farmers' fields, as well as the characteristic heterogeneity of tropical climatic conditions. Furthermore, while good formulae exist for the provision of nitrogen and phosphorus, the interaction with other nutrients, particularly micronutrients, remains largely undefined. A significant opportunity for development exists in this area of research now that very high priority is being given internationally to plant breeding for micronutrient provision. Most significantly, all the successes tend to remain disappointingly local in scale. The major challenge remains that of determining the necessary actions to multiply the local successes to achieve impact at a continental scale (FARA 2003). This requires better insight into the relationship between the technology performance and the prevailing conditions of the biophysical, institutional and socioeconomic environments. The first challenge therefore addresses both the adaptive range of the technological menu and the social and economic circumstances that influence farmers' willingness to adopt.

> ***Challenge 1:*** *What are the determinants of the adaptive and adoptive advantages of the available technological options for sustainable soil fertility management?*

Below the farm: harnessing the biosphere

The community of organisms in the soil perform many essential processes. They act as the primary driving agents of nutrient cycling; regulate the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission; modify soil physical structure and water regimes; enhance the amount and efficiency of nutrient acquisition by the vegetation through mycorrhiza and nitrogen-fixing bacteria; and influence plant health through the interaction of pathogens and pests with their natural predators and parasites. These processes also provide a range of services to humans, including maintaining the availability and quality of water resources, erosion control, biological control of pests, climate regulation and, of course, food production.

The status and activity of the soil community has only rarely been taken into account in modern approaches to soil management. Any form of integrated nutrient management nonetheless relies on the capacity of the decomposer community to process the organic inputs. Similarly, the benefits of conservation tillage rely on regulation of the soil's physical condition by earthworms and other biological ploughs. There is thus increased awareness of the need to understand the functioning of the living soil community, as expressed in the 'second paradigm' for soil fertility management proposed by Sanchez (1994) (see also Swift 1998), i.e. for improved crop growth, 'rely on biological processes by adapting germplasm to adverse soil conditions, *enhancing soil biological activity* and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use' (our emphasis). The second challenge directly addresses the central, but largely unrealized, clause in this paradigm.

> ***Challenge 2:*** *How can the functions of the soil community be optimized with respect to different ecosystem services?*

One of the major reasons for the slow progress in understanding the functional biology of the soil biota has been the lack of sensitive methods for investigating soil micro-organisms. This problem has come closer to solution since the advent of molecular methods for identifying and tracking specific soil organisms and for assessing changes in overall biodiversity (Amman and Kuhl 1998; Amman and Ludwig 2000). The Centre has already embarked on innovative studies of this kind (e.g. Bossio et al. 2005). Combining such work with continuing studies of the keystone role of trees in agroecosystems (see following section) offers great promise as a means of linking the driving functions of ecosystem services across scales from below the plot to the landscape.

Beyond the farm: landscapes and institutions

The biggest challenges for the management of natural resources probably lie at the broadest scales and can be placed under the inexact term of 'the landscape'. At these scales, predictions of effects derive not so much from specific biological processes, but from their aggregate and interactive effects. The main driver of these effects is the nature and location of different land-use systems on the landscape, including their history and management. Trees influence landscape scale dynamics more than any other organisms (although, of course, humans have now appropriated this claim). Investigation of this keystone role must remain not just a major part of the Centre's research agenda, but at the very heart of it, because of the huge number of secondary interactions that flow from the incorporation of trees within any land use system.

One specific feature that is strongly influenced by the presence of trees is the abundance and quality of soil organic matter. This, in its turn, influences both soil fertility and all the other ecosystem services derived from soil. It is therefore both a major resource and an indicator of soil status. The work of Shepherd and Walsh in developing methods for remote sensing and mapping of soil carbon status and its linkages to other soil properties at different scales has provided extremely powerful tools for both assessing and predicting the environmental effects of land use change (Shepherd and Walsh 2002).

Soil carbon is now of global interest because of the opportunity to utilize sequestration as a mechanism for correcting the imbalances in emissions of carbonic gases that are believed to be driving climate change at an unacceptable rate. However, organic matter is not an inert component of soil. It is the substrate for many soil organisms and thence contributes energy for many of the essential biological processes that support plant production and soil structure maintenance. There is thus a major challenge to assess (for different types of land use) how to optimize the use of soil carbon. This is fundamentally an issue of balancing the needs of the farmer (at the scale of the plot) to exploit soil organic matter energy for crop production with the needs of society in general (at the scale of the landscape) to conserve carbon (Tomich et al. 2005). It is possible to hypothesize that these two goals may be mutually incompatible or have significant quantitative

limits under some conditions. Izac and Swift (1994) argued, for instance, that a sustainable agricultural landscape might necessitate a balance between areas of exploitation of resources and areas in which they are permitted to accrue. This relates to the third challenge.

> ***Challenge 3:*** *What are the trade-offs between the storage of organic matter in the soil (to counter the climate change effects of increased gaseous emissions) and its use to drive nutrient cycling, crop production and other ecosystem services?*

Socio-biophysical interactions are apparent at all scales, but primarily at the landscape scale where the impacts of decisions made by different stakeholders across a range of scales interact (Figure 1). The two Systemwide Programmes managed by the Centre (the African Highlands Initiative and the Alternatives to Slash and Burn Programme) have been at the forefront in developing approaches and methods for assessing the interactions between environmental, economic, social and political factors in natural resource management (Stroud 2001; Stroud and Khandelwal 2003; Palm et al. 2005). The proposal for the Challenge Programme for sub-Saharan Africa drew upon these lessons by picturing an interactive chain of cause and effect in land degradation and unsustainable agriculture. This chain links the degradation of natural resources to failures in market access and performance, thence to inappropriate pathways of system intensification, and finally to inadequate policies (FARA 2003). The analysis provided in the Challenge Programme documentation serves in particular to direct attention to the 'interactions' between these sectors of the research enterprise as well as to the issues within each of them (the fourth challenge).

> ***Challenge 4:*** *What are the key questions arising from interactions in the chain linking resource management–system intensification–market access–policy?*

Integrating across scales

The rules governing resource management, and the institutions making them, change as scales change. For example, rules (or the lack of them) made from the national perspective can strongly influence local behaviour and may result in significant feedback effects (Figure 1). This complexity is compounded by changes in dominance of the factors determining natural resource dynamics at different scales (e.g. van Noordwijk et al. 2004 with respect to hydrological flows and Swift et al. 2004 in relation to the significance of biodiversity). The type of management (communal or individual, government or private) apparent within the land use types and the gender and wealth dimension is also important. Thus, a range of social parameters enters the equation. These issues have been analysed by the CGIAR Taskforce on Integrated Natural Resource Management and the reports and papers emanating from that group (e.g. Campbell and Sayer 2003; Sayer and Campbell 2001) together with the framework developed by Izac and Sanchez (2001) offer some of the best analyses of the methods, approaches, successes, opportunities and challenges that face a scientific community committed to issues of 'Land and People'.

In a recent study of watershed management issues that cut across scales and social perspectives in the East African Highlands (reported by German 2003 and Stroud 2003), five main categories were identified:

1. Issues involving the management of common property resources which compromise either the quantity or quality of these resources.
2. Issues involving limited access and inequitable distribution of resources (absolute and relative shortages).
3. Trans-boundary effects between neighbouring farms and villages.
4. Areas in which collective action could significantly enhance farm productivity, either through increased access to productive resources (natural resources, labour, capital) or through cooperation to conserve resources that are under threat (biodiversity, local knowledge).
5. Areas in which collective action is currently needed to enhance income or livelihood more broadly (public works, governance of existing resources, marketing).

Of equal interest to variation across spatial scale is the influence of change over different scales in time. Crowley and Carter (2000) provided a detailed and perceptive analysis of the historical factors that have influenced the current state of natural resources and agricultural practice in western Kenya. Such analysis influences an important debate in natural resource management research. It is often asserted that the characteristics of the natural resource base and its management are highly site-specific, an observation largely derived from the huge biophysical variation that is commonly seen between neighbouring fields with respect to soil fertility status and other biological properties. These observable differences may derive, in some cases, from variations in underlying materials, but are more frequently a product of the history of human management of the natural resources of the plots, farms and regions concerned in

response to risks posed by weather, market, food and feed needs, energy and land use policies, etc. This paints a potentially chaotic picture resulting from dynamic evolution over time. The evolutionary biologist, Stephen Jay Gould, has made an eloquent plea for scientists to appreciate the importance of historical analysis as an integral tool in the biological sciences (Gould 2000). In particular, he points to the importance of understanding the degree to which present conditions are contingent on events that occurred in the past. Whilst his arguments are largely concerned with the processes of biological evolution, they surely also apply to the development of ecological systems over time, particularly those influenced by agriculture.

The recognition of site specificity at the plot level has led to the pessimistic assertion that there is therefore no opportunity for generic scientific or technological solutions to natural resource management problems. This is a confusion of principle and practice. It is certainly now generally accepted that monolithic zonal technology recommendations (e.g. for fertilizer dosage) are ineffective. They have been largely replaced by menus of multiple options, and the choice of option is determined by local conditions. However, the origins of the menu options are no less based on scientific principles than are (for example) those created by producing different crop genotypes. Indeed, it could be argued that failures in realizing the potential of genotypes have often resulted from failure to recognize the environmental variations that are taken for granted in natural resource management research.

This brief analysis of multiscale issues in space and time serves to emphasize four cross-cutting issues:

1. Recognition of the hierarchical linkages across scales and their interactions in terms of problems and potential solutions (Swift 1999).
2. The value of understanding the historical basis of present conditions.
3. The importance of merging biological, social and institutional analyses in order to understand the dynamics of influence both across and within scales.
4. The value of identifying 'entry' points for research and intervention, i.e. simplifying access to the complexity of interactive effects within any natural resource management problem by tackling them through accessible and influential components.

These issues can be summarized as a fifth challenge.

Challenge 5: *What are the rules governing cross-scale transitions in natural resource management?*

Conclusion: what type of science, to do where, and for whom?

The five specific challenges presented above provide a response, but by no means a complete answer, to the question posed in the opening paragraph. The greatest challenge for any institution whose role is science for development is that of choice: choice of one scientific topic versus another; choice of criteria for research locations; choice of what type of scientific approach to use; and choice of which of the myriad stakeholders to work directly with, in what manner and across what scales in space and time.

The scientist in any development-related topic will always be faced by decisions as to where to place her or his activities in the research-to-adoption spectrum. Whether to concentrate on relatively basic research, removed from the ultimate client but generating knowledge that may open up areas of progress hitherto inaccessible; or to focus on actions to disseminate knowledge and technology that interact directly with, and provide identifiable benefits for, a selected group of such clients. This dilemma is far from peculiar to international agricultural research. The Nobel Prize laureate, immunologist and incisive writer on the philosophy of science, Sir Peter Medawar, pictured two 'Conceptions of Science' that exist in the popular imagination (Medawar 1982). He described the 'Romantic Conception' with the words of the English poet and essayist, Samuel Taylor Coleridge: "The first man of science was he who looked into a thing, not to learn whether it could furnish him with food, or shelter, or weapons, or tools, or play-withs, but who sought to know it for the gratification of knowing." Medawar contrasted this concept with what we may term a 'Pragmatic Conception': "Science above all else [is] a critical and analytical activity; …scientific research is intended to enlarge human understanding, and its usefulness is the only objective measure of the degree to which it does so." Medawar acknowledged that these two descriptions were caricatures and concluded that: "Anyone who has actually done or reflected deeply upon scientific research knows that there is in fact a great deal of truth in both [conceptions]." International agricultural research must indeed serve both these pursuits. By choosing to work for the poorest of the poor we have already chosen to follow the Pragmatic Conception. But our contribution is likely to be greater by applying what we are most suited to do – to exercise our curiosity and imagination to empower people with the best that the scientific adventure can provide.

The discussion in the preceding sections argues in almost every part for a holistic approach to agricultural research for

development – and this is perhaps the most exacting scientific challenge of all. The obvious danger in any broad approach, however, is that of working on absolutely everything and losing all useful focus. Ecosystem ecology is helpful in this regard, for it has become clear that, whatever the level of complexity, there are always some features of the system that are more influential in its regulation than others. This existence of keystone organisms and processes is particularly good news for agroforesters, because asking the question 'what is the role of the tree(s)?' in any given ecosystem is unlikely to be distant from asking 'how does this system work?' Likewise, the disciplines of anthropology and sociology draw upon knowledge of repeated patterns in social behaviour and actions that can be linked to bio-political processes. The key for the resource management scientist in agricultural research is thus to identify key features of the system during the diagnostic phase of a research programme, and to derive appropriate entry points to the research that will enable manipulation of these keystone organisms, processes or properties.

In seeking to wade in the 'bathwater' of holistic science we should not, however, cast out the 'baby' of reductionism. As mentioned above, Stephen Jay Gould argued forcefully throughout his career for a wider and less mechanistic concept of what constitutes the scientific method than mere reductionist experimentation. Yet, in so doing, he also said: "Only a fool or an enemy of science could possibly deny the extraordinary power and achievements of reductionism…" (Gould 2004). It is thus surely not a question of *either* reductionism *or* holism, but the challenge of when and in what manner to employ the power of the former within a framework of the latter. As outlined above, the tools to assist such choices are already part of the World Agroforestry Centre's armoury – what remains is how we choose to use them.

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