TREES on the Farm

Assessing the Adoption Potential of Agroforestry Practices in Africa

Edited by
S. Franzel and S.J. Scherr

ICRAF

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Foreword

This is a book that pushes forwards the emerging science of agroforestry. There are several syntheses on the biophysical aspects of agroforestry but little is available on the socioeconomics of agroforestry and its adoption by farmers, following rigorous scientific methods. This book fills such a gap by assessing the adoption potential of selected agroforestry practices, describing the appropriate methodologies and drawing lessons for improving the effectiveness of the research–development continuum. Five case studies are described and analysed in this book. Four of them are successful and one – hedgerow intercropping – was promoted before a rigorous biophysical assessment was made.

This book demonstrates how farmers in selected areas have tested and adapted these practices, incorporated them into their farming systems and improved their welfare and incomes. It also provides examples of scaling up within the areas where testing took place: farmer-to-farmer dissemination, partnerships among researchers, extension services, and non-governmental organizations (NGOs) to promote scaling up.

The key finding was that agroforestry reduces the risks that farmers face from input markets by investing small amounts of land and labour, rather than spending cash on expensive inputs, for improving soil fertility, feeding their livestock, or providing wood for fuel and construction.

There were also important methodological lessons, that add further value to this book. The authors should be congratulated for advancing the science of agroforestry.

Pedro A. Sanchez
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Introduction

1

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Background

Agricultural land use and management present major development challenges throughout sub-Saharan Africa. The area under cultivation has expanded notably, total yields are rising, and there is large-scale conversion from fallow-based cropping systems to continuous cultivation. None the less, per capita food production has declined by about 2% per year since 1960 (World Bank, 1996), and constraints on growth in agricultural sectors, which remain prominent in most African economies, are an important factor explaining a 1% per year decline in per capita incomes between 1983 and 1993 (Cleaver and Schreiber, 1994; World Bank, 1994).

Environmental problems associated with agricultural production have also become a major concern. With the marked expansion and intensification of farming, total forested area in Africa declined by 50 million hectares during the 1980s (Dembner, 1991), reducing the availability of wood products for fuel and construction, degrading range resources, and exposing vulnerable soils to degradation. In many areas, particularly in the densely populated highlands and in drylands, soil degradation due to inadequate agricultural practices and nutrient depletion threatens long-term productive potential (Scherr and Yadav, 1995; Buresh *et al.*, 1997).

Agroforestry is defined as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (Leakey, 1996). Agroforestry has considerable potential to contribute towards solving some of these problems. Nitrogen-fixing trees, as substitutes or complements for chemical fertilizer, can increase smallholder incomes, conserve foreign exchange and improve regional food security. By providing a supply of fuelwood from the farm, agroforestry can help reduce pressure on forests and communal woodlands. Moreover, agroforestry trees can supply farm households with a wide range of other products, including food, medicine, livestock feed, and timber for home use and sale. Other services that trees provide, such as boundary markers, windbreaks, soil erosion barriers, beauty and shade, are difficult to quantify but are none the less of substantial importance to farm families and for natural resource protection.

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Indeed, indigenous agroforestry practices are already widespread in Africa, as is the planting and protection of many tree species introduced during the colonial period and later through forestry and agroforestry extension projects (Le Houerou, 1987; Kerkhof *et al.*, 1990; Warner, 1993). However, most are suited to low-intensity agricultural systems, and function well below their potential productivity as a result of using poorly adapted species, provenances and management systems. Over the past 20 years, research and extension systems working in Africa have sought to improve the productivity of existing systems and develop new practices to meet new land-use challenges and opportunities (Scherr and Müller, 1990; Kang, 1993; Cooper *et al.*, 1996).

Assessment of Agroforestry from the Farmers' Perspective

There is now a substantial body of scientific literature on the biophysical features and potentials of agroforestry practices in Africa (Cooper *et al.*, 1996; Sanchez, 1996). However, these provide only a first indication of their suitability for widespread promotion, and their likely economic, social and environmental contributions. There is, unfortunately, almost no information available quantifying the contribution of agroforestry to household income, food security and welfare. This gap is especially surprising given the widespread use of agroforestry in development projects and extension programmes; as early as 1989, Scherr and Müller (1991) were able to identify 60 development projects promoting agroforestry in Africa.

But most agroforestry research has been conducted at research stations or research plots near development project sites; few studies are available on the performance of agroforestry practices under farmer-managed conditions. Even fewer quantify the financial returns of the practices[1] or examine their advantages and disadvantages, as perceived by farmers. For example, Swinkels *et al.* (Chapter 4) report finding only two studies on the testing of improved fallows for increasing soil fertility under farmer management, and neither included a financial analysis. They note that hedgerow intercropping (also called alley cropping or alley farming) for improving soil fertility is more widely tested, but the few farmer-managed trials conducted were mostly limited to the humid and subhumid tropics of west Africa. Moreover, assessment of adoption potential has been problematic in many hedgerow intercropping trials and analyses: targeting was inappropriate as the farmers' perceived priority problem was not low soil fertility; farmers' participation was obtained through the provision of material incentives which were likely to bias their views and actions; and there was inadequate monitoring of socioeconomic variables (Whittome, 1994).

[1] The economics profession distinguishes 'financial analysis' from 'economic analysis'. The former takes the perspective of the individual farmer and values inputs and outputs at prices farmers face. By contrast, the latter is defined from the perspective of society as a whole; market prices of inputs and outputs are corrected if these do not reflect their real economic values to society (Gittinger, 1982). For example, if the fertilizer price was subsidized, financial analysis would use the subsidized price and economic analysis would use the unsubsidized price.

A literature review by Swinkels and Scherr (1991) found 68 economic studies of agroforestry systems in Africa, from 17 countries, but most were *ex ante* analyses, or models based on research station data or assumptions not grounded in farmer experience, or general economic descriptions of the technology or market conditions. Scherr and Müller (1991) found only a few extension projects in Africa evaluating the financial impact of agroforestry systems being promoted. This situation is not unique to Africa; it reflects a global paucity of research on the economics and adoptability of agroforestry practices in developing countries. The only two comparative studies assessing the economics of agroforestry practices are Current *et al.* (1995) for Central America and the Caribbean and Sullivan *et al.* (1992) for selected practices in various parts of the world.

Social and financial analyses of agroforestry practices are important for several reasons. African governments, non-governmental organizations (NGOs) and donors need information on the performance of these practices and how they contribute to household welfare and to development objectives, in order to assess whether and how they should continue investing in their development and dissemination. Data are needed on the financial and non-financial benefits of the practices, what works where and why, why some farmers within specific communities adopt and others do not, and who within the family reaps the benefits.

Researchers and development practitioners also need information on how farmers are using and modifying the practices and what problems they encounter, so they can develop technologies and practices that better meet farmers' needs and circumstances. Similarly, policy makers need information on the influence of policy factors on the adoptability and performance of agroforestry practices. Different incentives, institutional mechanisms and policies could be implemented to facilitate agroforestry adoption.

Finally, and perhaps of greatest importance, farmers themselves need information on the performance of agroforestry practices, so they can make more informed decisions on whether to test and adopt them. Such information is especially important because many agroforestry practices require considerable resources, skills and time to bear fruit. In some areas, farmer groups and organizations are emerging to lead adaptive research, and can use this type of information in planning their agroforestry activities.

Objectives

This volume has two primary objectives. First, it assesses the adoption potential of several new agroforestry practices that researchers, development practitioners and farmers are currently testing in Africa. The adoption potential of a practice is defined as its feasibility, profitability and acceptability, as viewed from the farmers' perspective.

Secondly, the volume draws lessons for improving the effectiveness and efficiency of the process of developing, modifying and disseminating new agroforestry practices. These include recommendations to: (i) researchers on technology design and the implementation of on-farm trials; (ii) development organizations concerning the establishment of networks for adaptive research and extension; and (iii) policy makers on institutional mechanisms and incentives for promoting agroforestry. Feedback to research and extension is also critical for improving and promoting practices and for assessing impact, based on farmers' experiences in managing and using agroforestry practices. Farmers' experiences include their assessments, preferences, innovations and their problems, and how they cope with them.

The volume also presents methods that can be used to assess the adoption potential of agroforestry practices during the on-farm testing stage and just after, when farmers are deciding whether or not to adopt the practice. An extensive body of literature exists about methods for on-farm experimentation (e.g. Stroud, 1993), *ex ante* financial analysis (e.g. CIMMYT, 1988) and *ex post* analysis of agricultural technology adoption (e.g. CIMMYT Economics Program, 1993), especially for annual crops technology. But little is available on the assessment of adoption potential during that critical period when farmers are making adoption and design decisions. Nor have these methods been widely adapted to the special needs of agroforestry practices, where management is often more complex and the period of farmer testing is much longer than in conventional cropping systems. Whereas a farmer can harvest and evaluate a new crop variety after a few months, agroforestry practices often take 3–6 years before benefits are realized. The approach illustrated in this volume is promising for the evaluation of other sustainable agriculture and natural resource management practices with similarly long gestation periods and complex choices about components and management.

The book's primary audience is development practitioners and researchers working throughout the Third World who are interested in evaluating the performance of agroforestry practices. The book will interest persons from a wide range of disciplines in the social and biophysical sciences, involved in agricultural technology development and the promotion of sustainable agricultural systems.

Conceptual Premises

The approach and methods described in the book are based upon four conceptual premises. First, we assume that a systems approach is required in assessing adoption potential. Rural households operate complex farming systems, allocating their limited resources among many enterprises in a manner determined by their priorities, preferences and their biophysical and socioeconomic circumstances (Collinson, 1981; Scherr, 1997). This system complexity has several implications for researchers and development practitioners.

To begin with, they must understand the farming system and work closely with farmers to select and develop appropriate technologies. Since African farming systems are particularly heterogeneous, regarding both biophysical variables (e.g. soils) and socioeconomic variables (e.g. market access), some degree of targeting of new practices is usually required. At the same time, research has shown that when moving beyond simple interventions, such as varietal improvements, researchers and extensionists need to present farmers with a ‘basket of options’ from which they can choose the practices that are most suitable to them (Chambers *et al.*, 1987).

Indeed, small-scale farmers are rarely able to manage any single enterprise in the ‘optimal’ manner prescribed by researchers. Rather, they make compromises in the management of individual enterprises in order to reduce risk, alleviate constraints and increase the productivity of the whole household livelihood system. Thus, researchers and development practitioners must be willing to test low-cost, simple-to-implement practices that improve on farmers’ existing practices. Some complex technologies may have higher potential returns, but pose major risks and are unlikely to be adopted until after other marginal changes have been introduced successfully (Byerlee and Hesse de Polanco, 1986).

African farming systems are also quite dynamic, undergoing significant long-term changes in crop components, commercialization, input use and cropping intensity as populations grow and markets expand (Ruthenberg, 1971; Boserup, 1981). Given the relatively long life cycle of many agroforestry systems, improved technologies must be appropriate for farming systems of the future, not just the present.

The second concept is that participatory research approaches are needed to ensure that farmers play a leading role in problem diagnosis, testing and evaluation of new practices (Chambers *et al.*, 1987; Okali *et al.*, 1994). New methods in the late 1980s and 1990s helped researchers and other change agents to play a facilitative role in the on-farm research process, helping farmers to carry out their own appraisals, design their own experiments and conduct their own evaluations. This volume, for example, highlights farmers’ innovations, in experiments they designed and implemented themselves, that were later adopted by farmers on a wide scale. This approach can thus help substantially to streamline and focus the research process, rather than requiring that researchers predict on their own which of hundreds of possible tree species and dozens of technologies deserve development and dissemination under different farm conditions and different landscape niches.

The third concept highlighted in this book is that financial analysis and farmer assessment are both needed to complement biophysical assessment of a technology. Whereas financial analysis shows the economic attractiveness of a practice, farmer assessment highlights its advantages and disadvantages as perceived by the farmer, and is especially useful after farmers have had a chance to experiment with the practice. Farmer assessments may highlight the suitability of a product for use by a farmer (e.g. as fuelwood or construction wood), or growth characteristics of a tree that a farmer may like or dislike (e.g. interference with crop production or provision of a boundary marking), or socioeconomic constraints that inhibit the use of a practice, such as unsuitable land tenure or lack of labour during the peak work period.

Farmer assessment is especially important in agroforestry, since tree products often have multiple uses; new practices frequently involve significant management changes for the farmers, and the technology testing period is long. Also, in areas where markets are weak and it is difficult to value inputs such as labour and outputs such as fuelwood, farmer assessment may be more important than financial analysis for determining the advantage of a practice. Systematic analysis of farmers’ assessments of practices are rare; they have been considered by some researchers to be too ‘soft’ and subjective. However, methods are available from sociology and anthropology for quantifying data on farmers’ preferences, and subjecting hypotheses about those preferences to tests of statistical inference. Examples of these methods include hierarchical decision-tree modelling (Chapter 5) and matrix rating (Chapter 6).

The fourth concept is that the interaction of actors made possible through the on-farm research process itself can strengthen the technology development process, and accelerate dissemination of new information, by compressing in time the conventional sequential information transfer pattern. Benefits range from learning key lessons about how to communicate ideas about a technology and market it to farmers (i.e. simultaneous rather than sequential development of ‘extension messages’); identifying technology design tips for getting around farmer constraints with the technology (i.e. compressing the training of extensionists for effectively adapting the technology to farmer conditions); and recruiting farmer ‘champions’ of the new technology (i.e. getting an early start with farmer-to-farmer diffusion). On-farm research provides a defined ‘space’ for interaction among researchers, extensionists, farmers and community groups that would be unlikely to occur otherwise, particularly when these belong to different social groups. The communication channels opened up through on-farm research may make possible continued dialogue between groups even after projects are completed.

Overview

This book is composed of three parts. Chapter 2 provides an overview of the methods used in the studies. It defines the information needed to assess adoption potential, and explains different techniques for collecting and analysing data on those variables, including participatory on-farm trials, financial analysis and farmer assessment.

There follow five case studies assessing the adoption potential of specific agroforestry practices: hedgerow intercropping for improving soil fertility in western Kenya, improved tree fallows for improving soil fertility in eastern Zambia and western Kenya, multipurpose agroforestry trees in western Kenya, and fodder trees for dairy cows in central Kenya (Table 1.1). The studies are from three contrasting zones – a humid highland area in central Kenya located close to major markets, a humid highland area in western Kenya with poorer soils and farther from markets, and a subhumid plateau area in eastern Zambia far from major markets (Table 1.2). The Kenyan study areas have very high population densities, while the density is low in the Zambia study area.

The five case studies examine the feasibility, profitability and acceptability of the practices, based on farmers’ experience in testing them. All cases involve researcher-designed, farmer-managed trials. Four of the studies also include trials designed by farmers, that is, in which farmers test practices as they wish. Four studies also include some assessment of farmers’ post-trial experiences, that is, farmers’ preferences and actions following completion of the trials. One case, for improved

Table 1.1. Agroforestry practices examined in this volume.

Practices and tree species	Main problem addressed	Important by-products	Management
Improved fallows (southern Africa) (*Sesbania sesban* and *Tephrosia vogelii*)	Nitrogen deficiency in soil	Fuelwood	Farmers raise seedlings (sesbania) in nursery or direct seed (tephrosia). They plant in a pure stand or plant trees in a standing maize crop. After 2 or more years, trees are cut and leaves incorporated into the soil
Improved fallows (eastern Africa) (*Crotalaria* spp. and *Tephrosia vogelii*)	Nitrogen deficiency in soil	Fuelwood	Farmers direct seed into a standing maize crop. They leave trees to grow during the second season and cut trees and incorporate leaves before the beginning of the third season
Hedgerow intercropping (*Leucaena leucocephala* and *Calliandra calothyrsus*)	Nitrogen deficiency in soil, soil erosion	Fuelwood, fodder	Trees are planted in rows, about 30 cm apart within rows and 4 m between rows. Hedges are pruned at about 1 m and prunings are incorporated into soil as green manure
Boundary planting of upper-storey trees (*Grevillea robusta* and *Casuarina junghuhniana*)	Fuelwood shortage, lack of poles and timber for construction	Boundary markings, shade, beauty	Trees are planted on boundaries or around the homestead
Fodder trees (*Calliandra calothyrsus*)	Fodder shortages in dairy enterprises	Fuelwood, soil erosion control, boundary markings	Fodder shrubs are planted in hedges on boundaries and along contours. Beginning in the second year, they are pruned at about 1 m and prunings are fed to livestock

Table 1.2. Main characteristics of the study areas examined in this book.

Features of study areas	Eastern Zambia	Western Kenya	Central Kenya
Agroforestry technologies examined	Improved tree fallows	Improved tree fallows, hedgerow intercropping, multipurpose agroforestry trees	Fodder trees
Altitude (m)	900–1200	1500	1300–1800
Rainfall	Unimodal, 1000 mm	Bimodal, 1600–1800 mm	Bimodal, 1200–1500 mm
Soil type	Alfisols and Luvisols	Nitosols	Nitosols
Population density (km^{-2})	25–40	300–1000	450–700
Access to markets	Low	Medium	High
Main crops	Maize, groundnuts	Maize, vegetables	Coffee, maize, beans
Livestock types	Zebu cattle, goats	Zebu cattle, goats	Improved dairy cattle
Area cultivated (ha)	1.2–3.2	0.5–1.5	1–2

Sources: Chapters 3, 4 and 7.

fallows in Zambia, examines the role of an on-farm research and dissemination network, composed of farmer groups, NGOs, and research and development organizations, in promoting the practice.

Finally, common themes emerging from the case studies are examined. Chapter 8 concerns the role of policies, institutional mechanisms and farmer incentives in promoting agroforestry. In the concluding chapter, the results are set in the context of existing information, the prospects for different practices are assessed, and recommendations are made concerning priorities for research and development work in agroforestry.

Results and conclusions reported in this book about agroforestry potentials for specific practices must be considered preliminary. Most on-farm experiments in agroforestry did not begin until after 1990, some results are not yet definitive, and only a limited number of agroecological zones and socioeconomic conditions are considered. Also, this volume assesses agroforestry exclusively from the perspective of the individual farmer. Relatively little attention is given to projected impacts on the local economy or on environmental variables such as soil erosion or deforestation. Such analyses would require additional socioeconomic and biophysical data, not yet available at most of these sites.

Still, these case studies demonstrate that agroforestry is already contributing to the solution of some of Africa's challenges for increasing rural incomes and food security and mitigating land depletion. Some cases show significant social and financial impacts. Moreover, the studies illustrate a new and dynamic approach to generate effective and adoptable technologies, which accelerates the technology development process itself, as well as the process of farmer adoption. The dynamic partnerships between farmers, researchers and extensionists that are illustrated in the case studies offer promise for developing and disseminating other sustainable land-management practices.

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Methods for Assessing Agroforestry Adoption Potential

2

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Introduction

This chapter describes methods for assessing the adoption potential of agroforestry practices through participatory on-farm trials, and their application in the five Kenya and Zambia case studies. We discuss briefly the evolution of adoption assessments through on-farm research. We then define three types of on-farm trials and discuss their main features, management and suitability for generating information on adoption potential. The next section discusses the organization of participatory on-farm trials; the following section presents specific methods for determining the biophysical performance, profitability, feasibility/acceptability, boundary conditions and insights about dissemination of practices tested in on-farm trials. The chapter then discusses how this on-farm research approach fits into a new farmer-centred model of the research–development continuum, and concludes with some thoughts on future priorities.

Background

In conventional approaches to technology generation in the 1960s, assessment of adoption potential focused almost exclusively on biophysical variables such as a new crop variety's potential to increase yield per hectare. Where technologies were fairly simple and biophysical circumstances fairly homogeneous, as for rice varieties in the irrigated areas of South-East Asia, the approach achieved considerable success. But in Africa, where farming systems were often more complex, more subsistence-oriented and more variable than in the irrigated areas of South-East Asia, the biophysical approach was found wanting. In the late 1970s and early 1980s, farming systems research emphasized the need to determine adoption potential based on the priorities and circumstances of farmers (Byerlee and Collinson, 1980). Researchers emphasized the need for testing new practices under farmers' circumstances but research prototypes for on-farm trials still tended to be drawn up by researchers, following consultation with farmers (Zandstra *et al.*, 1981). Participatory approaches in the late 1980s and 1990s highlighted empowering farmers to choose the technologies they wanted to test and to design and implement the research themselves (Lightfoot, 1987; Chambers *et al.*, 1989; Haverkort *et al.*, 1991; Rocheleau, 1991; Scherr, 1991a). Little emphasis was given to statistical analysis or to extrapolating results to areas beyond the location where the research was conducted.

In the 1980s, there was considerable experimentation with adapting both researcher-led and participatory on-farm research methods to agroforestry (Scherr, 1991b,c). During the 1990s the International Centre for Research in Agroforestry (ICRAF) and other organizations devoted much effort to the design and testing of methods for on-farm research for different types of practices, and with an explicit view to understanding adoption potential. As ICRAF researchers gained experience in on-farm research and technology development in agroforestry, their approach has been refined. Assessment of adoption potential was observed to be multifaceted, requiring an understanding of biophysical performance under farmers' conditions, profitability from the farmers' perspective and its acceptability to farmers (in terms of both their assessment of its value and their willingness and capacity to access the information and resources necessary to manage it well). On-farm research should make it possible to define the 'boundary conditions' for a particular practice, that is, the biophysical and socioeconomic circumstances under which the practice is likely to be profitable, feasible and acceptable to farmers, and thus adopted by them.[1] Furthermore, it was realized that on-farm research offers researchers, extensionists, policy makers and farmers themselves an opportunity to learn important lessons about achieving effective dissemination of agroforestry practices, as well as feedback on further research priorities (Table 2.1).

The evolving approach outlined in this chapter includes elements of various on-farm research and adoption assessment approaches. During participatory appraisals and surveys, researchers and farmers identify farmers' problems and needs and select practices to test in on-farm trials, some of which may be researcher-designed and some of which may be farmer-designed. These trials, and the analyses that researchers and farmers conduct together, form the basis for determining whether farmers on a wider scale will adopt the practices.

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[1] The concept 'boundary conditions' complements the term 'recommendation domain', commonly used in farming systems research. A recommendation domain is a roughly homogeneous group of farmers with similar circumstances for whom we can make more or less the same recommendation (Byerlee and Collinson, 1980). Recommendation domains are defined in the early stages of the research process and technologies are sought that are appropriate for them. Once a technology is found that benefits farmers at particular sites in a recommendation domain, it is useful to try to assess that technology's boundary conditions.

Table 2.1. Framework for assessing the adoption potential of an agroforestry practice.

Factors	Key questions
Biophysical performance	Does the practice result in higher yields, lower variability and provide the anticipated environmental services? Are these biophysically sustainable?
Profitability	Is the practice profitable to the farmer as compared with alternative practices? How variable are returns, and how sensitive to changes in key parameters?
Feasibility and acceptability	Do farmers have the required information and resources, and are they willing and able to establish and manage the practice and cope with problems that occur? Do farmers perceive significant advantages of using the technology?
Boundary conditions	Under what circumstances (e.g. biophysical, household, community characteristics, market conditions) is the practice likely to be profitable, feasible and acceptable to farmers?
Lessons for effective dissemination: ● extension ● policy	What does farmer feedback suggest will help interest farmers in the practice? What type of extension support do they need most? What types of changes in institutional arrangements, public investments or market conditions would enhance the adoption potential of the practice?
Feedback to research and extension	How do farmers modify the practice? What does farmer experience suggest are research priorities for further modification and development of the practice?

On-farm research has been seen as especially critical in agroforestry technology development. This is due to the poor understanding of farmers' agroforestry strategies, lack of empirical information about on-farm agroforestry practices, agroforestry system complexity and variability (in terms of objectives, components, management and ecological interactions), the longer technology cycle and period required for farmer and researcher assessment and the lack of scientifically validated technologies (Scherr, 1991a). Many of these same features characterize other 'sustainable agriculture' and natural resource management practices and research challenges, with their greater spatial and temporal complexity. Thus many of the lessons learned from on-farm agroforestry research should be highly relevant to broader efforts in sustainable agricultural development.

Objectives of On-farm Experimentation

On-farm experimentation has several different objectives. First, it permits farmers and researchers to work as partners in the technology development process. The more, and the earlier, that farmers are involved in the technology development process, the greater the probability that the practice will be adopted. On-farm trials are important for getting farmers' assessment of a practice, their ideas on how it may be modified and for observing their innovations. Assessments are likely to vary and may be associated with particular biophysical (e.g. soil type) or socioeconomic (e.g. wealth status) circumstances. Farmers' innovations often serve as a basis for new research or for modifying recommendations (Stroud, 1993; van Veldhuizen *et al.*, 1997).

Secondly, on-farm testing is useful for evaluating the biophysical performance of a practice under a wider range of conditions than is available on station. This is especially important because soil type, flora and fauna on research stations are often not representative of those found on farms in the surrounding community.

Thirdly, on-farm trials are important for obtaining realistic input–output data for financial analysis. Financial analyses conducted on on-station experiments are unreliable because yield response is often biased upward, because estimates of labour use by station labourers on small plots are unrepresentative, and because operations often differ, as when tractors instead of oxen or hoes are used for preparing land.

Fourthly, on-farm testing provides important diagnostic information about farmers' problems. Even if diagnostic surveys and appraisals have already been conducted, researchers can still learn a great deal about farmers' problems, preferences and livelihood strategies from interacting with them in on-farm trials. Trials have important advantages over surveys in that they are based on what farmers do rather than on what they say.

Types of On-farm Trials

On-farm trials can thus provide critical information for determining the biophysical performance, profitability and acceptability of agroforestry, i.e. adoption potential. However, the design of a trial depends on its specific objectives.

Assessment of biophysical performance requires biophysical data on the products and services that the technology is planned to produce. These are likely to change with different adaptations of the technology as might occur if farmers were asked to manage them. To prevent such possible variation, trials designed to assess biophysical performance should be controlled in order to replicate specific technology designs. The trials should also be implemented in a way that farmers' willingness and ability to establish and maintain the trials does not affect the outcome. Thus trials to assess biophysical performance need a high degree of researcher control in both design and implementation.

The assessment of profitability requires biophysical data (to estimate returns), that must be generated from standardized experiments. However, the financial analysis also requires realistic input estimates, of which labour poses most difficulties. Realistic data can only be obtained if farmers manage the trials to their own standards. Thus profitability objectives require trials in which researchers have considerable input into the design but farmers are responsible for implementation. The objectives of assessing feasibility and acceptability require data on farmers' assessments and adaptations of the technology. These can only be assessed if farmers are left to experiment with little researcher involvement.

There are many different ways of classifying on-farm trials (Okali *et al.*, 1994). The differing requirements of the objectives of biophysical performance, profitability and acceptability mean it is helpful to classify trials according to the balance of researcher and farmer involvement in their design and implementation. The classification used in this volume involves three types of trials and draws upon Biggs (1989).

Type 1, trials designed and managed by researchers

These trials are simply on-station trials transferred to farmers' fields. They are useful for evaluating biophysical performance under farmers' conditions and require the same design rigour as on-station research with regard to treatment and control choice, plot size, replication and statistical design. In the design stage, researchers need to consult the farmer on the site's homogeneity and history. If possible, they should observe a crop in the field before establishing a trial.

Because type 1 trials take place on farmers' fields, trial results are generally more representative of farmers' biophysical conditions than are on-station trials (Shepherd *et al.*, 1994). More accurate information may be obtained on interactions between the biophysical environment and management; for example, how different species in an improved fallow trial compare on different soil types.

Type 1 trials are usually more expensive and more difficult to manage than on-station trials; they often involve renting land from farmers and bringing labourers from the station to implement them. Farmers' assessments are an important objective of type 1 trials; as with on-station trials, it is useful to get farmers' feedback on the different treatments (Sperling *et al.*, 1993; Franzel *et al.*, 1995).

Type 1 trials were conducted on three of the technologies reported in this volume. The numbers of farmers per trial was small, 1–5, because of the relatively high cost of conducting these trials. For the other technologies, on-station trials provided technical information before starting farmer-managed trials.

Type 2, trials designed by researchers but managed by farmers

Here, farmers and researchers collaborate in the design and implementation of the trial. The trial is labelled 'researcher-designed', because it follows the conventional scientific approach to conducting an experiment: one or more test treatments are laid out in adjacent plots and compared to one or more control treatments. Researchers consult farmers on the design of the trial and each farmer agrees to follow the same prototype (or chooses one of several possible prototypes), so that results may be compared across farms. Farmers are responsible for conducting all of the operations in the trial.

In type 2 trials, reliable biophysical data over a broad range of farm types and circumstances are sought. The trials also facilitate the analysis of costs and returns; inputs, such as labour, and outputs, such as crop yields, are relatively easy to measure because plot size is uniform and known. The trials are also useful for assessing farmers' reactions to a specific practice and its suitability to their circumstances. Farmers are encouraged to visit each other's trials and to conduct group field days to assess the practice at different stages of growth.

Type 2 trials were conducted in four of the five case studies reported in this book. In most cases, the number of farmers per type 2 trial ranged from 20 to 50. Trials usually started off small, with fewer than 10 farmers, in order to learn from experience. They were then modified and expanded in the following year.

Type 3, trials designed and managed by farmers

In type 3 trials, farmers are briefed about new practices through visits to field stations or on-farm trials. They then plant and experiment with the new practices as they wish. They are not obliged to plant in plots or to include control plots. Researchers monitor the farmers' experiments, or a subsample of them, focusing in particular on their assessment of the new practice and their innovations. In addition, farmer-to-farmer visits and meetings are useful so that farmers can compare their experiences and assessments with others. Any farmers experimenting with a new practice could be said to have a type 3 trial, regardless of whether they obtained planting material and information from researchers, other facilitators or other farmers. This 'hands-off' approach, which assumes that farmers know best how to test a new practice on their own farms, is supported by some in the literature (Lightfoot, 1987). Others emphasize training farmers to conduct trials following scientific principles, such as replication and non-confounding of treatments (Ashby *et al.*, 1995).

Three of the case studies in this book involve the use of type 3 trials. The number of type 3 trials was often quite high. In eastern Zambia in 1997, extension services and NGOs were helping about 2800 farmers to test improved tree fallows (Chapter 3). Researchers coordinated the monitoring of small samples of farmers, 60–110, depending on the task and available staff.

Suitability of Trial Types for Meeting Objectives

The suitability of the different trial types for differing objectives is summarized in Table 2.2. Suitability involves both the appropriateness of the trial for collecting the information and the ease with which it can be collected. Different types of trials are suited to different types of analyses. Biophysical measurements are most meaningful in type 1 and 2 trials; they are less useful in type 3 trials because each farmer may manage the practice in a different manner. Type 2 trials are well suited for collecting parameters (e.g. labour use) for financial analysis; such data are difficult to collect in type 3 trials because plot size and management vary. The data can

Table 2.2. The suitability of type 1, 2 and 3 trials for meeting specific objectives.[a]

Information types	Type 1 trial: researcher-designed, researcher-managed	Type 2 trial: researcher-designed, farmer-managed	Type 3 trial: farmer-designed, farmer-managed
Biophysical response	H	M	L
Profitability	L	H	L
Acceptability			
Feasibility	L	M	H
Farmers' assessment of a particular prototype[b]	L	H	M
Farmers' assessment of a practice[b]	L	M	H
Other			
Identifying farmer innovations	0	L	H
Determining boundary conditions	H	H	H

[a] H, high; M, medium or variable; L, low; 0, none. The suitability involves both the appropriateness of the trial for collecting the information and the ease with which the information can be collected.

[b] By particular prototype, we mean a practice that is carefully defined. For example, a prototype of improved fallows would include specific management options such as species, time of planting, spacing, etc.

be collected in type 1 trials but will be less relevant to farmer circumstances; yield response to new practices tends to be biased upward and labour use, measured using labourers hired by researchers and working on small plots, is unrepresentative of farmers' labour use.

Farmers' assessments are more accurate in type 3 trials for several reasons. Because farmers control the experimental process, they are likely to have more interest and information about the practice. Furthermore, because farmers in type 3 trials usually have less contact with researchers than farmers in other types of trials, their views of a technology are less influenced by researchers' views. Finally, whereas it is often necessary to provide inputs to farmers in type 2 trials to ensure that results are comparable across farmers, no inputs, with the possible exception of planting material, are provided in type 3 trials. Thus farmers' views in type 3 trials are more likely to be sincere than in type 2 trials, where positive assessments may simply reflect the farmers' interest and satisfaction in obtaining free inputs. For example, in the hedgerow intercropping trial in western Kenya (Chapter 5), 50% of the farmers claimed that hedges increased crop yields whereas technicians noted yield increases on only 30% of the farms; the technicians claimed that the difference was due to farmers trying to please researchers.

Finally, all three types of trials play a potentially important role in defining the boundary conditions for the technology. Which type of trial is best depends on the participants' (facilitators' and farmers') objectives and the particular circumstances.

Continuum and sequencing of trial types

The different types are not strictly defined; rather they are best seen as points along a continuum. For example, it is common for a trial to fit somewhere between type 2 and type 3, as in the case where farmers agree to test a specific protocol (type 2) but over time, individuals modify their management of the trial (type 3). For example, in the hedgerow intercropping trial in Chapter 5, farmers planted trials in a similar manner but most later modified such variables as the intercrop, pruning height and pruning frequency.

The types of trials are not necessarily undertaken sequentially; researchers and farmers may decide to begin with a type 3 trial, or to simultaneously conduct two types of trials. For example, in the case of upper-storey tree trials in western Kenya (Chapter 6), no type 1 or type 2 trials were needed, because much was already known about the growth of the trees in the area. Rather, farmers planted type 3 trials, in order to assess the performance of the species on their farms. In Zambia, many farmers planted type 2 and type 3 improved fallow trials in the same year (Chapter 3). They tested a prototype in their type 2 trials and used type 3 trials either to extend their plantings or to test a modification of the practice. Researchers wished to assess biophysical response in the type 2 trials and to monitor farmers' innovations in the type 3 trials. Type 2 and 3 trials often generate questions or sharpen hypotheses about biophysical factors which can then be best evaluated through type 1 on-farm or on-station trials. In western Kenya, several researcher-managed trials to explore specific aspects of improved fallow function and design were set up following farmer-managed trials (Chapter 4).

Handling complexity

'Complexity' involves the number and diversity of components (intercropping trees and crops, as opposed to trees or crops in pure stand), the length of the cycle of the technology (3+ seasons as opposed to single-season cycles), and the size of the trial (whether it takes up more than 10% of a farmers' cultivated area). In a trial comparing annual crop varieties, it is often possible to combine biophysical and socioeconomic objectives because, according to the above definition, the trial is not complex. However, most agroforestry trials are complex, and thus different trial types are needed to meet the differing objectives.

The type 1–2–3 classification system is useful for highlighting the different objectives for conducting on-farm trials and for illustrating that different types of trials are suitable for particular types of assessments (Table 2.2). For example, researchers often want to use an on-farm trial to collect information on biophysical responses and farmer assessment. But these objectives are often conflicting. A high degree of control is needed to collect accurate biophysical data whereas farmer assessment is most valid when individual farmers are allowed to use the practice in the manner they see fit. Researchers and farmers interested in biophysical and socioeconomic data may be better off conducting type 1 trials for biophysical data and type 3 trials for socioeconomic assessment, rather than a single type 2 trial that tries to do both. The more complex the trial or technology, the less effective a type 2 approach is likely to be for both biophysical and socioeconomic assessments.

Organization of Participatory On-farm Trials

Key aspects of the organization of participatory on-farm trials (principally types 2 and 3) discussed in this section include: farmer and technology selection, the village approach to technology testing, trial backstopping and supervision, adaptive research and dissemination teams, and provision of incentives.

Farmer and technology selection

The selection of farmers for the trials reported in this volume generally took place through the assistance of extension staff (eastern Zambia) or farmer groups (western Kenya). Interested farmers were asked to volunteer and participants were selected so as to represent a range of the types of different farmers in the area, including large and small farmers (all sites), male and female farmers (all sites), and farmers preparing land with oxen and hoe (eastern Zambia).

Providing farmers with different options to test was a key feature of the trials, for several reasons. Different farmers had different circumstances and preferences; farmers wanted to diversify; and any single option could have failed. For example, in eastern Zambia, farmers selected among six improved fallow practices for their type 2 trials (Chapter 3). In type 3 multipurpose tree trials in western Kenya, farmers chose among five tree species but were encouraged to plant all five so as to permit a comparison among them (Chapter 6).

To ensure appropriate analysis, interpretation and extrapolation of results, it is important to specify or characterize the technology design in detail. Key design elements considered in the case studies include: objectives (priority outputs or environmental services expected), site characteristics (location in the landscape, soil type, field size), components (tree crop/provenance/variety; crop species/variety; livestock species/breed), method of tree establishment (and re-establishment or coppicing), spacing and sequencing of components (including rotations), and tree and crop management practices.

Village approach to technology testing

A common approach to on-farm technology testing has been to identify a relatively small number of farmers in many different villages across a large area who are willing to undertake experiments. This 'scattered farmer' approach can be useful when key socioeconomic or biophysical factors such as farm size or soil type vary mainly across villages. In the mid-1990s, ICRAF researchers began to experiment with the ‘village approach’ to technology testing, that concentrates efforts in a relatively few contrasting but representative sites. The key feature of the approach is that all villagers are given equal access to information and germplasm, encouraging wider participation. As such, it is most appropriate for type 2 or 3 trials. The advantages of the village approach are:

- a reduction in monitoring costs per farmer through higher concentration of farmers;
- a wider participation ensures that different household types are involved in testing and development;
- the possibility to study inter-farm linkages and higher-scale effects (e.g. pest and disease outbreak, income from labour hiring) which require identification prior to wide dissemination;
- the mitigation of intra-village jealousies and the promotion of improved interaction with researchers;
- the involvement of village-based organizations, such as farmer groups, in the testing and dissemination process; and
- the spread of information across farms within the village is facilitated.

There is one disadvantage to the village approach: the more or less equal distribution of information and high participation rates make the study of diffusion processes within the village more difficult.

With a limited number of villages, it is important that they represent a large percentage of the target population (e.g. representing major agroecological zones). With the large number of households testing technologies, researchers need to select a smaller number of households for detailed monitoring. These should represent different types of households, for example, poor, moderate and well-off households; male- and female-headed households; and those using oxen and hoe for land preparation. With concentration of testing in a relatively small number of sites, it is important to establish a communications strategy as part of the research and for diffusion. Effective communication is needed within the community, between researchers and the community, and, most important, from the village to other villages.

Trial supervision and backstopping

At all sites, facilitators provided technical backstopping to farmers in types 2 and 3 trials, and helped lay out type 2 trials. In eastern Zambia, facilitators included researchers, extensionists and NGO staff. In central Kenya, researchers and extensionists were involved; and in western Kenya, until the mid-1990s, only researchers were involved. Facilitators also conducted the monitoring surveys during and following the trials. In most cases research technicians collected information; extension staff often participated (central Kenya and Zambia), or enumerators were hired (western Kenya).

Adaptive research and dissemination teams

Participatory on-farm experimentation and dissemination are better viewed as points along a research–development continuum than as separate activities. After all, when farmers participate in on-farm trials some degree of technology dissemination always takes place. Similarly, when a new technology is disseminated, each farmer trying the technology for the first time can be said to be experimenting with it. Therefore, at all case study sites, research, extension, NGOs and farmer groups have established partnerships called 'adaptive research and dissemination teams' (ICRAF, 1997). The teams plan, implement and evaluate on-farm research, training and dissemination activities (Cooper, 1999). Extension and NGO staff have much to offer and can benefit greatly from participating in on-farm research. Their involvement reduces the costs of the research and their knowledge of local circumstances improves the design and quality of the research. They also benefit from greater interaction with researchers and are likely to be more knowledgeable about a practice if they are involved with farmers in its development in on-farm trials. Similarly, it is important for researchers to be involved in disseminating practices, in order to assess adoption and impact, to obtain feedback from farmers and to identify issues for further research. One of the most important impacts of the teams is that all partners develop a sense of involvement, enthusiasm and ownership of promising innovations. A critical task of the team is to define clearly the roles and responsibilities of the different actors in on-farm research and dissemination.

The most developed adaptive research and dissemination team discussed in this volume is in eastern Zambia (Chapter 3). Seventy-five representatives of research, extension, NGOs and farmer groups meet 1–2 times per year to review progress and plan activities for testing and disseminating improved fallows and other soil fertility measures. The number of farmer-experimenters has increased from fewer than 10 in 1993–1994 to about 200 in 1994–1995, and to about 3000 in 1997–1998. The mechanisms in place for disseminating the practice and for providing feedback on performance will contribute greatly to the impact that improved fallows achieve in Zambia and elsewhere.

Provision of incentives

Farmers did not receive any financial or material incentives for participating in the trials. Farmers conduct their own research; there should thus not be any need to provide them with incentives to participate in collaborative trials with researchers. Moreover, giving incentives has four important disadvantages. It promotes a dependency relationship between facilitator and farmer, instead of a partnership; it sets an unfortunate precedent for other facilitators who come later and do not have the resources for offering incentives; it may create conflict, because in most programmes incentives cannot be offered to all farmers; and it biases farmers' assessments, as they may tend to give more positive opinions in the hopes of obtaining more free inputs.

However, most practitioners would agree that it is necessary, and even ethical, to provide free of charge the experimental variable, such as seeds or seedlings for a new tree species being tested. Unfortunately, this may bias farmers' assessment. Some practitioners have also found that farmers value their visits as a social benefit and may give positive assessments merely to encourage them to continue their visits (Chapter 5). Where the farmer's role expands far beyond that of a trial participant, to active involvement in dissemination, demonstration, etc., which demands significant time unrelated to on-farm experimentation, it may be appropriate to treat and remunerate such people as staff or consultants. Such arrangements are especially relevant where there are no extension agents.

Assessing Adoption Potential

This section focuses on methods for assessing biophysical performance, profitability, acceptability and boundary conditions. The use of on-farm trials to draw lessons for extension, policy and research is also described. Criteria for selecting which methods to use are also reviewed. The methods used in each case study for assessing profitability and acceptability are shown in Table 2.3.

Biophysical performance

Assessing the biophysical performance of a technology on-farm uses much the same general methods as used in analysis of on-station trials (see, for example, Little and Hills, 1972; Mutsaers *et al.*, 1997). The products and services of the technologies are measured and compared among different options. Great care must be taken in assessing whether all sites should be included in a particular analysis, especially when data are from trials managed by farmers. For example, in an analysis of an improved fallows trial, it would be important to exclude sites where a trial plot was shaded by adjacent shrubs, but the control plot was not.

Often the objectives in on-farm assessment include identification of environment (e.g. soil type) by technology interactions. Analysis then requires determining how the differences between technology options change with changing environment (Hildebrand and Russell, 1996). It is therefore necessary to measure the key environment variables. These key variables must be identified before the trial starts, as many (e.g. rainfall or frost incidence) cannot be measured after the trial has ended.

The most difficult issue in assessing biophysical performance is ensuring that the comparisons being made are representative of those that farmers would make. For example, on-station hedgerow intercropping trials showed a strong fertility response to the technology; type 2, on-farm trials did not, probably because farmers were unable to prune the hedges in time to avoid competition between the trees and adjacent crops (Chapter 5). On the other hand, yield responses obtained in type 1 improved fallows trials in Zambia were only 20% higher than those obtained

Table 2.3. Types of assessments conducted in analyses of the profitability and acceptability of selected agroforestry practices.

	Profitability				Acceptability							
Practices	Break-even analysis	Partial budget	Enterprise budget	Farm model	Resource budget	Evaluation of quality of practice	Survey of farmer problems	Risk assessment	Monitoring expansion	Matrix ranking	Farmer assessment survey	Decision trees
Improved fallows, eastern Zambia	*		*	*	*	*	*	*	*		*	
Improved fallows, western Kenya	*		*	*	*	*	*	*			*	
Hedgerow inter-cropping, western Kenya	*		*		*	*	*	*	*		*	*
Agroforestry trees, western Kenya						*	*		*	*	*	
Fodder trees, central Kenya	*	*			*	*	*	*	*		*	

in type 2 and type 3 trials, indicating that the type 1 trials were probably not managed much differently than the type 2 and type 3 trials (Kwesiga *et al.*, 1999). In type 1 and 2 trials, researchers need to ensure that the site, treatments compared, and trial management are each similar to those of the farmers for whom the practice is targeted.

Long-term monitoring of trials is likely to be required to assess the biophysical sustainability of different practices, in terms of maintaining soil quality, managing pests and diseases, etc. Assessing the sustainability of a practice involves identifying key elements that will be needed over the long term, at least 20 years, to ensure that the practice will remain feasible, profitable and acceptable to farmers. For example, high-yielding maize following improved fallows in eastern Zambia will draw down stocks of soil phosphorus. Thus it is likely that over the long term, improved fallows will have to be supplemented by phosphorus fertilizer in order to sustain high maize yields. The sustainability of an agroforestry practice may involve a range of different variables, such as seed production and distribution, soil nutrient balance, and pest and disease management.

Profitability

Profitability issues can usefully be divided into three categories. The first concerns whether the financial net benefits of the new practice are greater than for alternative practices, including those that farmers currently use. Secondly, it is important to assess the variability of benefits across farmers and seasons and the sensitivity of the results to changes in key parameters. Thirdly, benefits are appraised relative to total household income in order to assess their potential for contributing to improved household welfare.

Greater financial benefits may arise through increased biophysical productivity or through reduced input costs. Biophysical productivity and financial net benefits were assessed in the case studies by comparing results on treatment plots with those on control plots, which represented farmers' current practices. For example, researchers assessed the impact of hedgerow intercropping by comparing crop yields and net benefits on hedge plots with those on plots without hedges (Chapter 5). Where it was not possible to assess productivity responses, as in the case study of improved fallows in western Kenya (Chapter 4), the yield increases required to break even, that is, to cover the costs of planting and maintaining the practice under different assumptions, were calculated. Break-even analysis was also conducted in three other case studies to show the minimum returns needed to cover the costs of establishing and maintaining the practice (Chapters 3, 5 and 7). Break-even analysis thus provides useful information about profitability long before the yield response of a practice is known.

In all cases, financial analyses were based on the actual costs and returns that farmers face. Partial budgets were drawn up for those practices that had limited impacts on the costs and returns of an enterprise, as in the case of *Calliandra calothyrsus* as a fodder for dairy cows (Chapter 7). A partial budget is a technique for assessing the benefits and costs of a practice relative to not using the practice. It thus takes into account only those changes in costs and returns that result directly from using the new practice (Upton, 1987).

Where a practice was expected to have substantial financial effects, enterprise budgets were used. Here, all of the enterprises' costs and returns for a single period, a growing season or a year, were calculated. Prices were collected from local markets. Detailed information on labour use among participating farm households was collected using a range of methods, including farmers' recall just after a task was completed and monitoring of work rates through observation (Franzel, 1996). Collecting data on labour use in on-farm trials is problematic: monitoring farmers while they are in the field introduces an important 'observer' bias, while asking farmers to recall how much time they spent at a specific task is often unreliable. We found that interviewing farmers in the field just after a task was completed was the best way to collect data on labour use. Moreover, we found that only researchers could collect accurate labour data; the task was too complex to be relegated to enumerators. Finally, not all farmers could provide accurate data on labour used; the sample must be purposive based on the confidence that the researcher has in the quality of data being provided.

Net returns to farmers' production factors (land, labour and capital) are calculated by subtracting purchased inputs from the production value. After subtracting farmers' capital inputs, which are generally minor, the net returns are allocated among farmers' land and labour by valuing one factor at its opportunity cost and by attributing the remainder to the other factor. This permits a calculation of the net returns to land, which is relevant for farmers whose most scarce resource is land, and the net returns to labour, relevant for those who lack labour. Net returns to capital for agroforestry practices were often extremely high or infinite because little or no capital was used in implementing them. This finding explained the attractiveness of many of the options as the alternatives, such as fertilizer to improve crop yields or dairy meal concentrate to increase milk yields, were very expensive for farmers.

Data for a single period are usually inadequate for evaluating agroforestry. Therefore, cost–benefit analyses, also called investment appraisals (Upton, 1987), were developed in most of the case studies for estimating resource inputs, costs and benefits over the lifetime of the investments (2–6 years). Average values for costs and returns across the sample were used to compute net present values. Also, net present values were calculated for each farmer, based on his/her particular costs and returns. This latter method permitted a better understanding of the variation across farms in returns, and thus the risk of the practices.

To assess the actual changes in annual income generated by a new practice, farm models were developed in which the farm was partitioned to contain specified portions of land devoted to each phase (corresponding to a season or year) of the technology. For example, in the model of improved fallows in Zambia (Chapter 3), the farm was assumed to have equal portions of area in each of the practice's four phases: planting of the improved fallow (year 1), maturing of the fallow (year 2), the first post-fallow maize crop (year 3), and the second post-fallow maize crop (year 4). The net returns of this farm were compared to two other farms having the same amount of labour (the main constraining resource), one planting fertilized maize continuously without fallow and the other planting unfertilized maize continuously without fallow. The model was thus useful for estimating the impact of improved fallows on annual net farm income and maize production.

Acceptability and feasibility

To assess the adoptability of a technology, it must be analysed from the farmers' perspective, which means much more than its biophysical performance and profitability (Scherr, 1995). In particular, it must be feasible for farmers to plant and maintain, and it must be considered acceptable and desirable. Feasibility and acceptability are grouped together because the feasibility of a technology is dependent on its perceived value. For example, labour bottlenecks that appear when farmers attach a low value to an activity may disappear when the farmers' perception of the value increases.

Feasibility

Farmers' ability to plant and maintain agroforestry technologies depends on three factors: available resources (land, labour and capital), whether they have the required information and skills, and whether they are able to cope with any problems that arise. Several tools are available for assessing the feasibility of a practice in on-farm trials. Resource budgets may be assembled to compare the availability of the resource with the needs of the practice. For example, in Chapter 7, the number of calliandra trees that can be planted on boundaries and contours is compared to the numbers needed to feed a cow. In Chapter 5, household labour use in different weeks of the year is compared to the labour requirements of hedgerow intercropping. If the peak period for labour use of a new practice coincides with that of the household, farmers may have difficulty implementing the practice.

Another means for assessing feasibility is to evaluate the general biophysical performance of the technology as planted and maintained by the farmer. This assessment may involve quantitative data, such as survival rates of seedlings planted, or qualitative ratings, such as technicians' assessment of the amount of biomass in an improved fallow. Both are used in assessing the feasibility of improved fallows in Zambia (Chapter 3). Where performance is not as high as expected, technicians and farmers are asked their opinions as to what went wrong. Possible reasons might include:

- inappropriate biophysical conditions, such as soil type;
- lack of labour or other resources;
- lack of information or skills;
- incompatibility of gender with a particular task, as in cultures where females do not prune trees; or
- inability to cope with a problem that arose, such as pests, diseases or inadequate rainfall.

Finally, farmers may be interviewed in informal or questionnaire surveys about the problems they experienced implementing the trial. Their ranking of the importance and frequency of problems provides useful information on feasibility (Chapter 3).

Acceptability

Acceptability includes profitability, feasibility and a range of criteria that are difficult to quantify, such as risk, general compatibility with farmers' values and farmers' valuation of benefits, such as a tree's ornamental value or its use as a boundary marker.

Risk was assessed by: (i) measuring variability in the returns of individual farmers; (ii) conducting minimum returns analysis (CIMMYT, 1988), in which the average of the lowest 25% of the net benefits of each treatment are compared; and (iii) by conducting informal interviews with farmers. The interviews were particularly useful for understanding farmers' views towards risk. For example, in Zambia, farmers stated that even though fertilizer could be very profitable in a year of good rainfall, the risk of losing their investment in a year of poor rainfall prevented them from using the technology. Sensitivity analysis was conducted to assess the effect on net present value of changes in key parameters, such as prices of inputs and outputs, changes in input–output coefficients and changes in the discount rate. By assessing the effects of likely future market patterns on these sensitive parameters, the economic sustainability of the practice can be evaluated.

Asking farmers whether a practice was acceptable did not prove to be very useful; nearly all farmers gave positive assessments, probably because they felt that criticizing a practice would be insulting to the researcher. Rather, acceptability is best ascertained by monitoring whether farmers continue using and expand their use of a practice, and whether neighbouring farmers take it up. Important indicators of acceptability include the numbers of times farmers expanded their planted area, the numbers of trees planted and area planted per expansion, and the numbers of farmers to whom the original experimenters gave or sold planting material. Farmers' expansion of practices was assessed in four of the case studies and farmer-to-farmer dissemination was assessed in three of the case studies.

But using expansion or adoption as a proxy for acceptability is problematic for three reasons. First, in some cases, farmers may be interested in expanding but unable to do so because they lack access to critical information or inputs. Secondly, farmers may expand use of a practice not because they like it but because they expect to receive other benefits, such as free inputs or employment. Thirdly, agroforestry practices take a long time to evaluate and it was reasonable to assume that a farmer needed to experience the full cycle of a technology (4–5 years in the case of improved fallows in Zambia) before deciding whether to continue using it. Any expansion that took place before the end of the cycle could arguably have been called an expansion in testing rather than an indication of acceptability.

Assessments of farmers' preferences among alternative options can provide useful feedback for research and extension, especially when they are quantified. For example, in western Kenya, farmers used an indigenous board game, *bao*, to score upper-storey trees on criteria important to them (Chapter 6). In this variant of matrix ranking (Ashby, 1990), branches of each tree were laid out on the ground. For each criterion, farmers rated the tree by putting one to five seeds in the pocket next to each branch – five being a high rating and one being a low rating. In contrast with questionnaires, which farmers find tedious, the *bao* game can be used for collecting quantitative data on farmer assessments in an accurate, entertaining, yet statistically rigorous manner. It also allows farmers to assess their ranking visually and perhaps, on reflection, make changes (Franzel, 2001).

Farmer assessment surveys may be implemented to find out what farmers perceive as the advantages and disadvantages of a practice. These surveys may be informal, involving individual or group interviews, or formal, using a questionnaire administered by technicians. As with matrix ranking, they can be conducted at various times to find out farmers' assessments at each stage of the practice. Informal and formal farmer assessment surveys were conducted in all five of the case studies.

Hierarchical decision trees may be used to model complex decisions, such as whether or not to expand the use of hedgerow intercropping in western Kenya (Chapter 5). This method is useful for explaining the decisions that farmers make, by breaking them down into a series of subdecisions and mapping each farmer's decision path along the branches of the tree. Questions needed for decision trees can be included in both informal and formal surveys (Gladwin, 1989).

Farmer workshops are also an important means to find out farmers' views on the technologies and their potential impacts (Kristjanson *et al.*, 2002). To facilitate the exchange of information, farmers divide into small working groups, each addressing a specific issue. The workshops provide information on important effects of practices, 'invisible effects', such as secondary effects on other enterprises, indicators that farmers would use to evaluate the impact of adoption and clarification of possible constraints to adoption. Whereas in many cases the information provided by farmers in such workshops is what researchers might have anticipated, it is possible that important new information may be obtained. For example, a key finding in the Zambia workshop was that many farmers intended to use improved fallows not so much to increase the total amount of maize they produced, but rather to increase maize yields and reduce the area they devoted to maize, freeing up land for growing cash crops (Chapter 3). Farmer workshops can also be an important means for farmers to discuss issues related to new practices, exchange opinions and lessons, and come to consensus or clarify their differences.

Defining boundary conditions

The boundary conditions of a practice are defined by identifying the variables that are most important in determining who will and will not use the practice. Information on variables affecting biophysical performance, profitability, feasibility and acceptability are thus critical. The variables should be fairly easy to identify; otherwise, they will not be useful in distinguishing among farmers or areas.

Biophysical variables used for assessing boundary conditions in the case studies examined in this book included altitude (a proxy for temperature), rainfall, soil type and depth, and soil nutrient status. Critical socioeconomic variables included wealth, gender and farm size. The two groups of variables were found to be useful in different ways. Biophysical boundary conditions were often used to exclude a component or practice from particular areas. For example, calliandra did not perform well on acidic soils. Socioeconomic boundary conditions, on the other hand, were used mainly to inform researchers, extensionists and farmers about the appropriateness of choices. For example, the finding that improved fallows have a higher adoption potential among males than females is important for identifying and alleviating the constraints that women face or for understanding the need to identify alternative technologies for them (Chapter 3).

Some boundary conditions may be assessed through secondary data, as when it is known that a particular tree species does not perform well outside a certain altitude range. Modelling is also useful, as when a financial analysis shows that a practice is profitable only when the opportunity cost of labour is above a certain level (Chapter 4). But in most cases, assessments must be based on empirical data concerning where the practice performs well and who adopts it. Biophysical variables often vary spatially; type 1 trials are especially useful for assessing the biophysical boundary conditions of a practice (Chapter 3). Type 2 and type 3 trials are less reliable because variation in management practices across site may confound the results on biophysical performance.

The farm and household characteristics that were examined most frequently in the case studies, for their association with testing and continued use of a practice, included gender, household type, wealth level, farm size, soil type and soil nutrient status. These were investigated by testing the statistical association between individual variables and performance, as in Zambia, where farmers used a wealth ranking exercise to classify themselves into different wealth categories. They found that high-income households tended to use improved tree fallows more than low-income households (Chapter 3). In western Kenya, multiple regression was used to assess the relative importance of selected variables affecting farmers' preferences among upper-storey trees (Chapter 6). The small number of farmers that could be monitored in a type 2 trial, usually fewer than 50, limited the degree to which factors affecting adoption potential could be examined rigorously.

Drawing lessons for effective dissemination and diffusion

The multiyear dissemination, testing and evaluation of agroforestry practices with farmers was found to provide valuable lessons for the subsequent design of effective promotion efforts by extension organizations. Farmers' own innovations were identified in on-farm trials that can increase productivity and adoption potential. For example, low-cost tree establishment methods such as bare-rooted seedlings significantly reduced production costs and increased profitability. In establishing improved fallows, intercropping the trees with crops during the first year may be more acceptable to farmers than planting them in pure stands (Chapter 3).

Several methods are available for identifying 'best-bet' modifications of practices:

- participatory informal appraisals with farmers to determine their assessment of practices and what changes they propose (Ashby, 1990);
- visits to farmers' fields to identify modifications that farmers have tested;
- screening new practices and species from other sites for their relevance to farmers' needs and circumstances; and
- *ex ante* quantitative data on costs and returns of different modifications and practices.

By working closely with farmers during the technology development process, extensionists can identify effective 'selling points' for the new technologies, for different groups of farmers. The process of identifying boundary conditions helps with the formulation of extension materials and development of strategies for targeting different groups. The advantages of individual versus group or village approaches can be evaluated under different circumstances, prior to the launching of major dissemination initiatives.

Drawing lessons for policy support

Public policies and institutions can influence the feasibility, profitability and acceptability of agroforestry practices (Chapter 8). For example, public subsidies and seed distribution networks affect the price of seedlings, which in turn influences the scale of tree-planting by farmers. Land tenure legislation and local land-use regulations influence farmers' selection of sites and niches for tree planting. The design and targeting of agroforestry extension programmes influences the dissemination of information critical for farmer adoption.

On-farm research, particularly large-sample, type 3 trials, can provide both valuable diagnostic information about possible policy constraints and benefits, and also the opportunity to assess particular policy instruments on an experimental basis (such as a new subsidy, product marketing approach, type of farmer organization or a locally agreed land-use regulation). Depending upon the issue and the sample size, various methods can be used to obtain policy-relevant insights:

1. Direct observation and participant feedback about policy or institutional factors that constrain adoption or expansion of agroforestry. An example is the identification of the constraints to on-farm seed production for fodder trees and the need for seed bank development, described in Chapter 7.
2. Regression analysis of factors associated with adoption, to assess the importance of existing policy and institutional factors (for example, plot tenure status) and to identify factors that could be affected by policy action.

3. Sensitivity analyses from cost–benefit studies can be used to estimate the magnitude of the potential impact of policy changes (such as planting subsidies) on various types of farmer costs and benefits (Chapter 5).
4. Formal or informal evaluation of pilot policy interventions or institutional innovations. Examples include the pilot programmes for community-based extension in western Kenya (Chapter 4), and institutional mechanisms for research–extension linkages in Zambia (Chapter 3).

Feedback to research

The close interaction between researchers and farmers during on-farm research, and the opportunities for direct observation by researchers, can provide an excellent learning opportunity to identify research problems and priorities. Formal surveys to assess the frequency and severity of important problems can also help researchers to set priorities among problems and among different potential solutions to a given problem (Tripp and Wooley, 1989). All five of the case studies report on feedback to research, which often led to trials and results that alleviated or solved the original problems. For example, farmers' main problem with *Sesbania sesban* in improved fallows in western Kenya, that it germinated poorly when direct seeded, led directly to trials that were successful in selecting species with higher germination rates.

Selection of methods

The approach presented in this chapter for assessing adoption potential is eclectic in that it draws on a range of methods, including the formal surveys of economists, research trials of biophysical scientists, the participatory techniques of anthropologists, and the informal experiments and assessments that farmers themselves make. The case studies do not all use the same techniques for assessing adoption potential (Table 2.3). Rather, the selection of activities was driven by critical information gaps, identified jointly by researchers, extensionists and farmers, in technology design and in understanding boundary conditions. The choice of methods thus depended on several factors:

1. *The practice's resource requirements.* Improved fallows and hedgerow intercropping had relatively high labour requirements. Thus researchers decided to measure the practice's labour requirements and compare them with the seasonal and total labour requirements of the household. In contrast, upper-storey trees planted on farm boundaries have low labour requirements, so a formal assessment of labour requirements relative to total labour use was not viewed as critical.
2. *The practice's impact on farming enterprises.* Enterprise budgets are needed to assess profitability when a new practice has an important impact on the costs, returns, resource requirements and management of an enterprise. Thus, enterprise budgets were drawn up for improved fallows and hedgerow intercropping. But for

practices that have less impact, such as substituting calliandra leaves for a purchased protein concentrate in a dairy enterprise, a partial budget sufficed for determining profitability.

3. *The size of the sample*. Where the number of farmers testing a practice were few (for example, only 20 farmers tested improved fallows in western Kenya), tests of association between farmers' circumstances and use of the practice could be conducted, but the results were not usually statistically convincing.
4. *Farmers' experience with the practice*. Where farmers had not yet received the benefits of the practices, as with upper-storey trees in Chapter 6, it was not possible to assess factors affecting uptake. But farmers' preferences among the different trees could be examined.
5. *Availability of staff and resources*. Lack of human resources and a change of personnel and research priorities prevented the monitoring of uptake of improved fallows in western Kenya, following the end of the experiments in the early 1990s.
6. *Nature of the practice*. Where a practice involves choosing among several alternatives, as among five agroforestry species (Chapter 6), matrix ranking was a useful tool. It was not appropriate when a practice involved a single prototype, as with improved fallows in western Kenya (Chapter 4).

The Research–Development Continuum

The on-farm research experiences in Kenya and Zambia demonstrate that there are multiple sources of innovation in agroforestry – formal sector researchers, farming tradition, farmer-innovators, extensionist-innovators. Through shared experiences in on-farm research studies, their complementary strengths can be effectively exploited and integrated, at reasonable cost. Figure 2.1 presents a farmer-centred model that is evolving in western Kenya and eastern Zambia. Instead of a linear sequence whereby technology is developed by researchers, then passed to extensionists and finally to farmers, in the on-farm research-centred model there is continual interaction among these groups throughout the process. Input from farmers and extensionists is provided early on, opportunities for early extensionist and farmer innovation and adaptation are encouraged, and implementation on farmers' fields – and hence potential for farmer-to-farmer diffusion – begins much earlier in time. Moreover, building a coalition of organizations to conduct on-farm research and dissemination together is vastly more effective and efficient than leaving each to work independently on only one element.

Researchers and extensionists working together in particular sites can jointly develop locally appropriate extension recommendations for use by other extension programmes in the region. They can, meanwhile, report regularly to this broader community – as well as senior staff in their respective organizations – on progress in technology development and problems encountered, which can then be jointly addressed. Within this structure, technical specialists can collaborate more effectively with, and support, initiatives by existing or newly formed farmer-experimenter groups than can conventional research or extension organizations.

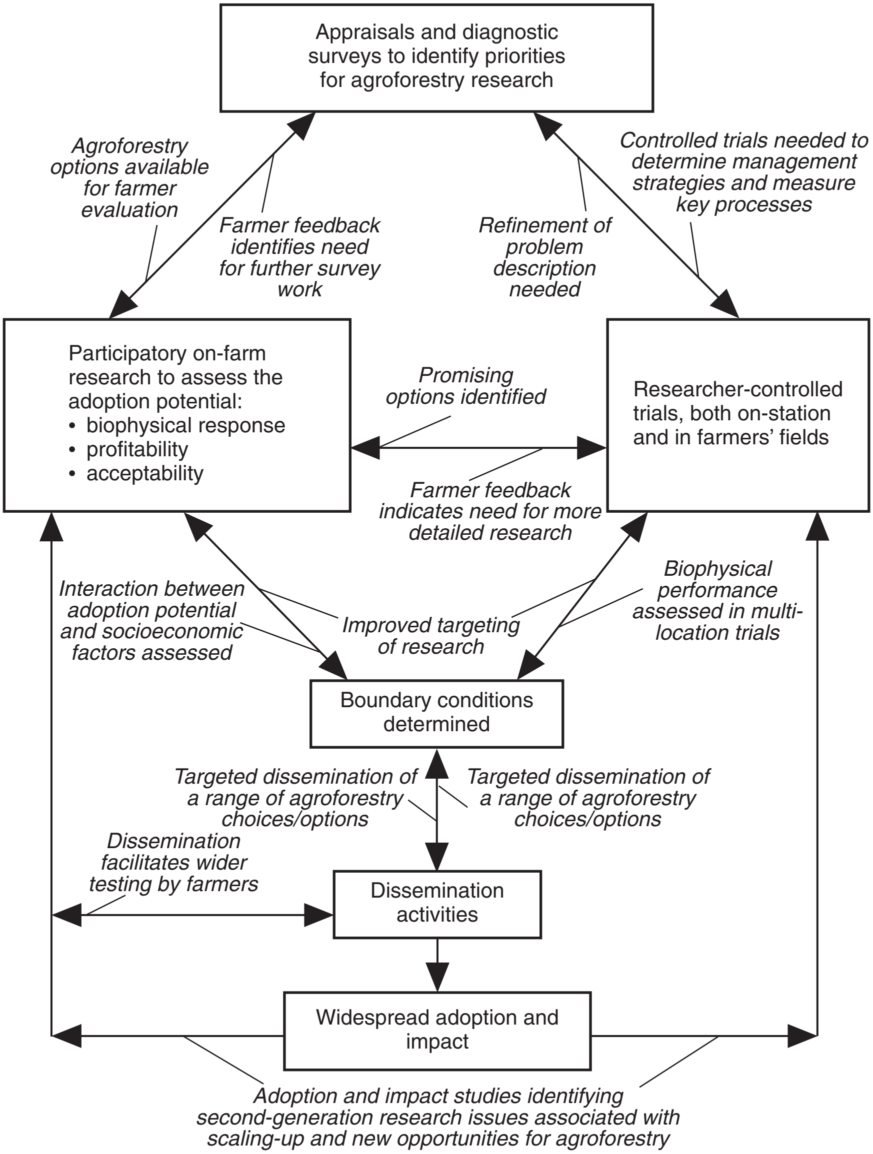

Fig. 2.1. Flow diagram of decisions and activities in farmer-centred agroforestry research and extension.

Conclusion

The experiences of ICRAF and its partners in Kenya and Zambia demonstrate the importance of assessing the adoption potential of agroforestry practices. First, such assessments improve the efficiency of the technology development and dissemination process, by feeding back information on farmers' problems, modifications and preferences to research, extension staff and policy makers. Secondly, the assessments help document the progress made in disseminating new practices, demonstrating the impact of investing in technology development and dissemination. Thirdly, because the activities are conducted with partner institutions, they facilitate interdisciplinary and inter-institutional cooperation. Finally, the assessments help to identify the factors contributing to successful technology development programmes as well as the constraints limiting achievements.

Future assessments need to take advantage of farmers' increased experience with agroforestry practices. Analyses of social, economic, biophysical and ecological impacts will thus be possible at community, landscape and regional scales. Improvements in the development of spatially explicit databases and models should permit the use of geographic information systems for assessing the boundary conditions of new technologies. Efforts are also needed to hand over many of the activities in assessing adoption potential to local institutions, such as farmer groups and organizations. The greater control they have over assessing adoption potential, the more responsive technology generation activities will be to their needs.

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Assessing the Adoption Potential of Improved Fallows in Eastern Zambia

3

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Summary

Declining soil fertility is a key problem faced by farmers in eastern Zambia. This chapter assesses farmers' experiences of testing improved tree fallows in participatory on-farm trials to increase soil fertility. It also highlights the development of an adaptive research and dissemination network of institutions and farmer groups for testing and disseminating improved fallows. *Sesbania sesban* and *Tephrosia vogelii* performed well, but *Cajanus cajan* was discontinued because it was browsed heavily by livestock. The economic analysis compared a 2-year improved fallow, followed by maize cropped for 3 years, with fertilized and unfertilized continuously cropped maize. Over a 5-year period, farmers used 11% less labour on the improved fallow plot than on unfertilized maize, but harvested 83% more maize. Improved fallows had higher returns to land and to labour than continuously cropped unfertilized maize; returns compared to fertilized maize were mixed. Farmer interest is strong, as the number of farmers planting improved fallows has increased from under 20 in 1993–1994 to roughly 10,000 in 2000. Key elements contributing to the progress made thus far include: (i) effective diagnosis of farmers' problems and screening of potential solutions; (ii) farmer participation in the early stages of testing of improved fallows; (iii) testing of a range of management options by farmers and researchers, and encouraging farmers to innovate; and (iv) development of an adaptive research and dissemination network.

Introduction

Land depletion and declining soil fertility are viewed increasingly as critical problems affecting agricultural productivity and human welfare in tropical Africa

Trees on the Farm (eds S. Franzel and S.J. Scherr)

(Cooper *et al.*, 1996; Sanchez *et al.*, 1997). Much attention has focused on biological technologies, such as agroforestry, for solving these problems because of the increasing costs of inorganic fertilizers, their limited availability and the need to increase soil organic matter and improve soil structure. Improved tree fallows, the enrichment of natural fallows with trees to improve soil fertility, are a promising agroforestry practice for small-scale farmers and are being tested at many sites throughout the tropics.

There is considerable evidence from many areas that farmers use leguminous trees on fallow plots for improving soil fertility (Raintree and Warner, 1986). But there is little evidence that farmers have benefited from researchers' efforts to build upon the performance of farmers' traditional practices, or from efforts to introduce improved tree fallows in areas where farmers are unfamiliar with them.

In 1987, following farmer surveys that highlighted the soil fertility problem (Zambia/ICRAF, 1988), the Zambia/ICRAF Agroforestry Research Project began research at Msekera Research Station, Chipata, Eastern Province, Zambia, on improved fallows to increase crop production. In on-station trials, improved fallows using *Sesbania sesban* seedlings transplanted from nurseries greatly increased maize yields (Kwesiga and Coe, 1994; Kwesiga *et al.*, 1999). Moreover, economic analysis showed that 2-year improved fallows were likely to be profitable for small-scale farmers (Place *et al.*, 1995). Species that can be established directly from seed, such as *Tephrosia vogelii* and *Cajanus cajan*, have also been tested on station, with encouraging results (Kwesiga *et al.*, 1995). Farmer experimentation began in 1992–1993 and 1993–1994 with five farmers, and involved 204 farmers in 1994–1995 and about 3000 in 1996–1997.

The objective of this chapter is to assess the adoption potential of improved tree fallows in Eastern Province, based on farmers' experiences. We examine:

1. Feasibility: the degree to which farmers are able to manage the technology, that is, whether they have the required information, are able to plant and maintain the fallows, and cope with any problems that arise.
2. Profitability: whether the financial benefits obtained are greater than the costs incurred and how the benefits compare with farmers' alternative practices.
3. Farmer interest: farmers' views and actions to expand testing and use of the practice.
4. Institutional support: particularly the adaptive research and dissemination network that has emerged for evaluating and extending improved fallows.

First, the study area is described and the design of the trials and monitoring surveys are examined. Next, results from the trials are discussed and the strategy for institutional support is examined. Finally, conclusions are drawn.

Methods

Study area

The plateau area of eastern Zambia is characterized by a flat to gently rolling landscape and altitudes ranging from 900 to 1200 m (Fig. 3.1). Seasonally waterlogged,

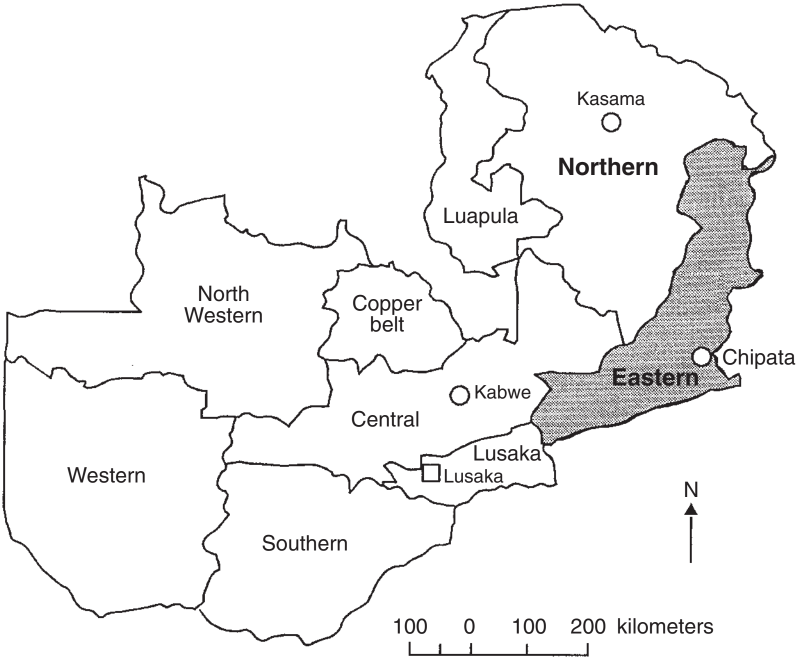

Fig. 3.1. Eastern Province, Zambia.

low-lying areas, known locally as *dambos*, are also common. The main soil types are loamy sand or sand Alfisols, interspersed with clay and loam Luvisols. The Alfisols are well-drained and relatively fertile but have low water and nutrient-holding capacities (Zambia/ICRAF, 1988; Raussen *et al.*, 1995). Rainfall averages about 1000 mm year^{-1}, with about 85% falling in 4 months, December–March. Rainfall is highly variable; the area received less than 600 mm in 2 of 8 years between 1990 and 1997. The growing season lasts for about 140–155 days. Average air temperatures range from 15 to 18°C during June–July to 21–26°C in September–October (Zambia/ICRAF, 1988).

Population density varies between 25 and 40 persons km^{-2}. About half of the farmers practice ox cultivation, the others cultivate by hand-hoe. Average cropped land ranges from 1.1–1.6 ha for hoe cultivators to 2.3–4.3 ha for ox cultivators. The two groups are mixed amongst each other and grow similar crops, though ox cultivators tend to use more purchased inputs. Maize is the most important crop accounting for about 60–80% of total cultivated area. Other crops include sunflower, groundnuts and cotton. Average numbers of cattle per household range from 1.5 to 3, depending on the district, and goats are also common. The main ethnic groups are the Chewa and the Ngoni. Rural households are concentrated in village settlements of up to 100 homesteads, a legacy of government-sponsored village regrouping programmes (Zambia/ICRAF, 1988; ARPT, 1991; Celis and Hollaman, 1991; Jha and Hojjati, 1993; FSRT, 1995; Peterson *et al.*, 2000).

Farmer surveys have identified declining soil fertility as one of farmers' main perceived problems (Zambia/ICRAF, 1988; ARPT, 1991). Nitrogen deficiency was judged to be the most important problem responsible for low maize yields. Increased pressure on land has reduced fallow periods, farmers' main method for maintaining soil fertility, to 1–3 years. Many farmers even practise continuous cropping while having land in 'reserve fallow' that they have never cultivated (Zambia/ICRAF, 1988; Peterson *et al.*, 2000). Fertilizer use was common during the 1980s but the cessation of subsidies caused the ratio between the price of nitrogen and the price of maize to increase from 3.1 in 1986/87 to 11.3 in 1995/96. Fertilizer use in Zambia declined by 70% between 1987/88 and 1995/96 (Howard *et al.*, 1997) and the decline in the smallholder sector was even greater.

Trial design

In 1992/1993 and 1993/1994, five farmers established type 3[1] (farmer-designed, farmer-managed) improved fallow trials, using sesbania seed or bare-rooted or potted seedlings obtained from researchers. The objective of the trials was to give farmers the opportunity to experiment with improved fallows, to assess their ability to establish and maintain improved fallows, and to obtain their assessment of the practice. Farmers were advised on how to manage improved fallows and they each designed their own trial, planting the trees where and how they wished on their farms. Spacing averaged 1 m × 1 m (10,000 trees ha^{-1}) and plot size ranged from 400 m^2 to 800 m^2. In the third year of the trial, farmers were given fertilizer to use on an adjacent plot of 200 m^2, so as to be able to compare the post-fallow maize yield with yields of fertilized maize. A non-fertilized maize plot was also identified for the comparison.

In 1994/95, 157 farmers planted type 2 (researcher-designed, farmer-managed) trials. The farmers selected one of six improved fallow technologies to plant: sesbania, tephrosia or cajanus as well as the same three species intercropped with maize during fallow establishment in the first year and then allowed to grow into a pure stand fallow in the second year. Sesbania was planted using bare-rooted seedlings; tephrosia and cajanus were planted by direct seeding. Bare-rooted seedlings were inoculated with rhizobia from the already established stands of sesbania at farmer-training centres or on farm. The treatments included:

- the improved fallow plot (pure stand or intercropped with maize) in a 400 m^2 plot – trees were planted at a density of 0.9 m × 0.75 m or 14,763 trees ha^{-1}, whether in pure stand or intercropped with hybrid maize;
- unfertilized maize in a 200 m^2 plot;

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[1] Type 1 on-farm trials are researcher-designed and researcher-managed and are similar to trials done on station. Type 2 trials are researcher-designed and farmer-managed. Type 3 trials are farmer-designed, farmer-managed, that is, farmers experiment as they wish and thus may not have control plots (see Chapter 2).

- maize fertilized at the recommended level, 112–40–20 kg N–P–K per hectare, in a 200 m^2 plot.

Maize was planted at the recommended density of 75 cm × 30 cm, whether in pure stand or intercropped, giving a density of 44,444 plants ha^{-1}. When intercropped, trees and maize were planted in the same rows, to permit space for weeding between the rows. The project supplied hybrid maize seed and fertilizer for the maize plots and farmers supplied labour for all of the operations. Farmers were advised to manage the plots uniformly in order to ensure that the results among them would be comparable. They agreed to continue growing maize on the maize plots for 5 years.[2] On the improved fallow plots, farmers agreed to maintain the trees for 2 years, and to then cut them down, incorporate the leafy biomass, and plant maize in the third, fourth and fifth years.

In 1995/96, 35 type 2 trials were added, primarily to assess the effects of differences among seasons on the improved fallows. The sample was stratified by technology and included 12 farmers with sesbania in pure stand, 13 with tephrosia in pure stand, 4 with intercropped sesbania and 6 with intercropped tephrosia. Cajanus was omitted because of the browsing problems the previous year.

Type 3 trials, in which farmers experimented on their own with improved fallows, expanded greatly, from 37 farmers in 1994/95 to about 800 farmers in 1995/96 and about 3000 in 1998. Farmers received no incentives for experimenting with improved fallows.

Overall, the on-farm experimentation programme was designed to provide farmers with different options for testing. Table 3.1 shows that by 2000, five of eight variants of the technologies were being used by farmers; three had been rejected.

Monitoring and analysis

Monitoring surveys were conducted by a researcher, a technician and collaborating extension staff. Data were collected on labour use and other costs from selected type 2 and type 3 farmers; these were supplemented by data from other farmers, local markets and secondary sources (Appendix 3.1). Enterprise costs and returns were drawn up for each farm and used to calculate net present values per hectare to assess returns to land (in which household labour is valued) and net returns per work day to assess returns to labour (in which household labour is not valued). The analysis covered a period of 5 years: 2 years of fallow and the 3 subsequent years for which it is assumed that maize yields would be affected. Maize yields following sesbania fallows were available for five farmers for 1996 and seven farmers for 1997. Average data on costs were used in each individual farmers' budget; maize yield figures were specific to each farm. Since data on maize yields during the second and third years

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[2] Maize yields in the control plots were approximately equal to average maize yields in the area.

Table 3.1. Improved fallow practices tested by farmers.

	Sesbania sesban			*Tephrosia vogelii*		*Cajanus cajan*		*Gliricidia sepium*
	Potted seedling	Bare-root seedling		Direct seeded		Direct seeded		Bare-root seedling, intercropped
Year	Pure stand	Pure stand	Intercropped	Pure stand	Intercropped	Pure stand	Intercropped	
91–92	*							
92–93	*	*	*	*	*			
93–94	*	*	*	*	*			
94–95		*	*	*	*	*	*	
95–96		*	*	*	*			
96–97		*	*	*	*			
97–98		*	*	*	*			*
98–99		*	*	*	*			*
99–00		*	*	*	*			*

following improved fallows were not available from on-farm trials, data on the percentage decline in the maize yield response from on-station trials, 30% for the second year and 60% for the third year, were used in the analysis. Where cost was a function of yield, as in the case of harvesting labour, costs were adjusted in relation to yield. Sensitivity analysis was conducted to show the effects of changes in parameters on the results of the economic analysis. A semi-structured survey was conducted following the first post-fallow maize harvest, to assess farmers' experiences and opinions.

Farm models using the Microsoft Excel Program were drawn up to assess the impact of adopting improved fallows on maize income. Models were drawn up for the same three scenarios as for the enterprise budgets: farms that adopt improved fallows, farms that cultivate unfertilized maize and those with fertilized maize.

For the 157 type 2 farmers planting in 1994/95, four subsamples were surveyed during the first 2 years:

1. Three months after the 1994/95 planting, a survey assessed survival rates and problems inhibiting tree survival and growth. The survey included 110 of the 157 farmers; sample farmers were chosen on the basis of their accessibility.
2. Six months after planting, maize yields were measured on 20 farms to assess the effects of intercropping trees with maize on maize yields.
3. One year after planting, a questionnaire survey was conducted of the 68 farmers who had achieved high survival rates, that is, rates of over 60% in the first survival survey, and were thus expected to have successful improved fallows.[3] The sample was stratified by technology. Farmers were interviewed concerning their management of the improved fallows and problems encountered.
4. Two years after planting, 31 farmers with low survival rates, that is, rates below 60% 6 months after planting, were interviewed to find out whether they had continued with their experiments and whether they had started new ones.

The 35 type 2 farmers planting in 1995/96 were surveyed 6 months after planting, using a questionnaire, to assess their experiences and problems they encountered.

A random sample of 65 of the roughly 800 type 3 farmers planting in 1995/96 was surveyed 6 months after planting, using a questionnaire, to assess their experiences.

For assessing the uptake of improved fallows by gender and wealth group, a census of households was conducted in 1998 in four villages where substantial proportions of farmers were planting improved fallows. Community members conducted a 'wealth ranking exercise', in which they defined the different wealth groups – well off, fairly well off, poor and very poor – and classified households into the groups (Phiri *et al.*, 2001).

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[3] We estimated that for sesbania a minimum survival rate of 60%, 6 months after planting, would ensure a survival rate of at least 30% at the time of cutting the trees, and that 30% was the minimum required to obtain benefits. For tephrosia and cajanus, the minimum is higher, about 40%, because these species do not have as wide a canopy.

Results

Feasibility

In the five type 3 trials planted in 1992/93 and 1993/94, the farmers represented a range of types of farmers found in the area: three were male, while two were female heads of households; two were considered to be of high income, one middle income, and two low income. Two farmers used oxen for land preparation while three used hoes, and three were on Alfisols while two had Luvisols. Four of the five farmers were able to establish dense sesbania fallows. Lack of weeding and bush fires, which are common during the dry season, constrained tree growth on the fifth farm. One female farmer made an important modification in the technology, intercropping trees with maize during the first year of establishment, that was later tested by researchers and is now used on a wide scale by many farmers.

In the type 2 trials planted in 1994/95, sesbania was the most popular species, planted by 42% of the farmers. Tephrosia was planted by 34% and cajanus by 22%. Most (83%) planted their trees in pure stand whereas 17% intercropped them with maize during the season of establishment.

Survival rates were used in this and other trials as rough indicators of the feasibility of planting improved fallows. Tree survival and growth were hampered by the season's low rainfall, 580 mm. Overall mean survival rates 3 months after planting were highest for tephrosia, 74% (standard deviation (SD) = 27) in pure stands. Survival rates for cajanus averaged 68% (SD = 19), and for sesbania, 58% (SD = 28). The higher survival rates of tephrosia and cajanus were associated with the relative ease in 'gapping up' directly seeded species as compared with bare-rooted seedlings, which become either in short supply or too large for successful transplanting as the season advances.

Farmers cited dry spells of up to 2 weeks early in the season as the principal reason for low survival (Table 3.2). Other important problems affecting survival and growth, noted by farmers and technicians, included weed competition, live-

Table 3.2. Reasons for low survival of tree seedlings on 33 farms with survival rates lower than 60%, 3 months after planting, 1996.[a]

	Number of farmers			
Problem	Sesbania	Tephrosia	Cajanus	Total
Dry spells	12	1	3	16
Weeds	6	0	0	6
Browsing	1	3	1	5
Poor germination	0	1	4	5
Seedlings remaining too long in nursery	5	0	0	5
Number of farmers	20	5	8	33

[a] Reasons as given by research staff or farmers. In some cases more than one response was given, thus numbers in columns do not sum to column totals.

stock browsing, low germination (particularly with cajanus), and sesbania seedlings remaining too long in the nursery (in part, because of the late start of the rain). Lack of experience also affected performance, as this was the first time that most of the farmers had ever planted tree nurseries or transplanted bare-rooted seedlings.

In the survey of farmers with high survival rates, two-thirds had gapped up or replanted seedlings. Fifteen per cent did so twice. As is common in years of poor rainfall, many farmers had to replant their maize as well.

During the 1995/96 dry season (March–November), there was a significant reduction in the mean survival rates for all species because of moisture stress and uncontrolled communal grazing. A paired comparison of survival rates 3 months and 1 year after planting showed that sesbania ranked highest in its ability to withstand the long dry season. On 19 farms that had high survival rates on pure stands of sesbania, survival dropped from 81% at 3 months to 63% after 1 year. Tephrosia survival dropped from 91% to 51% (15 farms) and cajanus from 72% to 21% (13 farms). Because cajanus was so heavily browsed, it was discontinued from on-farm trials the following year. The differences in the reduction in survival rates among the species were significant at $P = 0.01$.

Intercropping appeared to reduce tree survival and maize yields, probably because of competition for resources, especially for moisture in a dry year. Seedling survival rates 3 months after planting in intercropped fields were 9–13 percentage points lower than for seedlings planted in pure stands, depending on the species. The proportion of farmers achieving survival rates over 60% was generally higher for pure stands than for intercropped trees (Table 3.3). Furthermore, the dry season had a greater negative impact on intercropped trees than those in pure stands. For example, whereas the survival rate of tephrosia in pure stand declined by 44% between 3 and 12 months, intercropped tephrosia declined by 59%. Trees planted in pure stand grew more vigorously because of the lack of competition for resources by maize, and were thus better able to develop a deep rooting system, necessary to withstand the long dry season. Moreover, intercropped trees were more susceptible to trampling by livestock, which feed on the crop residues remaining after harvest.

Table 3.3. Proportion of farmers with survival rates greater than 60%, 3 months after planting, 1996.

Species and arrangement	% farmers with survival rates >60%	% farmers with survival rates <60%	Number of farmers
Sesbania pure	50	50	40
Tephrosia pure	74	26	23
Cajanus pure	72	28	9
Sesbania intercropped with maize	40	60	18
Tephrosia intercropped with maize	100	0	10
Cajanus intercropped with maize	44	56	9
Total	62	38	110

Data from on-farm trials also suggested that intercropping reduced maize yields during the season of establishment by 18–28%, depending on the species. But because of high variability, differences in maize yields between pure stand and intercropping were not significant for any of the tree species.

As 1995/96 was a season of average rainfall, survival rates were considerably higher than in 1994/95. Overall, 80% of the type 2 farmers planting pure-stand sesbania in 1995/96 and 84% growing pure-stand tephrosia achieved high survival rates, that is, rates over 60%. Intercropping did not appear to affect survival negatively, as three of four intercropping sesbania and five of six intercropping tephrosia also achieved acceptable survival rates. Only 46% needed to replant or gap up.

There was also a marked reduction in the numbers of farmers reporting problems. Twelve of 19 tephrosia growers and 3 of 16 sesbania growers reported that they did not experience any problems. The mesoplatys beetle (*Mesoplatys ochroptera*) was the most frequently cited problem affecting sesbania. Our observations indicated that, in most cases, trees once established were able to recover fully after a beetle attack, even without being sprayed. No other problem was mentioned by more than four farmers. All but one farmer weeded their plots; half weeded two or three times.

The results in the type 3 trials during the same year were somewhat less favourable. Ninety-five per cent of the tephrosia growers and 61% of sesbania growers had survival rates over 50%. Nursery management and transplanting techniques were suboptimal, probably because sesbania growers in type 3 trials received less training than those in type 2 trials. Farmers with pure stands of sesbania and tephrosia had slightly higher survival rates than those who intercropped. The problems reported by type 3 farmers were similar to those reported by type 2 farmers.

Performance was also assessed by soil type. Survival rates after 6 months did not vary between Luvisols and Alfisols. But mean survival rates after 12 months, that is, after the long dry season, were significantly lower on the Alfisols for tephrosia (41% versus 75%, $P < 0.05$), because Alfisols are lighter than Luvisols and retain less moisture. Tephrosia and cajanus were less able than sesbania to survive the long dry season because they are direct seeded and are thus less able to develop an extensive root system. Moreover, cajanus and, to a lesser extent, tephrosia were subject to browsing during the dry season.

The last management task, cutting the trees, was not a serious problem for farmers for three reasons. First, the trees were cut during the dry season before land preparation begins, a slack period for farmers. Secondly, sesbania and, in particular, tephrosia were easier to fell than other trees. Thirdly, females traditionally clear bush fallows, so the task of cutting trees is not new to them, as it is in other countries.

The above analyses assess feasibility of improved fallows on very small plots; but will farmers be able to manage them on a scale needed to maintain fertility on their entire farms? A family manually cultivating 1.2 ha needs to plant 0.27 ha improved fallow each year, assuming they crop for 3 years following each 2-year fal-

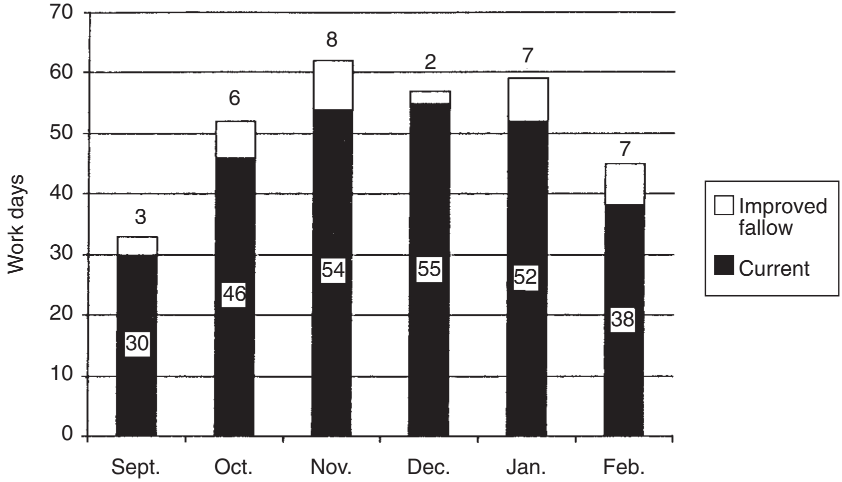

Fig. 3.2. Extra monthly labour required for practising improved fallows (0.27 ha), as compared to current labour used for maize production, eastern Zambia.

low.[4] Planting 0.27 ha in pure-stand sesbania increases labour use by 35 work days, 5–16% per month during the September–February peak period (Fig. 3.2). Fortunately, the extra labour is distributed fairly equally among the peak months; however, it is still a substantial amount. The other improved fallow options, pure-stand tephrosia, intercropped sesbania, or intercropped tephrosia have much lower labour requirements, increasing labour use by 22, 16 and 3 days per 0.27 ha, respectively (Fig. 3.3). Intercropped tephrosia, the least labour-intensive option, increases labour use during the peak months by less than 2%.

Profitability

In the economic analysis, the benefits of improved fallows, relative to continuously cropped maize, were: labour saved in years 1 and 2 because maize was not planted, fuelwood production in year 2, increases in maize yields in years 3–5, and reduced land preparation and weeding costs in the first post-fallow maize crop. Added costs included sesbania seed, labour for establishing the nursery, transplanting and maintaining the fallow, and labour for harvesting and threshing the increased maize produced.

Maize yields following the improved fallows averaged 3.6 t ha^{-1}, as compared to yields of 1.0 t ha^{-1} for continuous, unfertilized maize and 4.4 t ha^{-1} for continuous, fertilized maize (Table 3.4). There was no significant difference in the response to improved fallows or to fertilizer between the 2 years surveyed, 1996 and 1997. The post-fallow plot out-yielded the unfertilized plot on all 12 farms, and the fertilized plot on four of the 12 farms.

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[4] It is assumed that the family owns 1.35 ha and uses 119 work days cultivating 1.2 ha maize. Using sesbania improved fallows and, allowing for the use of only 119 work days, the family could cultivate 0.81 ha maize and plant 0.27 ha in improved fallows each year.

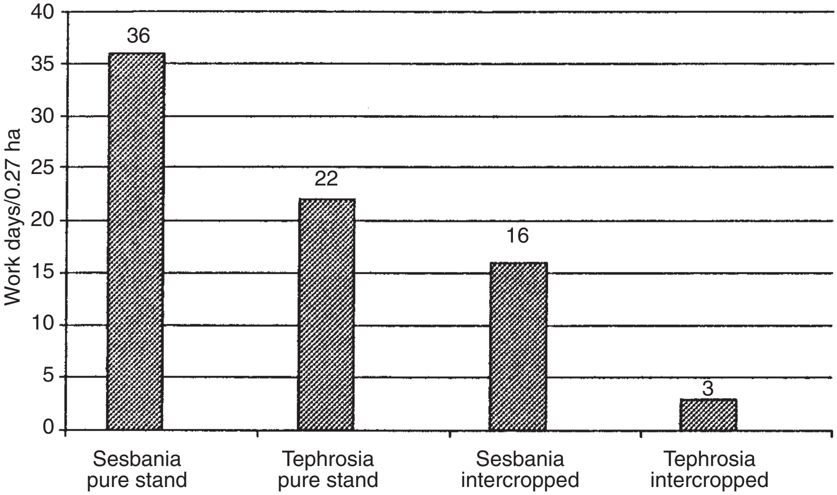

Fig. 3.3. Extra labour (work days/0.27 ha) for different improved fallows options.

Results of the economic analysis of the 12 farms, using average values across farms, are summarized in Table 3.5; the detailed budgets for improved sesbania fallows and fertilized and unfertilized maize are shown in Appendix 3.1. Over a 5-year period, a hectare of improved fallows required 11% less labour than a hectare of unfertilized maize and 32% less labour than fertilized maize. Relative to unfertilized maize, the improved fallow increases total maize production per hectare over the 5-year period by 77%, even though it does not produce maize during the first 2 years of the fallow. But fertilized maize gives the highest 5-year maize yield, 2.5 times that of improved fallows. The value of fuelwood produced in the fallow was low, only about 3% of the value of maize following the improved fallow.[5]

For economic data, two scenarios are presented, one using prices for a year following a bumper harvest when prices were low (1996) and one following a poor harvest when prices were high (1998). Values in both years are expressed in 1998 US dollars, taking into account inflation between 1996 and 1998. In the analysis of returns to land using 1996 prices, net present values (NPVs) per hectare for fertilized maize were over 30% higher than those of improved fallows; both were much higher than for unfertilized maize. Six of the 12 farmers obtained higher NPVs for improved fallows than for fertilized maize; 11 obtained higher NPVs for improved fallows than for unfertilized maize. Using 1998 prices, NPVs for fertilized maize were over double those for improved fallows, because of the much higher maize prices.

A main disadvantage of improved fallows relative to continuous maize is that farmers have to wait until after the fallow to recoup their investment; in continuous maize farmers earn positive net benefits in the first year. The payback period, that is,

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[5] The value of sesbania wood varies: in some areas, farmers burn the wood in the field to get rid of it, whereas in other areas, they carry it to the homestead to use as fuelwood.

Table 3.4. Maize yield (kg ha^{-1}) following 2-year *Sesbania sesban* improved fallows, as compared to yields in continuous unfertilized and fertilized maize, type 2 and type 3 trials, 1996 and 1997.

	I. Continuous unfertilized maize	II. Maize following improved fallow	III. Continuous fertilized maize	Ratio: II/I
Phiri Tikozenji	440	3000	2860	6.8
Isaac Phiri	1310	4720	3630	3.6
Whyson Mbewe	2200	5010	5100	2.3
Harrison Chogwe	960	3790	4580	3.9
Maine Mwale	700	3560	4150	5.1
Lazarus Mwanza	970	2760	6570	2.8
Peniyas Tembo	190	1420	2820	7.5
T.Phiri[a]	1300	2300	5100	1.8
Z. Mwanza	300	4400	3700	14.7
M. Jere	1100	3500	4200	3.2
P. Nthani	800	4800	4200	6.0
J. Zulu	1300	4400	5700	3.4
Mean	964	3638	4384	3.8
SD	548	1108	1108	

[a] Fallow period was for 3 years.

the period required for improved fallows to yield higher cumulative net present values than unfertilized maize, was 3 years for 10 of the 12 farmers. This indicates that even without residual maize yield increases during the second and third post-fallow maize harvests, improved fallows were still more profitable than unfertilized maize for 10 of the 12 farmers.

Assessing returns to labour is more relevant to most Zambian farmers than returns to land, because labour tends to be scarcer than land. On returns to labour, improved fallows outperformed unfertilized maize by a wide margin and fertilized maize narrowly, using average values across the 12 farms and 1996 prices (Table 3.5). Improved fallows gave higher net returns to labour than for unfertilized maize on 11 of the 12 farms and higher net returns to labour than for fertilized maize on 8 of the 12 farms. Even assuming no maize yield response to improved fallows in year 4 and year 5, returns to labour on improved fallows were higher than those for unfertilized maize on 10 of 12 farms. Using 1998 prices, fertilized maize had higher returns to labour than improved fallows. In summary, improved fallows had much higher returns to land and labour than unfertilized maize but lower returns to land than fertilized maize. On returns to labour, the improved fallows did better using 1996 prices while fertilized maize did better using 1998 prices.

The performance of improved fallows relative to continuous, unfertilized maize is fairly stable under a wide range of possible changes in parameters (Table 3.6). For example, improved fallows have returns to land and labour at least double those of

Table 3.5. Labour requirements, maize production, and returns to land and labour of *Sesbania sesban* improved fallows and continuously cropped maize over a 5-year period, using an average farm budget.[a]

Option	Work days ha^{-1}	Tons maize ha^{-1}	Returns to land: net present value (US$ ha^{-1}) 1996	1998	Returns to labour: net returns (US$) per work day 1996	1998
Continuous unfertilized maize	499	4.8	6	6	0.47	0.79
Improved 2-year sesbania fallow	441	8.5	170	215	1.11	1.64
Continuous fertilized maize	645	21.9	229	544	1.04	2.18

[a] Means of values from individual budgets of the 12 trial farmers were used. Monetary values for 1996 and 1998 are in 1998 constant US dollars adjusted for inflation. Details on budgets and coefficients are provided in Appendix 3.1.

unfertilized maize under most tested changes, including a 500 kg decline in post-fallow maize yields, and 50% increases or decreases in the discount rate, and the prices of fertilizer and labour. An increase in post-fallow maize yield of only 1.1 t ha^{-1} is needed in the third year to cover the costs of establishing and maintaining the fallow, relative to unfertilized maize, in terms of returns to land or labour.

In contrast, the performance of improved fallows relative to continuous, fertilized maize is sensitive to changes in key parameters (Table 3.6). Increases in maize prices (such as between 1996 and 1998) raise the returns to fertilized maize at a much faster rate than they raise the returns to improved fallows. Similarly, the relative profitability of the two practices is highly sensitive to the price of fertilizer; reductions in fertilizer price greatly increase the profitability of fertilized maize relative to improved fallows. Changes in the discount rate and in the cost of labour and seedlings have little effect on the performance of improved fallows relative to fertilized maize.

The risk of drought is critical for farmers in Zambia; unfortunately the effects of drought in the season following an improved fallow cannot be assessed using the data collected for this study. But there are four reasons why improved fallows are likely to be much less risky than fertilized maize. First, in the event of a complete crop failure, a farmer using fertilizer would lose his investment in fertilizer, US$154 ha^{-1}, whereas a farmer with improved fallow would lose his investment in planting and maintaining the trees, only about US$90 ha^{-1} (using 1998 prices). In addition, both farmers would lose their investment in growing maize that year. Secondly, whereas nearly all of a farmer's investment in fertilizer is in cash terms, improved fallows require little or no cash input. The opportunity cost of cash is extremely high, and in the case of the farmer buying fertilizer on credit, loss of the maize crop may result in substantial losses in productive capacity in order to repay the loan. Thirdly, the benefits of improved fallow are likely to be spread over a 3-year period,

Table 3.6. Sensitivity analysis showing the effects of changes in parameters.[a]

	Continuous unfertilized maize		Improved fallows		Continuous fertilized maize	
	Returns to land	Returns to labour	Returns to land	Returns to labour	Returns to land	Returns to labour
Base analysis	6	0.47	170	1.11	229	1.04
Maize price + 50%	114	0.83	330	1.73	718	2.31
Maize price – 50%	–101	0.11	10	0.49	–260	–0.23
Labour price + 50%	–61	0.47	117	1.14	142	1.04
Labour price – 50%	73	0.47	223	1.05	315	1.04
Discount rate 30% instead of 20%	5	0.47	119	1.02	186	1.04
Discount rate 10% instead of 20%	8	0.47	246	1.20	290	1.04
Seedling cost + 50%	6	0.47	164	1.06	229	1.04
Seedling cost – 50%	6	0.47	176	1.16	229	1.04
Fertilizer price + 50%	6	0.47	170	1.11	–11	0.42
Fertilizer price – 50%	6	0.47	170	1.11	469	1.66
Yield response to improved fallows + 500 kg ha^{-1}	6	0.47	209	1.25	229	1.04
Yield response to improved fallows – 500 kg ha^{-1}	6	0.47	131	0.96	229	1.04
No response to improved fallow (years 4–5)	6	0.47	72	0.89	229	1.04
No response to improved fallow (year 5)	6	0.47	138	1.09	229	1.04

[a]Values are based on 1996 prices expressed in 1998 US dollars.

whereas those of nitrogen fertilizer take place in a single year. Thus in the above case, where a farmer's crop fails in the first post-fallow season, there is likely to be a substantial response the following year. Fourthly, improved fallows appear to improve the soil structure and organic matter content of the soil, thus enhancing the soil's ability to retain moisture during drought years.

The above analysis of profitability examines returns per hectare; but how will adoption of improved fallows affect farm income once they have been incorporated into the farming system? A farm household cultivating manually and having 1.4 ha and 120 work days available for cultivating maize would earn US\$262 year^{-1} using fertilized maize, US\$225 year^{-1} growing improved fallows, and only US\$95 year^{-1} cultivating continuous maize without fertilizer (Table 3.7). Even if there is no residual effect on maize yields in the third year following improved fallows, earnings are still twice as high as on unfertilized maize.

Table 3.7. Farm models comparing net returns to labour per year of a 1.4 ha farm practising *Sesbania sesban* improved fallows with farms cultivating continuous maize, with and without fertilizer.[a]

Farm practising improved fallows (farm adds 0.28 ha of improved fallow per year)					Farm with unfertilized maize (1.2 ha cultivated)				Farm with fertilized maize (0.92 ha cultivated)			
Crop	Area (ha)	Work days year^{-1}	Maize production (kg year^{-1})	Net returns (US$ year^{-1})	Crop	Work days (year^{-1})	Maize production (kg year^{-1})	Net returns (US$ year^{-1})	Crop	Work days year^{-1}	Maize production (kg year^{-1})	Net returns (US$ year^{-1})
Fallow, 1st year	0.28	31	0	0	Maize	120	1157	95	Maize	120	4077	262
Fallow, 2nd year	0.28	1	0	1								
Maize 1st post-fallow	0.28	7	1026	97								
Maize 2nd post-fallow	0.28	31	800	75								
Maize 3rd post-fallow	0.28	30	573	52								
Total	1.4	120	2390	225								
Net returns to labour if maize in the 3rd post-fallow season yields the same as on the farm with unfertilized maize				195								

[a] Household is assumed to have only 120 work days available during the cropping season for maize production; the amount needed to cultivate 1.2 ha maize manually without using fertilizer. Costs and returns are from Appendix 3.1. Improved fallows are 2 years in length and are followed by 3 years of maize crops.

Farmer interest and innovation

Determining farmers' interest in improved fallows is problematic, as 5 years are required for a full cycle of the technology, that is, 2 years of fallow and 3 years of cropping. Moreover, farmers often state that they like a technology, even when they do not, because they hope to obtain material or social benefits from interacting with facilitators, or because of cultural taboos against criticism. Nevertheless, there is considerable evidence that farmer interest in improved fallows is extremely strong. First, there has been a rapid expansion in the number of farmers testing and using the technology: the number of type 3 trials, for which farmers receive no incentive for planting the trees, rose from 37 in 1994–1995 to about 2800 in 1996–1997. By 2000, roughly 10,000 farmers in Eastern Province were planting improved fallows. Secondly, most farmers planting the improved fallows continue to plant them: in a study of 100 farmers planting improved fallows in 1996–1997 or earlier, 71% continued to plant them over the following three seasons (Keil, 2001). Thirdly, even farmers with low survival rates have continued testing improved fallows on parts of their plots where survival was higher (71% of farmers with low survival rates) or have planted new improved fallow plots the following year (32%).

The main intention of farmers in using the technology is undoubtedly to increase returns to land and labour. But it is not clear how they will actually incorporate the technology into their farming system. For example, in workshops to discuss the potential impact of improved fallows, some expressed interest in rotating improved fallows around their farm, so that their supply of maize would be stable and all areas of their farm would benefit from the fallows. Some intended to use the technology to reduce their area cropped to maize, so as to be able to devote more land to cash crops (Place, 1997).

Fuelwood availability varies considerably within the province and thus farmers' interest in using the trees for fuelwood is variable. Some claimed that the larger sesbania trees were good substitutes for the fuelwood they collected from off the farm. Others mentioned that the quality of the wood was poor and that it was useful only as kindling. Tephrosia and cajanus produce lower-quality fuelwood than sesbania.

Farmers' preferences between sesbania and tephrosia vary considerably. Maize yields following sesbania fallows are generally higher than those following tephrosia fallows, but some farmers prefer tephrosia because it can be direct seeded and thus requires less labour than sesbania. In type 2 trials in 1994/95, 42% chose sesbania and 30% tephrosia; in type 3 trials the following year 64% chose sesbania and 32%, tephrosia. By 2000, tephrosia had surpassed sesbania; 85% of farmers with improved fallows were planting tephrosia while 69% were planting sesbania (Keil, 2001).

Farmers' innovations of the improved fallow technology have been one of the main elements contributing to its success. Two of the main technological options, bare-root seedlings instead of potted seedlings, and intercropping instead of planting in pure stands, were innovations that farmers introduced in type 3 trials in the early 1990s. In these trials, farmers were given potted seedlings grown at farmer-training centres, but to reduce the cost of transporting them to their farms, they removed the seedlings from the pots and carried them 'bare-rooted' in basins. When farmers' plantings of these seedlings proved successful, researchers conducted type 1 trials to compare the performance of bare-rooted seedlings, grown in raised seedbeds, with potted seedlings. They found no significant difference in performance and as potted seedlings were much more costly to produce, they were phased out (Kwesiga *et al.*, 1999).

The farmers' second main innovation, intercropping during the year of tree establishment, was also tested later in on-farm trials. The trials found that intercropping reduces maize yields and tree growth during the year of establishment, but many farmers prefer it because it economizes on land and labour use relative to planting in pure tree stands. Intercropping appears to be increasing; the percentage of farmers practising it rose from 17% during the planting of 1994/95 type 2 trials to 42% in the 1995/96 type 3 trials.

Researchers have also noted several other farmer innovations. One farmer planted seedlings into a bush fallow without preparing the land first. Another planted sesbania seedlings behind the ox-plough; as the plough moved along an adjacent furrow, it covered the seedling roots with soil. Several farmers gapped up their sesbania fields with seedlings planted 1 year after the first planting. Several planted sesbania at weeding time into parts of fields where maize was performing poorly. Some also tested the effect of improved fallows on crops other than maize, such as sunflower and groundnuts.

Gender and wealth

The data support the hypothesis that females were able to manage improved fallows as well as males. In the type 3 trial planted in 1995/96, half of the participants were females and they had somewhat higher survival rates for sesbania than males. For example, 47% of females and 29% of males had survival rates for sesbania of over 75%, 6 months after planting. For tephrosia, males had somewhat higher survival rates. Males and females reported similar problems with similar frequency and did not differ in the number of times they weeded their trees. But females had smaller plot sizes, 332 m^2, as compared to 679 m^2 for males. Since the same percentage of males and females stated that they had obtained enough planting material, it appears that females wanted smaller plots than males.

In the four villages where a census was conducted on the use of improved fallows in 1998, 32% of the male-headed households and 23% of the female-headed households had planted improved fallows. There was no significant difference across villages between the two proportions. Moreover, whereas single females are often disadvantaged relative to female heads of household whose husbands live away (Bonnard and Scherr, 1994), the data showed that the same proportions of these two groups were testing the technology. In fact, Peterson (1999) found a higher proportion of single females planting improved fallows than married females; the latter needed permission from their husbands and thus were sometimes prevented from testing the practice.

As could be expected, there was an association between wealth level and planting improved fallows (log linear model, $P < 0.08$). As wealth status declined, the proportion of farmers planting improved fallows also declined. Whereas 53% of the well-off farmers planted fallows, 40% of the fairly well off, 22% of the poor and 16% of the very poor planted fallows (Phiri *et al.*, 2001). Interestingly, though, the proportion of farmers continuing to plant improved fallows after their first planting did not appear to vary by wealth status; 59% of the farmers in the well-off and fairly well-off groups expanded whereas 58% of the farmers in the poor and very poor groups expanded (Peterson, 1999)

Institutional Support

In some areas of Eastern Province, the planting of improved fallows has spread almost spontaneously, that is, largely through the efforts of farmers without much support from researchers or extension staff. For example, during the dry season, 1995, a lorry load of 78 farmers arrived unannounced at Msekera Research Station. The farmers came from Kapinde, a village bordering a village having on-farm trials, and they had hired the truck to come to the station to learn about improved fallows. The farmers were members of self-help groups and were accompanied by their camp officer. Project staff gave them a tour of the station and nearby on-farm trials. The farmers were given sesbania seed and instructions on raised-bed nursery methods to produce bare-rooted seedlings. Several months passed without contact but in December, project staff went to visit the village, arriving unannounced. The camp officer quickly assembled some of the group leaders and accompanied Chipata staff to the nursery. It was well-managed, weed-free and well-watered, with 40,000 seedlings ready for planting. Seventy-one farmers planted improved fallows using seedlings from the nurseries.

But in most cases, substantial support, that is, training and planting material, is required. In the above case, Kapinde farmers had significantly lower survival rates than in nearby camps, probably because of less training and experience. The Zambia/ICRAF project has helped facilitate the establishment of an informal network to conduct adaptive research, training and facilitate dissemination of improved fallows (Fig. 3.4). The network has two functions: to provide coordinated and analytical mechanisms for participatory monitoring and evaluation of on-farm research in improved fallows, and to act as a catalytic and action-oriented group for the widespread dissemination of the technology. The network began when the project started supplying planting material, training, and information to extension services, development projects, NGOs and farmer groups that wanted to help their members test improved fallows. In exchange, these organizations provided the project with feedback on the performance of the technology.

The network is based on the principle that adaptive research and extension are really two sides of the same coin; once on-farm research has confirmed that a technology has adoption potential, dissemination is already beginning. Researchers need to be involved to obtain feedback from farmers and extension staff on problems and

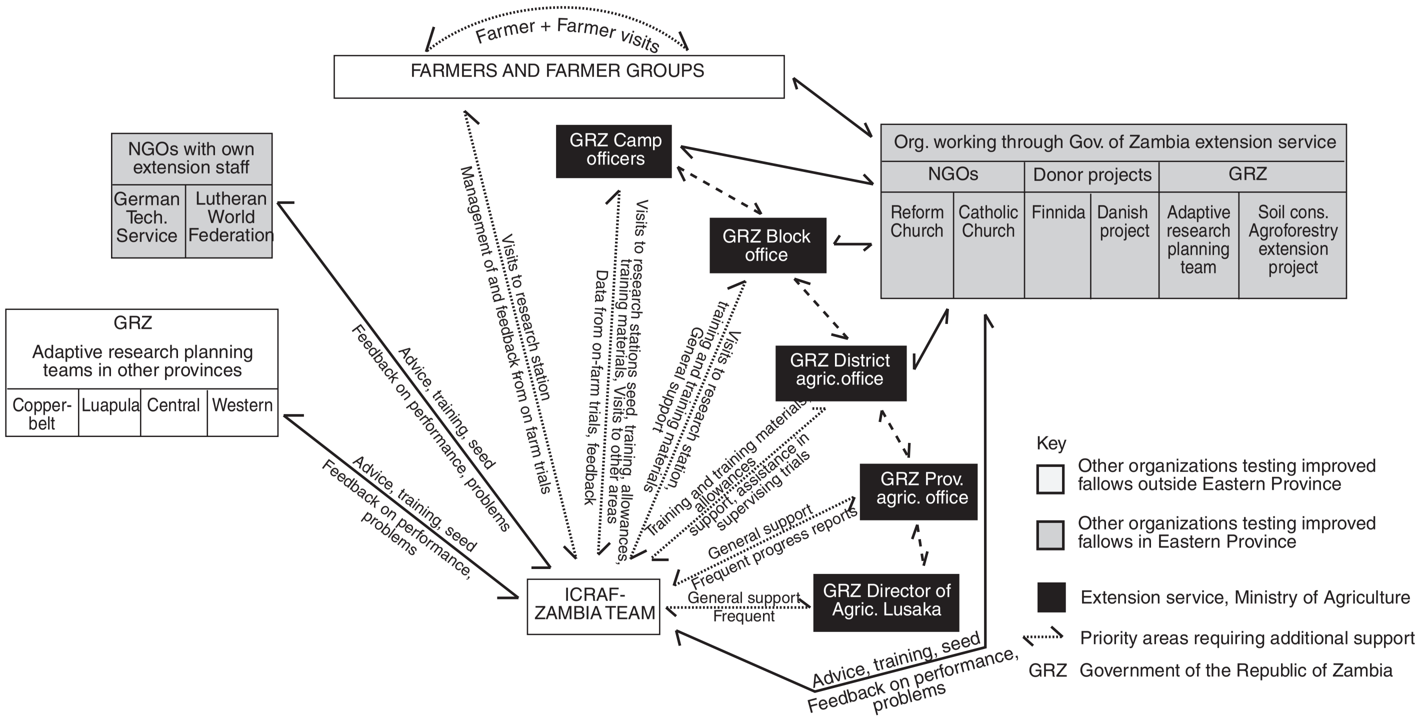

Fig. 3.4. Institutional links between ICRAF/Zambia team, farmers and other organizations testing improved fallows.

to identify researchable issues. Moreover, the more extension staff become involved in on-farm research, the more knowledgeable and enthusiastic they will be in extending the practice. Their involvement helps to save scarce research resources and improves the feedback to research.

The extension service in Zambia is a full partner in the on-farm research. In fact, about half of the type 2 trials were laid out by extension staff in the absence of researchers. Extension staff also play an important role in supporting the village nurseries and in monitoring the trials. They view the trials as joint research–extension work. Relations are also excellent at higher levels. Throughout the system, the managing of on-farm trials is seen as a normal duty of extension and NGO staff, rather than a burden imposed on them from outside. Development projects provide some incentives to extension staff, such as bicycles and lunch allowances, which facilitate institutional linkages and raise the effectiveness of the extension staff. That only one researcher and technician from the Zambia/ICRAF project were involved in the establishment and monitoring of the hundreds of on-farm trials in the mid-1990s attests to the strength of the network.

Development projects, NGOs and community-based organizations are also active members of the network. The World Vision International Zambia Integrated Agroforestry Project (financed by the United States Agency for International Development) plays a major role in promoting improved fallows. Farmer groups are also important members of the network. The groups (often called clubs) are generally composed of farmers in a single village; sometimes they are limited to a specific group such as females or youths. Most have several different self-help activities, but some were formed specifically to promote improved fallows. The groups manage nurseries, distribute seed and seedlings, and exchange knowledge, training and experience on improved fallows.

The first meeting of the network was hosted by the Zambia/ICRAF project in April 1996 and was attended by 75 representatives of extension services, projects, NGOs and farmer groups (FSRT/SCAFE, 1997). Participants planned for the wider testing of improved fallows, reviewed the problems and the state of knowledge about them, and developed a draft extension manual. The network meets 1–2 times yearly and meetings are chaired by the Provincial Agricultural Officer, who leads the government's agricultural programmes in the province. Representatives of extension and NGOs present the progress they have made and problems encountered in helping farmers use agroforestry. Farmers present their experiences and researchers report on the results of on-station and on-farm trials. Participants also plan training exercises and germplasm production and distribution.

Conclusion

Improved fallows have generated a high degree of enthusiasm among farmers, extension staff, NGOs and researchers. But several critical biophysical, socioeconomic, institutional and policy issues remain. On the biophysical side, the farmers' most important problem was poor tree growth and the low tree survival rate. Poor rainfall was the main contributing factor, followed by poor nursery and transplanting techniques and attacks by the mesoplatys beetle. Despite poor rainfall in some years, the quality of fallow stands will likely improve as farmer's knowledge of nursery and tree management increases. But sustained training of extension staff and farmers is needed to ensure progress in improving survival rates. Efforts to address the beetle problem focus on improving tree management, especially early planting, so that trees will be better able to withstand the attacks, and selecting sesbania provenances that the beetles do not attack. Researchers at Makoka Research Station, Malawi, have identified one such provenance.

Type 1 trials established across Zambia and three other countries in southern Africa confirmed that sesbania does not perform well on sandy soils, because of nematode attacks, or on shallow soils, because of mortality during the dry season (ICRAF, 1996). These problems, along with that of mesoplatys, highlight the need to screen new species for improved fallows. *Gliricidia sepium* is the most promising new species; farmers like it because it can be coppiced, that is, it regrows after cutting. Thus it is not necessary to replant it after using it in an improved fallow.

Several socioeconomic issues are also critical. Research is needed to monitor farmers' uptake of improved fallows and to assess their appropriateness for different types of farmers in the area. Researchers need to monitor carefully how those farmers testing the practice differ from those not testing and, eventually, how adopters differ from those rejecting the practice. The most important variables influencing adoption appear to be wealth level and gender.

Preliminary assessments presented in this chapter suggest that improved fallows are a gender-neutral technology; women are planting them about as frequently as men. Although wealth is associated with planting improving fallows, the fact that about one-sixth of the poor and very poor farmers are planting them suggests that there are no absolute constraints preventing these groups from doing so. More work is needed on understanding why some poor households participate while others do not. For example, participation in farmer groups may be an important factor.

An additional variable, labour availability at the time of planting, also needs to be assessed. Labour availability does not appear to be constraining farmers from testing improved fallows, but it may be important in limiting the area a farmer allocates to the practice. Farmers' apparent lack of concern about devoting labour to planting trees during their peak period of labour use reflects their high expectations concerning the benefits of the practice. Nevertheless, increased attention is needed for reducing labour requirements of improved fallows through such techniques as coppicing species, direct seeding and intercropping trees with maize during the year of establishment.

Several other socioeconomic issues need to be assessed. The economics of alternative improved fallow practices (e.g. sesbania versus tephrosia; pure stand versus intercropping; trees versus herbaceous legumes) needs to be examined. Also, as farmers expand their use of improved fallows, impact assessment is important to determine the financial and environmental effects of the technology at the farm, household and village scales. For example, will widespread adoption of improved fallows reduce deforestation, that is, tree felling in the woodlands for fuelwood?

Will farmers use improved fallows to reduce their area under maize so as to grow more cash crops? Researchers have conducted two village-level workshops to find out farmers' views on potential impacts and are planning participatory monitoring of the uptake of improved fallows and their impact in selected villages (Place, 1997).

On the institutional side, priority needs to be given to developing sustainable systems of producing and distributing seed; in 1996, it was necessary to import 7 tons of sesbania seed from Kenya to meet seed demand. Seed orchards are now in place and the area is self-sufficient in seed, but production and distribution are largely through NGOs, ICRAF and other organizations, the private sector and farmer organizations play less of a role. The advantages and disadvantages of collective and private nurseries also need to be examined. Large, collective nurseries facilitate the training of farmers, but dividing labour duties and distributing seedlings have proved problematic. Farmer groups need to be strengthened to take over some of the functions of research and extension (Ashby and Sperling, 1995). Such devolution not only reduces the costs of research and extension; it permits increased scale of testing and more appropriate research to meet farmers' needs. For example, group members could decide on research issues they want to investigate (e.g. intercropping versus pure stand) and could allocate responsibilities among members. At the end of the experimental cycle, the testers could draw their own conclusions and present them to the community.

Policy research can help identify how communities can control the free grazing of livestock to limit browsing damage to improved fallows, as well as to off-season gardens and woodlots. Several communities are currently trying to regulate browsing; their progress and lessons learned need to be monitored (FSRT/SCAFE, 1997). An alternative means to addressing the grazing problem is to identify tree species that are not palatable to livestock. Also, if improved fallows increase the quantity of produce marketed, marketing constraints, already severe, may be exacerbated. With market liberalization in the early 1990s, parastatal marketing of maize and cash crops has greatly declined and the private sector has not filled the gap.

In spite of the problems, much progress has been made in developing and disseminating improved fallows and it is useful to identify key elements that have contributed to the achievements thus far. First, diagnostic surveys were effective in identifying farmers' problems and drawing up research projects that could help solve them and fit farmer circumstances. Secondly, farmers participated in the design and testing of improved fallows at an early stage and their feedback was critical in modifying the technology. The early experimenters also played an important role, hosting visits from other farmers and training them. Thirdly, researchers and farmers tested a wide range of management options, not just a single prototype, and encouraged farmers to modify and innovate. Fourthly, an adaptive research and dissemination network was critical for mobilizing research, extension, NGOs and farmers, and for testing and extending the technology in new areas. Emphasis on these four elements can help promote success in technology development and dissemination efforts elsewhere.

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Appendix 3.1. Cost–benefit analysis of improved fallow and cropping options (ZK ha^{-1}).

	Maize cropping without fertilizer					Two-year sesbania fallow					Maize cropping with fertilizer				
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 1	Year 2	Year 3	Year 4	Year 5	Year 1	Year 2	Year 3	Year 4	Year 5
Costs															
Cash costs															
Maize seed	22.24	22.24	22.24	22.24	22.24			22.24	22.24	22.24	22.24	22.24	22.24	22.24	22.24
Nursery costs						2.93									
Fertilizer								0.00	0.00	0.00	142.82	142.82	142.82	142.82	142.82
Fertilizer transport								0.00	0.00	0.00	6.40	6.40	6.40	6.40	6.40
Total cash costs	22.24	22.24	22.24	22.24	22.24	2.93		22.24	22.24	22.24	171.46	171.46	171.46	171.46	171.46
Labour															
Tree nursery						10.52									
Land preparation	12.00	12.00	12.00	12.00	12.00	12.00		9.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
Ridging	4.00	4.00	4.00	4.00	4.00	4.00		3.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Planting maize	2.00	2.00	2.00	2.00	2.00	0.00		2.00	2.00	2.00	2.80	2.80	2.80	2.80	2.80
Planting trees	0.00	0.00	0.00	0.00	0.00	11.24		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1st weeding	8.00	8.00	8.00	8.00	8.00	8.00		6.00	8.00	8.00	10.00	10.00	10.00	10.00	10.00
2nd weeding	4.00	4.00	4.00	4.00	4.00	4.00		3.00	4.00	4.00	6.00	6.00	6.00	6.00	6.00
Tree cutting	0.00	0.00	0.00	0.00	0.00	0.00	2.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harvesting maize	5.96	5.96	5.96	5.96	5.96	0.00	0.00	8.88	8.00	7.13	9.58	9.58	9.58	9.58	9.58
Maize shelling	3.96	3.96	3.96	3.96	3.96	0.00	0.00	6.88	6.00	5.13	7.58	7.58	7.58	7.58	7.58
Total labour costs	39.92	39.92	39.92	39.92	39.92	49.76	2.08	38.76	44.01	42.26	51.96	51.96	51.96	51.96	51.96
Total costs	62.16	62.16	62.16	62.16	62.16	52.68	2.08	61.00	66.25	64.50	223.42	223.42	223.42	223.42	223.42
Labour work days	99.8	99.8	99.8	99.8	99.8	124.4	5.2	96.9	110.0	105.6	129.9	129.9	129.9	129.9	129.9
Benefits															
Maize	63.74	63.74	63.74	63.74	63.74	0.00	0.00	257.63	199.47	141.30	304.11	304.11	304.11	304.11	304.11
Fuelwood	0.00	0.00	0.00	0.00	0.00	0.00	6.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total benefits	63.74	63.74	63.74	63.74	63.74	0.00	6.40	257.63	199.47	141.30	304.11	304.11	304.11	304.11	304.11
Net benefit to labour	41.50	41.50	41.50	41.50	41.50	–2.93	6.40	235.39	177.23	119.06	132.66	132.66	132.66	132.66	132.66
Net return to labour day^{-1}	0.42	0.42	0.42	0.42	0.42	–0.02	1.23	2.43	1.61	1.13	1.02	1.02	1.02	1.02	1.02

Net benefits	1.58	1.58	1.58	1.58	1.58	–52.68	4.32	196.63	133.22	76.80	80.70	80.70	80.70	80.70	80.70
Work days	499.0					442.2					649.5				
Net present value	4.74					168.00					241.33				
Discounted days	0.24					0.21					0.31				
Discounted net benefit to labour	124.12					271.54					396.72				
Discounted net benefit/discounted days	0.42					1.05					1.02				
Quantity of maize	5 t/5 years					9 t/5 years					23 t/5 years				

Prices are from local markets for the 1996 cropping season. Exchange rate: US$1.00 = 1250 Zambian Kwacha (ZK), 1996.

Cash costs

Maize seed: seed rate of 20 kg ha^{-1}. Cost: 1340 ZK kg^{-1}.

Nursery cash costs: total costs per seedling, including cash and labour costs, is 1.4 ZK, median from cost analysis of eight farmer nurseries. Mean cost was 1.9 ZK, SD = 1.2. It is assumed that 12,000 seedlings are raised in order to achieve a density of 10,000 seedlings ha^{-1} in the field. Nursery cash costs accounted for 22% of the total cost of the nursery and included rent of land in the valley bottom and purchase of a watering can.

Fertilizer: the recommended rate is 112–40–20 kg of N–P_2O_5–K_2O per hectare. In 1996, it required 200 kg of D compound, purchased, at 459 ZK kg^{-1}, and 200 kg of urea, purchased at 433 ZK kg^{-1}. 1998 prices were 580 ZK kg^{-1} and 520 ZK kg^{-1}, respectively.

Fertilizer transport: estimated at 1000 ZK 50 kg bag^{-1}, from Chipata to farm in 1996 and 1350 ZK/bag in 1998.

Labour: labour data for maize cultivation are assembled from DOA (1991), Kwesiga *et al.* (1995) and Place *et al.* (1995) and from survey farmers. Labour data concerning trees are from surveyed farmers.

Labour cost: costed at 500 ZK work day^{-1} in 1996. A work day is assumed to involve 7 hours of work. Hiring labour is not common; reported wage rates were highly variable. 500 ZK day^{-1} represents the approximate average returns per labour in maize production for 1996, that is, the value of labour at which a farmer growing maize without fertilizer breaks even. In 1998, this value was about 1300 ZK work day^{-1}.

Nursery: see 'nursery cash costs' above. Activities included collecting and threshing seeds, constructing beds, collecting sand, compost and soil, planting, covering with grass, watering, weeding, digging out the seedlings, and transporting them to the field. Mean number of work days required to produce 12,000 seedlings, sufficient to plant and gap up one hectare, was 26.8. (SD 22.7).

Land preparation and ridging: 30 and 10 work days ha^{-1}, respectively. They are 25% less during the year after the improved fallow, according to estimates of trial farmers.

Appendix 3.1. *Continued.*

Planting maize: 5 work days ha^{-1}. When applying fertilizer, 7 work days ha^{-1}.

Planting trees: 420 trees per day, median of data from 12 farmers (mean = 499, SD = 424).

Weeding: assumed to be the same for trees as for maize, as claimed by farmers. Weeding requirements decline by 25% during the year after the improved fallow, according to estimates of trial farmers. Weeding requirements are assumed to increase 33% with fertilizer use.

Harvesting and post-harvest: labour varies with quantity. A yield of 1 t ha^{-1} requires 15 work days for harvesting and 10 days for post-harvest activities (shelling and transportation). A yield of 4.6 t ha^{-1} is estimated to require 60% more harvest labour and 90% more post-harvest labour.

Benefits

Eleven of the 12 trial farmers had 2-year fallows; one had a 3-year fallow. For the purpose of comparison with the other sample farms for drawing up enterprise budgets, we assumed that Phiri had a 2-year fallow. This assumption increased the net present values in the table above by 1% and the net benefit day^{-1} by 1%.

Maize: yields are from the 12 trial farmers for the season following the improved fallow and are compared with yields on continuously cropped adjacent fields, with and without fertilizer (Table 3.4). For the continuously cropped maize fields, yields are assumed to be constant over the 5-year period (964 kg ha^{-1} without fertilizer and 4384 kg ha^{-1} with fertilizer). Maize yields following the improved fallows are 3638 kg ha^{-1} for the first post-fallow season (Table 3.4), 2836 kg ha^{-1} for the second, and 2034 kg ha^{-1} for the third season. The latter two figures are based on a 30% and 60% reduction in response, as obtained in on-station trials. The maize price was 83 ZK kg^{-1}, the estimated farm-gate price during the harvest period, 1996. The 1998 price was 167 ZK kg^{-1}.

Fuelwood: fuelwood is not normally sold; yield is estimated at 4 t ha^{-1} and price at 2000 ZK t^{-1}.

Discount rate: 20%.

The Adoption Potential of Short Rotation Improved Tree Fallows: Evidence from Western Kenya

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Summary

This study assesses the economics of improved fallow in the densely populated areas of western Kenya, where soils are nutrient depleted. A formal survey of 71 randomly selected farmers showed that half fallow 10–50% of their land for at least one season, mainly for soil fertility restoration. An improved-fallow prototype, established by direct seeding *Sesbania sesban*, an indigenous tree, into the maize crop preceding the fallow, was subjected to an economic analysis, based on 20 farmer-managed trials where the technology was tested. One would expect intuitively that the yield of maize grown after a one-season fallow would need to be at least double that obtained before the fallow, in order to compensate for the lost production during the fallow period. Instead, the break-even yield increase following the one-season fallow, compared to continuous cropping, was only 21% of the long rains yield of 600 kg ha^{-1} for the base scenario. It was relatively low, because the foregone maize yield during the fallow was compensated by savings in crop labour. Improved fallow is a promising technique for reclaiming depleted land, especially for households with access to off-farm income or having low labour-to-land ratios. The farm trials facilitated a realistic economic analysis and farmers' input into the design of the technology to help focus research on improving the practice. Insights from this trial led to a new phase of on-farm research, with researcher-designed, researcher-managed trials to screen potential improved fallow species, researcher-designed, farmer-managed trials on a range of design variables, a large network of farmer-designed, farmer-managed trials, and a rapidly expanding extension programme promoting improved fallows.

Introduction

Soil nutrient depletion is a worldwide problem affecting 135 million ha, mostly in South America and Africa (Oldeman *et al.*, 1991). In the East African highlands, soil depletion is a common feature of food-crop oriented small-scale farms, and has led to low labour and land productivity. Rapid population growth has resulted in an increase in continuous cropping of farmers' fields, while little use is made of organic or inorganic fertilizers. Organic inputs, such as manure, are limited by their availability, and the use of inorganic fertilizers is constrained by the unreliable returns to recommended 'packages' of hybrid seeds and fertilizers (Ruthenberg, 1980; Anderson, 1992) and lack of access to capital (Hoekstra and Corbett, 1995). As off-farm income has become relatively important for farm households in eastern and southern Africa (Low, 1988), technologies are required that not only are able to recover depleted soils and are appropriate to the suboptimal production conditions of small-scale farmers, but also offer attractive returns per work day.

Work in Zambia has shown that improved fallows (enrichment of natural fallows with trees or shrubs to improve soil fertility) have the potential to increase crop yields, while also providing fuelwood (Chapter 3). Results have been positive using *Sesbania sesban*, a rapidly growing (though short-lived), nitrogen-fixing tree that seeds profusely. It is indigenous throughout eastern and southern Africa; in western Kenya it is often found in cropland and in fallowed plots (Bradley, 1991). Farmers sometimes scatter sesbania seed in cropland for fuelwood production and as a means for soil enrichment (Bradley, 1991; Scherr, 1993).

Uses of sesbania species as green-manure crops have been documented extensively (Evans and Rotar, 1987). In on-station trials in western Kenya, sesbania is reported to produce up to 9 t ha^{-1} of dry leafy biomass per 6-month season (Onim *et al.*, 1990), equivalent to about 252 kg of nitrogen. However, few studies have examined improved fallow for soil fertility improvement under farmer management, particularly in areas of high population density, where one would think they have little potential (Hoefsloot *et al.*, 1993; Versteeg and Koudokpon, 1993).

The objectives of this work were to: (i) assess the extent and role of fallowing in the densely populated farming systems of the area; (ii) obtain farmers' evaluations of improved fallow and determine problems farmers had in managing them; (iii) assess the economics of improved fallow in terms of yield increase following the fallow required to cover the costs; and (iv) assess possible management options based on observation of farmers' experimentation with the technology. As there had been no earlier research on improved fallow in the area or in a similar environment, the work was important in guiding decisions regarding further research on the technology. Assessing yield response following the fallows was originally an objective, but this was not possible due to high managerial variability: farmers often planted test and control plots at different times in different crop densities with varying amounts of manure and weeding labour. Determining yield response would have required controlling non-experimental variables, which was inimical to the objective of assessing farmer management of the technology. Therefore, yield response was measured in separate researcher-managed trials under controlled conditions.

Study Area

The study area is located around the town of Maseno in western Kenya (0°00′ N 34° 35′ E) (Fig. 4.1). The area lies on the equator, and includes adjacent portions of Siaya, Vihiga and Kisumu Districts, i.e. Yala, Emuhaya, Winam and Maseno Divisions. These represent humid parts of the food-crop-based land-use system of western Kenya. The area has high agricultural potential (high rainfall, well-structured soils) but the land is nutrient depleted (Shepherd *et al.*, 1996). The altitude is about 1500 m above sea level and the mean annual temperature is 21.0°C. Rainfall is bimodal, averaging 1600–1800 mm year^{-1} and divided over the long rains season,

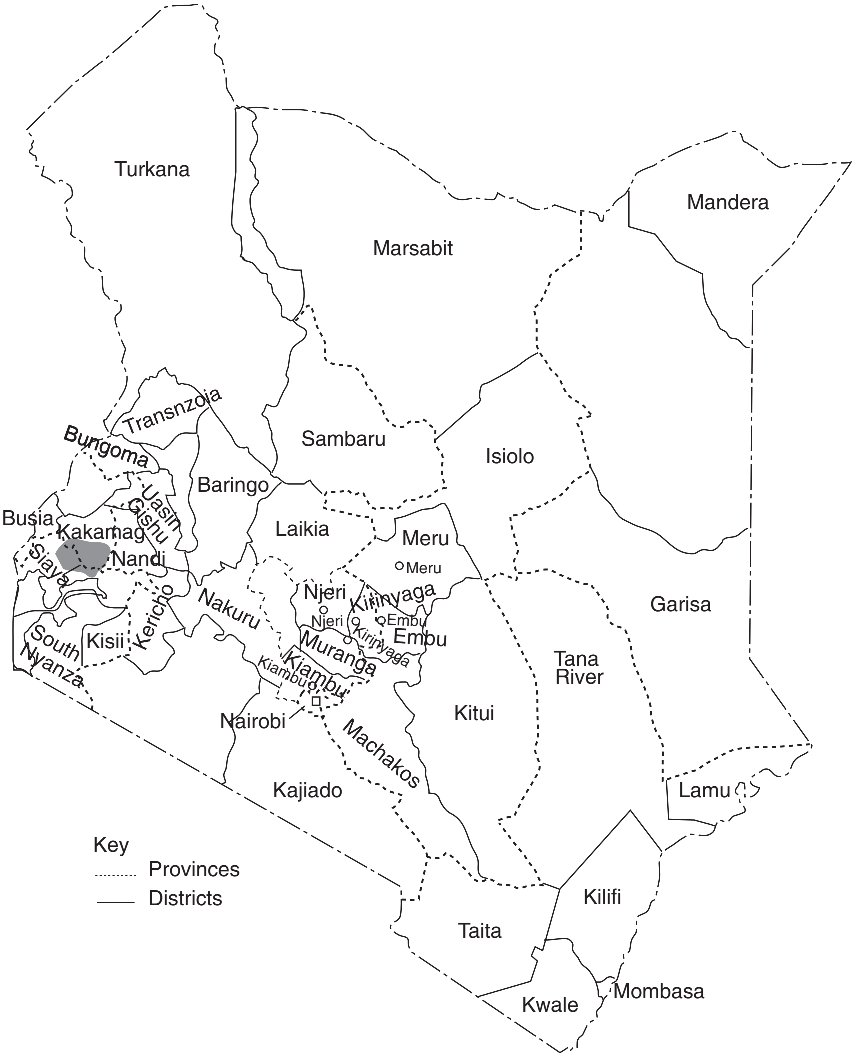

Fig. 4.1. Study area in western Kenya.

from March to July, and the short rains season, from August to November. During the trial period, rainfall varied within the research area and was slightly lower than usual in 1991 (1350–1500 mm) and about the average in 1992 (1400–2050 mm). The landscape is undulating with slopes of 2–8%. Main soil types are Ferralsols, Acrisols and Nitisols with pH 5 to 7, and moderate to high base. Nitrogen and phosphate deficiencies in soils are widespread (Shepherd *et al.*, 1996; Sanchez *et al.*, 1997).

Farm size varies between 0.5 and 2.0 ha, with a median of 1.2 ha (David and Swinkels, 1994), and population densities range from 300 to over 1000 persons km^{-2}. Maize, often intercropped with beans, dominates the cropping pattern. Cash crops are rare: only 14% sell either sugarcane, French beans, coffee or tea. Maize yields are low: about 700–1200 kg ha^{-1}. Most households (74%) own a few local Zebu cattle (median is four cattle). Land is privately owned. About half of the heads of households are involved in off-farm money-making ventures. Roughly half of all households are female-headed. Use of hired labour is variable; some households hire labour for almost all their farm work, while others use only household labour. Less than one-third use mineral fertilizer (David and Swinkels, 1994).

Methods

The methods used include a formal survey of a randomly selected sample of farmers, a participatory rapid appraisal of farmers with dense stands of sesbania fallows, and a participatory on-farm trial in which interested members of self-help groups tested improved fallows.

Formal surveys and participatory rapid appraisals

In 1991, informal discussions with farmers were conducted regarding their methods of soil fertility maintenance, including existing fallowing practices. A formal survey of 71 randomly selected farmers using a structured interview schedule was conducted in 1992. Its aim was to verify hypotheses developed from the earlier informal discussions with farmers. The methods of maintaining soil fertility were then correlated with key parameters, such as household characteristics, farm size and labour available for agricultural work.[1] Fallowing was defined as leaving land, which is normally cropped, temporarily uncultivated. A participatory rapid appraisal was conducted in 1993 among six farmers who had dense stands of sesbania, to assess the role of these stands in their existing fallowing practices. Semi-structured interview techniques were used to stimulate free expression of farmers' views.

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[1] This variable was calculated by adjusting household size for age composition and the reported primary activity of each member. It is only indicative of available labour, as households may also hire labour.

Trial design

Farmers were selected from self-help groups during 1991; after discussions with the group members, the most interested ones were invited to participate (Ndufa *et al.*, 1995). Twelve planted a trial in 1991 and eight others planted in 1992. Researchers provided farmers with tree seed, some seedlings for gapping up, and advice on planting method. The researchers marked out plots, but farmers conducted all operations. The trial thus began as a 'type 2' (researcher-designed, farmer-managed) trial (Chapter 2).

The trial included two adjacent plots managed by each farmer: (i) an improved fallow rotation, maize→improved fallow→maize (6 months per phase); and (ii) a control plot under continuous maize or maize→unimproved fallow without sesbania→maize, depending on the farmers' choice (unimproved fallow without sesbania is the most common fallow practice in the area). On the improved-fallow plots, the prototype recommendation was to: (i) establish sesbania rows by direct seeding as a relay crop between 3-week-old maize during the long rains season; (ii) fallow during the subsequent short rains season; and (iii) cut down the trees just before the next long rains season, incorporate the leafy biomass, and plant a maize crop. The improved-fallow prototype helps farmers to achieve a higher density of sesbania in their fallow fields.

The sesbania were planted in continuous lines 4 m apart in 1991, but 2 m apart in 1992. A linear planting arrangement was chosen to facilitate crop cultivation. Farmers were given about 150 g of tree seed (110 seeds g^{-1}) per 100 m of sesbania line. Sizes of plots were variable: 300–900 m^2. Just before the start of the long rains following the fallow, farmers were given the option of cutting the trees at ground level to kill them, or cutting at 0.5–1 m height to maximize regrowth. The latter option would turn the tree lines into hedges, but these would not be long-lived as sesbania at this altitude does not withstand frequent removal of all its leaves (Yamoah and Burleigh, 1990; ICRAF, 1992).

Informal interviews with the trial farmers were conducted each season to determine methods and criteria farmers used to evaluate improved fallow, to obtain their assessments and to examine the problems they encountered. We also monitored their willingness to repeat the improved fallow by offering them seed during 1992 and 1993. Formal questionnaire surveys at the end of the trial period were used to test hypotheses developed from the informal interviews, to quantify farmers' perceptions on yield responses, and to assess household characteristics so as to determine whether they were representative of the population in the area (David and Swinkels, 1994).

Data on labour inputs for planting and managing the trees were collected by monitoring work rates through observation. Crop input–output data were collected from 150 maize plots, including those of the trial farmers as well as an additional 50 farmers with other on-farm trials in the area, using farmers' recall just after a task was completed (Chapter 5). Prices were collected from six local markets. Yields of tree foliage and wood at the time of tree harvest were determined from quadrat samples.

Economic analysis

Enterprise budgets were developed for the maize with the improved fallow prototype, for continuous maize, the most common practice on the control plots, and for maize with an unimproved fallow without sesbania. Intercropped beans and groundnuts were omitted in the economic analysis as their yields were low and formed only a minor part of the production value. As this regards an economic analysis from the farmers' point of view, we incorporate the inputs, outputs and prices that the farmer faces. Net returns to farmers' production factors (land, labour and capital) were calculated by subtracting purchased inputs from the production value. After subtracting farmers' capital inputs, which were minor, the net returns were allocated among farmers' land and labour by valuing one factor at its opportunity cost and by attributing the remainder to the other factor. This enabled us to calculate the net returns to land, which is relevant for farmers whose most scarce resource is land, and the net returns to labour, relevant for those who lack household labour.

As comparing crop yields between test and control plots was not meaningful, due to a high managerial variability, we are not able to report crop yield responses here. Instead, we calculated the break-even maize yield relative to continuous cropping, that is, the yield increase over continuous maize that is required to cover the costs of the improved fallow (including the maize yield foregone during the fallow period and including the cost of postponing consumption, i.e. the social time preference rate, estimated at 20%). We also calculated the break-even maize yield increase relative to an unimproved fallow. This is the extra yield required over the yield after an unimproved fallow, to cover the cost of improved fallow. Equations were developed for the calculation of the break-even yield increase for the comparison with continuous maize, based on an analysis of returns to land (Appendix 4.1); for the comparison with unimproved fallow; and for both types of comparisons based on an analysis of returns to labour. Only the first season after the fallow is included in the analysis and thus residual effects of the improved fallow are not considered. The analysis is therefore likely to underestimate benefits. Furthermore, negative effects of the trees on adjacent fields during the fallow and positive effects on adjacent fields after the fallow are not considered.

The economic analysis incorporates two maize yield scenarios: low and high. To represent severely depleted soils the average 25th percentile seasonal yields for 1991 and 1992 were taken from the sample of 150 maize plots (600 kg ha^{-1} in the long rains and 400 kg ha^{-1} in the short rains). To represent less depleted soils the average 75th percentile sample yields were taken (1900 kg ha^{-1} and 1200 kg ha^{-1}). For each yield scenario, yields under continuous maize were assumed to remain constant for the three seasons. Under unimproved fallow, yields were assumed to remain the same before and after the one-season fallow. These assumptions allow an assessment of the break-even yield increase of improved fallow relative to the two alternative systems. Crop labour inputs were about 50% higher for the high-yield scenario compared to the low-yield scenario.

In situations of high population density where land is scarce and farms are small, the marginal product of labour is usually lower than the wage rate (Ellis, 1988). Therefore, we valued cropping labour according to three different scenarios: 25, 50 and 75% of the hired labour price. The first scenario would be applicable where labour is abundant and the farmer is usually not able to find off-farm work; the third one is applicable where the farmer is usually able to do off-farm work, but incurs some transaction costs in finding it (De Janvry *et al.*, 1991). The second scenario represents an intermediate situation.

Land was valued at its rental rate of about US\$33 ha^{-1} $year^{-1}$, but as tenancy and land transactions are uncommon,[2] this is only indicative of its opportunity cost. In the analysis we therefore incorporate two other land values: (i) double the rental rate, approximating the opportunity cost of land based on the relatively high purchase price (US\$660 ha^{-1}); and (ii) half the rental rate, to estimate the opportunity cost of severely depleted land.

For each yield scenario, the average of the 1991 and 1992 medians of other inputs, such as quantities of maize seed, farmyard manure and fertilizer, were used. Sensitivity analysis was conducted to measure the effects of changes in some of the base assumptions on the break-even maize yield increase.

Results

Formal survey results

Farm sizes are small: the mean was 1.7 ha (SD = 1.6 ha; median = 1.2 ha). Labour–land ratios were variable: the mean was 3.1 equivalents of adult full-time workers per ha (SD = 5.1; median = 1.8).

More than half the farmers (52%) mentioned that they fallow some of their land periodically, about 10–50% of total farm land at a time. During the short rains season of 1992, on average 32–47% of farmers' cropland was under fallow, depending on the district. The length of the fallow varies between one season (24% of those who fallow), 1 year (35%) and 2 or more years (41%). As expected, farmers who fallow have on average significantly larger farms (2.2 versus 1.2 ha; $P < 0.01$). However, fallowing is not limited to the larger farms as 31% of households with farms smaller than the median also fallow periodically. Labour–land ratios were not significantly lower than for farmers who do not fallow.

Of the farmers who fallow, 84% mentioned that they did so to restore soil fertility, while 51% mentioned shortages of labour or cash to hire labour. Other reasons mentioned by less than 5% of farmers included need for grazing land/fodder, lack of seeds and need for fuelwood (farmers were allowed to give more than one answer). Farmers that mentioned lack of labour as a reason for fallowing had lower labour–land ratios than the rest (1.4 versus 3.6 adult full-time workers; $P < 0.08$). A higher proportion of farmers with off-farm income mentioned that they fallow peri-

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[2] Tenancy is infrequent because of enforcement problems and lack of credit, while land transactions are rare due to high land prices and lack of credit (Collier, 1989). Usually land is obtained through inheritance.

odically, compared to those without off-farm income (68% versus 32%; $P < 0.003$). No association was found between fallowing and gender or age of head of household.

Three-quarters of the farmers reported that they had some sesbania growing in their crop land; tree density ranged between 20 and 200 trees ha^{-1}. The proportion of farmers varied between 33% and 94%, depending on the district. A fifth of the farmers claimed they sometimes scatter sesbania seeds in the cropland after land preparation.

Results of participatory rapid appraisal

Among the six farmers with dense sesbania stands, sesbania usually grows naturally in cropland. In case the population of sesbania drops below desirable levels, farmers may broadcast sesbania seeds. During land preparation or weeding, farmers sometimes remove sesbania trees or branches to prevent excessive shading of crops. The farmers' main reason for growing sesbania is for fuelwood for domestic use, but they are aware of its beneficial effect on soil fertility, although the impact is limited as tree densities are low.

When land is left fallow, the sesbanias are allowed to grow tall and seed, which may result in a dense stand. After a fallow, all sesbania trees are cut down, the land is prepared and a maize crop planted. None of the farmers interviewed had sown sesbania during the season prior to a fallow or at the start of a fallow in order to encourage a dense stand.

Trial results

The average farm size of trial farmers was 1.2 ha (SD = 1.4 ha). Seven of the 20 trial households were female-headed; ten farms were managed by a female, five by a couple, three by a male and two by permanent labourers. These results are in line with findings for the broader population of the area (David and Swinkels, 1994).

Tree establishment failed on five of the 20 farms because of washing away of seed during heavy rains (four farms) and poor weeding (one farm). In the remaining 15 trials, the mean number of trees germinating was 13 m^{-1} (SD = 7), leading to tree stands of 32,500 trees ha^{-1} for trees in rows 4 m apart and 65,000 trees ha^{-1} for trees in rows 2 m apart. Farmers did not do any extra weeding of the trees, apart from the normal weeding of the maize. Tree height 6 months after sowing was extremely variable, ranging between 0.5 and 2.5 m, with a mean of 1.3 m.

Of the 15 remaining trials, another five failed in the course of the first year after establishment. Causes included browsing by dik-diks (*Madoqua kirki*) (three farms, all in areas of low population density where such antelopes are still common), browsing by the farmer's cow (two farms), farmer leaving the area (one farm) and trees accidentally uprooted during land preparation (one farm). On some farms, there were more than one cause of failure.

Trial management was highly variable. In four of the remaining ten trials, the farmer followed the prototype recommendation for the test plot of fallowing for one season and cutting down the trees about 1 year after sowing. Quantities of dry leafy biomass on three of these four farms for which data were available were 9000 kg ha^{-1}, 3700 kg ha^{-1} and 700 kg ha^{-1}. Assuming 18 g nitrogen kg^{-1} leafy biomass (Shepherd *et al.*, 1996), the leafy biomass provided about 162, 67 and 13 kg nitrogen ha^{-1}. Dry weights of wood were 7900 kg ha^{-1}, 3400 kg ha^{-1} and 500 kg ha^{-1}, and the amounts of nitrogen removed in the wood (assuming 7.3 g nitrogen kg^{-1} wood) were 58, 25 and 4 kg ha^{-1}. Thus about one-third of the nitrogen in the standing biomass was removed from the field. Tree yields were lower on the third farm partly because trees were planted in rows 4 m apart, compared to 2 m apart on the other two farms.

Five other farmers cut down the trees at 1.5–3 years after establishment. Three of these fallowed only during the last season before cutting, cropping in between the tree rows during the other seasons. They side-pruned the trees to prevent shading. One other farmer fallowed for two seasons, and another one for three seasons, before harvesting the trees. Tree biomass data were available only for the latter farmer; he harvested about 2400 kg ha^{-1} of dry leaves and 2500 kg ha^{-1} of dry wood (trees in rows 4 m apart). One other farmer still had not cut down the trees 3 years after sowing. Only 1 of the 10 farmers fallowed the control plot at least once during the trial period. The rest planted maize (eight farmers) or sweet potato (one farmer). Average long-rains maize yields before the fallow on 6 of the 10 successfully established trials for which data were available was 1073 kg ha^{-1} (SD = 667). Data on long-rains crop yields in the trial plot after the fallow were only available for three farmers: their mean maize yield was 658 kg ha^{-1} (SD = 238). In the control plot, long-rains maize yields during the trial period were, on average, 995 kg ha^{-1} (SD = 610; n =7) in the long rains and 633 kg ha^{-1} (SD = 356; n = 19) in the short rains.

Farmers' evaluations of the ten successfully established improved fallows were positive. All of them stated that, in the establishment season, the young sesbania seedlings had no influence on maize yields and weeding requirements. However, the four farmers who cut down the trees within 1 year after sowing mentioned that regrowth of the remaining tree stumps made land preparation and weeding more difficult. In contrast, the five farmers who cut down their trees 1.5–3 years after sowing saw a much higher tree mortality and said that the remaining tree stumps had no effect on labour requirements for land preparation or weeding. The three farmers who intercropped the trees for more than one season before fallowing, observed that after the first season the crops were negatively effected by shading of the trees.

Six of eight farmers for whom data were available claimed that the improved fallow increased crop yields; two mentioned the trees had made no difference. Three farmers noted the trees had caused a decrease in weeds and two reported that the trees helped curb soil erosion. Five asked for more sesbania seed and four planted a new improved fallow on their own.

Economic analysis

Extra costs of improved fallow, compared to continuous cropping, consisted of tree seeds, labour for establishing and removing the trees, and the maize yield foregone during the fallow; extra benefits included crop labour and other crop inputs saved during the fallow, fuelwood and the increased maize yield after the fallow (Table 4.1). Improved fallow required less labour than continuous cropping: over three seasons the reduction was 83 work days ha^{-1}, or 21% under the low-yield scenario (Table 4.1). Thus, the higher the opportunity cost of labour, the more profitable is the improved fallow. The extra costs of improved fallow compared to an unimproved fallow consisted of planting and cutting down the trees, minus the cost of clearing the natural fallow, which is estimated to require 5.8 work days ha^{-1} (one-third of the labour required to cut down an improved fallow).

Returns to land

The break-even maize yield increase required to cover the costs of improved fallow, as compared to continuous cropping, was calculated from Equations (4.1) and (4.2) (Appendix 4.1). Using values from Table 4.1 to calculate (Equation 4.2) we get:

$$\mathrm{BEYI}^{\mathrm{land}} = -\frac{41}{Y^{\mathrm{L}}} + P_{\mathrm{L}}\,\frac{275 - 8.6\,L_{\mathrm{m}}^{\mathrm{S}}}{Y^{\mathrm{L}}} + 1.2\,\frac{Y^{\mathrm{S}}}{Y^{\mathrm{L}}}$$

where,

$\mathrm{BEYI}^{\mathrm{land}}$ = the break-even yield increase in the long rains following the fallow (% of long-rains yield under continuous cropping) for the analysis of returns to land, and
Y^{L} = maize yield in the long rains under continuous cropping (kg ha^{-1}),
P_{L} = opportunity cost of labour (US\$ day^{-1}),
$L_{\mathrm{m}}^{\mathrm{S}}$ = maize labour input in the short rains (work days ha^{-1}), and
Y^{S} = maize yield in the short rains (kg ha^{-1}).

Under the low-yield scenario, the break-even yield increase required to cover the costs of improved fallow was 21% (Table 4.1), and ranged between −5% and 47% of the long-rains yield of 600 kg ha^{-1}, depending on the opportunity cost of labour (Table 4.2). In the high-yield scenario, the break-even yield increase for improved fallow was between 31% and 59% (Table 4.2). Thus at higher base yields, improved fallow becomes less attractive (Fig. 4.2), reflecting the higher maize yield foregone while fallowing. Under a high-yield scenario, the break-even yield increase also becomes less sensitive to changes in the opportunity cost of labour compared to the low-yield scenario (Table 4.2).

A higher opportunity cost of labour reduced the break-even maize yield increase because higher labour costs were foregone during fallowing, increasing the attractiveness of improved fallows (Table 4.2; Fig. 4.3). In the low-yield scenario, the break-even yield increase is negative when the opportunity cost of labour is higher than US\$0.59 day^{-1} (70% of the wage rate) (Table 4.2). This is because at that labour cost, the present value of net returns per hectare of continuous maize is negative (Fig. 4.2).

Table 4.1. Enterprise budget showing the 21% maize yield increase, following the improved fallow, required under the base analysis to cover the costs of adopting it, relative to continuous cropping, based on returns to land (US\$ ha^{-1}).[a]

	Improved fallow			Continuous maize		
	Year 1		Year 2	Year 1		Year 2
Costs and returns[b]	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3
Returns (US\$ ha^{-1})						
maize yield	82	0	99	82	55	82
fuelwood	0	0	10	0	0	0
Costs (excluding labour) (US\$ ha^{-1})						
maize seed	4	0	4	4	4	4
tree seed	8	0	0	0	0	0
Net returns to farmers' land, labour and capital (US\$ ha^{-1})	74	0	109	82	55	82
Net returns to farmers' land and labour (US\$ ha^{-1})	70	0	105	78	51	78
Present value of net returns to farmers' land and labour (US\$ ha^{-1})	131			161		
Labour input (work days ha^{-1})						
maize	136.4	0	136.4	136.4	118.2	136.4
tree sowing	17.5	0	0	0	0	0
cutting trees	0	0	17.5	0	0	0
Total labour	153.9	0	153.9	136.4	118.2	136.4
Present value of labour input (work days ha^{-1})	235.1			306.9		
Present value of net returns to land (US\$ ha^{-1})	33			33		

[a] Maize yield increases are expressed as percentages of long-rains yield. The base analysis uses the low maize yield scenario: 600 kg ha^{-1} in the long rains and 400 kg ha^{-1} in the short rains; opportunity cost of labour is 50% (US\$0.42 day^{-1}) of wage rate. 1991 prices, 1 US\$ = 30 Kenya Shillings.

Table 4.1. *Continued.*

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[b] Costs and returns:
Maize price = US$0.14 kg^{-1} (market price at planting time and harvesting time).

Fuelwood yields varied between 3 and 10 tons dry wood ha^{-1}, but as fuelwood is not particularly scarce, we value only the first ton; estimated value is one-third of the market price of US$0.03 kg^{-1}.

Maize seed rate is 32 kg ha^{-1}.

Tree seed rate is 6.1 kg ha^{-1} of sesbania seeds, valued at the price of US$1.3 kg^{-1}, at which it is bought by NGOs in the area.

Net returns to land, labour and capital is production value minus purchased inputs; only tree seeds are assumed to be purchased.

Net returns to land and labour: farmers' capital inputs are assumed to consist only of own maize seeds; value of farm tools is negligible and their depreciation costs are not included.

Present value uses a discount rate of 20%.

Labour input on maize: in western Kenya a working day in agriculture consists of 5.5 hours.

Labour input for tree sowing: 13.1 work days ha^{-1} for sowing plus 4.4 work days ha^{-1} for gapping up a few weeks later.

Labour input for cutting trees consists of two cuts: one at the end of the fallow and one cut of regrowth during the cropping season.

Table 4.2. Break-even yield increase (expressed in percentage of long-rains yield) required to cover the costs of improved fallow under different assumptions, comparisons and types of analysis.

		Analysis of returns to land					
				Low opportunity cost of labour[d]		High opportunity cost of labour[e]	
Maize yield[a]	Comparison[b]	Equation[c]		%	kg ha^{-1}	%	kg ha^{-1}
low	IF vs CM	$0.731 - 1.239\ P_L$	(1)	47%	282	–5%	–30
high	IF vs CM	$0.736 - 0.679\ P_L$	(2)	59%	1121	31%	589
low	IF vs UF	$0.005 + 0.389\ P_L$	(3)	9%	54	25%	150
high	IF vs UF	$0.002 + 0.123\ P_L$	(4)	3%	57	8%	152
		Analysis of returns to labour					
		Equation		Low opportunity cost of land[f]		High opportunity cost of land[g]	
low	IF vs CM	$0.090 + 0.0060R^{LR} + 0.0034R^{SR}$	(5)	17%	102	42%	252
high	IF vs CM	$-0.047 + 0.0033R^{LR} + 0.0018R^{SR}$	(6)	–2%	–38	13%	247
low	IF vs UF	$0.186 - 0.0027R^{LR} - 0.0015R^{SR}$	(7)	15%	90	4%	76
high	IF vs UF	$0.166 - 0.0009R^{LR} - 0.0003R^{SR}$	(8)	16%	96	12%	228

[a] Low-yields scenario is the 25th percentile sample maize yield: 600 kg ha^{-1} in the long rains and 400 kg ha^{-1} in the short rains. Corresponding crop labour inputs are 136.4 and 118.2 work days ha^{-1}, respectively. High yields are the 75th percentile sample maize yields: 1900 kg ha^{-1} in the long rains and 1200 kg ha^{-1} in the short rains. Corresponding crop labour inputs are 200.0 and 181.8 work days ha^{-1}, respectively.

[b] IF = improved fallow, CM = continuous maize, UF = unimproved fallow.

[c] P_L = opportunity cost of labour in US\$ day^{-1}; R^{LR}, R^{SR} = opportunity cost of land in the long rains and short rains, respectively, in US\$ ha^{-1}.

[d] US$0.21 per work day, i.e. 25% of wage rate.

[e] US$0.63 per work day, i.e. 75% of wage rate.

[f] Half the rental rate, i.e. US$16.5 ha^{-1} year^{-1} (US$10 ha^{-1} in the long rains and US$6.5 ha^{-1} in the short rains).

[g] Double the rental rate, i.e. US$66 ha^{-1} year^{-1} (US$40 ha^{-1} in the long rains and US$26 ha^{-1}); buying price for land is about US$660 ha^{-1}; if the interest rate is 20%, in a perfect market rent should be about US$132 ha^{-1}, showing that the land market is highly imperfect and land rent relatively cheap.

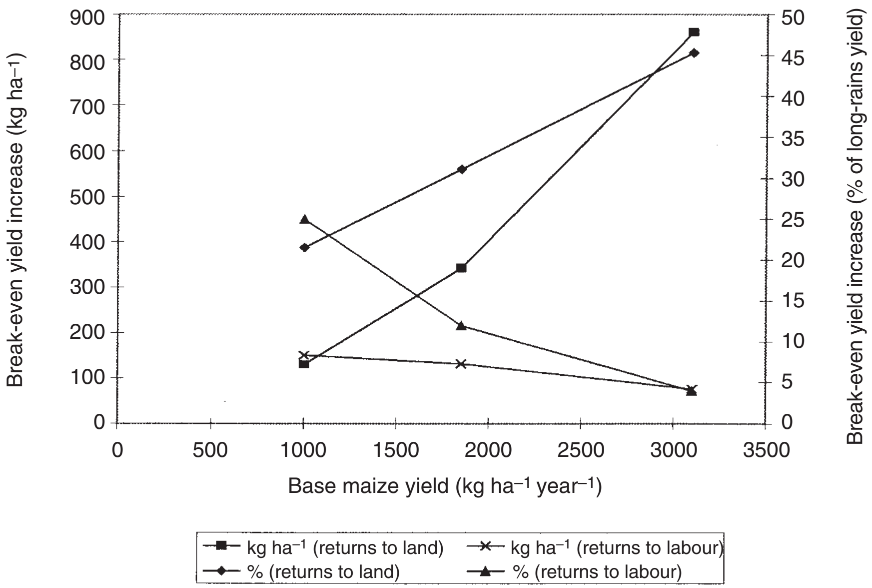

Fig. 4.2. Break-even yield increase of improved fallow as a function of base maize yield. For the returns-to-land analysis, labour was valued at 50% of the wage rate; for the returns-to-labour analysis, land was valued at the rental rate.

The percentage break-even yield increase was not greatly affected by changes in the value of most of the economic parameters (Table 4.3). However, using potted seedlings instead of direct seeding raised the break-even maize yield increase from between −5% and 47% to between 126% and 147%. An increase in the length of the improved fallow, or an increase in the firewood price, also greatly affected the results. Compared to the unimproved fallow prototype, the break-even yield increase for improved fallow (Equations 4.3 and 4.4 in Appendix 4.1) is low under all assumptions (Table 4.2).

Returns to labour

As improved fallow required less labour than continuous cropping, the break-even maize yield for improved fallow, compared to continuous maize, was generally lower when the analysis was based on returns to labour than when on returns to land (Table 4.2). Furthermore, the break-even yield increase, when expressed in kg ha^{-1}, is hardly affected by a change in yield scenario (Fig. 4.2). The outcome is highly sensitive to changes in the fuelwood price and establishment method (Table 4.3).

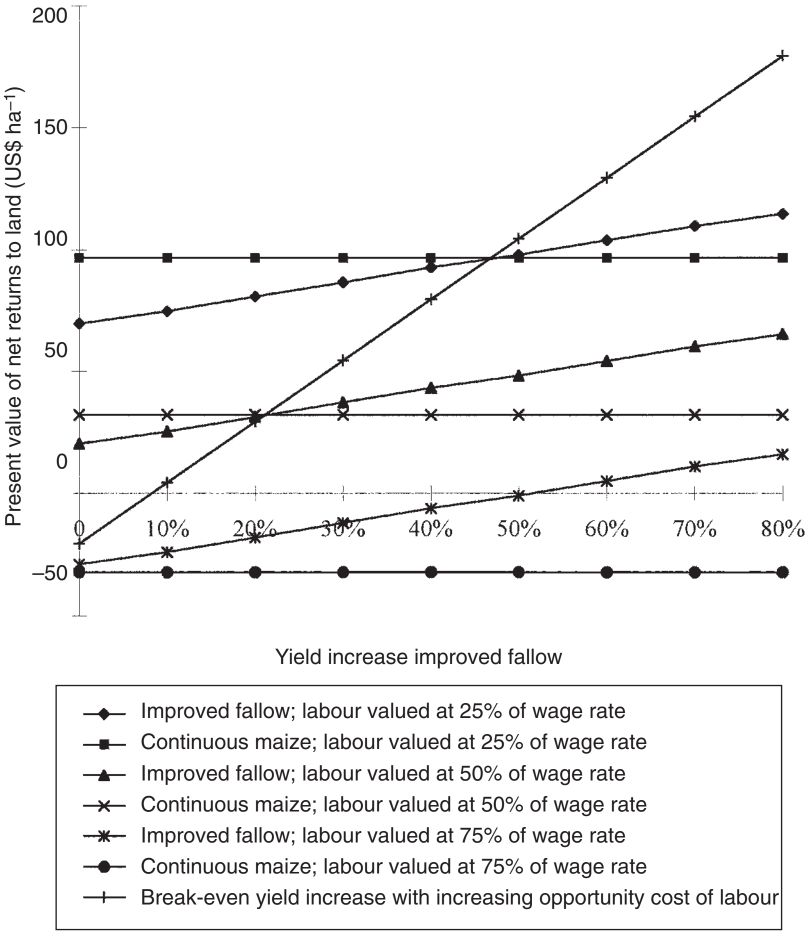

Fig. 4.3. Effect of opportunity cost of labour on break-even maize yield increase of improved fallow, relative to continuous cropping (low-yield scenario).

Discussion

Extent of fallowing

The survey finding that periodic fallowing for soil-fertility restoration is a common practice in western Kenya is in conflict with the theories and empirical findings of others concerning areas of high population density. For example, Boserup (1965) claims that as population increases, fallowing is replaced by continuous cropping. Ruthenberg (1980) regards continuous cropping on impoverished soils as the final steady state in the land-use development process, although fallowing may occur as a consequence of labour shortages and the need for grazing. The survey results suggest that labour shortages were not the main reason for fallowing. Instead, it was depleted land often in combination with the availability of off-farm income that caused farmers to fallow. As farmers with off-farm income are likely to have a higher opportunity cost of labour, they are more likely to conclude that cropping depleted land is uneconomical to them, compared to those with no off-farm income. Moreover, off-farm income also makes it easier for them to forego crop production during the fallow period, as they can purchase food. Off-farm employment of household members leading to more extensive land use has been observed elsewhere, e.g. in Zambia (Low, 1988), in Java, Indonesia (Nibbering, 1991), in Central Province of Kenya and in north-west India (Dewees and Saxena, 1995). The potential beneficial effect of this extensification process on soil recovery in the Java uplands has been suggested by Barbier (1990) and Nibbering (1991).

Before our survey, Maseno agroforestry researchers had not considered improved fallow as relevant to the area, because it was thought that farmers do not

Table 4.3. Sensitivity analysis showing the effect of changes in assumptions on the break-even maize yield increase (expressed as a percentage of long-rains yield) of improved fallow for the low-yield scenario[a] and relative to continuous cropping.

	Returns to land opportunity cost of labour[b]		Returns to labour opportunity cost of land[c]	
Other assumptions	Low	High	Low	High
‘Base assumptions’	47%	–5%	17%	42%
Maize price + 50%	55%	27%	13%	29%
Maize price – 50%	21%	–67%	23%	73%
Discount rate 50% instead of 20%	61%	4%	20%	52%
Valuing 10 tons DM ha^{-1} of fuelwood instead of 1 ton ha^{-1}	–59%	–100%	–92%	–67%
Establishment with potted seedlings instead of direct seeding	147%	126%	158%	168%
3 seasons fallow instead of 1 season[d]	170%	–45%	–67%	36%

[a] 25th percentile sample maize yield: 600 kg ha^{-1} in the long rains and 400 kg ha^{-1} in the short rains; corresponding labour inputs are 136.4 and 118.2 work days ha^{-1}, respectively.

[b] For the low scenario, US\$0.21 day^{-1}, i.e. 25% of the wage rate. For the high scenario, US\$0.63 day^{-1}, i.e.75% of the wage rate.

[c] For the low scenario, half the rental rate, i.e. US\$16.5 ha^{-1} $year^{-1}$ (US\$10 ha^{-1} in the long rains and US\$6.5 ha^{-1} in the short rains). For the high scenario, double the rental rate is used, i.e. US\$66 ha^{-1} $year^{-1}$ (US\$40 ha^{-1} in the long rains and US\$26 ha^{-1} in the short rains).

[d] Increased fuelwood production compared to a one-season fallow not valued; cutting back labour is assumed to be the same as with one-season fallow.

fallow their land. As a result of the survey showing the prevalence of fallowing and the on-farm trials demonstrating the feasibility of improved fallow, the technology became one of the main research foci of the Maseno Agroforestry Research Centre.

The existing occasional dense sesbania stands in fallow land usually originate from wildlings. It is not clear why farmers in western Kenya had not previously thought of deliberately planting sesbania in high densities just before a fallow. Some farmers indicated that they did not consider it because sesbania is a common indigenous tree in the area, and that they instead look for 'new' technologies to solve their problems.

Feasibility and farmers' evaluation of improved fallow

The on-farm trial showed that improved fallow to restore depleted land appears promising under farmers' conditions. Almost half of the farmers with good tree establishment planted a new improved fallow on their own. Farmers on degraded soils in densely populated areas of Benin gave similar positive evaluations of fallows improved with *Mucuna pruriens* (Versteeg and Koudokpon, 1993).

Costs and break-even yield increase

With low yields equivalent to the quartile for the area, maize growing is only profitable when opportunity costs of labour are below 70% of the rural wage rate (Fig. 4.3). As hiring of labour is common in the area, even among farmers with low yields, this means that some farmers grow maize at a loss and would financially gain by leaving land fallow. That they do cultivate maize even when it is not profitable is probably associated with: (i) the cultural value that a household should be self-sufficient in maize; (ii) the high maize price during pre-harvest months, relative to just after the harvest, the frequent need to purchase maize at this time and the poorly functioning credit markets that make it difficult for farmers to finance such purchases; and (iii) risk management to cope with the occasional seasons when maize is only available at extremely high prices. Thus improved fallow technology may also have a role in reclaiming depleted land that is currently being continuously cropped, as farmers are often making a financial loss in such situations. Improved fallow need not threaten food self-sufficiency of the household in any given season, as a farmer would likely have only a portion of land under fallow at a time and the fallow rotates within the farm. However, improved fallow will not substantially increase food production at a farm scale, unless yield responses (including the residual effects) are much larger than the lost production during the fallow.

Direct seeding and relay cropping were two key features that reduced the labour requirements of improved fallows and made them relatively inexpensive, as compared to using potted seedlings and planting trees at the beginning of the fallow period. Direct seeding reduces the break-even yield increase by at least two-thirds compared to potted seedlings (Table 4.3). Relay cropping the trees into maize greatly reduces the extra weeding requirement of the trees. In addition, relay cropping permits tree growth to be extended for two seasons while crops are being fallowed for only one season. However, improved fallows do have to be planned in advance and therefore cannot be adopted in cases where unpredictable labour shortages occur at planting time and prevent a farmer from planting part of his land. Access to off-farm income or remittances may increase farmers' ability to practice improved fallows, depending on the reliability of the food market, that is, whether or not food is available in the market at a reasonable price.

One would intuitively expect that the yield of maize grown after a fallow would need to be at least double that obtained before the fallow in order to compensate for the lost production during the fallow period. Thus, one would expect the break-even yield increase to be at least 100%. However, the results of the economic analysis show that the break-even yield increase required was much less than that under almost all assumptions. The main reason is that the foregone maize yield during the fallow is partly compensated by the savings in crop labour and other crop inputs. Thus the break-even maize yield increase of improved fallow depends on the amount and opportunity cost of the saved labour and the amount and value of the crop yield foregone. The lower the base maize yield is, and the higher the opportunity cost of the household labour, the more attractive improved fallows become. This confirms results from available theoretical economic models for the optimal private and social utilization of soil. For example, Barbier (1990) shows that only when soil is severely degraded do soil restoration measures become economical for a farmer that maximizes long-term income. Krautkraemer (1994) demonstrates that recurring cycles of cropping and fallow cycles can be an optimal soil management strategy because there are seasonal 'fixed costs' in farming that can be avoided by not farming. Such 'fixed costs' include the minimum amount of labour required before any yield is obtained, e.g. land preparation labour. Incurring such costs can result in an annual return to continuous cropping which is less than the average return from a cycle of farming and fallow.

Factors affecting adoption potential

The analysis shows that improved fallow is especially attractive to farmers on depleted land and in areas where the opportunity cost of labour is high. It is especially suited to farmers with off-farm income because they can afford to fallow land and are more likely to be interested in saving labour than full-time farmers. Improved fallow may qualify as an 'induced innovation', i.e. an innovation that reflects farmers' changing resource scarcities and uses less of resources that have become scarcer (and thus expensive) (Hayami and Ruttan, 1985). Improved fallow is also likely to be more profitable for higher-value crops, such as kale (*Brassica oleracea*), than for maize, assuming a similar biophysical response.

The technology seems to be particularly beneficial for high-income households, as they have a higher opportunity cost of labour. However, high-income households may prefer to put more emphasis on the use of other improved soil management practices, such as fertilizer. When labour is scarcer than land, improved fallow requires only low amounts of yield increase to become more profitable than continuous cropping (rows 5–8 of Table 4.2; Fig. 4.2). Thus, the scarcer labour is relative to land for a household, the lower the required break-even yield increase. Therefore, improved fallows may be of greatest benefits to poor households that have little labour available per unit of land.

Because improved fallow with sesbania provides only small quantities of phosphorus, it needs to be supplemented with phosphorus fertilizers on phosphorus-deficient soils, which are common in western Kenya (Sanchez *et al.*, 1997). On-farm research and dissemination of rock phosphate, available from Tanzania, has begun in western Kenya (Niang *et al.*, 1999)

Management options and implications for research

The surveys and trials reported in this chapter have confirmed the high degree of fallowing in the densely populated farming systems of western Kenya and the potential of improved tree fallows to improve farmers' incomes. Two examples highlight how the trials have helped focus further research on problematic aspects of improved fallows:

1. The variable success rates farmers had with tree establishment prompted researchers to initiate a new trial evaluating different seeding methods for sesbania, as well as to look for new tree species with a larger seed size to decrease the chance of seeds being washed away by rain.
2. The high variability in tree growth triggered a new trial investigating the effect of early phosphorus applications on sesbania tree growth. Research is also needed to assess the role of inorganic fertilizer as an alternative or complement to improved fallow.

The trials have also demonstrated various management options of the technology. In 1991, one farmer doubled the tree density we had initially recommended, planting in rows 2 m apart instead of 4 m. As this led to a much faster biomass accumulation, we adopted this tree spacing for our recommended prototype in 1992 and for later researcher-managed trials. Farmers' experiences also showed that: (i) species planted to improve fallows should be easy to uproot; and (ii) improved fallow using palatable tree species are not suitable in areas where wild antelopes are common or where farmers' animals graze freely.

In summary, the surveys and on-farm trials on improved fallows have proven to be effective means of demonstrating the potential of the technology to increase returns to farmers' resources, the socioeconomic limits to adoption of improved fallows, and how research may alleviate the main constraints and improve the productivity and adoptability of the technology. Following completion of this study in 1994, an expanded programme of tree species screening for improved fallows was initiated in researcher-designed, on-farm trials. Those showing consistently high biomass production and crop response, *Crotalaria grahamiana*, *Crotalaria ochroleuca*, *Tephrosia vogelii* and sesbania were advanced to type 2 and 3 trials (Niang *et al.*, 1996, 1998). Concurrently, new type 1 on-farm trials were established to further evaluate fallow performance and management. By 2000, an extension programme was rapidly expanding and several thousand farmers were planting improved fallows (Niang *et al.*, 1999; Place *et al.,* 2002).

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Appendix 4.1 Derivation of the Break-even Equations

Returns to land

In the analysis of returns to land, labour was valued but land was not.

Improved fallow compared to continuous maize

In order to break even, the extra costs per unit of land of improved fallow should equal the extra benefits:

$$\frac{P_{ts}S_t + P_L L_{ts} + P_m Y^S}{1 + r} + \frac{P_L L_c}{(1 + r)^2} = \frac{P_m S_m^S + P_L L_m^S}{1 + r} + \frac{P_f F + P_m \mathrm{BEYI}^{\mathrm{land}} Y^L}{(1 + r)^2} \tag{4.1}$$

where,

P_{ts} = price of tree seed (US\$ kg^{-1}),

S_t = amount of tree seed required to plant the improved fallow (kg ha^{-1}),

P_L = opportunity cost of labour (US\$ day^{-1}),

L_{ts} = amount of labour required for tree sowing (work days ha^{-1}),

P_m = market price of maize (US\$ kg^{-1}),

Y^S = maize yield in the short rains (kg ha^{-1}),

r = social time preference rate (discount rate),

L_c = amount of labour required to cut back the trees at the end of the fallow (work days ha^{-1}),

S_m^S = amount of maize seed used in the short rains (kg ha^{-1}),

L_m^S = maize labour input in the short rains (work days ha^{-1}),

P_f = opportunity cost of sun-dried firewood (US\$ kg^{-1}),

F = amount of dry firewood (kg ha^{-1}),

$\mathrm{BEYI}^{\mathrm{land}}$ = the break-even yield increase in the long rains after the fallow (% of long rains yield under continuous cropping) for the analysis of returns to land, and

Y^L = maize yield in the long rains under continuous cropping (kg ha^{-1}).

The break-even yield increase can then be derived:

$$\mathrm{BEYI}^{\mathrm{land}} = \frac{(1 + r)(P_{ts}S_t + P_L L_{ts} + P_m Y^S - P_m S_m^S - P_L L_m^S)}{P_m Y^L} + \frac{(P_L L_c - P_f F)}{P_m Y^L}. \tag{4.2}$$

Improved fallow compared to unimproved fallow

As above, in order to break even, the extra costs per unit of land of improved fallow should equal the extra benefits:

$$\frac{(P_{ts}S_t + P_L L_{ts})}{1 + r} + \frac{P_L L_c}{(1 + r)^2} = \frac{(P_f F + P_m \mathrm{BEYI}^{\mathrm{land}} Y^L)}{(1 + r)^2} \tag{4.3}$$

from (Equation 4.3) follows:

$$\mathrm{BEYI}^{\mathrm{land}} = \frac{-P_{\mathrm{f}}F + (1 + r)(P_{\mathrm{ts}}S_{\mathrm{t}} + P_{\mathrm{L}}L_{\mathrm{ts}}) + P_{\mathrm{L}}L_{\mathrm{c}}}{P_{\mathrm{m}}Y^{\mathrm{L}}} \qquad (4.4)$$

Returns to labour

In the analysis of returns to labour, land was valued, but labour was not; instead the net returns were divided by the amount of labour. Thus, for improved fallow compared to continuous maize, to break even:

$$\frac{\text{present value of net returns improved fallow}}{\text{present value labour input improved fallow}} = \frac{\text{present value of net returns continuous maize}}{\text{present value labour input continuous maize.}}$$

Or, for the comparison with unimproved fallow:

$$\frac{\text{present value of net returns improved fallow}}{\text{present value labour input improved fallow}} = \frac{\text{present value of net returns unimproved fallow}}{\text{present value labour input unimproved fallow.}}$$

Assessing the Adoption Potential of Hedgerow Intercropping for Improving Soil Fertility, Western Kenya

5

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Summary

The biophysical and socioeconomic performance of hedgerow intercropping for soil fertility improvement was assessed in a farmer-participatory trial in western Kenya over 3 years. Farmers successfully established dense hedgerows but planting and pruning considerably increased labour use during the busiest period of the year. Women did not generally prune the hedges. The yields of hedgerow prunings of *Leucaena leucocephala* and *Calliandra calothyrsus* (1–4 t ha^{-1} year^{-1}, $n = 24$) were low compared to potentials in the region (4–8 t ha^{-1}). The hedgerows had no effect on grain yield over five seasons. But they reduced slopes from 7.2 to 4.5% within alleys ($P < 0.01$) and thus were likely to have decreased soil erosion.

The average extra maize yield required each year, beginning in the second year, to cover the added cost of hedgerow intercropping was 10.5% (SD = 5.5%) when based on returns to land, and 17.5% (SD = 6.5) based on returns to labour. Although about half the farmers claimed that hedges improved crop yields, after 3 years of experimentation, only about a fifth planted additional hedges and only 14% did so to improve soil fertility. It thus appears that the potential for its adoption as a soil fertility practice in this area is low. Hedgerow intercropping appears to have greater adoption potential if its aim is to provide feed for an intensive dairy operation or for curbing soil erosion. Control plots were of little use as farmers were more interested in contrasting test-plot yields with past yields than comparing the

test and control plots. Different types of trials may be required to obtain reliable biophysical data on yield response and socioeconomic data on farmer assessment of complex agroforestry technologies.

Introduction

There is a considerable body of research showing that crop yields can be increased significantly by hedgerow intercropping (also called alley cropping or alley farming), a technology in which crops are grown between rows of nitrogen-fixing trees and the trees' leafy biomass is applied to the crops (Kang *et al.*, 1990; Kang, 1993). But there is little scientific data on the performance of hedgerow intercropping for soil fertility improvement under farmer-managed conditions in the tropics, despite considerable extension (Müller and Scherr, 1989; Carter, 1995). Potential difficulties in conducting on-farm trials with complex agroforestry technologies have been reviewed by Shepherd and Roger (1991). Earlier analyses of the adoption potential of hedgerow intercropping were based mainly on *ex ante* analysis of on-station trial results (Swinkels and Scherr, 1991). Few on-farm trials or social or economic analyses have been reported, and these are mostly from subhumid to humid areas in west Africa (Whittome, 1994; Dvorak, 1996). Even these trials had several limitations for the assessment of adoption potential: (i) targeting was inappropriate as often farmers' priority problem was not low soil fertility; (ii) farmers' participation was obtained through the provision of incentives, such as free fertilizer and improved crop material; and (iii) there was limited monitoring to establish labour requirements and crop and economic performance relative to existing systems (Whittome, 1994). Better farmer participation was obtained where soil fertility decline was perceived by farmers as a serious problem (Versteeg and Koudokpon, 1993). The limited adoption of hedgerow intercropping that has occurred has been for soil conservation on sloping land (particularly in the Asian/Pacific region) and for fodder production in intensive dairy systems, or because of indirect benefits provided by the projects themselves (Whittome, 1994; Carter, 1995).

This study uses 3 years' results from a farmer-participatory trial to assess the adoption potential of hedgerow intercropping, primarily for soil fertility improvement, in a subsistence-level crop/livestock farming system in the humid highlands of western Kenya. The components were:

1. Biophysical response:[1] What were the effects of the trees on slope and crop yields?
2. Feasibility: Are farmers able to manage the technology? Do they have the required information and are they able to plant and maintain the hedges, and to cope with any problems that arise?

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[1] Several agronomic substudies were conducted to assess the degree of competition between hedges and adjacent maize rows, to confirm maize yield responsiveness to applied nutrients and tree prunings, and to test the response of hedge biomass production to nitrogen and phosphorus applications. These studies are reported in Shepherd *et al.* (1997).

3. Profitability: Are the financial benefits obtained greater than the costs incurred?
4. Acceptability: Do farmers perceive that the advantages of using the technology are greater than the disadvantages? Acceptability thus includes a range of criteria in addition to profitability and feasibility, such as riskiness and compatibility with other enterprises.

For each of the above components, selected farm and household characteristics were examined to assess whether they were associated with the uptake of the technology.

Materials and Methods

Study area and background

The study area included parts of Siaya, Kisumu and Vihiga Districts, located between 0°05′S and 0°10′N, to 34°31′E to 34°40′E, chosen to represent humid areas of the food-crop land-use system of western Kenya which have high agricultural potential but where land has become nutrient depleted (Fig. 4.1) (Shepherd *et al.*, 1992). The population density ranges from 300 to over 1000 persons km^{-2} in some areas. There are two cropping seasons: the long rains from March to July and the short rains from August to November, totalling 1500–1800 mm year^{-1}, with a mean annual temperature of 21.0°C. The landscape is undulating with average slopes of 2–8%, dominated by Acrisols, Ferralsols and Nitisols (Shepherd *et al.*, 1992).

Hedgerow intercropping had been introduced to farmers in the area in 1983 by the CARE-Kenya Agroforestry Extension Project, to address soil fertility constraints and produce fuelwood. Several hundred farmers planted hedges of primarily *Leucaena leucocephala* (leucaena) but no quantitative data on biophysical or economic performance were available. An evaluation in 1988 found that spacing and management were highly variable and that median tree density was very low, 2000 trees ha^{-1}, roughly half of the density required to supply adequate nitrogen to impact on crop yield. Not surprisingly, only one-quarter of plots showed notably higher crop yields, according to farmers' qualitative assessments (Scherr and Oduol, 1989; Scherr, 1995).

Farmer selection and treatment design

In participatory rapid appraisals, farmers identified soil fertility as a key problem and expressed interest in testing hedgerow intercropping (Ohlsson *et al.*, 1992). Two to three farmers from 29 farmer groups in the area participated in the trial: the groups were selected to represent the main variation in soils and ethnic groups in the area (Ohlsson *et al.*, 1992). The recommended prototype, which was developed with farmers, consisted of *L. leucocephala*, *Leucaena diversifolia*, *Calliandra calothyrsus* (calliandra), or *Gliricidia sepium*, planted from inoculated seedlings, with 0.30 m between trees in contour-aligned rows about 4 m apart (8333 trees ha^{-1}) (Ohlsson *et al.*, 1992). Crops were planted close to the trees so there was no loss of cropped area due to trees. The trial was started with 24 farmers from ten groups in August 1990, and with a further 29 farmers, including six additional groups, in February 1991. Farmers received advice from the project technicians on hedgerow management throughout the reported period, but farmers made all crop and tree management decisions.

Trial design and measurements

The trial design consisted of a control plot without hedges and an adjacent plot with hedges on each farm. The *L. leucocephala* seedlings were a mixture of Hengchun, Kisumu, Gede, Siakago and Baobab provenances (29 farms), *C. calothyrsus* was Guatemala provenance (18 farms), *L. diversifolia* was Veracruz/Mexico provenance (four farms), and *G. sepium* was established from cuttings from a local source (two farms). The 1990 plantings were all of *L. leucocephala*. The seedlings were inoculated with compatible rhizobia in polythene tubes in a nursery before being delivered to the farms.

Project technicians recorded the number of trees planted, the number surviving at 6 months, and the causes of plant death on each tree plot. Crop harvest yields were measured on the whole area of test and control plots in five consecutive seasons from the short rains in 1990, on farms where annual crops were grown and the trial maintained (n = 41). The total produce of maize cobs and pods of any intercrops from each plot were weighed and subsamples taken to determine oven-dry grain weight. Farmers' estimates of numbers of green maize cobs harvested earlier in the season were converted to dry grain weight on the basis of average cob weights. Crop plant populations were estimated from quadrat counts, and the incidence of pests, weeds and diseases were scored on each plot.

Soil properties were determined in each plot (Shepherd *et al.*, 1996). Average slopes were measured on all farms using a clinometer. On eight of the steeper farms, the average slope of the hedgerow plot and the slope within each alley were determined in October 1994, using a surveying level.

Social and economic analysis

Project staff conducted informal, semi-structured surveys during the trial's first 2 years to define the methods and the criteria farmers used to evaluate hedgerow intercropping, to obtain their assessments, and to examine the problems they encountered (David, 1992). Formal surveys using structured questionnaires were used to test hypotheses developed from the informal surveys and to quantify critical parameters, including household characteristics (David and Swinkels, 1994) and farmers' assessments of the technology. Data on the use of labour and other inputs were collected on each plot using two different methods: farmers' recall just after a task was completed (for crop management) and monitoring of work rates through observation (for planting and cutting back trees). The number of farmers included in the above surveys ranged from 33 to 46.

To assess profitability, enterprise budgets for maize with and without hedges were drawn up, using input and output data from the 23 farms for which complete data sets were available. The only data not used were for the response of maize yields to the hedgerows, although the available evidence indicated that the hedgerows had no effect on yields (Shepherd *et al.*, 1997). Therefore, break-even maize yields were calculated, that is, the increase in maize yields required to pay for the costs of establishment and maintenance of the hedges. Separate budgets were drawn up for each farmer in order to assess the variability in costs and returns among farms. Two types of analysis were carried out: net returns to land and net returns to labour. In net returns to land, household labour was valued at its opportunity cost, as estimated by the hired labour price. Land was not valued; returns were instead expressed on a per-hectare basis. This measure was relevant for farmers whose most scarce input was land. Net returns to labour, on the other hand, were most relevant for farmers whose most scarce input was labour. Land was valued at its opportunity cost, as estimated by rental rates. Household labour was not valued and returns were expressed per unit of labour. The break-even analysis was based on a 5-year time period with maize yields increasing in the second year and remaining constant thereafter.

Sensitivity analysis was conducted to measure the effects of changes in some of the base parameters on the break-even maize yield increase. The riskiness of hedgerow intercropping was also assessed, using two methods. First, the variability in the net returns was compared between the two treatments, that is, maize with and without hedges. Secondly, minimum returns analysis (CIMMYT, 1988) was used to compare the average of the lowest 25% of the net benefits for the two treatments.

Three methods were used to assess acceptability. First, project staff asked farmers to compare yields on the control and test plots. Secondly, the other criteria used by farmers to evaluate the technology were identified and farmers were asked how the technology performed by these criteria. Thirdly, their willingness to expand the hedgerows on their farms was monitored by offering them seed in the third year after establishment. Data on acceptability were collected using informal interviews, farmer-to-farmer group visits, formal surveys and monitoring of expansion through observation. A hierarchical decision tree was constructed to model farmers' decisions to expand their plantings (Gladwin, 1980). This method was useful for explaining the decisions farmers made by breaking them down into a series of subdecisions and mapping farmers' decision paths along the branches of the tree.

Results and Discussion

Farmer and seasonal rainfall characteristics

Participants were broadly representative of the range of types of farmer found in the area; over one-quarter were female-headed, most were of average wealth, and farm size ranged from 0.1 to 6.1 ha (Table 5.1; David and Swinkels, 1994). Eleven of the

Table 5.1. Characteristics of farmers participating in the hedgerow intercropping trial ($n = 45$).

Variable	Min.	Median	Max.	Frequency (%)
Farm size, all parcels (ha)	0.1	1.3	6.1	–
Household size (members)	2	6	15	–
Labour:land ratio (adult equivalent workers ha^{-1})	0.6	2.2	23.6	–
Farm first cultivated (year)	1935	1977	1991	–
Ethnic group				
Luhya				22
Luo				78
Household type				
male				72
female *de jure*				13
female *de facto*				15
Age of household head (years)				
<40				24
40–60				52
>60				24
Education of household head				
<primary				19
primary				59
>primary				22
Wealth category				
<average				26
average				67
>average				7
Off-farm income (one or both partners)				82
Use of hired labour				87
Ownership of cows				80
Ownership of improved-breed dairy cows				6

Source: David and Swinkels, 1994.

56 participating farmers dropped out of the trial within the first year but the participatory approach was otherwise successful in maintaining farmers' interest in the trial.

The seasonal total rainfall at Maseno for each of the seven seasons from the short rains 1990 did not differ by more than 25% from the long-term average values (1960–1993; 895 mm in long rains, and 774 mm in short rains).

Tree establishment and early growth

The size of plots planted with hedges ranged from 270 to 2010 m^2 with a median of 790 m^2 ($n = 42$). Tree density, which ranged from 3660 to 10,040 with a median of 6680 trees ha^{-1}, was negatively correlated with plot size ($r = -0.45$, $P < 0.01$). This indicated that the potential benefits of the technology, resulting from biomass production, would decrease with increasing plot size. The proportion of the originally planted trees surviving at 6 months after planting (MAP) ranged from 0.33 to 1.00 with a median of 0.91. Termite damage was observed to be the primary cause of tree mortality on 30 farms, whereas other causes were important on only a few farms: moles, 4; drought, 3; uprooting, 1; erosion, 1; and fire, 1. Browsing, mostly by Kirk's dik-dik (*Madoqua kirki*), occurred on ten farms, primarily those near uncultivated land.

Survival was not related to browsing, but there was a higher frequency of low survival rates in leucaena (40% farms had <80% survival, $n = 25$ farms) than in calliandra (6% farms had <80% survival, $n = 17$). The frequency of termites as the main cause of damage was similar for the two species (68% leucaena, 76% calliandra), but the survival differences could have been due to differences in rainfall during the 2 months after planting. This was lower in the short rains of 1990 when most ($n = 22$) of the leucaena was planted (302 mm) than in the long rains of 1991 when all of the calliandra was planted (537 mm).

At 6 months after planting, median tree height was 97 cm (range 34–140) for leucaena (12 farms) and 152 cm (range 90–196) for calliandra (12 farms), while median stem basal diameter was 1.4 cm (range 1.0–1.8) and 1.5 cm (range 0.8–2.1), respectively. The median early growth rates were substantially (about 40%) lower than those obtained with the same provenances in researcher-managed experiments at the Maseno Agroforestry Research Centre (Heineman *et al.*, 1990). However, trees in the on-station experiments received 25 g diammonium phosphate per tree at transplanting and were established with well-weeded and phosphate-fertilized beans for the first two seasons.

Tree yield

Farmers cut the hedges between four and seven times during the 2 years of monitoring of hedge biomass on 24 farms. There was no significant effect of species, provenance, season or year on tree total biomass yield and dry matter partitioning ($P > 0.05$). However, total biomass was significantly greater ($P < 0.001$) at the first cut (1.68 t ha^{-1}) than at the second cut (0.74 t ha^{-1}) in the season. Woody stem comprised 33% of the total biomass at the first cut but only 4% at the second cut, reflecting the younger growth at the second cut.

On the farms the annual amount of biomass returned to the soil ranged from 1.2 to 4.3 t ha^{-1} $year^{-1}$ (median = 2.4 t ha^{-1} $year^{-1}$) and was below on-station levels measured over the same growth phase (about 4.4 t ha^{-1} $year^{-1}$ for leucaena (Hengchun) at a spacing of 3.75 × 0.25 m, and 7.3 t ha^{-1} $year^{-1}$ for leucaena (Hengchun) and 10.8 t ha^{-1} $year^{-1}$ for calliandra (Guatemala) both at a spacing of 2.8 × 0.25 m (Heineman *et al.*, 1990; Otieno *et al.*, 1991). In experiments in the subhumid and humid tropics with the same species and management, maximum annual yields of prunings were 4–8 t ha^{-1} $year^{-1}$ (Balasubramanian and Sekayange, 1991; Kang, 1993). The amounts of nutrients returned in prunings were correspondingly low, but on all farms the amounts are significant in relation to crop requirements (Shepherd *et al.*, 1997).

The growth of leucaena was affected by an infestation of the psyllid *Heteropsylla cubana* from March 1993 onwards. Total biomass over the five cuts was 590 g m^{-1} of hedge (range 90–810) in leucaena compared with 1850 g m^{-1} (range 1000–2860) in calliandra; before 1993 there was no difference in yields between the two species. Thus the potential effects of leucaena on soil fertility are likely to be limited as long as the psyllid infestation persists.

Crop yields and terracing effect of hedges

Farmers grew a wide range of crop mixtures and fallows in the test and control plots, making it difficult to evaluate the effects of the hedgerows on yields. For example, in the long rains of 1992, out of 86 plots, 68 had maize; six, sorghum; 39, beans; 18, groundnuts; and 16, weedy fallow. Farms where maize was grown as the main crop in both plots, either as a sole crop or with grain intercrops, were selected for analysis of yields in each season. There was no significant difference in mean grain yields (expressed as sum of maize and intercrop grain dry weights) between the hedgerow and the control plots in any individual season. Averaged over five seasons, mean grain yields were 16% lower in the hedgerow plots than the control plots, but the significance of this difference was marginal ($P = 0.05$). The lack of evidence for an effect of the hedges on yield in the researcher-managed competition study (Shepherd *et al.*, 1997) suggests that the difference was due to variation in farmer management between the two plots.

Regression models were used to test the hypothesis that selected soil and management variables (nitrogen and phosphorus concentration in the subsoil, purchased inputs, and manure application) account for the variation in control plot grain yields and the difference in grain yield between the hedgerow and control plots. However, little of the variation could be accounted for by linear regression with the measured variables (Shepherd *et al.*, 1997). Apparently, variation in yield among plots and farms was determined by a wide range of biophysical and socioeconomic factors, and could not be explained adequately by the measured variables within the limitations of the sample size.

Average slopes ranged from 1 to 13% with a median of 5.8% (44 farms). The hedgerows had a significant terracing effect: the mean slope within alleys was 4.5% compared with 7.2% over the length of the hedgerow plots ($P < 0.01$, eight farms).

Feasibility

The hedges required planting just after the rainy season began, when farmers were busy preparing land and planting their crops. In fact, hedgerow establishment greatly exacerbated peak periods of labour use; when hours spent planting seedlings were added to those for the other cropping activities, labour use during the busiest week of the year increased by 50%. Variation in labour inputs also rose; the coefficient of variation of the mean weekly labour inputs increased from 103% to 120%. Three-quarters of the households relied solely on family labour for planting the trees; the rest hired some casual labour.

Pruning (or cutting back) the hedges involved a single upward slash of a machete and was a completely new task for the farmers. In most cases, they pruned at planting time in order to reduce shading, and then pruned again about 2 months later, during weeding (Fig. 5.1). Farmers pruned on average 240 trees h^{-1} (SD = 140), including spreading the mulch (Swinkels and Franzel, 1992). Pruning required only 40–60 h $season^{-1}$ ha^{-1} or less than 5% of total labour input for maize cultivation. Nevertheless, it was problematic for two reasons. First, it had to be done on a timely basis and during maize planting and weeding, which are periods of peak labour use. When pruning was added to other cropping activities (Fig. 5.1) the number of weeks in the cropping season in which labour requirements were over 60 h ha^{-1} increased from one to three.

Over time, farmers coped better with the task of pruning. In the first season that it needed to be done, half of the farmers delayed and noted a negative effect on yields. However, overall, there was no significant difference between control and treatment maize yields during the first season of pruning (Shepherd *et al.*, 1997). In subsequent years less than 10% of farmers delayed pruning and noted negative effects.

The second problem was that women did not generally prune the hedges. Of the 90% of the households in which females were actively involved in managing the

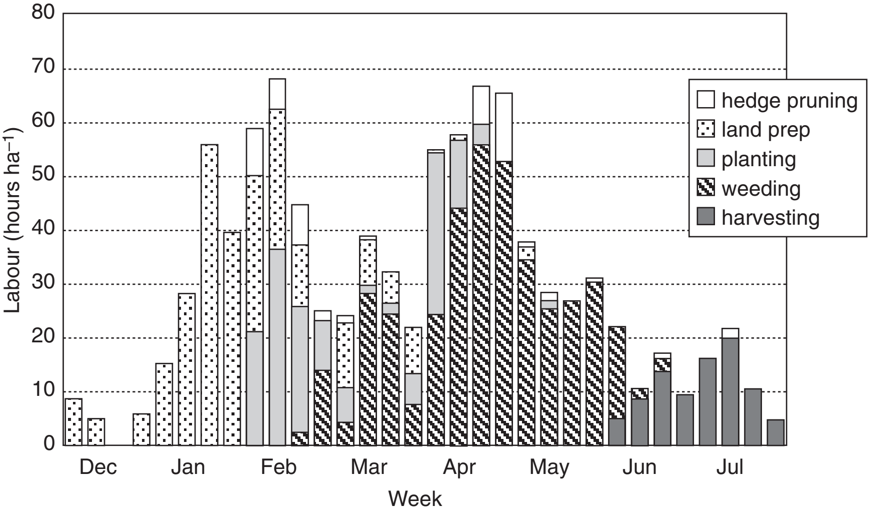

Fig. 5.1. Labour profile of pruning and cropping activities (long rains 1992, hedgerow intercropping trial farmers). Cropping labour is the average of 126 maize/sorghum plots of 31 farmers. Pruning labour is the average of 31 hedge plots of the same 31 farmers. Labour includes both household and hired labour.

farm, only 19% of prunings were done by women. Only in female-headed households did females prune. Women claimed that they lacked the strength to do it and that using a machete was a man's task (David, 1992).

Neither browsing of trees by animals nor the effects of the hedges on other cropping activities were important problems for the farmers. Browsing by wild and domestic animals was reported by 8–19% of the farmers per season over the years but in most cases only a few trees were browsed. Problems in land preparation were reported by 25–33% of farmers, including both oxen-users, who complained that hired oxen did not plough close enough to the hedges, and farmers preparing by hand, who mentioned interfering tree roots and branches. In contrast, between 5% and 15% reported that the hedges reduced labour required for preparation, because the hedges reduced weed incidence and softened the soil. Roughly equal numbers (10–25%) felt that the hedges increased and reduced labour requirements for weeding.

Profitability

The costs of hedgerow intercropping were highest in the first season, when hedges were established (Table 5.2). Seedling costs and planting labour added 78% to the production costs of maize during this season. Thereafter, pruning was the only extra cost on the hedge plots, adding only 3% (SD 2%) to maize production costs.

Fuelwood was harvested each year from the hedge treatment, and extra maize from increased soil fertility was assumed to be harvested each season, beginning in year 2. During the first year, the hedges did not affect maize yields; no evidence of an effect was found in either the maize yield data (Shepherd *et al.*, 1997) or in farmers' own assessment. The analysis (Table 5.2) showed that variability of the net benefits was high. The extra maize yield required each year to cover the added costs of hedge establishment and maintenance was 242 kg ha^{-1} (SD = 65 kg), or on average 10.5% (SD = 5.5%) of farmers' mean maize yields, which were 1521 kg ha^{-1} (SD = 873) in the long rains and 1180 kg ha^{-1} (SD = 1118) in the short rains; median yields were 1220 kg ha^{-1} and 794 kg ha^{-1}, respectively.[2]

Because household labour inputs were higher for hedgerow intercropping than for conventional maize, the technology was less profitable and the break-even maize yield increase higher in returns to labour analysis than in returns to land analysis. An annual maize yield increase of 475 kg ha^{-1} (SD = 267 kg), or, on average, 17.5% (SD = 6.5%) of farmers' mean maize yield, was required to break even.

The break-even maize yield increase was fairly stable under a range of changes in the assumptions and values (Table 5.3). For the returns to land analysis, the break-even increase ranges from 6% to 21%, and in the returns to labour analysis, from 12% to 35%. For the returns to land analysis, a change from potted seedlings to bare-rooted seedlings, which resulted in a 60% reduction in establishment costs,

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[2] The average of all individual break-even yield increases is 10.5%; when the average of the value of all individual maize yield increases is divided by the value of the average maize production, the outcome is 8.5%.

Table 5.2. Enterprise budget showing the amount of extra maize yield required to cover the costs of adopting hedgerow intercropping relative to conventional maize (in US$ ha^{-1}).[a]

	Hedgerow intercropping		Conventional maize			Hedgerow intercropping		Conventional maize	
Costs[b]	Mean	SD	Mean	SD	Benefits[c]	Mean	SD	Mean	SD
Season 1									
Seedlings	90	23	0	0	Maize	365	182	365	182
Tree planting labour	34	20	0	0	Intercrop	46	54	46	54
Crop seed	18	10	18	10					
Fertilizer/manure	20	27	20	27					
Crop labour	122	45	122	45					
Subtotal season 1	283	80	159	65	Subtotal season 1	411	185	411	185
Season 2									
Pruning labour	2	2	0	0	Fuelwood	2	3	0	0
Crop seed	14	10	14	10	Maize	272	224	272	224
Fertilizer/manure	6	14	6	14	Intercrop	24	34	24	34
Crop labour	117	51	117	51					
Subtotal season 2	139	63	137	62	Subtotal season 2	298	234	296	234
Total: year 1	422	116	296	99	Total: year 1	709	316	707	316
Season 1									
Pruning labour	5	3	0	0	Fuelwood	4	3	0	0
Crop seed	18	10	18	10	Maize	365	182	365	182
Fertilizer/manure	6	14	6	14	Extra maize	32	13	0	0
Crop labour	122	45	122	45	Intercrop	46	54	46	54
Subtotal season 1	164	66	159	65	Subtotal season 1	447	192	411	185

Table 5.2. *Continued.*

	Hedgerow intercropping		Conventional maize			Hedgerow intercropping		Conventional maize	
Costs[b]	Mean	SD	Mean	SD	Benefits[c]	Mean	SD	Mean	SD
Season 2									
Pruning labour	5	3	0	0	Fuelwood	1	2	0	0
Crop seed	14	10	14	10	Maize	272	224	272	224
Fertilizer/manure	6	14	6	14	Extra maize	23	12	0	0
Crop labour	117	51	117	51	Intercrop	24	34	24	34
Subtotal season 2	142	63	137	62	Subtotal season 2	320	243	296	185
Total: year 2	276	88	271	87	Total: year 2	766	320	707	316

[a] In two cases there was sorghum instead of maize. Exchange rate in 1992 was US$1 = 43 Kenya shillings.

[b] Costs:

Seedlings: Mean number of trees planted was 6949 ha^{-1} (SD = 1785); seedlings costed at US$1.16 per 100 (price in small private nurseries).

Tree planting: Mean tree planting rate was 33 trees h^{-1} (SD = 16) (including transport homestead to field), labour costed at hired labour price.

Seed: Mean maize seed input was 32 kg ha^{-1} (SD = 12) in the long rains and 41 kg ha^{-1} (SD = 17) in the short rains; 18 out of 23 farmers planted an intercrop (mostly beans) in the long rains, while 12 did so in the short rains; bean seed input quantities were similar to those of maize.

Fertilizer and manure: Mean fertilizer input was 17 kg ha^{-1} (SD = 43) in the long rains and 4 kg ha^{-1} (SD = 15) in the short rains; fertilizer was valued at US$0.37 kg^{-1}. Farmyard manure input was 1037 kg ha^{-1} at 37% moisture content, costed at US$13.50 ton^{-1} DM.

Crop labour: This includes both hired and farm household labour; both are valued at the hired labour price of US$0.116 h^{-1}; hired labour accounted for about 30% of the total average labour input. Mean labour input in the long rains was 1054 h ha^{-1} (SD = 385) and 1007 h ha^{-1} (SD = 436) in the short rainy season. Labour inputs did not vary significantly between test and control plots.

Pruning labour: Mean pruning labour input was 25 h ha^{-1} (SD = 14) for the first cut of the long rains, and 22 h ha^{-1} (SD = 18) for the second cut that season; the first cut of the short rains took on average 30 h ha^{-1} (SD = 18), while the second cut that season took on average 18 h ha^{-1} (SD = 16). First pruning was about 6 months after planting (14 farmers) or about 10 months after planting (nine farmers).

[c]Benefits:

Maize: Mean maize yield was 1521 kg ha^{-1} (SD = 873) in the long rains and 1180 kg ha^{-1} (SD = 1118) in the short rains; maize market price was US\$0.25 kg^{-1} at the harvest period for the long rains season and US\$0.20 kg^{-1} for the harvest period of the short rains crop.

Intercrop: Mean bean yield was 117 kg ha^{-1} (SD = 125) in the long rains and 71 kg ha^{-1} (SD = 88) in the short rains, valued at the market price at harvest time of US\$0.38 kg^{-1}.

Fuelwood: Mean measured fuelwood yield in long rains was 518 kg dry matter ha^{-1} (SD = 421) for the first cut and zero for the second cut; for the first cut of the short rains it was 127 kg ha^{-1} (SD = 267) and 30 kg ha^{-1} (SD = 139) for the second cut (12 farmers). (Based on their sample of 24 farmers, Shepherd *et al.* (1997) reported a median yield of 1.05 t ha^{-1} of fuelwood per annum.) As fuelwood is not commonly traded in the area, its value was estimated at one-third (US\$7.7 t^{-1} dry weight) of the market price.

Extra maize: The average extra maize yield required to cover the added cost of hedgerow intercropping, compared to conventional maize, was 10.5% (SD = 5.5%) or 242 kg ha^{-1} year^{-1} (SD = 65 kg) (includes two seasons for each of 4 years, over years 2–5 of a 5-year production period) when based on returns to land.

reduced the maize yield required to break even from 10.5% (SD = 5.5%) to 6% (SD = 3%). (A change to bare-root seedlings also reduced tree growth by about 60%. Therefore, with bare-rooted seedlings, the first cut back was assumed to take place in the second year instead of the first.) The analysis also showed that increasing or reducing the value of fuelwood, even to zero, had little effect on the results, because little fuelwood was generated in the hedgerow system.

On a few occasions, farmers were unable to prune due to absence or illness and yields were greatly reduced. Therefore, it was hypothesized that the technology was risky and that it would increase the variability in net benefits. However, the standard deviation of net benefits per ha of the hedge plots differed very little from those of the other plots. It was higher in one season and lower in three seasons. Data from eight on-farm trials that were researcher-managed during one season also showed no important difference in the variability in returns between the control plots and the plots with the hedges. Similarly, minimum returns analysis did not show the hedge plots to be any riskier than the conventional maize plots. In the first three seasons, minimum returns per ha were slightly lower on the hedge plots (US$22–34 ha^{-1} lower) and in the fourth season US$39 higher.

Table 5.3. Sensitivity analysis, showing mean break-even maize yield increases of hedgerow intercropping under different assumptions.

	Returns to land		Returns to labour	
Assumption	Mean	SD	Mean	SD
Base assumptions	10.5%	5.5%	17.5%	6.5%
Land not valued[a]	10.5%	5.5%	19%	7%
Bare-rooted seedlings (instead of potted seedlings) @ US$0.46 per 100	6%	3%	13%	6%
Fuelwood sold at market price (US$23 per ton dry weight)	8%	5%	15%	7%
Fuelwood has no value	12%	6%	19%	7%
Maize price 50% higher	7%	4%	12%	4%
Maize price 50% lower	21%	11%	35%	13%
Labour cost 100% higher[b]	15%	7%	18%	6%
Labour costs 50% lower[b]	8%	5%	18%	6%
Discount rate is 50% instead of 20%	16%	9%	26%	9%
Ten-year period considered instead of five	7%	4%	13%	5%
Fallow in short rainy season[c]	48% (median 39%)	65%	15% (median 5%)	48%
Fallow in short rainy season, fuelwood no value	65% (median 49%)	64%	33% (median 19%)	50%
Fallow in short rainy season, fuelwood sold at market price	6%	73%	–27%	54%

[a] In an analysis of returns to land, land is never valued; this assumption therefore does not affect the outcome of the analysis of returns to land.
[b] Includes farm household and hired labour.
[c] Fallowing in short rains from year 2 onwards.

On farms where there was no crop response to the hedgerows, only 6% (about US\$7 ha^{-1}) of the average investment costs of the technology were earned back through fuelwood production. Median returns to labour were reduced by 22%, from US\$0.37 h^{-1} to US\$0.29 h^{-1}.

Acceptability

Eleven (20%) of the 56 farmers that planted hedgerows dropped out of the trial during the first year after establishment. The main reasons included land tenure problems, intra-household disputes, and poor tree establishment (Fig. 5.2). Thus, after the first season, 45 farmers remained in the trial, and percentages given below are based on this group. During subsequent monitoring, over 3.5 years, another two farmers dropped out: one because of an intra-household conflict and one lost interest.

Farmers' management practices varied considerably between the test and control plots: crops and intercrops changed (Shepherd *et al.*, 1997) or manure was applied to one plot and not the other. There were two reasons for this variation. First, the size of the trials, averaging 40% of cropped area, made it difficult for farmers to manage the two plots in the same manner. For example, farmers often lacked the labour required to conduct operations in a timely manner throughout the two plots.

Secondly, in interviews during the first year, we found that farmers' evaluation methods differed considerably from ours. Only five farmers (11%) concurred with our approach to treat the control and test plots in the same manner and then compare crop yields on the two plots to determine the impact of the hedges. Instead, 18 (40%) sought to compare the hedges with another soil fertility amendment, such as manure or fertilizer, to see if the hedges were as effective. Further, we found that 17 (38%) did not compare test plot yields with control plot yields at all. Rather, these farmers wanted to compare present yields with past yields on the same plot, that is, yields before they planted the hedges. (We were unable to determine the method that eight farmers (18%) used to assess yield impact. Farmers were permitted to give more than one response.)

Moreover, farmers' assessment methods changed during the course of the trial. Comparing performance on the test and control plots was the main evaluation method of 61% of the farmers during the first year, but only 18% during the second through fourth year. Over the same period, comparing past and present yields on the test plot as the favoured evaluation method increased from 38% to 67%. In two-thirds of the cases where farmers assessed yield performance during the second through fourth years, they cited changes in yields over time on the test plot; in only one-fifth of the cases did they compare test and control yields. We suspect that many farmers initially stated that they intended to assess yield impact by comparing test and control yields because they knew that that was what the researchers expected them to do.

The percentage of farmers claiming that hedges improved crop yields rose from fewer than 10% during the third season (the first after pruning) to around 50% during the third to seventh seasons. But project technicians and field assistants, using

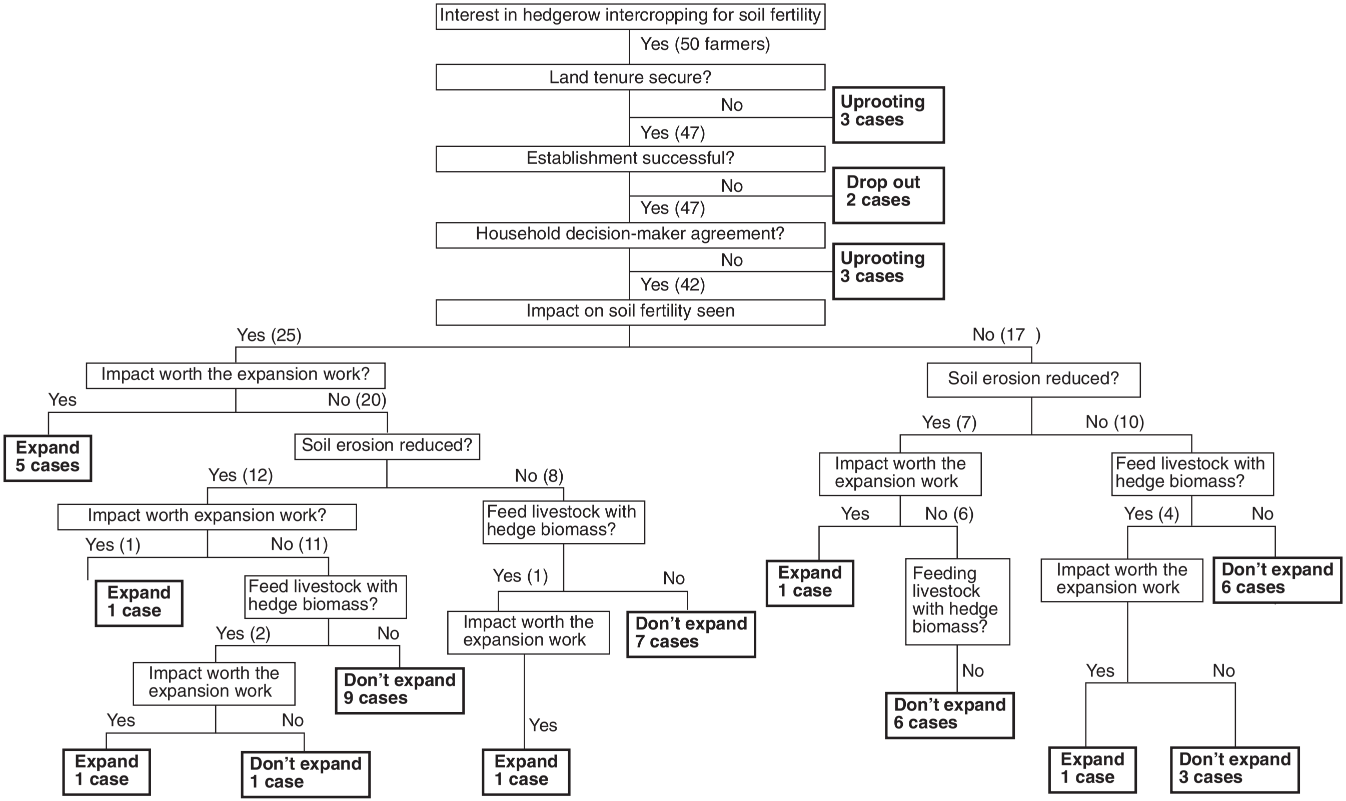

Fig. 5.2. Decision tree: expansion of hedgerows by trial farmers. Six farmers are excluded (four because of lack of reliable information and two because they migrated from the area).

subjective judgements based on frequent farm visits, noted yield increases on only 20–40% of the trials. The difference may be due to farmers noticing yield increases that field assistants did not, to field assistants not taking into account management differences between the plots, or to farmers simply trying to please researchers.

Farmers noted a number of other benefits from the hedges. By the sixth season after planting, one-fifth were feeding some of the tree leaves to their livestock, mostly local-breed cattle. The three farmers with improved-breed dairy cows were feeding all of their leafy biomass. Feeding leaves to livestock was not associated with opinions on the effectiveness of the biomass for improving crop yields. Forty per cent mentioned fuelwood as a valuable benefit. However, quantities were small; wood harvested after the first and second prunings of the third season provided fuel for only 11 days (SD = 14) and 6 days (SD = 3), respectively. The proportion of farmers reporting that the hedges curbed soil erosion increased from 20% during the first few seasons to 50% in the seventh season. These farmers did not have steeper sloping hedge plots than other farmers. The overall effects of the hedges were judged to be positive by 60–64% of the farmers in the fourth to seventh seasons. Others felt the positive and negative (that is, shading) effects were offsetting, or saw no effect (13–25%). The number of farmers reporting mainly negative effects declined from 25% in the first season to 3% in the sixth season, reflecting their increasing ability to cut back in time.

By the fifth season, 18 (40%) of the farmers indicated their interest in expanding the hedges. They were given seed and advised on raising them in nurseries for production of bare-rooted seedlings, but over the next two seasons, only 10 (22%) established a nursery and transplanted the seedlings. Five expanded hedges in their crop fields while five planted on boundaries. The decision tree (Fig. 5.2) showed that five farmers expanded mainly for improving soil fertility, three for fodder production (all three had improved cattle breeds and regularly sold milk), and two for controlling soil erosion.

The ten expanders differed from the rest of the farmers in several important respects. They were more likely to be households where a male or a couple managed the farm ($P < 0.02$), to be visited regularly by extension agents ($P < 0.01$), to have a cash crop such as coffee or tea ($P < 0.003$), and to manage their hedges well, according to ratings by technicians ($P < 0.07$). There was some evidence that expanders had less depleted soils than others, based on analyses of the soil of four expanders and 28 non-expanders. Expanders had significantly higher cation exchange capacities ($P < 0.04$) and higher amounts of calcium ($P < 0.01$) and exchangeable bases ($P < 0.04$), in topsoil, subsoil and deep soil, compared with non-expanders. Maize yields in the test plots of expanders were significantly higher than in the test plots of non-expanders in the first, second and third season, but not in the fourth season after hedge establishment.

The expanders did not appear to have different levels of wealth, off-farm income, farm size, or crop sales, to have different labour : land ratios, to be more self-sufficient in food, to use more purchased inputs, or to be of different ages compared with the non-expanders. Furthermore, the species of hedge did not influence expansion; five grew *Leucaena leucocephala* and five, *Calliandra calothyrsus*.

Discussion

Farmers were able to establish the hedges effectively, as has been shown in Nigeria (Reynolds *et al.*, 1991), Malawi (ICRAF, 1993) and the Philippines (Fujisaka, 1993). The low labour requirements for pruning are similar to those reported from on-farm trials by Reynolds *et al.* (1991). Although pruning had to be done during periods of peak labour use, farmers appeared to cope better with this task over time. However, the fact that women do not generally prune hedges greatly reduces the adoption potential of the technology among the 40–60% of the farm households in the survey area which are headed by women.

Given the greater demands on their time, women may avoid pruning as part of a strategy to force men to bear the risks and costs of the technology (David, 1992). Should the hedges improve soil fertility, more women might be prepared to make trade-offs and prune their hedges.

Reduction in the labour requirements for weeding was not an important benefit, and this differs from the findings of other trials in the tropical humid lowlands (Reynolds *et al.*, 1991; Fernandes *et al.*, 1993).

Break-even yield increases are fairly low, indicating that only relatively low yield increases are required to cover the costs of the technology. That the break-even yield increase is lower in the returns to land analysis highlights the attractiveness of the technology in areas of high population density, small farms and plentiful labour. Sensitivity analysis showed the importance of reducing establishment costs for increasing the profitability of the technology. Our data do not support the hypothesis that hedges increase variability in returns, although it is clear that farmers who were unable to prune on time would suffer yield decreases.

In the end, only seven farmers (14%) expanded their hedges to improve soil fertility or soil erosion control. Non-expansion is not necessarily a sign of non-adoption; several farmers indicated that they appreciated the practice but only wanted to adopt it on a portion of their field. The general lack of expansion, however, indicated that overall confidence in the technology was low.

Given the disappointing data on yield impacts and economic returns from hedgerow intercropping, extension efforts were reduced and focused more on erosion control. On-farm research was reoriented to focus on improved fallows, which produced greater biomass, had lower establishment and overall labour costs, and greater yield effects. New on-station trials were established at Maseno in 1994 using calliandra, to better understand crop and tree productivity in contour plantings, and the possible effects of phosphorus application on performance (Niang *et al.*, 1996).

The low adoption potential of hedgerow intercropping for improving soil fertility has been noted in several other farmer-managed on-farm trials in the semiarid areas of Kenya (David, 1995), in the subhumid plateau areas of Malawi (Minae, 1994), and in the humid lowlands of Nigeria (Whittome, 1994) and Cameroon (Degrande and Duguma, 2000). The practice appears to have more adoption potential if its main aim is to provide feed for an intensive dairy operation, as in

Kenya (Chapter 7 of this volume; Reynolds, 1994; Reynolds and Jabbar, 1994) or for soil erosion control, as in the Philippines (Fujisaka, 1993).

For reducing erosion, the practice appears to be most relevant to:

- areas with erosive soils on sloping land;
- areas with high rainfall, where competition for moisture between trees and crops is minimal; and
- farmers with high labour–land ratios, because the labour requirements of the practice are high.

But incentives may be needed to motivate farmers to adopt hedgerow intercropping on a wide scale, if reducing erosion is the only benefit.

The trial results also had important implications for participatory on-farm research methods. First, where trial plot size is large (for example, 40% of cropped area) or trials are long-term (more than two seasons), farmers will find it difficult to manage non-experimental variables in a uniform manner.

Secondly, in trials designed to facilitate farmer assessment, farmers' own evaluation methods should be factored into the design. In our trial, as in others (Reynolds *et al.*, 1991; CIAT, 1992; Versteeg and Koudokpon, 1993), farmers were not as interested in the comparison between the test and the control plot as were the researchers. If farmers are not interested in comparing test yields with control yields, control plots are not needed. Where farmers do want to compare test and control plots, the exact comparison should be the one they are interested in. For example, in our trial, more farmers were interested in comparing hedges with manure than were interested in the with- and without-hedges comparison.

Thirdly, the trials provided reliable socioeconomic data on feasibility, costs and farmers' expansion. Farmers' assessment of the hedges were less reliable, as evidenced by disparities between farmers' and technicians' opinions on yield response and between farmers' stated appreciation of the practice and their willingness to plant new hedges. We believe that farmers' assessments were biased towards reporting more positive impacts for two reasons, because criticism of a practice is impolite in their culture, and because of their belief that positive assessments would help them obtain free inputs or even employment from the project.

Finally, the findings suggest that it may not be possible to obtain reliable biophysical data on yield response and socioeconomic data on farmer assessment from the same trial (Shepherd and Rodger, 1991). In order to obtain a good socioeconomic evaluation, individual farmers need to use the technology in the manner they see fit. Thus it is unlikely to be possible to compare yields between plots or across farms. Conversely, a high degree of control of experimental and non-experimental variables is required to measure biophysical response. Under such management, farmers will not be able to assess the adoptability of a technology adequately. Farmer-participatory trials are useful in the early stage of the development of a technology for obtaining farmer feedback, for identifying critical constraints affecting performance and to define realistic conditions for researcher-managed trials, which are recommended for assessing biophysical performance (Shepherd and

Roger, 1991). Following these, adoption potential and acceptability can then be determined in extension-led, farmer-participatory trials, rather than through experiments aimed at collecting biophysical and socioeconomic data of the kind reported here.

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Farmer-designed Agroforestry Trials: Farmers' Experiences in Western Kenya

6

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Summary

In farmer-designed tree trials, farmers experiment on their own with new tree species, planting them where and how they wish on their farms. In western Kenya, 50 farmers (half female) planted and evaluated five different species: two upper-storey species (*Grevillea robusta* and *Casuarina junghuhniana*), primarily for timber and pole production, and three shrub species (*Leucaena leucocephala*, *Leucaena diversifolia*, *Calliandra calothyrsus*), mainly for improving soil fertility. Results revealed important criteria that farmers use in evaluating tree species. For example, casuarina was widely appreciated for its ornamental value, despite its relatively poor ratings on survival and growth. The findings also highlighted the importance of testing new species under farmer conditions, as their ranking on growth was different than in on-station trials. Farmers appreciated the upper-storey species but most did not find the shrub species to be effective in improving soil fertility. The trials also provided important information on farmers' management problems, preferred niches for tree planting, and intended uses of tree products.

Introduction

In most African countries, farmers have little input into decisions about which tree species are made available to them. Rather, scientists or extension services generally make the decisions – screening new species in on-station trials or from available literature and evaluating them according to well-known criteria such as growth and form. In order to enhance farmers' role in species introduction, scientists of the Kenya Forestry Research Institute and the International Centre for Research in Agroforestry and members of 13 self-help groups initiated farmer-designed trials in western Kenya, in which farmers evaluated new tree species on their own farms. Farmers' assessments of the trees were an important input into the decision on whether to disseminate them.

Farmer-designed trials, also called collegial trials (Biggs, 1989) or type 3 trials (see Chapter 2), are an important means for increasing farmers' role in the technology development process. In these trials, farmers experiment on their own with new technologies or components and, together with researchers, they monitor their experiences (Haverkort *et al.*, 1991). Because each farmer controls the testing procedure on his/her farm, farmer-designed trials are not seen as being appropriate for the collection of quantitative data, either biophysical or socioeconomic, or for the formal testing of hypotheses. Thus they are often dismissed as being 'soft' research and are rarely reported on in refereed journals. Nevertheless, farmer-designed trials are important for obtaining farmers' assessments and for understanding the process by which farmers test new practices and incorporate them into their farming systems. As illustrated in this study, quantitative and statistically valid data on preferences can be collected by asking farmers to rate alternative species across different criteria (Fransella and Bannister, 1977).

Study objectives were to: (i) examine how farmers in western Kenya experiment with new tree species, that is, where they plant them, how they manage them, how they use them, and the problems they encounter; (ii) elicit farmers' evaluation criteria and evaluation of the species across criteria; (iii) assess how the species perform on farmers' fields and under farmer management, as compared to on-station; (iv) associate farmers' assessment of species with selected farm and household characteristics; and (v) recommend which new species should be made available to farmers by development institutions.

Methods

The trials were conducted in a maize-based land-use system, encompassing parts of Siaya, Kisumu and Vihiga Districts, in western Kenya (Fig. 4.1). Altitudes range from 1450 m to 1650 m and rainfall is bimodal, averaging 1500 mm to 2000 mm year^{-1}. The landscape is undulating, with slopes of 2–10%. The main types of soil include Ferralsols, Acrisols and Nitisols, and are generally infertile with a low pH (5–7). Most farms range in size from 0.5 ha to 2.0 ha and population densities are 400 to 1200 persons km^{-2}. Maize accounts for over half of the cultivated area and the use of purchased inputs, such as seed and fertilizer, is low. Most households own cattle, predominantly of the local breed. About 45% of the households are female-headed. *Eucalyptus* spp. (mainly *Eucalyptus saligna*) is the most common type of tree in the area and is widely grown for poles, for domestic use and for sale, and for fuelwood, for domestic use (David and Swinkels, 1994).

The collaborating farmer groups selected 50 farmers who were interested in testing new tree species on their farms. The selected farms included the range of types of farms found in the area; over half were female-headed, median farm size was 1.1 ha, and two-thirds had cattle. Technicians provided farmers with information about each species (e.g. growth characteristics and end uses) and, following group discussions, farmers decided to test three shrub species (*Leucaena leucocephala*, *Leucaena diversifolia*, *Calliandra calothyrsus*) and two upper-storey species (*Grevillea robusta* (Meru) and *Casuarina junghuhniana* (Australia)). The shrub species were intended to improve soil fertility through application of prunings to crops, and to provide livestock feed during the dry season, thus addressing two of farmers' most important problems in the area (Minae and Akyeampong, 1988). The upper-storey species were intended to provide timber and poles, two highly preferred tree products that farmers use for both domestic use and cash sales (Muturi and Franzel, 1992). The shrub species were new to the farmers; before planting, they were able to view them in on-farm hedgerow intercropping trials. Farmers were familiar with grevillea and casuarina but lacked information about them as they were not widely planted in the area.

Planting took place during the short rains season, September through November, 1991. Researchers raised trees in nurseries and delivered an average of 273 trees, 29–103 per species, to each farmer, depending on their availability. Technicians demonstrated planting methods, but all planting and management of the species was done by the farmers themselves. Rainfall during the season of planting was 20% lower than the 30-year average.

Trials were monitored using both informal and formal survey methods. Informal interviews were conducted during researchers' visits to the trials. Group visits were also organized in which farmers visited one another's trials and discussed trial performance. Formal surveys using structured questionnaires were conducted 3, 15, 30 and 52 months after planting; the number of farmers interviewed ranged from 30 to 43. The questions concerned farm and household characteristics, tree management, preferred end uses and problems encountered. Some biophysical data were collected; survival rates were measured 3 months after planting and tree height and root collar diameter 30 months after planting. In the latest survey, 52 months after planting, researchers rated farmers' level of interest in the trees as high, medium or low, according to the level of management and perceived benefits. A random sample of 22 neighbours of participating farmers was also interviewed to assess whether they had planted any of the trees in the trial (Bekele, 1997).

Two methods were used to get farmers' ratings of different trees. In informal visits, farmers were asked to explain the advantages and disadvantages of various species on their farm and the criteria behind their preferences (Bruin *et al.*, 1994; Franzel, 2001). In subsequent visits, farmers used a local board game, *bao*, to rate species according to the criteria by moving seeds among pockets of the board (Franzel *et al.*, 1995; Franzel, 2001). Farmers rated a species on a particular criterion, e.g. growth rate, by placing 1–5 seeds (5 represented a high rating) in a pocket next to a branch of that species. *E. saligna* was also used in the *bao* game ratings as a control for the rating of upper-storey species, although it was not planted in the trial.

The influence of various farm and household characteristics on farmers' ratings of their interest in planting different species was assessed using a linear logistic model for ordered category response data (Collet, 1991). The variables considered included wealth level, farm size, off-farm income, ethnic group, age, gender, district and livestock ownership.

Results

Tree establishment, management and intended uses

About two-thirds of the farmers planted all of their seedlings; the others gave away or sold some. Most farmers planted the shrub species in hedgerows in their crop fields, others planted on external or internal boundaries, on terraces, or in fallow land. Grevillea tended to be planted on external boundaries whereas casuarina was equally distributed among the homestead, internal and external boundaries. Only a few farmers planted any of the five species in woodlots or scattered in their fields (Table 6.1).

Survival rates 3 months after planting were over 70% for all species except casuarina, which had a rate of 46%. According to farmers, principal causes of mortality were termites, drought and browsing (both by wild and domestic animals). Each of the above causes was mentioned by 11–16% of the farmers.

Over 80% mixed their shrub species in the field; this was partly because, in many cases, the farmers, could not distinguish between them. About 40% mixed grevillea and casuarina, even though they are easy to distinguish.

Farmers planted the shrubs at spacings of 1.0–1.7 m in hedgerows. These are much wider than the recommended 0.5 m. Spacings on boundaries for grevillea

Table 6.1. Niche where farmers planted existing upper-storey trees and the test species (% of farmers responding).

Niche	Existing upper-storey trees[a]	*Grevillea robusta*	*Casuarina junghuhniana*	*Leucaena leucocephala*	*Leucaena diversifolia*	*Calliandra calothyrsus*
Hedgerows in crops	0	0	0	63	59	70
External boundary	44	50	29	9	9	6
Internal boundary	75	36	29	6	6	9
Homestead	92	13	29	2	0	2
Other[b]	83	12	20	18	20	18

Data from 43 farmers. Column percentages do not sum to 100 because a farmer can plant in more than one niche.

[a] From Muturi and Franzel (1992).

[b] Other niches include scattered in cropland, woodlots and pasture.

were 2.3 m (SD = 1.9) and for casuarina, 3.2 m (SD = 2.9), as compared to the recommended 1 m (to be later thinned to 2 m). About two-thirds said they made their own decision about the spacing, one-third said they based the decision on advice from others. Farmers justified their wide spacings on the basis that they had received few trees and were interested in maximizing the area covered.

Most of the farmers intended to use the shrub species for improving soil fertility (Table 6.2); other reasons expressed by over 40% of the farmers were to produce fuelwood and fodder. Grevillea and casuarina were being planted primarily for timber and poles. Only 29% claimed that one of the two main uses of grevillea would be for firewood, and there were no differences in responses among males and females.

Farmers' evaluation of tree growth

Farmers used a wide range of criteria to evaluate the growth of the trees, including survival, rapidity of growth, compatibility with crops, and resistance to pests, drought and browsing. Fifteen months after planting, farmers rated grevillea and calliandra highest on survival and growth (ratings of 3.8–4.5 out of 5); casuarina was rated lowest (1.7–2.6) (Table 6.3). These data were in line with the actual data on survival and growth collected by the technicians. On resistance to termites, only casuarina received a low rating (1.6).

Two other growth characteristics were also rated. Grevillea and calliandra received high ratings (4.5 and 4.0 respectively) on drought resistance, casuarina was lowest (2.3). Grevillea and eucalyptus were the only species with high ratings on resistance to browsing (4.1 and 4.0, respectively); casuarina was rated low (2.6), in part because it was frequently planted around the homestead, where livestock were common.

Thirty months after planting, grevillea and eucalyptus were rated high on rapidity of growth (4.4 and 4.3, respectively); casuarina was rated medium (3.2) (Table 6.4). In fact, growth data from the farms showed grevillea outperforming

Table 6.2. Farmers' intended uses for the trees they planted in the farmer-designed trial (% of farmers responding).

Use	*Grevillea robusta*	*Casuarina junghuhniana*	*Leucaena leucocephala*	*Leucaena diversifolia*	*Calliandra calothyrsus*
Firewood	29	16	52	48	52
Fodder	0	0	43	41	39
Soil conservation	0	0	11	11	7
Soil fertility	0	0	72	73	77
Timber	93	71	0	0	2
Poles	48	43	0	0	0
Shade/beauty	9	25	0	2	2

Data from 43 farmers. Column percentages do not sum to 100 because a farmer can have more than one use for a tree.

Table 6.3. Farmers' mean rating of species, using the *bao* game, on criteria important to farmers, 15 months after planting (standard deviation in parentheses).

Species	Survival	Growth	Termite resistance	Drought resistance	Browsing resistance
Grevillea robusta	3.9 (1.4)	3.8 (1.3)	3.4 (1.5)	4.5 (1.2)	4.1 (1.6)
Casuarina junghuhniana	1.7 (1.2)	2.6 (1.5)	1.6 (1.4)	2.3 (1.6)	2.6 (1.9)
Leucaena leucocephala	3.9 (1.1)	3.5 (1.3)	3.6 (1.6)	3.5 (1.4)	2.5 (1.6)
Leucaena diversifolia	3.9 (1.1)	3.5 (1.3)	3.6 (1.6)	3.5 (1.4)	2.5 (1.6)
Calliandra calothyrsus	4.2 (1.2)	4.5 (1.0)	3.9 (1.5)	4.0 (1.4)	2.7 (1.7)
Eucalyptus spp.	3.5 (1.7)	3.3 (1.7)	2.6 (1.4)	3.6 (1.4)	4.0 (1.7)

Data from 37 farmers. The rating of 1 to 5 refers to the score in number of seeds the farmers gave to a tree on a particular criterion. A rating of 5 was excellent, a rating of 1, poor.

casuarina (Table 6.5). Among the shrub species, calliandra received high ratings on biomass production (4.9); *L. leucocephala* rated lowest (3.4) primarily because of attacks by psyllids (*Heteropsylla cubana*). On compatibility with crops, casuarina and grevillea rated highest (4.5 and 4.0, respectively) and eucalyptus lowest (1.4). Ratings for the shrub species were intermediate (3.3–3.8) but their high standard deviations reflected the varying opinions of farmers, as well as differences in pruning management.

Table 6.4. Farmers' mean ratings of species, using the *bao* game, on growth characteristics, intended uses and preference for future planting, 30 months after planting (standard deviation in parentheses).

Species	Growth	Biomass production	Compatibility with crops	Fodder	Firewood	% farmers preferring for future planting
Grevillea robusta	4.4 (0.9)	–	4.0 (1.3)	–	4.1 (1.0)	73
Casuarina junghuhniana	3.2 (1.1)	–	4.5 (0.7)	–	–	46
Leucaena leucocephala	–	3.4 (0.8)	3.8 (1.8)	4.0 (1.4)	3.8 (1.0)	29
Leucaena diversifolia	–	3.7 (0.9)	3.6 (1.6)	3.4 (1.5)	3.8 (0.7)	24
Calliandra calothyrsus	–	4.9 (0.2)	3.3 (1.8)	4.1 (1.3)	4.1 (1.1)	41
Eucalyptus spp.	4.3 (1.0)	–	1.4 (0.9)	–	3.6 (1.2)	27

Data from 37 farmers. The rating of 1 to 5 refers to the score in number of seeds the farmers gave to a tree on a particular criterion. A rating of 5 was excellent, a rating of 1, poor.

Table 6.5. Mean height and root collar diameter (standard deviations in parentheses) for species in farmer-designed trials and on-station trials, 30 months after planting.

	Grevillea robusta		*Casuarina junghuhniana*		Ratio: casuarina/grevillea	
District	Height (cm)	Root collar diameter (cm)	Height (cm)	Root collar diameter (cm)	Height (cm)	Root collar diameter (cm)
On-station	678 (36)	8.05 (0.56)	694 (87)	9.14 (0.94)	1.02	1.14
On-farm	382 (138)**	4.9 (1.80)**	416 (135)*	3.5 (1.5)**	1.09	0.71
Ratio: on-station/ on-farm	1.77	1.64	1.67	2.61		

For grevillea, 84 accessions from local collections were tested in the on-station trial; for casuarina, 20.

** and * denote significance at the 1% and 5% level, respectively, between on-station and on-farm parameters.

Comparison of tree growth on-farm and on-station

Both grevillea and casuarina were grown in on-station trials near the survey area. Thirty months after planting, heights and root collar diameters (RCDs) were significantly higher on-station than on-farm (Table 6.5), probably because of the higher level of management, including application of phosphorus fertilizer, better weeding and less competition from adjacent crops. Root collar diameters of grevillea in on-station trials were 1.6 times greater than those in on-farm trials, the corresponding ratio for casuarina was 2.6 times. In the on-station trial, casuarina outperformed grevillea in RCD (14% higher, significant at $P < 10\%$). In the on-farm trial, the RCD of casuarina was only 71% that of grevillea. However, the difference was not significant due to the high variability (coefficients of variation ranged from 32% to 43%) in the on-farm trial results.

Farmers' use and evaluation of trees

By the 30th month after planting, farmers had coppiced the shrub species about seven times and thus had considerable experience using the leafy and woody biomass. Ninety per cent used the leaves as a mulch, 81% used the branches for firewood and 46% used the leaves for fodder. Three farmers (7%) also sold leaves to other farmers to use as fodder. Fifty-six per cent claimed that their main intention in using the shrubs was to improve soil fertility; 17% cited fodder.

Farmers' perceptions of the effect of the shrub species on their crop yields varied considerably. For calliandra, the best-performing shrub species in terms of biomass production, nine farmers (39% of those using the species primarily to improve soil fertility) saw a positive effect, while 61% saw no effect or were not sure. Of the 17 (41%) who had a strong interest in planting calliandra in the future, only seven intended to use it primarily for improving their soil fertility. Only about one-third of the farmers who used the leucaenas for improving their crop yields claimed that it was effective.

Farmers' experiences using the shrubs as a fodder were also varied. Thirty per cent of those who had tried using them claimed that they were of low palatability to cattle; 50% gave them a high rating. None of the farmers who rated them low had tried to mix the shrubs with other fodder and gradually increase their proportion, a recommended strategy to get livestock accustomed to new forage species. Of the 17 farmers with a strong preference for planting calliandra in the future, six wanted to use it primarily for fodder.

Concerning firewood, grevillea and calliandra received the highest ratings: grevillea because its fire lasts long (the wood is of high density) and calliandra because it makes a strong fire (has high calorific value) and dries quickly. The leucaenas and eucalyptus also received fairly high ratings. Farmers were unable to rate casuarina because they had not yet used it.

No one had yet used the upper-storey species for timber or poles, their main intended uses. However, farmers had some knowledge of eucalyptus and grevillea for timber and poles. Concerning use as timber, grevillea was rated high (4.8) because the wood is durable, workable and does not crack easily. Eucalyptus also received good ratings (4.0) because it is weevil resistant, but it is difficult to work with and cracks easily. For pole production, eucalyptus rated high (4.9) because of its straightness, its hard, durable wood, and its resistance to termite attack. Grevillea received medium ratings (3.2) because the wood is less resistant to weevils and rots quickly if used as a ground post or for roofing.

Farmers' preferences for future plantings were viewed as a composite of all the criteria and thus an overall rating of the tree. Seventy-three per cent expressed a strong interest (rating of 5) for planting grevillea, 46% for casuarina, and 41% for calliandra. Casuarina, while performing relatively poorly on growth, was preferred for its beauty and the pleasant sound it made when the wind was blowing. Fewer than 30% expressed interest in planting the leucaenas or eucalyptus. The leucaenas were not preferred because of their poor growth, relative to calliandra, and eucalyptus, because of its poor compatibility with crops.

The farm and household characteristics examined were not very useful in explaining farmers' ratings of their interest in planting a species. Using the linear logistic model, only the district emerged as a significant variable (t = 4.3; P = 0.000) affecting the rating of calliandra. The district was probably a good proxy for biophysical performance, as Kisumu District, where ratings were particularly low, was a low-potential area and calliandra performed relatively poorly. The findings, t values and significance levels were similar for the other two shrub species. No variables were found that affected the ratings of grevillea, in part because there was little variation in the ratings. There was considerable variation in the ratings of casuarina, but no variable was found that influenced the ratings. The inability of the model to explain variation in ratings is probably due to the limited range of variables (for example, soil nutrient status and tree growth were not included) and the small sample size.

Fifty-two months after planting, 63% of the farmers showed a high interest in planting upper-storey trees; only 30% in hedgerow intercropping. Sixty-three per cent showed a high interest in grevillea, 47% in calliandra and 43% in casuarina. Less than 10% showed a high interest in the leucaenas. Uptake by neighbours was low; only 3 of 22 neighbours sampled had planted grevillea since the start of the survey, one had planted calliandra, and one, casuarina. Lack of seed or seedlings was the main reason that farmers cited for not planting (Bekele, 1997).

Discussion

The farmer-designed trials reported in this chapter served four important functions. First, they provided important information about farmers' management problems, preferred niches for tree planting and intended end uses of tree products. The main problems reducing tree survival were termites, drought and browsing. External boundaries were the most important niche for the planting of upper-storey trees, whereas they ranked fourth among existing trees (Table 6.1). This finding suggests that farmers consider the other three niches (homesteads, internal boundaries and in crop fields) to be fairly saturated, and that external boundaries represent the most important niche for future plantings. Casuarina was the species most likely to be planted around the homestead, reflecting its utility to farmers as an ornamental tree.

Shrub species were planted mainly in hedges in crop fields, as their major purpose was to increase soil fertility. Many farmers were influenced by the experiences of their fellow group members, who had planted shrub species in hedgerow intercropping trials.

Upper-storey trees were planted primarily for timber and poles. These results confirm findings from previous surveys that firewood is not a particularly scarce product in the area and that it is considered, by both men and women, as a by-product rather than as a main product from tree harvests (Bradley, 1991). In contrast, farmers in central Kenya plant grevillea mainly for firewood (Tyndall, 1996).

Secondly, the trials were important for determining farmers' evaluation criteria and for obtaining farmers' assessment of each species across the criteria. Six growth characteristics and six end uses were found to be important. Most were well known to researchers but one, the importance of ornamental value, came as a surprise. Its importance was highlighted by the finding that many farmers were interested in planting casuarina as an ornamental despite its relatively poor ratings on other criteria. The results show the usefulness of the trial in providing researchers with information on the criteria farmers use to evaluate trees.

Concerning other upper-storey trees, grevillea outperformed eucalyptus on every growth characteristic except rapidity of growth, and outperformed casuarina on every one except compatibility with crops. Judgements on uses of the upper-storey species for poles and timber are pending, as farmers have not yet harvested them.

Among the shrub species, calliandra outperformed the leucaenas on all criteria except compatibility with crops. Thirty-nine per cent of the farmers using calliandra to improve soil fertility found that it was effective in this respect. This result is similar to the findings from the researcher-designed, farmer-managed hedgerow intercropping trial in the same area, which showed that about 50% of the farmers reported positive effects (see Chapter 5).

Thirdly, comparisons between on-farm and on-station trials showed that growth rates of both upper-storey species were much higher in the on-station trials, probably reflecting higher soil fertility and more effective weed and termite control measures. Even though casuarina outperformed grevillea in on-station trials, the reverse was true on farms. In the on-farm trials, casuarina was more susceptible to stress factors (drought, and possibly lack of inoculant in the soil) and pests (termites and browsing) and had lower survival rates and slower growth than grevillea. The results demonstrate the importance of assessing the performance of species under farmer management and farm conditions; rankings of species on growth in on-station trials will not necessarily hold under farmers' conditions. They also suggest that on-farm research is needed to assess the use of fertilizer in growing high-value trees to reduce the time to harvesting the products.

Concerning farmer recommendations, the trial is on-going – the upper-storey species have not yet been harvested. Moreover, only one provenance of each of the species was used in this trial; there is high variation among provenances of a species and thus recommendations concerning one provenance may not be relevant for others (Simons *et al.*, 1994). On the basis of the findings, and those of other on-station and on-farm trials, several interim recommendations can be made.

Calliandra can be recommended for distribution as a fodder tree, based on this trial and results presented in Chapter 7 and in van der Veen (1993). But many livestock do not take to eating it on the first try; thus, care has to be taken to introduce it gradually into the diet, by mixing it with other feeds. The other two shrub species should not be recommended – *Leucaena leucocephala* because of its susceptibility to psyllid damage, and *Leucaena diversifolia* because of low leafy biomass production. None of the shrub species should be recommended for improving soil fertility as evidence on their effectiveness is lacking, even when the shrubs are planted at the recommended density (see Chapter 5). Moreover, some of the farmers who claimed that the trees were improving their soil fertility may have been doing so because they believed such a response would please the researchers.

Casuarina may also be recommended, based on its preference as an ornamental and its use for construction poles in eastern Kenya (Jama *et al.*, 1989). However, farmers need to be warned about the slower growth of this species than of grevillea and eucalyptus, its low survival rate and its susceptibility to termite damage, browsing and moisture stress. Grevillea may be recommended, based on its widespread use in central Kenya. Research there has shown that grevillea trees planted along boundaries offer net benefits from fuelwood and timber that are as high as the maize they displace. In addition, they provide other difficult-to-quantify benefits, such as boundary marking, windbreak, erosion control and improved microclimate (Tyndall, 1996).

Researchers need to continue monitoring the trial, especially with respect to end uses of casuarina, and farmers' and neighbours' experience with, and interest in, expanding production of the test species.

Conclusion

Farmer-designed trials are an effective means for finding out how farmers manage trees, for determining their planting criteria and preferences, for assessing tree performance under farmers' conditions and for helping to decide which species should be recommended to farmers. Because few biophysical data are collected, the cost of conducting such trials is relatively low. Also, most of the data on farmer assessment may be taken during slack periods, such as following the crop harvest. Farmer-designed trials are thus a relatively low-cost method to help increase farmer participation in species introduction and agroforestry tree research, enhancing the effectiveness of research systems to meet farmers' needs and improve their welfare.

The trial reported on in this chapter also provided important feedback on researchable problems. For example, the poor performance of upper-storey species on farms, relative to on-station trials, has led researchers to implement on-farm trials to assess the growth response of trees to phosphorus fertilizer (Niang *et al.*, 1996).

Farmer-designed trials are also an important tool for extension programmes to help farmers and extensionists decide which species should be promoted in a specific area. In 1994, farmer-designed trials were formally institutionalized in Kenya's Forestry Master Plan and the Forestry Extension Services Division was given the mandate to conduct them (Franzel *et al.*, 1996). Farmer-designed trials, as described in this chapter, in central Kenya (Holding *et al.*, 1995) and in Eastern Province (O'Neill *et al.*, 1994) are giving farmers major responsibility in screening new species for extension programmes. But two factors impede the technology development and dissemination process. First, linkages between research and extension are weak; information exchange on appropriate technology and farmers' problems is scant. Secondly, germplasm is lacking; farmers cannot get seed for 5–10 years from the grevillea and casuarina trees that they planted, and there are no other sources of seed. As discussed in Chapter 9, researchers, extensionists and non-governmental organizations are establishing an adaptive research and dissemination network to facilitate linkages between research and extension and to ensure that germplasm and information are made available to farmers. This will greatly strengthen linkages and improve the effectiveness of the technology development and dissemination process for agroforestry in western Kenya.

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Calliandra calothyrsus: Assessing the Early Stages of Adoption of a Fodder Shrub in the Highlands of Central Kenya

7

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Summary

The uptake of *Calliandra calothyrsus* as a fodder shrub by small-scale dairy farmers was assessed several years after the shrubs were introduced to farmers in on-farm trials. There was strong evidence that farmers were adopting the shrub. A random sample of 45 farmers had increased their average number of shrubs from 84 in their first plantings in 1991–1992 to 311 after 6–7 years. Moreover, farmer-to-farmer dissemination appeared to be high, as 47% had harvested seed and 70% of these had given or sold seed or seedlings to other farmers. The net benefits of using 6 kg of fresh calliandra leaves per day as a substitute for 2 kg purchased dairy meal or as a supplement to farmers' base feeding regime amounted to about US\$130 per cow year^{-1}. By 2000, several thousand farmers in central Kenya were feeding calliandra to their dairy animals. Potential benefits from adopting calliandra or similar fodder shrub species in Kenya's smallholder dairy sector amounted to about US\$139,000,000 year^{-1}. Several measures were proposed to help realize this potential: facilitating on-farm research and dissemination of information and planting material, research to identify new fodder shrub species, and assessing the constraints and incentives affecting fodder shrub adoption.

Introduction

The low quality and quantity of feed resources is the greatest constraint to improving the productivity of the livestock sector in sub-Saharan Africa (Winrock

Trees on the Farm (eds S. Franzel and S.J. Scherr)

International, 1992). With milk and meat imports projected to increase dramatically, there is increasing interest in leguminous fodder shrubs to help solve the feed problem, for three reasons. First, the uptake of herbaceous legumes in African smallholder systems has been disappointing (Thomas and Sumberg, 1995), encouraging interest in other protein sources. Secondly, the growing popularity of agroforestry has helped promote research and extension activities on integrating fodder shrubs into farming systems. Thirdly, there is widespread evidence that shrub legumes are an important component of indigenous livestock production systems throughout the world (Gutteridge and Shelton, 1993) – cultivation of fodder shrubs can thus be viewed as a modification of existing systems rather than a new, and thus more difficult to introduce, practice.

Despite the strong interest, a literature review did not reveal a single case of widespread adoption of introduced, managed fodder shrubs by small-scale farmers in Africa. Several studies discuss on-farm research on fodder shrubs but give little or no indication as to whether farmers adopted and expanded their use of the technology following the trials (Reynolds *et al.*, 1991; Jabbar *et al.*, 1996). This chapter examines the adoption of *Calliandra calothyrsus*, a leguminous fodder shrub, among smallholder dairy producers in the highlands of central Kenya. The objectives are to:

- examine the expansion of calliandra plantings by farmers after initial testing, and determine which farm and household characteristics are associated with expansion;
- document farmers' experiences and assessments in testing, managing and using calliandra;
- determine the economic impact of calliandra from the farmers' perspective;
- provide feedback and recommendations to research, extension and policy makers for improving and promoting calliandra and fodder shrub production in the Kenyan highlands.

First, the study area is described. Then research on the management of calliandra as a fodder shrub and as a feed to dairy cows is summarized. Next, the survey methods used in the research are described, followed by the results and the conclusions.

Description of the Study Area

The coffee-based land-use system of central Kenya, ranging in altitude from 1300 m to 1800 m, is located on the slopes of Mt Kenya (Fig. 7.1). Rainfall occurs in two seasons, March–June and October–December, and averages 1200–1500 mm annually. Soils, primarily Nitosols, are deep and of moderate to high fertility. Population density is high, ranging from 450 to 700 persons km^{-2}. This study was conducted in the portion of Embu District that falls within the coffee-based system. Farm size averages 1.9 ha (SD = 1.5), and 39% of farmers have plots away from their homesteads. Most farmers have titles to their land, thus tenure is relatively secure. About 18% of all households are female-headed (Minae *et al.*, 1988; Kimenye, 1998; Murithi, 1998).

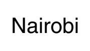

Fig. 7.1. Study area in central Kenya.

The main crops are coffee, produced for cash, and maize and beans, produced for food. Most farmers also grow napier grass (*Pennisetum purpureum*) for feeding their dairy cows, and crop their fields continuously because of the shortage of land. About 80% have improved dairy cows, 1.7 cows per family, kept in zero- or minimum-grazing systems. Milk yields average about 8 kg per cow day^{-1} and production is for both home consumption and sale. Forty per cent of the farmers also have goats, averaging 3.2 per family (Minae *et al.*, 1988; Murithi, 1998). Dairy goats are a rapidly growing enterprise and are particularly suited for poorer households.

The main feed source for dairy cows is napier grass (*P. purpureum*), supplemented during the dry season with crop residues, such as maize and bean stover, banana leaves and pseudostems, and indigenous fodder shrubs. Herbaceous legumes have not been widely adopted, in part because of farmers' inability to establish them in mixed stands with napier grass (Paterson *et al.*, 1996b). Forty-five per cent of the farmers buy commercial dairy meal (nominally 16% crude protein) to supplement their cows' diet (Murithi, 1998). Whereas the extension service recommends 4 kg dairy meal be fed per day, depending on the level of milk production, farmers' feeding rates are considerably lower. Farmers complain that the price ratio between dairy meal and milk is not favourable, that they lack cash for buying dairy meal, that its nutritive value is suspect and highly variable, and that it is difficult for them to transport dairy meal from the market to the homestead (Patterson *et al.*, 1996a).

Research on Calliandra Management

Research on fodder shrubs began in Kenya in the 1980s by the International Livestock Research Institute (ILRI) and the Kenya Agricultural Research Institute (KARI). The first on-farm trials in the Embu area were initiated by the National Agroforestry Research Project (NAFRP), a project jointly managed by KARI, the Kenya Forestry Research Institute and the International Centre for Research in Agroforestry (ICRAF). In 1991, NAFRP scientists tested three promising species – calliandra, *Sesbania sesban* and *Leucaena leucocephala* – to find out which niches farmers preferred for planting the shrubs. Because of the limited size of farms, farmers and researchers focused on integrating the shrub into the existing cropping system rather than planting the tree in pure-stand fodder banks. In type 3 (farmer-designed, farmer-managed trials, see Chapter 2) farmers planted the shrubs as they wished in niches of their choosing, including:

1. As hedges around the farm compound. Hedges are a common feature of homesteads in central Kenya, and were traditionally planted to relatively unproductive, non-browse species, to prevent free-ranging livestock from eliminating them. But livestock are now confined and there is great potential for replacing unproductive hedges with fodder hedges (Thijssen *et al.*, 1993).
2. Along contour bunds and terrace edges on sloping land. They thus help conserve soil and, if pruned continuously, have little effect on neighbouring crops.
3. Intercropped with napier grass. Results from intercropping experiments suggest that introducing calliandra into napier grass has little effect on napier yields (Nyaata *et al.*, 1998).
4. Between upper-storey trees, which are commonly planted along boundaries. The growth of fodder trees is hardly affected by taller species, such as *Grevillea robusta*, planted in the same line (NAFRP, 1993).

Pruning management has also been examined. The shrubs are first pruned for fodder 9–12 months after planting, and pruning continues at the rate of four or five times per year (Roothaert *et al.*, 1998). Leafy biomass yields per year rise as pruning frequency decreases and cutting height increases. But adjacent crop yields are negatively affected (ICRAF, 1992). The most productive compromise is probably in the range of 4–6 prunings per year at 0.6–1 m cutting height, which would yield roughly 1.5 kg dry matter per tree year^{-1} planted at 2 trees m^{-1} in hedges under farmers' conditions. Thus a farmer would need about 500 trees to feed a cow throughout the year at a rate of 2 kg dry matter day^{-1}, providing about 0.6 kg crude protein. A typical farm of 1.5 ha would have available about 500 m of perimeter and several hundred metres in each of three other niches: along terrace edges or bunds, along internal field and homestead boundaries, and in napier grass plots. Only 250 m of hedges would be needed to accommodate 500 trees, in order to feed a dairy cow (Paterson *et al.*, 1996a,c).

On-farm feeding trials have confirmed the effectiveness of calliandra as both a supplement to the basal diet and as a substitute for dairy meal. One kilogram of dry calliandra (24% crude protein and digestibility of 60% when fed fresh) has about the same amount of digestible protein as 1 kg dairy meal (16% crude protein and 80% digestibility) (Paterson *et al.*, 1996b); each increases milk production by about 0.75 kg (from 10.0 to 10.75 kg day^{-1}) under farm conditions, but the response is variable, depending on such factors as the health of the cow and the quantity and quality of the basal feed (Paterson *et al.*, 1996c). The effects of calliandra and dairy meal were found to be additive, suggesting that the two feeds are nutritionally interchangeable (Paterson *et al.*, 1996c). Unfortunately, data are not available for constructing a response curve to show the effect of varying quantities of calliandra on milk production. Calliandra was also found to increase the milk production of dairy goats (Kiruiro *et al.*, 1999).

Calliandra seedlings are raised in nurseries and transplanted following the onset of the rains. Experiments on seedling production have confirmed that plants may be grown in raised seedbeds rather than by the more expensive, labourious method of planting in polythene bags (O'Neill *et al.*, 1997). Researchers are also conducting studies on other shrubs species, exotic and indigenous (Roothaert *et al.*, 1997), to help farmers further diversify their feed sources. These species include *Leucaena trichandra*, *Morus alba* (mulberry) and *Sapium ellipticum*.

Methods

Informal, semi-structured interviews were conducted in April 1995, with six farmers who had tested calliandra, in order to develop an understanding of the issues involved in adoption and to formulate hypotheses. In order to draw up a sample frame for the formal survey, a list of farmers who had received calliandra seedlings during, or previous to, 1993 was assembled. The year 1993 was selected as the cut-off year in order to ensure that sample farmers had at least 2 years' experience of growing, and thus 1 year of feeding, calliandra. The list included:

- All of the 64 farmers who had participated in the two on-farm calliandra trials of the National Agroforestry Research Project (NAFRP) up to 1993, including those who had dropped out of the trials. These farmers had been selected for the trials on the basis of their interest in testing calliandra.

- Nineteen farmers who had received seedlings from the National Dairy Development Project (NDDP). Unfortunately, a complete list of the farmers who received seedlings was not available, nor were the criteria for their selection known. It is likely that the list drawn up by extension staff for this survey was biased towards farmers who were adopters.

Assessing adoption among farmers who participated in on-farm trials and special projects is sometimes suspect, as extensive contact and incentives may bias the farmers in favour of the technology being assessed. In this particular case, we feel that such concerns were negligible. None of the farmers in either group received any incentives apart from free seed and seedlings. All received some advice about calliandra but, as the findings show, lack of information about calliandra was an important problem (one farmer did not know that calliandra could be fed to livestock!). Monitoring and contact with research and extension varied; about half of the farmers had completed their trials by 1993 and afterwards had little or no contact with researchers. About one-third participated in type 2 (researcher-designed, farmer-managed) on-farm trials during 1994 and 1995, involving feeding and pruning, and thus had repeated contact with researchers. The NDDP ended in 1994, so the NDDP farmers had had no contact with the project for a year or longer.

A random sample of 45 farmers from the lists was interviewed twice, in 1995 and in 1998, using a structured questionnaire. The authors conducted all interviews themselves. In addition, three farmers who had obtained seed from interviewed farmers were visited, to find out their experience in testing calliandra.

For the economic analysis, partial budgets were drawn up to show the effects on net income under two scenarios: (i) using calliandra as a supplement to the normal diet; and (ii) as a substitute for purchased dairy meal. The base analysis assumed a 1.5 ha farm with 500 shrubs and one zero-grazed dairy cow and covers a 5-year period. The benefits included in the analysis were the effect of calliandra on milk production (in the supplementation case) and the cash saved by not purchasing dairy meal and interest on cash freed up (in the substitution case). Costs were those of the seedlings and labour for planting, cutting and feeding calliandra. Average prices over a 3-year period, 1996–1998, were used for dairy meal, milk and labour. Returns are expressed in 1998 US dollars, adjusted for inflation. Coefficients, prices and sources of data used in the economic analysis are shown in Table 7.1.

Results

Farm and household characteristics

Most (91%) of the households were male-headed, while four (9%) were female-headed. Of the latter group, in three cases the husband was living away and in one, the woman was not married. Household heads were generally middle aged; 48%

Table 7.1. Coefficients and prices used in the economic analysis.

Items	Values	Data sources
Coefficients		
Period of analysis	5 years	Assumption
Lactation period	300 days	Assumption
Days fed calliandra	365 days	Assumption
Days fed dairy meal	365 days	Assumption
Calliandra quantity fed per cow day^{-1}	6 kg fresh (equivalent to 2 kg dry)	Assumption
Dairy meal quantity fed per cow day^{-1}	2 kg	Assumption
Milk output day^{-1} from 1 kg dry calliandra	0.75 kg	Paterson *et al.* (1996c)
Milk ouput day^{-1} from 1 kg dairy meal	0.75 kg	Paterson *et al.* (1996c)
Calliandra leafy biomass yield per shrub in year 1	0 kg	Farmers' experience
Calliandra leafy biomass yield per shrub year^{-1}, years 2–5	1.5 kg (dry)	Paterson *et al.* (1996c)
Shrubs required to feed 1 cow year^{-1}	487	Computed from above
Shrub survival rate	80%	Survey data
Calliandra planting labour	20 shrubs h^{-1}	Farmers
Calliandra cutting and feeding labour	15 min day^{-1}	Farmers
Discount rate	20%	Assumption
Interest on capital freed up by using calliandra instead of purchasing dairy meal	Capital tied up for an average of 2 weeks, 20% annual interest rate	
Prices		
Dairy meal	US\$0.201 kg^{-1}	Market survey, 1996–1998
Transport of dairy meal	US\$0.008 kg^{-1}	Market survey, 1996–1998
Seedling cost (bare-rooted)	US\$0.526 per 100 seedlings	R. Swinkels (unpublished data from on-farm trial)
Labour cost	US\$0.118 h^{-1}	Farmers, 1996–1998
Milk price (farm gate)	US\$0.296 kg^{-1}	Farmers, 1996–1998
Annualized value of fixed cost for seedling establishment for 500 shrubs	US\$2.18	Use of capital recovery formula[a] (Spencer *et al.*, 1979)
US\$1 = 59 Kenya shillings		Average exchange rate, 1996–1998

[a] $K=(rv)/(1-(1=r)^{-n})$ where K is the annual service user cost, v is the original (acquisition) cost of the fixed capital asset, r is the discount rate and n is the expected life of the asset. This procedure allows both the depreciation on capital and the opportunity cost of capital to be costed out.

were between 30 and 55 years old, with 36% older and 17% younger. Eighty-nine per cent of the females and 77% of the males work full time on the farm. Over half (55%) were judged to be high-income farmers, 38% were of middle income and 7%, low income.

Farm size averaged 2.3 ha (SD = 1.6; median = 1.6). Of the total, 1.8 ha was situated around the homestead and 0.5 ha at some distance away. Main enterprises, as ranked by the farmers themselves, were dairy, coffee, tea and maize. Ninety-six per cent had dairy cows, averaging 1.9 cows per farm. Sixty per cent had heifers, 47% had bulls or steers and 53% had calves. Goats were owned by 58%, averaging 2.3 per farm, and 27% owned sheep. Eighty-five per cent owned poultry and 68% had rabbits. Overall, the sample farmers appeared to have somewhat higher incomes and were more oriented towards dairy farming than average farmers in their area. Their farms were about 20% larger than average farms in the area.

Establishment and expansion of calliandra plantings

Farmers' first plantings of calliandra averaged 90 shrubs, of which 84 shrubs survived. The high survival rate, 93% (SD = 13%), was consistent with data collected in farmer-managed trials in the same area and including some of the same farmers (NAFRP, 1993). Two-thirds were participants in NAFRP on-farm trials, 20% obtained planting material from NDDP, and 13% from other sources. Four-fifths of the farmers used potted seedlings to establish their first calliandra plantings, 16% established their own nursery, and 4% direct seeded. First plantings occurred between 1988 and 1993, with over half taking place in 1992 (Fig. 7.2).

Over four-fifths of the farmers expanded their calliandra plantings after their first planting (Table 7.2). Over one-third expanded twice and 18%, three or four times. As farmers expanded, the number of shrubs planted[1] per expansion appeared to increase, although because of the high variability, the differences were not statistically significant (Table 7.2). In farmers' fourth and fifth plantings, the average number of shrubs planted was 54% higher than in their first plantings.

Table 7.2. Expansion of calliandra plantings and numbers of shrubs per plantings.

Planting	No. of farmers	Average no. shrubs per planting (SD)
Initial planting	45 (100%)	84 (65)
1st expansion	37 (82 %)	85 (54)
2nd expansion	16 (36%)	97 (99)
3rd and 4th expansions	8 (18%)	129 (143)

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[1] The number of shrubs that survived is used instead of the number that were planted, because in many cases the farmers could not remember how many they had planted, whereas we were able to count the numbers of surviving shrubs. As survival rates averaged 93% for the 31 cases where data were available, the differences between numbers planted and numbers survived was probably small.

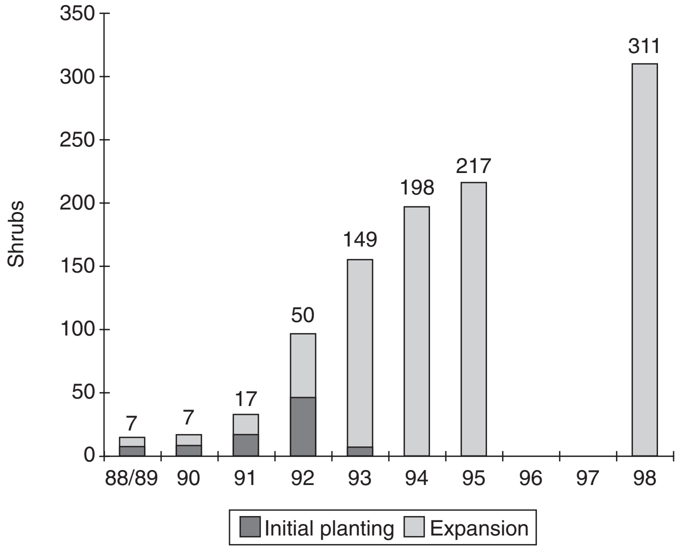

Fig. 7.2. Farmer expansion following testing: numbers of calliandra shrubs planted by 45 surveyed farmers who first planted before 1993.

By 1995, the average number of shrubs per farmer had increased from 84 (SD = 65) in their first planting to 218 (SD = 225; median = 166), an increase of over 2.5 times. The rate of increase slowed somewhat over the next 3 years; by 1998 farmers averaged 311 shrubs (Ondieki, 1999).

There were important differences in the method of planting and source of planting material between farmers' successive plantings (Table 7.3). Whereas the principal method in farmers' first and second plantings was to use potted seedlings obtained from projects, the most important method in the third and subsequent plantings was to establish a nursery. Similarly, farmers' own farms and other sources (e.g. shrubs from friends and relatives) replaced projects as the principal source of planting material, beginning in the third planting. Of the 65 incidents of expan-

Table 7.3. Planting method and source of planting material for successive plantings of calliandra.

	Method (% of plantings)			Source of planting material (% of plantings)		
Planting	Direct seed	Nursery	Potted seedlings	Project	Own shrubs	Other
1st	4	16	80	87	0	13
2nd	0	11	89	92	5	3
3rd	17	44	39	31	42	26
4th and 5th	0	60	40	44	44	11

sion, 33 involved planting seeds or seedlings obtained from projects, and 32, seeds or seedlings obtained from farmers' own farms or from other persons. By mid-1995, 36% of the farmers had established calliandra nurseries. Three-quarters of these used seed from their own shrubs.

The niches where farmers planted calliandra were sometimes determined by farmers and sometimes by researchers, as when an on-farm trial concerned a particular niche. Overall, the most common niches were in lines on contours (62% of farms), intercropped with food crops or coffee (40%), and on homestead boundaries (35%) (Table 7.4). In plantings where farmers chose the niche, the most common choices were homestead boundaries, external boundaries and in lines on contours. Only two farmers planted calliandra in pure-stand fodder banks, reflecting farmers' reluctance to allocate even small plots to calliandra.

There did not appear to be much association between uptake of calliandra and selected farm and household characteristics, but the assessment was constrained by the small size of the sample. Defining an adopter as a farmer who had expanded at least once and had more than 100 shrubs, 73% of the sample could be termed adopters. There was no association between adoption and farm size, wealth, size of farm adjacent to the homestead, or number of cows. There was a tendency for adoption to be associated with age; six of seven farmers under 30 adopted, whereas only 9 of 15 over 55 did so. The dairy enterprise's rank in importance among other enterprises was significantly associated with adoption at the $P < 0.10$ level (chi-square test); the higher the rank of dairy, the more likely farmers were to adopt.

Management and uses of calliandra

Pruning methods were quite variable. The most common method was to periodically cut calliandra when it reached a height of about 1.0–1.4 m (before it becomes

Table 7.4. Niches where farmers planted calliandra.

Niche	All plantings (numbers and percentages of sample farmers)[a]	Plantings where farmer chose niche (numbers and percentages of farmers who chose niches) ($n = 35$)
In lines on contours	28 (62%)	8 (23%)
Intercropped with food crops or coffee	18 (40%)	6 (17%)
Homestead boundary	16 (35%)	11 (31%)
Intercropped in napier grass plots	15 (33%)	2 (6%)
External boundary	11 (24%)	10 (28%)
Internal boundary	9 (20%)	6 (17%)

[a] Percentages do not sum to 100 because farmers often plant in more than one niche. In some of the on-farm trials, farmers were asked to plant in a particular niche.

too difficult to reach and shades neighbouring crops too much), reducing the height to about 0.5–1 m. About 80% used pruning shears, which they already owned for use on their coffee and tea. Thirteen per cent use a machete, claiming that the stem was too thick for using shears. Nine per cent broke off branches by hand, primarily in order to save time. Pruning shears are recommended because they make a cleaner cut, thus promoting regrowth and preventing disease and damage to the shrub.

Farmers fed calliandra to a wide range of types of animals. Ninety-one per cent fed it to dairy cows, 47% to goats and 42% to heifers. Between 5% and 20% fed to each of the following: bulls, sheep, rabbits, calves and poultry. Sixty-nine per cent fed dry cows as well as lactating ones. This was often because a dry cow and a lactating cow fed from the same trough and it was not practical to separate their rations. Nearly all farmers chopped calliandra before feeding, as recommended, as opposed to giving the branches to the cows to strip off the leaves. Over 90% mixed calliandra with napier grass when feeding, about 44% also fed calliandra separately at times. Like dairy meal, calliandra is often fed during milking to help keep the cow still.

Only one farmer claimed to have fed calliandra to his cows throughout the year. On average, farmers fed their cows calliandra about one-third of the time, because the quantities they had were not sufficient and shrub growth was low during the dry season. Only 12% reduced cutting during the wet season in order to have increased supplies during the dry season. Farmers were sceptical about this strategy, because not cutting calliandra would increase its competition with crops. Three-quarters of the farmers fed their animals within an hour after cutting, in line with the recommendation to feed only fresh leaves (Roothaert *et al.*, 1998). This recommendation has since been changed; recent research shows that calliandra can be fed fresh or dry (Stewart, 2000).

Eighty-four per cent fed dairy meal to their cows, although many said that because of cash shortages, they did not feed continuously. Most (62%) used calliandra as a supplement to dairy meal, that is, they did not reduce their use of dairy meal when they fed calliandra. On the other hand, 27% used calliandra as a complete substitute for dairy meal, and 10% as a partial substitute. Eighty-eight per cent claimed that calliandra increased their milk production and 89% claimed that their cows found it highly palatable.

Some farmers claimed that they obtained benefits from calliandra in addition to increases in milk production. In response to an open question, 24% per cent said that fuelwood production was a benefit, 13% cited soil conservation, and 7% each cited increases in milk quality, calliandra's appearance and money saved by not having to buy dairy meal. The only negative aspects cited were scales (18%), a minor pest that does not appear to reduce productivity very much, and that calliandra reduces the yield of adjacent crops (7%).

The farmers varied considerably in the way they used the seed produced by their calliandra shrubs. Forty per cent harvested seed; those that did not cited their lack of interest or lack of knowledge about propagation techniques. One-third of the farmers gave seed to others; each gave to an average of 13 other farmers (this figure is skewed upwards because of two farmers who gave seeds to 110 farmers – the median number of persons given seed was four). Two farmers sold seed or seedlings to other farmers. Two-thirds of the farmers had left some shrubs to seed at the time they were interviewed, indicating their strong interest in expanding calliandra production or in distributing seed.

Interviews were conducted with three farmers who obtained seed from the sample farmers. Two used the seed to establish nurseries in 1995. One had transplanted 67 shrubs from the nursery to his farm; the other was waiting for the seedlings to reach sufficient size before transplanting. A third farmer purchased 500 seedlings in 1994 from a sample farmer and he planted them on internal and external boundaries. He purchased an additional 100 seedlings in 1995. He also established a nursery in late 1995, and planned to transplant seedlings to his farm in 1996. As these farmers were not randomly selected, they cannot be said to be representative of farmers receiving seed from sample farms. But their experiences indicated the high potential for dissemination beyond the original farmers.

Each person who harvested seed harvested from an average of only eight shrubs. It is advisable to harvest from at least 30 shrubs in order to conserve the genetic diversity of the germplasm. If the genetic base in an area is too narrow, inbreeding causes a significant decline in productivity (Roothaert *et al.*, 1998). Farmers were unaware of the need to harvest from at least 30 shrubs. Some may be reluctant to leave so many shrubs for seed because they become tall and reduce the growth of adjacent crops.

Ninety-one per cent of the farmers indicated an interest in increasing their calliandra plantings. When asked about constraints limiting expansion of calliandra, 19 (42%) claimed they lacked seedlings. Since some farmers had received seedlings from projects two or more times, they clearly were hoping to receive seedlings again so as not to have to develop their own nurseries. Three mentioned that they lacked knowledge on propagation techniques.

Surprisingly, most of the farmers (58%) had never visited another farmer who had planted calliandra. Nineteen per cent had visited other calliandra farmers as part of extension tours and 34% had visited other calliandra farmers on their own.

Monitoring, farmer innovation and feedback

Informal monitoring takes place in which farmers and extension staff provide feedback to project staff and researchers on their progress and problems. In one case, feedback on a farmer innovation has resulted in a change in extension recommendations. Farmers in Kandara Division, Maragua District, conducted experiments on soaking calliandra seeds before planting and found that seeds soaked for 48–60 h had higher germination rates than those soaked for the recommended 24 h. Researchers at KARI-Embu confirmed the farmers' findings and extension staff now recommend the longer soaking time.

Farmers' problems with pests and their innovations in controlling them have also led to the design of new on-farm trials. For example, in 2001, researchers and farmers are comparing the effectiveness of using netting and local measures (spraying solutions made from tobacco, marigold, neem, hot pepper or *Tephrosia vogelii*) to control crickets, hoppers and aphids damaging seedlings in nurseries. These findings demonstrate the importance of monitoring farmer innovations and feeding them back to research and extension.

Economic analysis

Partial budgets for calliandra as a supplement to farmers' basal feed and as a substitute for dairy meal are shown in Tables 7.5 and 7.6. Shrub establishment costs (including the costs of seedlings and planting) are modest, US$6.58 per 500 shrubs.[2] Beginning in the second year, harvesting and feeding 2 kg dry calliandra day^{-1} as a supplement throughout the lactation period increases milk production by about 450 kg year^{-1}, an increase of about 10% over base milk yields. Incremental benefits per year after the first year are over 12 times higher than incremental costs. Net benefits per cow year^{-1} after year 1 are US$120.11. Treating the establishment costs as depreciation spread over the 5-year period, the annualized net benefit is US$117.91 per cow year^{-1}. The net present value (NPV), assuming a 20% discount rate, is US$258.39.

In the partial budget assessing calliandra as a substitute for dairy meal, establishment, cutting and feeding costs are the same as in the preceding analysis. By feeding calliandra, the farmer saves the money he would have spent buying and transporting 730 kg dairy meal during the year. Incremental benefits per year after the first year are over 14 times higher than incremental costs. Milk production does not increase but net benefits are slightly higher than in the supplementation case. The net benefits per cow year^{-1} after year 1 are US$141.68. The annualized net benefit is US$139.48 per cow year^{-1}. The NPV, assuming a 20% discount rate, is US$300.15. Therefore, using calliandra increases farmers' annual income by about

Table 7.5. Partial budget: extra costs and benefits of using calliandra as a supplement for increasing milk production (US$).

	Extra cost		Extra benefits		Net benefit
Year	Item	US$	Item	US$	(US$)
1	Shrub seedlings	3.05		0	
	Planting labour	3.53			
	Subtotal	6.58			–6.58
2	Cutting/feeding labour	10.75	450 kg milk	133.07	122.32

Years 3–5 same as year 2
Net present value at 20% discount rate = US$258.39 year^{-1}
Net benefit per year after year 1 = US$120.11
Annualized net benefit treating establishment costs as depreciation = US$117.91

Base farm model: the farm has 500 calliandra shrubs and one dairy cow. The cow consumes a basal diet of 80 kg napier grass day^{-1} and produces 10 kg milk day^{-1}.

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[2] US$1 = 59 Kenya shillings on average for the period 1996–1998.

Table 7.6. Partial budget: extra costs and benefits of using calliandra as a substitute for dairy meal in milk production (US$).

	Extra cost		Extra benefits		Net benefit
Year	Item	US$	Item	US$	(US$)
1	Shrub seedlings	3.05		0	
	Planting labour	3.53			
	Subtotal	6.58			–6.58
2	Cutting/feeding labour	10.75	Saved dairy meal cost	147.10	
			Saved dairy meal transport	5.32	
			Interest on capital freed up	0.90	
	Subtotal	10.75	Subtotal	152.43	141.68

Years 3–5 same as year 2
Net present value at 20% discount rate = US$300.15
Net benefit per year after year 1 = US$141.68
Annualized net benefit treating establishment costs as depreciation = US$139.48

Base farm model as in Table 7.5.

US$120–142 per cow year^{-1}, depending on whether the farmer is supplementing or substituting. As the average farmer owns 1.7 cows, calliandra increases farmers' income by about US$204–241 year^{-1}, representing an increase of about 10% in total household income (Murithi, 1998).

Returns varied somewhat among the 3 years (1996–1998) for which economic data were collected. For example, net benefits per cow year^{-1} after year 1 varied from US$94–120 in the supplement scenario and US$107–151 in the substitute scenario.

The costs of establishing, maintaining and feeding calliandra are low. In both the substitute and supplement scenarios, farmers recover their costs very quickly, in the second year after planting. In order to break even, a farmer using calliandra as a supplement needs to obtain only 0.08 kg of milk from 1.0 kg of calliandra (dry), rather than the 0.75 kg milk kg^{-1} of calliandra obtained in on-farm trials and assumed in the analysis.

Several intangible, or otherwise difficult to measure, benefits and costs have been omitted from this analysis. Calliandra provides benefits to some farmers as firewood, in erosion control, as a boundary marker, a fence and as an ornamental. It also increases the butterfat content of milk, giving it a richer taste and creamier texture. When used as a supplement, calliandra may improve animal health and fertility and reduce the calving interval. Finally, several farmers noted that calliandra had important benefits relative to dairy meal: it was available on the farm, cash was not needed to obtain it and its nutritional content was more reliable than that of dairy meal. These views support Haugerud's thesis that farmers prefer enterprises and practices that do not rely on uncertain governmental or market mechanisms (Haugerud, 1984).

The main costs not assessed are the opportunity cost of the land occupied by the shrubs and the effect in reducing yields of adjacent crops. However, these are likely to be relatively low, especially when calliandra replaces, or is added to, an existing hedge or bund, is pruned frequently, is planted between upper-storey trees, or when calliandra hedges border on homesteads, roads, paths or external boundaries.

The sensitivity analysis suggests that the net benefits of using calliandra as a supplement or as a substitute are fairly stable (Table 7.7). Despite the range of negative situations tested, net present values and net benefits remain positive. For example, a 30% reduction in milk price reduces the NPV in the supplement scenario by 33%, but using calliandra would still be profitable. In the substitution scenario, a reduction of the dairy meal price by 30% reduces the NPV by 32%. If one assumes that 1 kg dry calliandra gives 0.5 kg milk instead of 0.75 kg milk, the NPV in the supplement scenario declines by 37%.

Conclusions

This chapter presents considerable evidence that test farmers in the Embu area are adopting calliandra as a fodder shrub and that farmer-to-farmer dissemination is substantial. By 1997, it was estimated that roughly 1000 farmers had planted calliandra. During 1999–2000, a project implemented through the Systemwide Livestock Program of the Consultative Group on International Agricultural Research helped an additional 3000 farmers to plant calliandra across seven districts of central Kenya. This project, implemented by ICRAF, KARI and ILRI also intro-

Table 7.7. Sensitivity analysis showing the effect of changes in key parameters on the profitability of using calliandra (US$ per cow year^{-1}).

	Calliandra as supplement		Calliandra as substitute	
	Net present value	Annualized net benefit	Net present value	Annualized net benefit
Base analysis	258	118	300	139
Milk price +30%	344	158	300	139
Milk price –30%	172	78	300	139
Dairy meal price +30%	258	118	395	184
Dairy meal price –30%	258	118	205	95
Discount rate 30%	199	118	231	140
Labour cost +30%	250	114	292	136
2 kg dairy meal or 1 kg dry calliandra gives 1 kg milk	354	162	300	139
2 kg dairy meal or 1 kg dry calliandra gives 0.5 kg milk	163	73	300	139

Data based on Tables 7.5 and 7.6.

duced two other fodder shrubs to farmers, *Leucaena trichandra* and *Morus alba* (mulberry), and one herbaceous legume, *Desmodium intortum*.

Calliandra appears to be appropriate for smallholder dairy farmers throughout eastern Africa – it can grow at altitudes between sea level and 1900 m, requires a minimum of 1000 mm rainfall, can withstand dry seasons up to 4 months long and is suitable for cut-and-carry feeding systems or for grazing systems (Roothaert *et al.*, 1998). There are approximately 625,000 smallholder dairy farmers in Kenya with improved cows; each has about 1.7 cows per farm (Omore *et al.*, 1999). Therefore, the potential benefits from adopting calliandra, as measured in this chapter, amount to about US\$139,000,000 year^{-1} in the Kenya smallholder dairy sector alone.

Calliandra's actual potential benefits are much higher. Calliandra also has important potential in the large-scale dairy 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. Moreover, the shrub is being used by dairy farmers at numerous other sites in east and southern Africa, including Rwanda, Uganda, Tanzania and Zimbabwe, and results are promising. But several important problems remain; the proposed measures in the following section can help to solve these problems and enhance the benefits that calliandra can offer to African dairy farmers.

Issues for research and extension

Whereas the project has successfully expanded the use of fodder shrubs across seven districts, it is still reaching only a small percentage of dairy farmers in these districts, and less than 1% of Kenya's smallholder dairy farmers. Like many agroforestry practices, fodder trees spread slowly on their own; considerable facilitation in terms of training, information and germplasm is required. Further scaling up should focus on institutions working in areas of the country where smallholder dairy farmers predominate. ICRAF, the Oxford Forestry Institute, the Regional Land Management Unit and other partners are planning a project that will help the government extension services, NGOs, and farmer organizations throughout East Africa to assist farmers to plant fodder trees.

Commercial seed production and distribution are slowly emerging in project areas, but it is not clear if seed production will continue to grow and meet local demand. Greater emphasis is needed on promoting community-based seed production and distribution through a range of partners: farmer groups, individual seed producers and private nurseries. Research is also needed to compare the effectiveness and efficiency of different mechanisms for producing and distributing planting material.

Four other on-farm research issues need to be addressed:

1. Greater diversification of fodder shrubs is needed to reduce the risk of pest and disease attacks and improve feed quality. KARI-Embu has a strong on-farm research programme for evaluating fodder trees and is increasing its emphasis on the testing of indigenous species.

2. Many farmers now have 5–10 years of experience feeding calliandra to their cows; the knowledge that these farmers have gained on feeding calliandra needs to be captured and shared.
3. More research is needed on the constraints and incentives affecting the adoption of calliandra. For example, a survey of neighbours of calliandra adopters could be useful for identifying the problems they have in testing and adopting calliandra.
4. Networks of farmer experimenters need to be established. During the survey reported in this chapter, a considerable amount of farmer experimentation was observed. For example, individual farmers were found to be experimenting on the effect of different cutting heights, on substitutability between dairy meal and calliandra, and on methods of establishment. Farmers and researchers could both gain if farmers were able to organize themselves to conduct research on particular issues, using farms as replicates. Farmer-experimenters working together on a topic could meet periodically to assess progress and, at the end of the experiment, could draw conclusions.

Finally, more research is needed for expanding smallholder dairy production. Milk demand in Africa greatly outstrips locally available supplies. Dwindling feed resources and high transaction costs for production and marketing limit productivity and smallholder participation (Winrock International, 1992; Staal *et al.*, 1996). Fodder shrubs help reduce costs and improve the productivity and profitability of smallholder dairying. Even when dairy production is stagnant, fodder shrubs may be attractive to farmers as substitutes for purchased concentrates. But expansion of fodder shrubs will likely be greatest when dairy production is increasing.

Factors contributing to success and challenges

Several factors have contributed to the achievements thus far in developing and disseminating fodder shrubs:

1. The demand among farmers for fodder shrubs was huge, mainly because the shrubs save cash, farmers' scarcest resource, and require only small amounts of land and labour.
2. Initial on-farm trials were farmer-designed and farmer-managed, permitting farmers to plant the trees in farm niches of their choice and to manage them as they saw fit.
3. The project area is noted for the dynamism of its farmers, and access to markets is fairly high, enhancing the adoption of new practices.
4. Because researchers and extensionists worked through partner organizations, they were able to build on local organizational skills and knowledge and reach far more farmers than would otherwise have been possible.
5. The strong partnership between researchers, extensionists and farmers in the project facilitated the flow of information among the three.

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Promoting New Agroforestry Technologies: Policy Lessons from On-farm Research

8

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Summary

Successful diffusion and adoption of new agroforestry practices depend not only upon the technical performance of those practices and their 'fit' with farming systems, but also on the broader policy environment. Key policy factors relate to: tree germplasm supply, agricultural input supply, markets for agroforestry products, land and forest tenure systems and strategies and institutional arrangements for extension and research support. On-farm research during the technology development process provides a strategic opportunity to begin evaluating policy constraints and ways to address them. Researchers need to involve policy makers in the design and evaluation of assessments and to communicate effectively with them. Based on data and experience from on-farm research programmes in Kenya and Zambia, general policy lessons are drawn, and specific policy recommendations are made for promoting hedgerow intercropping, improved fallows, pole and timber trees, and fodder banks in the eastern and southern Africa context.

Introduction

Successful diffusion and adoption of new agricultural practices depend not only upon the technical performance of those practices and their 'fit' with farming systems and management constraints, but also on the broader policy environment. The successful dissemination of improved maize production technology in Zimbabwe, Zambia and Malawi, for example, was due not just to varietal improvements on farm, but also to technological innovations in processing, price and support policies, institutional and market changes, and coordination of these various components (Howard *et al.*, 1997).

The technology development and testing phase of on-farm research provides a strategic opportunity to begin evaluating policy effects and devising options to deal with policy constraints and opportunities. Research results reported in this volume indicate that there is considerable potential for many agroforestry practices to increase farm income, meet household needs, contribute to local economic growth and possibly improve environmental conditions in different regions of Africa. However, those same studies revealed the need for specific types of policy action to achieve widespread adoption and significant aggregate impact from the new agroforestry practices. Key factors strongly influenced by public policy include: tree germplasm supply, agricultural input supply, markets for agroforestry products, land and forest tenure systems, technology design for extension and institutional arrangements for on-farm research and extension support (Oram, 1993; Place and Dewees, 1999). In this chapter, we review briefly key findings and insights in relation to these six policy areas, and recommend priorities for policy action.

Tree Germplasm Supply

Place and Kindt (1997) note many weaknesses in current policy frameworks towards improved agroforestry tree germplasm supply, including the fragmentation of institutional mandates and functions, lack of coordination of planning, lack of forecasting demand for species, and the poor and unstable funding environment of institutions. The case studies revealed specific issues of germplasm supply for the various agroforestry practices being developed, related to the cost of tree establishment, seedling production and seed supply.

Promote low-cost planting methods

For fodder banks in central Kenya, establishment costs represent only a modest share of total costs, and for timber and pole trees in western Kenya, seedling quality is a much more important consideration than cost. But for improved fallows in western Kenya and Zambia and for hedgerow intercropping in western Kenya, establishment costs are much more important, because tree densities are high and, in the case of improved fallows, trees need to be replanted after only 3–5 years. Reducing the cost and labour required for planting is thus an important means for increasing the adoption potential of improved fallows and hedgerow intercropping.

Two strategies are to promote the use of bare-root seedlings and direct seeding. For hedgerow intercropping in western Kenya, the economic break-even maize yield increase drops from 10.5% to 6% by using bare-root rather than potted seedlings. In the case of improved fallows in western Kenya, direct seeding (where feasible) is far more profitable than the use of potted seedlings. Even in these cases, though, there is no evidence that financial subsidy policies are required to promote these types of agroforestry practices, except perhaps during an initial trial period for farmers to become familiar with the species or practice.

Promote small-scale farm seedling supply

While centralized tree nurseries offer some advantages for training, seed dissemination and quality control early in the extension process, they appear to be neither needed nor likely to persist as important sources for farmers once broader adoption takes place. As shown in the Zambian on-farm research experience, they also present some tricky problems for division of labour inputs and of seedling outputs.

The alternative of using small-scale farm nurseries has been very successful. Such nurseries have several advantages. The production of seedlings from seeds or cuttings is a very labour-intensive process; farmers can manage nurseries as complementary activities to farming, thus keeping labour costs lower than in large-scale nurseries where full-time hired labour is used. Also, they are more convenient for farmers who avoid the costs of transporting seedlings long distances, and also the damage and loss experienced during transport. Nurseries also provide additional income opportunities for farmers. The only major disadvantage of farm nurseries is that farmers usually require training in nursery establishment. Nevertheless, a small amount of facilitation can go a long way. For example, a single extension facilitator in central Kenya was able to assist 150 farmer groups, composed of about 2600 farmers, to establish 250 calliandra nurseries over an 18-month period, 1999–2000 (ILRI, 2000).

An active market mechanism has developed for seedlings of multipurpose trees in western Kenya, through small-scale private nurseries. In the case of fodder trees in central Kenya, there has been a rapid switch from project to farmer group and private nurseries, some of which use farm-produced seed. The major recommendations for promoting small-scale nurseries, once farmers are aware of the potential benefits of a practice, are: (i) to focus training on existing farmer groups and private nurseries rather than individual farmers; (ii) to work through non-governmental organizations (NGOs) and community-based organizations as well as government extension services; (iii) to facilitate farmer-to-farmer training and exchange visits; and (iv) to assist farmers to maintain quality and genetic diversity of seed stocks. The case from central Kenya mentioned above illustrates how these recommendations can be effectively implemented. The extension facilitator was able to reach so many farmers by collaborating closely with three departments of the Ministry of Agriculture, two provincial administrations, one international NGO, four local NGOs, ten community-based organizations and 150 farmer groups (ILRI, 2000). Nearly all the groups had been formed for other purposes, such as church groups, groups to buy water storage tanks, and groups to manage dairy goat breeding stock. Groups managed one or more nurseries; in most cases the nursery was located in the field of a member where water was available during the dry season, and group members shared the labour and distributed the seedlings equally. The groups themselves paid for the exchange visits and these were useful for motivating them and enabling them to exchange information on how nurseries and fodder trees could be managed and used. Group nurseries are not necessarily permanent, in many cases farmers indicated that they worked together only to attract assistance and training and that their future plans were to start their own nurseries.

Expand the supply of high-quality seed through decentralized seed orchards

The lack of tree seed has already become a significant constraint for expansion of improved fallows in Zambia, pole and timber trees in western Kenya, and fodder trees in central Kenya. The on-farm research projects are currently the major source of seeds for farmers, either producing seed or helping to procure it from elsewhere. In addition, farmer seed collection has become increasingly important for the more popular new species, such as calliandra in western Kenya, and for traditionally available species, such as sesbania and grevillea in western Kenya. But a reliable seed supply and distribution system on a much greater scale is required for large-scale adoption.

In contrast to the situation for annual crop seed, where the private sector is becoming more active in development and replication throughout Africa (although government agencies continue to play a critical role), there are as yet few incentives for private sector investment. Some trees require many years before they produce seeds, which delays investment returns and locks producers into selected products; future markets for the variety of tree species and provenances are highly uncertain. We suggest several policy actions to promote seed production and distribution.

First, we propose that high-quality, high-productivity seed orchards be established earlier in the technology development process. These typically require several years to be in full production. Past policy has been to wait until species and on-farm research trials have been completed and superior species and varieties are selected, before establishing seed orchards. The on-farm research experience in Kenya and Zambia suggests that a more effective strategy is to establish seed orchards in the technology development process, so that sufficient seed is available for large-scale adoption by the end of the trial period (Simons, 1996). This may result ultimately in the seed of large numbers of trees not being used. However, the cost is not high relative to the benefits foregone from farmers' having to wait many years until germplasm is available.

The argument for earlier seed orchards is validated by the economic analysis presented in Table 8.1, which compares the strategy of earlier orchards with later ones, using data from calliandra trials and seed orchards in central Kenya. On-farm fodder tree trials began in 1991 involving three species, but, by 1993, it was clear that only calliandra was appreciated by farmers. Seed orchards were established in 1994 and seed became available for on-farm distribution in 1996. The question analysed in the economic analysis is, 'Would it have been better to start 1-ha seed orchards for each of the three species at the beginning of the on-farm trial in 1991, so that calliandra seed would have been available 2 years earlier, even though two of the seed orchards

Table 8.1. Net present value of establishing early seed orchards, when knowledge of which species to extend is still uncertain, versus waiting until trials are completed (US$).

(A) Model 1: On-farm trials begin in year 1 on three species. One-hectare orchards are established in year 3 for the one species that performs well. Adoption begins in year 5.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15
Costs															
Seed and inoculant			18												
Land preparation			42												
Nursery			297												
Planting			85												
Weeding			34	34											
Harvesting and post-harvest			0	678	678	678	678	678	678	678	678	678	678	678	678
Fencing			212												
Guarding			102	102											
Stand management			17												
Land rental			254	254	254	254	254	254	254	254	254	254	254	254	254
Total costs	0	0	1,060	1,068	932	932	932	932	932	932	932	932	932	932	932
Benefits	0	0	0	0	0	23,316	93,265	186,529	279,794	373,058	466,323	559,587	652,852	746,116	839,381
Net benefits	0	0	–1,060	–1,068	–932	22,384	92,332	185,597	278,861	372,126	465,390	558,655	651,919	745,184	838,448
Net present value	487,754														
Seed harvest (kg ha^{-1})	0	0	0	11.1	22.2	33.4	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5
No. farmers receiving seed	0	0	0	0	359	1,076	1,435	1,435	1,435	1,435	1,435	1,435	1,435	1,435	1,435
No. farmers earning benefits				0	0	359	1,435	2,870	4,305	5,739	7,174	8,609	10,044	11,479	12,914

Table 8.1. *Continued.*

(B) Model 2: On-farm trials begin in year 1 on three species. One-hectare orchards are established in year 1 for all three species. One species performs well and adoption begins in year 3.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15
Costs															
Seed and inoculant	53														
Land preparation	127														
Nursery	890														
Planting	254														
Weeding	102	102													
Harvesting and post-harvest	0	678	678	678	678	678	678	678	678	678	678	678	678	678	678
Fencing	636														
Guarding	203	203													
Stand management	51														
Land rental	763	763	254	254	254	254	254	254	254	254	254	254	254	254	254
Total costs	3,079	1,746	932	932	932	932	932	932	932	932	932	932	932	932	932
Benefits	0	0	0	23,316	93,265	186,529	279,794	373,058	466,323	559,587	652,852	746,116	839,381	932,645	1,025,910
Net benefits	–3,079	–1,746	–932	22,384	92,332	185,597	278,861	372,126	465,390	558,655	651,919	745,184	838,448	931,713	1,024,977
Net present value	839,308														
Seed harvest (kg ha^{-1})	0	11.1	22.2	33.4	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5
No. farmers receiving seed	0	0	359	1,076	1,435	1,435	1,435	1,435	1,435	1,435	1,435	1,435	1,435	1,435	1,435
No. farmers earning benefits	0	0	0	359	1,435	2,870	4,305	5,739	7,174	8,609	10,044	11,479	12,914	14,348	15,783

Data are based on experiences developing *Calliandra calothyrsus* seed orchards and disseminating calliandra in the Embu area, Kenya. 31 g of seed are needed to plant 250 trees. It is assumed that an adopting farmer plants 250 trees, which provides an increase in annual net income US$65, beginning in the second year (Chapter 7). The discount rate used in the analysis is 20%.

would have been of no use?'. The analysis shows that the net present value of the strategy of early seed orchards was 72% higher than the strategy of waiting for the results of the on-farm trial before establishing seed orchards. In fact, early seed orchards would be justified even if 20 1-ha seed orchards were established early in order to get a head start in disseminating, but only one of the species was ever disseminated. The results highlight the huge benefits associated with getting a head start on disseminating new practices, as compared to the costs of establishing seed orchards.

We also propose that a range of different entities be involved in seed production; ICRAF and partners are currently helping research institutions, NGOs, private nurseries, farmer groups and individual farmers to establish seed orchards. In western Kenya, ICRAF has supplied seed and information to several farmers planting calliandra orchards and has agreed to purchase seed at an agreed price during the first 2 years of production, after which they will have to market seed on their own (James Were, ICRAF, personal communication).

Maintaining genetic diversity is critical because, after planting some technologies, such as trees for fodder, poles or firewood, farmers may not plant again for another 20 years. Participants in fodder on-farm trials have been encouraged to harvest seed from at least 30 trees, but this has been very difficult for them, as allowing a tree to seed means it will shade an area that might otherwise be used for crops. One option being pursued is to promote members of farmer groups to each establish 5–10 different seed trees, which are used as sources by the whole group.

The active local seed propagation and distribution of calliandra by on-farm research participants in central Kenya suggests that a strategy of decentralized distribution to trained farmers in different geographic areas could induce broad diffusion. In the future, as adoption demand for seed increases, there is also potential for farmer-managed seed orchards to develop commercial supply agreements with local agricultural supply stores and other rural retail outlets.

Agricultural Input Supply

The market distribution networks, price and price variability and regulations affecting agricultural input supply have significant impacts on the adoption and profitability of the agroforestry systems evaluated here. In some cases, agroforestry represents an option for farmers to bypass poorly functioning input markets through direct substitution of agroforestry products or services. In other cases, these are complementary to non-agroforestry inputs and depend for their effectiveness or profitability on a stable supply of those inputs. Financial credit appears to be less important for agroforestry in this region than commonly assumed.

Promote agroforestry for input substitution

In many African smallholder farming systems, working capital is a binding constraint to expanding production (Ellis, 1988). Thus one of the most attractive features of many agroforestry systems is the provision of products that substitute for cash inputs, for example, the substitution of improved fallows for mineral nitrogen fertilizer or of leaf fodder for dairy meal.

In the Zambian case study, farmers especially appreciated improved fallows as nitrogen fertilizer became unaffordable after the elimination of the parastatal distribution and credit systems in the late 1980s and early 1990s. These changes caused the ratio between maize and fertilizer (urea) price to decline from 0.27 (1985–1988) to 0.13 (1989–1991) (FAO, 1998). There was a dramatic decline in maize area and in the use of improved inputs, especially fertilizer, the use of which declined by 70% between 1987/88 and 1995/96 (Howard *et al.*, 1997). Farmers had seen the benefits of using nitrogen fertilizer, but it was no longer affordable; they were thus excited about the possibility of using improved fallows to supply nitrogen.

In western Kenya, fertilizer is widely available, but is used by only about 20% of farmers and at low rates of application. The ratio between the maize and fertilizer (urea) price ranged between 0.18 and 0.26 between 1985 and 1995, but did not follow any noticeable trend (FAO, 1998). Available evidence suggests that farmers prefer to spend scarce working capital on other investments, such as off-farm businesses or education, rather than on fertilizer (Crowley *et al.*, 1996). The recent high enthusiasm for planting improved fallows suggests that farmers are more willing to use additional labour, rather than working capital, to increase the fertility of their soils.

The on-farm research studies found that while improved fallows in Zambia did not produce yields as high as those with fertilizer, yields were far higher than in non-fertilized fields, and returns to labour were actually highest with improved fallows. Sensitivity analysis shows that a decline in fertilizer prices (or increase in maize prices) does greatly increase the profitability of fertilized, continuous maize relative to improved fallows, although in drought years improved fallows offer a much lower-risk alternative.

Calliandra tree fodder is highly attractive to farmers as a substitute for dairy meal on central Kenyan dairy farms, in part because of the poor performance of the dairy meal market. Meal prices fluctuate sharply, because maize, the nation's main food staple, is the main ingredient. Also, farmers are often uncertain about the composition, and hence quality, of the meal (Chapter 7). Many farmers face cash constraints which make purchase difficult, and many also face difficulties in transporting the meal to their farms. Financial sensitivity analysis suggests that the use of calliandra is not very sensitive to the price of dairy meal, and these other favourable factors should lead to a robust demand for fodder bank technology. At this time, nearly two-thirds of the farmers using calliandra feed it together with dairy meal, but this is, in part, because of limited calliandra supplies. The share of calliandra can be expected to increase unless there is a very large decline in meal prices.

Ensure availability of complementary inputs

Agroforestry returns and adoption are not always more attractive where input markets are poorly developed. Chemical fertilizer can, in some cases, be complementary to soil nutrients provided by trees and shrubs, such that assured fertilizer access is important to the productivity of agroforestry systems. Agroforestry technologies can provide nitrogen, but phosphorus is a limiting nutrient in many farming systems, and can only be replenished from off-farm sources (either rock phosphate or phosphate fertilizers) (Sanchez *et al.*, 1997). Phosphorus deficiency will become an important issue in Zambia as the farming system intensifies. In western Kenya, improved fallows may not work at all in some of the areas with severe phosphorus deficiency. In many areas, there appears to be a strong nitrogen × phosphorus interaction. Thus current efforts to make phosphorus more available to farmers are essential to the long-term success of these agroforestry systems, and should be promoted vigorously (Sanchez *et al.*, 1997).

Encourage self-financing of agroforestry

The provision of credit is commonly mentioned as an important policy issue for agroforestry and forestry, because of the presumed lag in time between initial investment in tree establishment and maintenance and the beginning of significant benefit streams (Gregersen *et al.*, 1992). The five case studies in this volume suggest that lack of financial credit should not be a significant constraint to widespread adoption among smallholders in Africa. This is largely due to small farm size (and hence a small scale of operation), farmers' incrementalist approach to tree establishment, and their preference for strategies that reduce cash costs and reduce risks. Payback periods for fodder trees and improved fallows were 3 years or less, since farmers were able to intercrop annual crops with trees, or harvest some tree products, such as fuelwood or leaf fodder, during the first and second years.

Lack of credit is certainly a constraint to smallholder use of inputs such as fertilizer, where cash costs account for a high proportion of total costs of the practice. But for all of these agroforestry practices, direct cash costs for seed or seedling purchase actually account for a relatively small share of total costs, even in the year of establishment, as most farmers rely on family labour for establishment, maintenance and harvest, and can usually time these operations so that they do not conflict significantly with other income-earning activities. Largeholder farmers are, by contrast, likely to require financial credit to establish agroforestry on a broad scale.

Where credit might be available, there is no evidence that subsidized rates would increase smallholder agroforestry adoption. Financial sensitivity analysis shows relatively low sensitivity of returns to the discount rate used in improved fallows in Zambia, Kenyan fodder banks, and hedgerow intercropping. In the case of improved fallows in western Kenya, using low estimates of the opportunity cost of land and labour, discount rate sensitivity is low; however, the effects become quite important if high opportunity costs are assumed. For lenders, short-term agroforestry systems are likely to be more attractive than long-term systems. However, given the severe limitations on agricultural credit in these areas, it is likely that farmers would divert any available credit to higher priorities, such as off-farm businesses or education (Crowley *et al.*, 1996).

Direct subsidies to farmers, in the form of cash payments for tree planting and maintenance might indeed accelerate adoption. In some cases, not evaluated in these studies, they may be justified on social policy grounds. Even so, the record for sustainability of agroforestry practices established through subsidies has not generally been successful in Africa or most other developing countries (Scherr and Current, 1999).

Processing industries involved in outgrower schemes for higher-value crop and livestock products may be encouraged to subsidize some of the cash costs of agroforestry investments that contribute to higher crop or livestock yields or reduce input costs. This would most likely be provided in kind rather than in cash. For example, in Tanzania, private tobacco companies are providing seedlings to farmers so that the farmers can produce fuelwood to cure their tobacco (Ruvuga *et al.*, 1999). But in the case studies presented in this volume, where the end products are maize, milk and construction wood, processing industries are not involved, or likely to become involved, in subsidizing agroforestry investments.

Product Markets

In the past, agroforestry extension has often been ‘supply-driven’; that is, the emphasis has been on increasing production levels of trees and crops, with little attention paid to trends in product demand or price. Recent studies and experience suggest that product market conditions and market institutions can play a critical role in farmer adoption and the economic contribution from agroforestry (Leakey and Newton, 1994; Dewees and Scherr, 1996). For the agroforestry practices developed and evaluated in these on-farm research trials, market conditions for both trees and associated agricultural products had important effects.

Promote marketing of farm-grown tree products

Having a marketable component contributed significantly to farm profits and to the incentive to expand agroforestry technologies. Farmers testing hedgerow intercropping in western Kenya did not find soil erosion control benefits sufficiently compelling for enthusiastic adoption, given the lack of significant impacts on crop yields or economically important tree by-products. Fuelwood, although economically unimportant in eastern Zambia, was an important by-product from improved fallows in western Kenya and sensitivity analysis showed that the price of fuelwood had a strong effect there on system profits. While multipurpose trees in western Kenya were grown mainly for timber and poles, early subsidiary products, such as mulch, fuelwood or fodder, provided important benefits.

Further development of new marketing channels, quality standards, efficient marketing practices and market information systems will be essential for improving smallholder participation and benefits from new tree product markets. Poorly developed tree product markets are a significant limitation for large-scale agroforestry adoption. For example, for any new tree species, sawmillers must learn their uses, milling characteristics, strength, etc., and must be able to sell their product to consumers who want to know what they are getting (Tyndall, 1996). The lack of quality criteria or regulation means that risks of dealing in new woods are high. Sawmillers in central and western Kenya still rely for their supplies mostly on illegal timber from the forest. They are not very familiar with grevillea, which is widely grown by smallholders, and at the moment have few market connections with smallholders (Tyndall, 1996). Casuarina, by contrast, is known by construction people in most urban areas and does not face similar market problems.

Product market characteristics and function should be analysed not only to predict price and supply trends, but also to estimate the nature and scale of environmental effects from market development. For example, studies of farmers with improved fallows in both Zambia and western Kenya, and multipurpose trees in western Kenya, suggest that fuelwood and other products produced from farm-grown trees may actually be substituting, at least on a small scale, for supplies from natural forests and woodlands. More careful market analysis is needed to determine the scale of impact, especially in Zambia, and whether more active public intervention to promote agroforestry may be used as a forest protection policy.

Promote agroforestry to reduce risk in unstable crop and livestock product markets

Conditions in basic grains markets have clearly affected farmers' strategies in adopting agroforestry. In Zambia, the parastatal maize and cash crop marketing systems – with their stable outlets and price subsidies for maize producers – collapsed in the early 1990s, and private markets have not developed sufficiently to replace them. Farmers in Eastern Province are concerned that the marketing system itself (as distinct from aggregate demand) will not be able to absorb big increases in basic grains production. Thus many farmers indicated that they prefer to use improved fallows to reduce the area under maize, allowing them to emphasize higher-value cash crop production on their other fields. Financial sensitivity analysis shows that a future increase in maize prices would increase returns to fertilized maize much more than returns to improved fallows. The instability common to markets for higher-value products also affects farmer agroforestry strategies. For example, the milk industry in Kenya became very unstable after the Kenya Cooperative Creameries lost its monopoly, in part due to mismanagement, and new dairies emerged. Increased risk motivated farmers to substitute farm-produced calliandra for dairy meal to reduce cash costs. Financial returns to calliandra are not very sensitive to changes in the milk price itself, especially when calliandra is used as a substitute for dairy meal rather than as a supplement. Over the long term, policy makers should seek to improve milk-market stability and livestock health services, to strengthen the sector. This would encourage widespread adoption of calliandra as farmers learn about its benefits, even in a lower-risk environment. Policy analysts need to address broader sectoral reform, such as milk-market reform or credit provision for purchasing dairy animals, in addition to specific changes that encourage adoption of a particular agroforestry practice.

Promote agroforestry for high-value crops

Using trees to increase the production of higher-value crops, rather than basic grains, may greatly increase the income effects of agroforestry adoption. In western Kenya, researchers tested new agroforestry practices on maize, because maize accounted for most of the cultivated area and because increasing yields of the staple grain was seen as the way to improve food security. But many farmers preferred to test the practices on higher-value crops because, if the agronomic response of higher-value crops were similar to that of maize for equal inputs, then profitability would be higher. These farmers may have been motivated by food security as well, but their means to achieve it was to increase their cash income by growing more high-value crops, not by increasing maize production. For example, farmers in western Kenya with good market access are improving soil fertility through the application of mulch from *Tithonia diversifolia* hedges on kale (*Brassica oleracea*) and tomatoes, rather than on maize plots (ICRAF, 1997). Policy makers, extensionists and researchers should redirect more of their investment to promote agroforestry that increases production and income from high-value crops.

Land and Forest Tenure and Regulatory Systems

Land and forest tenure and regulatory systems, including rules governing women's control and management of tree resources, have been widely cited as constraints to agroforestry adoption (Bruce and Fortmann, 1989; Gregersen *et al.*, 1992). However, Place (1995) examined tree planting in four countries of east and southern Africa and did not find tenure issues to be as constraining as supply-side issues, such as the availability of planting material or information. On-farm research reported in this volume did not reveal tenure issues to be especially important for the practices studied in Kenya and Zambia, which were generally established by farmers on privately owned or controlled crop fields. Nor did regulatory issues emerge as constraints in any of the case studies.

Few tenure limitations at all were observed for hedgerow intercropping, improved fallow or agroforestry tree planting in western Kenya. Only 3 of 50 farmers dropped out of hedgerow intercropping trials in western Kenya because of land tenure disputes. In central Kenya, farmers did not plant fodder trees on fields away from the homestead. However, this was not due to tenure concerns, but to the difficulty in carrying fodder from the fields back to the homesteads where the cows are kept. Most farmers in this location do have at least one such far field.

Promote agroforestry equally to women and men

Traditional or legal rules on women's control or management of land and trees appeared to have little effect on the adoptability of the agroforestry practices studied here. Only 2 of 14 women dropped out of hedgerow intercropping trials because of disagreements with their spouses. Traditional taboos against tree planting by women appear to have broken down, or are not applied to the planting of agroforestry species.

Women in western Kenya did not participate in the pruning of hedges in hedgerow intercropping, but this may have been a way to encourage greater labour contributions by the men or a reflection of lower perceived benefits. There were few problems with women clearing trees in Zambia, as they have customarily been involved in bush clearing. However, improved fallow plots of female farmers were significantly smaller than those of male farmers, probably because they had less access to land and labour. In central Kenya, there are fewer female-headed households than in Zambia and western Kenya, and in male-headed households, both men and women appeared to be involved in growing and harvesting calliandra for fodder. However, gender issues were not evaluated systematically.

Encourage community solutions to reduce free-grazing risks to agroforestry

In Zambia, the widespread practice of free grazing eliminated one species of improved fallow, and is a threat to others. Researchers are now seeking to introduce species unpalatable to livestock. Free grazing also discourages intercropping of unpalatable trees with crops because cows feeding on maize stalks trample the trees.

ICRAF and its partners have been active in organizing workshops of local policy makers, including traditional chiefs, to address the free-grazing problem. Some local chiefs in Zambia are seeking to enforce controlled grazing, and some local administrators in Uganda are establishing by-laws against tree destruction by free-grazing cattle. Researchers are monitoring these efforts to determine their success and potential application in other sites.

Technology Design for Extension

While the case studies of fodder trees in Kenya and improved fallows in Zambia provide some evidence of spontaneous diffusion of high-performing agroforestry practices, all of these technologies are complex and farmers require information, training and assistance with planting materials, if they are to achieve production and income potentials. Hence, extension must play a significant role in large-scale implementation. The case studies highlight several key elements for agroforestry extension, especially tailoring recommendations to farmer and regional socioeconomic conditions, the need to provide information on agroforestry management, and involving farmers strategically in technology selection and diffusion.

Tailor recommendations to farmer and regional conditions

The case studies clearly show the need for more systematic targeting of agroforestry practices to the socioeconomic, as well as the biophysical, conditions of the programme areas, and to the varying needs of individual farmers within those areas. In particular, the technical mix of land, labour and cash requirements affects their suitability for farmers with different resource endowments.

Expansion of hedgerow intercropping in western Kenya was associated with management by males or couples, regular technical assistance, cash crops, good hedge management and less depleted soils. The degree of expansion was *not* observed, in this case, to be associated with wealth, off-farm income, farm size, crop sales, labour to land ratios, age or use of purchased inputs. Patterns of expansion for improved fallows were quite different in western Kenya and eastern Zambia. In the former, improved fallows were most attractive to farmers facing labour scarcity or participating in off-farm employment and with serious fertility problems, while in the latter the major explanatory factors appeared to be soil water-holding capacity, wealth and labour availability. By contrast, expansion of calliandra fodder banks in central Kenya was associated most with middle-aged, full-time, male farmers in the middle- to high-income range, who gave priority to dairy production.

The opportunity cost for labour is a key factor operating at both regional and farm scales. While hedgerow intercropping seems most suitable to areas and farmers with low opportunity costs and less degraded soils, improved fallows are suited to areas of high opportunity costs and more depleted soils. In both technologies, the importance of labour costs in farm profitability means that careful attention should be paid in both research and extension to strategies for reducing labour costs (such as direct seeding and relay cropping in improved fallows). In the case of fodder banks, since farm profits are only minimally sensitive to labour costs, labour costs are a less important consideration.

The evidence of inter-farm diversity argues for a ‘basket of options’ approach, with extensionists well informed about technology performance under a range of conditions. Greater species diversity is needed, to reduce risks and meet a wider range of farmer needs and preferences as to niche, agroecological condition, use and management.

Disseminate more information on agroforestry management

The case studies show how important it is for farmers to have good information not only about species selection and tree establishment – the principal foci of most extension programmes – but also on tree management. Different management practices are desirable for a given agroforestry technology under different conditions, as illustrated by differences in optimal improved fallow management in western Kenya and eastern Zambia, and for farmers with different farm size and commercial orientation. For example, intercropping trees with crops during the first year of establishment of improved fallows reduces tree and crop growth, but may be optimal for farmers with limited land and labour. Extensionists should be able to provide to farmers information relevant for this decision process.

Strengthen farmers' roles in technology selection and diffusion

The case studies illustrated that farmers can play a much more central role in extension programmes, both in technology selection and design, and in the diffusion process. Farmer evaluation played a critical role, in several sites, in the selection and adaptation of technologies for subsequent promotion by extension services. The agroforestry study in western Kenya used a systematic approach to farmer evaluation – with farmers' own on-farm trials as the evaluation focus – which has wide potential application in extension. Each farmer experimented on his or her own with the trees; farmers monitored progress in group visits and researchers used participatory techniques, such as an adaptation of the traditional *bao* game, to monitor farmer preferences. Using this tool, the popularity of certain species based on criteria unrelated to production, such as the ornamental value of casuarina, was discovered. By evaluating farmers' choices for new plantings, a preference for external boundary niches was identified, which would not have been predicted from existing patterns of farm tree location.

Farmers' evaluation criteria for tree species and agroforestry practices may differ from those of researchers or extensionists (Raintree, 1991; Franzel *et al.*, 1996). For example, in the hedgerow intercropping trials in western Kenya, farmers evaluated yield performance by comparing current with past yields, rather than control and test plots. They compared hedgerow intercropping performance not with control plots using no nutrient applications (as was common in researcher's experiments and extensionists' demonstration plots), but rather with other nutrient management strategies known in the area. Such information can be valuable in designing extension information and strategies for technology introduction.

There is considerable potential for improving agroforestry management by promoting active information exchange among farmer users. Over half of the farmers experimenting with calliandra fodder in central Kenya had never even seen another farmer growing the tree, which greatly limited their knowledge and the scope for generating and sharing local innovations, as well as their economic returns. By contrast, the diffusion of improved fallows in Zambia and the community-wide assessment processes in western Kenya expanded and institutionalized local knowledge about tree management. Specific mechanisms utilized in the case studies have promising application in extension networks, including farmer-to-farmer visits, group meetings to exchange information and evaluate new practices, identification of farmer experts and their integration into extension efforts, and village-based change processes.

Institutional Arrangements for On-farm Research and Extension

Agroforestry extension has been problematic in Africa because of the lack of rigorously validated and locally adapted extension messages, the general weakness and limited resources of public extension systems, lack of agroforestry training for extensionists, and the unclear assignment of responsibility for agroforestry among agricultural and forestry extension institutions. Agroforestry research suffers from similar institutional weaknesses, as well as a weak field presence (Kerkhof *et al.*, 1990; Scherr, 1990b, 1995; Scherr and Müller, 1990), and poses particular challenges for the implementation of on-farm research (Scherr, 1990b, 1991; Merrill-Sands, 1991; Shepherd and Roger, 1991). While enthusiasm for on-farm research within the scientific community has increased steadily, it has been seen as an expensive instrument that cannot be replicated very widely. The evolution of large-scale on-farm research efforts in Kenya and Zambia has generated insights and potential models for the design of more robust, efficient, and farmer-responsive research and extension programmes which address these challenges.

Institutional evolution in the study sites

At all three sites – central Kenya, western Kenya and eastern Zambia – on-farm research in the early 1990s included both 'researcher-led' (type 1 and type 2) trials and 'farmer-led' (type 3) trials, in which farmers experimented on their own with new species and technologies. There was considerable exchange of information between researchers and other organizations, such as extension services, development projects, NGOs and farmer groups. But there was initially little collaboration with such organizations in the management of farmer surveys or on-farm trials. Farmers interacted with each other at group meetings and farmer-to-farmer visits but, in general, researchers interacted with farmers on an individual basis. Gradually, however, researchers at all three sites have strengthened working relationships with other institutions, especially farmer groups and extension services, projects and non-governmental organizations involved in testing and disseminating agroforestry practices. Different approaches evolved in the three sites.

Central Kenya

In Embu in 1993, extension staff became actively involved in the implementation of trials and monitoring surveys. The project began to facilitate broader adoption in 1996–1997 when researchers and extension staff of three government services helped 12 farmer groups, including 410 farmers, to start 14 calliandra nurseries. The farmers planted, on average, about 233 trees per farm. As a result of the high profitability and suitability of the calliandra technology, there has been some farmer-to-farmer diffusion of seeds and management information. None the less, the aggregate impact has been quite limited because of the geographic dispersion of the trials, shortages of seeds, and the small numbers of farmers initially involved. The recent emphasis on dissemination through farmer groups is designed to accelerate diffusion of the technology.

Western Kenya

In western Kenya, the on-farm trials reported in this volume took place in the early 1990s through women's self-help groups. These groups helped select members to participate in the trials and hosted meetings to discuss trials and provide feedback. No other organizations were involved in managing this first round of on-farm trials. Further on-farm research was started in 1996 on improved fallows and biomass transfer. This second set of trials involved several other organizations, including the Ministry of Agriculture's extension service, the Organic Matter Management Network and CARE International.[1] A distinguishing feature of the programme was a village-scale approach, in which members of entire villages jointly agreed to participate in selecting, testing and evaluating new technologies. The KARI-KEFRI-ICRAF team is the hub and coordinator of the research. In 1996, the team helped farmers establish 133 on-farm trials on the two technologies. Through involvement of the other organizations, especially the public extension service, they were able to expand to 1642 farmers in 1997 and several thousand farmers in 1999.

Eastern Zambia

Since 1996, the Zambia-ICRAF project has helped facilitate the establishment of an informal network of organizations to conduct adaptive research, training and facilitate dissemination of improved fallows. The project and its collaborators helped farmers establish 194 improved fallow on-farm trials in 1994–1995; by 1998 there were several thousand farmers using or experimenting with the technology. The on-farm research project included only one senior researcher and a technician. The extension service was a full partner in the on-farm research, laying out most of the over 200 type 2 trials, supporting village nurseries and monitoring the trials. Managing on-farm trials was seen as a normal duty of extension and NGO staff. Development projects provided some incentives to extension staff, such as bicycle repair allowances. Farmer groups managed nurseries, distributed seed and seedlings, and exchanged knowledge, training and experience on improved fallows. About 75 representatives of the dozen or so organizations, including farmer groups, met one to two times per year between 1996 and 2000 to plan for wider testing and extension of the improved fallows, to review the problems and state of knowledge about them, and to develop and update extension materials.

Promote integrated efforts of research and extension organizations

Experience in the three study sites demonstrates the potential benefits for farmer adoption of integrating research and extension activities. In Zambia and western

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[1] CARE's Agroforestry Extension Program was originally designed in the mid-1980s to integrate technology research and design with extension, in response to the lack of agroforestry practices tested or adapted to local conditions (Buck, 1990). Researcher-controlled on-farm trials were established jointly with KEFRI and technology monitoring of farmer-designed trials (type 3) was instituted. As a result of staffing changes, high demand for extension services, and an institutional mandate favouring extension (rather than research), the on-farm technology design and testing component declined. None the less, CARE's experience widely influenced thinking about agroforestry research and extension linkages (Scherr, 1990a).

Kenya, the enthusiastic interest of the many NGO and public extension programmes, as well as spontaneous farmer-to-farmer diffusion of the improved fallow technology, led to the evolution of an integrated on-farm research approach that resulted in rapid dissemination of new practices. The Zambia-ICRAF project coordinates the network for participatory monitoring and evaluation of on-farm research and acts as a catalytic and action-oriented group for widespread dissemination of the technology in pilot areas. Furthermore, the Zambian network association provides a forum for identifying policy-related problems and opportunities and promoting action to address them. For example, at a workshop of policy makers held in 1996 several issues emerged, including the need to control free grazing, that stimulated local policy action.

By contrast, in central Kenya, there was an almost complete absence of international and national NGOs involved in agricultural development, largely because the area has a relatively high per capita income by Kenyan standards. The Ministry of Agriculture has been active in on-farm research and extension, as have the many village-level farmer groups and community-based organizations. Research and extension efforts have required more facilitation in central Kenya than in western Kenya and Zambia, but have been just as effective.

Promote a village-based approach to on-farm research and extension

A second factor that distinguished the central Kenya experience was that the farmers involved in on-farm research in the early 1990s were geographically separated and unrelated. They had no opportunity to generate the synergy or collective initiatives that led to rapid farmer-to-farmer agroforestry learning and dissemination in the other sites. The western Kenya and Zambia experiences demonstrate the benefits of using a village approach to on-farm research and extension. The village-wide group ensured farmer-relevant trial design, attracted farmer collaborators, facilitated farmer evaluation of technologies, and encouraged rapid local dissemination of successful practices. In central Kenya, the new emphasis on working with farmer groups has led to greater farmer-to-farmer learning and increased opportunities for the spontaneous spread of fodder-tree practices.

Informing the Policy-making Process

Effective policy analysis does not only include rigorous assessments and sound recommendations; it also requires effective communication with policy makers. An entire discipline, agricultural extension, exists for promoting communication between researchers, development specialists and farmers. In contrast, little attention is given to the area of communication between researchers and policy makers. This is indeed surprising, given researchers' frequent difficulties in influencing policy.

Several critical lessons emerge from the case studies and from research elsewhere. First, policy makers need to be involved from the start in designing and implementing policy research. Whereas farmer involvement in technology design and research is widely accepted, policy makers are often not consulted at the design stage. Workshops involving researchers and policy makers are an effective means of improving consultation. At workshops in Tabora, Tanzania in 1997 and 1998, policy makers discussed and chose among various policy problems and topics associated with agroforestry, food security and the environment. Proposed interventions that required research included discouraging shifting cultivation, promoting herders to keep their livestock from harming crops, controlling and protecting against burning, and assessing the causes of, and reducing, deforestation (Ruvuga *et al.*, 1999). Furthermore, policy makers provide crucial insights about their perception of problems and opportunities, and institutional mechanisms for policy implementation (Tomich *et al.*, 1998). A key principle of marketing is that the more consumers are consulted and involved in the design of a product, the more it is likely to be used. Certainly, the same principle applies to policy research.

Further, policy research is most effective when it informs policy makers about the implications of different options rather than simply advocating one policy over others (Weber *et al.*, 1988). In eastern Zambia, advocates of improved fallows often state that livestock owners should be forced to prevent their cattle from destroying improved fallows, on the grounds of farmers' rights to grow trees on their plots during the dry season. A more balanced and insightful approach to the problem would be to bring together the various stakeholders, including cattle owners, assess the implications of alternative policies, and inform policy makers about the implications. In eastern Zambia, this would involve assessing the effects of allowing free grazing, and thus limiting improved fallows, on maize yields and food security. Alternatively, how could improved fallows contribute to food security if free grazing was curbed? And, finally, are there compromise arrangements where both livestock owners and improved fallow planters could reduce or share the burden of protection, through, for example, a rotational grazing system?

Also, there is often considerable misunderstanding about who policy makers are. Policy makers are often characterized as high-level persons in the capital city when, in fact, local officials and traditional leaders in the countryside often wield considerable power. Even if local officials and leaders do not make policies, they are the ones responsible for implementing them, which is often at least as important! In fact, the influence of local leaders has increased in recent years as many governments in eastern and southern Africa have decentralized authority and budgeting. ICRAF and its partners have also found that local leaders can play an important role as advocates of technology dissemination and in mobilizing communities to test new practices (Raussen *et al.*, 2001).

Finally, the packaging of policy analyses is critical as policy makers, whether local or national, lack the time to read lengthy academic reports. Policy communications need to be brief, to the point, and targeted as specifically as possible to bodies responsible for making and implementing policy. Richards and Asare (1998) provide an example of an effective policy briefing note designed to assess incentives for Ghanaian farmers to keep timber trees in their cocoa plots.

Conclusions

The scale and pace of adoption of new agroforestry practices is likely to depend, to a greater extent than for new crop varieties, upon an improved policy environment. Table 8.2 summarizes some key policy recommendations for promoting the four agroforestry practices, which were identified through on-farm research programmes.

Germplasm policy must focus more on reducing the cost of planting material, especially important for technologies such as hedgerow intercropping and improved fallows. Large-scale seed supply and distribution networks are particularly important for improved fallows, and small-scale tree nursery promotion is needed for improved fallows in Zambia and timber, pole and fodder trees in Kenya. Species diversification is critical for all technologies. Subsidies and other direct incentives are not needed.

Agroforesters working with improved fallows should follow closely the price and availability trends for chemical fertilizers, and understand how these will affect farmer adoption. More studies still need to be done on farmer nutrient management strategy under different price and risk regimes, and on the biophysical interactions of tree-derived nutrients and chemical fertilizers. A similar focus and studies are needed for the dairy meal input market and farmer use. While formal and informal financial credit markets will have indirect effects on farmers' decisions to invest in agroforestry, provision of production credit itself is unlikely to be a critical policy issue for smallholders.

For improved fallows and hedgerow intercropping, the main product markets of importance are basic grains and high-value crops. More research is needed to understand the effectiveness of these technologies with crops other than basic grains. In the case of fodder trees, the interactions of milk, dairy meal and maize markets need to be better understood, and linked with overall farmer decisions about feeding practices.

For the practices studied, there was little observed effect of tenure and regulatory policy factors on agroforestry adoption or farm profitability. Damage to trees from free-grazing animals can probably be addressed through choice of suitable tree species and planting sites, although exploratory work on changing community-level norms and regulations is worth pursuing. Women's participation in testing and using practices appears to be as high as men's, but further monitoring is needed and new mechanisms to enhance women's participation should be explored.

The general lessons about extension strategy can be applied to all of the technologies studied. The on-farm trials already implemented can guide the targeting of farmers and design of extension messages, but probably need to be supplemented with additional on-farm studies in other environments. More research is needed on the functioning of farmer information networks and community group learning and diffusion mechanisms, as these are relevant for agroforestry practices. Such information, at subregion or local levels, should be used to guide decisions about the balance of extension communication effort among individuals, groups and across communities.

Table 8.2. Policy recommendations to promote adoption of specific agroforestry practices.

Agroforestry practice	Germplasm policy	Agricultural input supply	Product markets	Tenure systems and regulation	Extension strategies
Hedgerow intercropping (western Kenya)	Reduce cost/improve access to planting materials; increase species diversification	None	Identify market demand for by-products, especially fodder and fuelwood	None	Target labour-abundant farms, sloping, erosive land, better soils
Improved fallows (western Kenya)	Expand seed supply; reduce cost/improve access to planting materials; increase species diversification	Promote where nitrogen fertilizer is costly or unavailable; increase supply of phosphorus	Promote demand for high-value crops; assess fuelwood markets	None	Target farmers with depleted soils, with off-farm income, or those who cannot afford mineral fertilizers
Improved fallows (eastern Zambia)	Expand seed supply and reduce costs; promote small-scale tree nurseries; increase species diversification	Promote where nitrogen fertilizer is costly and unavailable	Strengthen basic grain marketing system	Encourage community norms/regulations to control free grazing	Support diffusion networks. Target farmers with depleted soils and those who cannot afford mineral fertilizers
Multipurpose trees (western Kenya)	Promote small-scale tree nurseries; increase seed supply for new species; increase species diversification	None	Provide species information for processors and consumers; link smallholders to markets	None	Target boundary niche; promote use of farmer criteria for selecting species
Fodder trees (central Kenya)	Expand seed supply; support small-scale tree nurseries and group seed-sharing	Promote where dairy meal is costly, low quality or unavailable	Stabilize milk markets; strengthen livestock health services	None	Support diffusion networks and nursery groups; provide management assistance

The most suitable institutional arrangements to foster useful interaction between agroforestry research and extension will vary, depending upon the density and type of existing extension and farmers' organizations and the commitment to field-based operations by research organizations. That adaptive research and extension represent points along a continuum, rather than distinct activities, suggests that integrating research and extension efforts should receive high priority. The principle of linking research and extension efforts by working together in specific sites around core on-farm research activities, rather than through centralized bureaucratic mechanisms, is strongly endorsed.

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Assessing Adoption Potential: Lessons Learned and Future Directions

9

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Land degradation, low soil fertility and lack of quality livestock feed are increasingly recognized as key problems for farmers throughout sub-Saharan Africa. The research reported in this volume documents the experiences of farmers in testing and assessing the potential of agroforestry practices to address these problems and increase their incomes. The volume presents five case studies from three contrasting zones: a humid, highland area in central Kenya located close to major markets; a humid, highland area in western Kenya with poorer soils and further from markets; and a subhumid plateau area in eastern Zambia with degraded soils, lower population density, and far from major markets. Maize, the main food staple in eastern and southern Africa, is the most important crop component of all of the agroforestry practices examined in the case studies.

Three case studies assess soil fertility interventions, including improved tree fallows and hedgerow intercropping (Table 9.1). In eastern Zambia, the number of farmers using improved, 2-year tree fallows rose from 20 in 1993 to about 10,000 in 2000. Main trees planted were *Sesbania sesban*, which requires a nursery, and *Tephrosia vogelii*, which may be direct seeded. In western Kenya, farmer-managed experiments in the early 1990s helped researchers identify a range of brief, one-season fallow species, which, by 1999, were being planted by several thousand farmers. The most popular species were *Crotalaria grahamiana*, *Crotalaria ochroleuca*, and tephrosia, all of which were direct seeded. Hedgerow intercropping in western Kenya, while not contributing significantly to improving soil fertility and crop yields in the short run (1–4 years), was shown to be an important means of reducing soil erosion, and can thus improve fertility and yields in the long run. The main species included *Calliandra calothyrsus* and *Leucaena leucocephala*. One case study, also from western Kenya, assesses the introduction of trees for wood production,

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Table 9.1. Recommendation domains: conditions most suited to selected agroforestry practices.

Practices and area	Main problem addressed	Ecoregion	Soils	Agricultural intensity^a	Land requirements	Labour requirements	Cash requirements	Payback period^b (years)	Other countries where practice is being used	Other factors affecting adoption
Improved fallows, eastern Zambia (*Sesbania sesban* and *Tephrosia vogelii*)	Nitrogen deficiency in soil	Subhumid areas, unimodal rainfall	Sesbania poorly suited to sandy, shallow soils	Suited for medium zone	Relatively high	High, planting is at peak period. Less of a problem if trees are direct seeded	None – minimal	3	Cameroon, Uganda, Tanzania, Malawi, Zimbabwe	
Improved fallows, western Kenya (*Crotalaria* spp. and *Tephrosia vogelii*)	Nitrogen deficiency in soil	Subhumid areas, bimodal rainfall		Suited for medium zone, some potential for high zone	Medium	Medium, only trees that are direct seeded are suitable	None – minimal	2	Uganda	
Hedgerow intercropping, western Kenya (*Leucaena leucocephala* and *Calliandra calothyrsus*)	Soil erosion	Humid, subhumid areas. Up to 1900 m in altitude in Kenya	Suited to erosive, sloping areas	Suited for high zone, some potential in medium zone	Minimal	High, planting and pruning are at peak periods. Delays in pruning may reduce crop yields	Low	3+	Throughout sub-Saharan Africa	Females may have problems pruning trees
Boundary planting of upper-storey trees, western Kenya (*Grevillea robusta* and *Casuarina junghuhniana*)	Fuelwood shortage, poles and timber for construction and cash	Grevillea: humid and subhumid highlands. Casuarina: humid, subhumid and semiarid areas		Suited for high and medium zones where farmers lack access to trees off the farm	Minimal	Low, planting is at peak period but problem not serious as few trees are planted	Low, only for seedlings	5+	Uganda, Rwanda	

Fodder trees, central Kenya (*Calliandra calothyrsus*)	Fodder shortages in dairy enterprises	Humid, subhumid areas. Up to 1900 m in altitude in Kenya	Susceptible to frost, waterlogging	Suited for high zone, some potential for medium	Minimal, especially when planted on boundary	Low, planting is during peak period but relatively few trees are planted	None – minimal	2	Uganda, Rwanda, Burundi, Tanzania, Zimbabwe	Suited for cut and carry dairy systems. May have potential in other, more extensive dairy systems

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[a] Low: farmers use natural fallows to restore fertility. Medium: most farmers fallow but fallow periods not sufficient to restore fertility. High: continuous cultivation is common, most fallows are brief, that is, one or two seasons.

[b] The payback period is the time required for revenue earned to cover the cost of the investment.

such as *Grevillea robusta* and *Casuarina junghuhniana*, planted along boundaries and in other arrangements. The last case study reports on the uptake of calliandra in the mid-1990s, which farmers planted to provide fodder for increased milk production in central Kenya. By 2000, about 4000 smallholder dairy farmers had planted calliandra and numbers expanded rapidly over the next 3 years.

This chapter reviews the adoption potential of the practices within and outside the areas they were tested and assesses policy support needed to promote their adoption. Next, we summarize lessons learned for improving the effectiveness and efficiency of developing and disseminating new practices, focusing on the complementarity of different types of on-farm trials, the promotion of farmer participation, adaptation and innovation, and on creating adaptive research and dissemination networks. Finally, suggestions are made concerning areas for future research.

Adoption Potential of Promising Agroforestry Practices

Benefits to farmers

Agroforestry practices, as shown in this volume, can increase farmers' incomes and make important contributions to solving some of their most important problems. For example, farmers in Zambia planting improved fallows can increase their annual net farm income from maize, their most important enterprise, by US$130 (more than twofold). In central Kenya, calliandra substituted for purchased dairy meal increases household income by US$220 per household, an increase of about 10%. Moreover, both technologies have important by-products and services that are difficult to quantify and value – improved fallows provide firewood and improve the soil's structure and organic matter content and calliandra improves milk quality, provides firewood and helps conserve the soil.

The other two practices examined in this volume, hedgerow intercropping and upper-storey trees, offer more modest, but still important, benefits. While the contributions of hedgerow intercropping to soil fertility are minimal in the short term, this practice is effective in curbing soil erosion and providing useful by-products, such as fodder and fuelwood. Grevillea trees planted along boundaries in western Kenya provide fuelwood and timber, and earn net benefits as high as the maize they displace. In addition, the trees have other difficult-to-quantify benefits as windbreaks, boundary markers and in controlling erosion.

The studies also demonstrate that farmers value agroforestry practices for three 'hidden' reasons aside from the products and services they provide. First, agroforestry reduces the considerable risks that farmers face from input markets by providing home-produced substitutes for purchased inputs such as mineral fertilizer or dairy concentrates. For example, farmers in central Kenya complain that concentrates are, at times, not available, are difficult to transport because of poor road networks, and are of unreliable quality. With home-produced calliandra, none of these problems arise.

Secondly, agroforestry practices help reduce risk from uncertain rainfall. For example, in Zambia the benefits of improved fallows are spread over a 2–3-year period, whereas nitrogen fertilizer provides benefits for only a single year. A farmer experiencing a crop failure would lose her cash investment in fertilizer, US\$154 ha^{-1}, whereas a farmer planting an improved fallow would lose only her investment in planting the trees, which amounts to one-quarter of the fertilizer cost. In addition, tree fallows improve the soil's structure and organic matter content, thus enhancing its ability to retain moisture during drought years.

Finally, farmers in the case studies expressed a strong preference for investing their labour, through agroforestry practices, rather than their cash, which in most cases is scarce or unavailable for investment. Farmers in Zambia emphasized that the profitability of mineral fertilizer is irrelevant to them – they simply do not have the cash to purchase it. In western Kenya, farmers prefer to plant trees on their farms for fuel and construction wood rather than purchasing wood from outside. Even in central Kenya, where incomes are higher and cash more available, farmers greatly appreciate the cash that they can save by feeding calliandra as a high-protein supplement to their cows instead of purchasing dairy meal.

Suitability of practices outside areas where they were tested

The case studies indicate the usefulness of agroforestry practices in the sites in which they were tested. But how likely are they to be of use to farmers in other areas? As discussed in Chapter 2, the boundary conditions of a technology are defined by identifying the variables that are most important in determining who will and will not use the practice. Information on variables affecting biophysical performance, profitability and acceptability are thus critical.

Improved tree fallows

Improved tree fallows have greatest potential in areas where farmers have 'some experience with the struggle to maintain soil fertility' but still have lands that they leave fallow (Raintree and Warner, 1986). Eastern Zambia and large portions of Zambia, Zimbabwe, Tanzania and central Malawi fit this picture. But the research presented on improved fallows in western Kenya shows that the technology has potential in certain densely populated areas as well; that is, where rainfall is bimodal, permitting farmers to fallow for one season per year. The technology is thus of relevance to farmers throughout the highlands of Ethiopia, Kenya, Tanzania and Uganda, where most of the people of these countries live.

Type 1 trials (on-farm trials designed and managed by researchers) in four countries of southern Africa showed that sesbania-improved fallows performed well across a range of environments, but not on sandy soils (because of nematode attacks), on shallow soils (because of mortality during the dry season), or in frost-prone areas. Tephrosia appears to be more widely adapted than sesbania. *Cajanus cajan* is of limited use because it is susceptible to browsing by livestock, which range freely during the dry season in most of southern Africa. By 2000, improved tree fallows were being planted by roughly 25,000 farmers in four countries in southern Africa, two countries in eastern Africa, and Cameroon. Each of these plantings involved ICRAF and its partners; in addition, improved fallows were reported to be planted by farmers in North West Province, Cameroon, without ICRAF involvement.

Hedgerow intercropping

Widely promoted for improving soil fertility, hedgerow intercropping has not been found to increase crop yields under farmers' conditions in eastern and southern Africa. But it still has an important role to play in curbing soil erosion and providing important by-products, such as fuelwood and fodder. It is suited to farmers on sloping, erosive land where population densities are fairly high and labour is available for planting and pruning the hedges. Hedgerow intercropping is only suitable in humid and subhumid areas, because in drier areas trees and crops compete for available moisture.

Upper-storey trees for wood production

Often planted on boundaries, these are appropriate for farmers in a range of circumstances. As forests and other off-farm sources of wood become scarce, farmers in many areas of eastern and southern Africa have started planting trees on their own farms, because the cost of growing trees is less than the cost of collecting wood. But there is often a lag in this transition, primarily because farmers lack information or planting material. Research and extension programmes throughout eastern and southern Africa are helping farmers to plant upper-storey trees that meet their needs and circumstances – that is, those that are compatible with crops and that provide high-quality wood for fuel and construction. *Eucalyptus* spp. and grevillea are probably the two most commonly planted species for wood production, the former in woodlots and the latter along boundaries.

Calliandra as a fodder tree

This is suitable for smallholder dairy farmers throughout eastern and southern Africa. In Kenya, there are about 625,000 smallholder dairy farmers – with improved breed or cross-bred dairy animals fed in zero- or minimum-grazing systems. Smallholder dairy farmers are less numerous in other countries of eastern and southern Africa but are found around virtually every city and large town in the region. By 1998, calliandra was being used by several thousand farmers around seven cities of Kenya, Uganda, Zimbabwe and Tanzania, each with support from ICRAF and partner institutions. Fodder trees are probably profitable only when fed to improved or cross-bred dairy animals, as indigenous-breed animals convert only small percentages of additional feed to increased milk production.

Wealth level and gender

Many policy makers are particularly interested in whether poor and female farmers can adopt income-increasing technologies such as agroforestry practices. Wealth level can influence adoption in several ways. Poor farmers may be more risk averse, have less access to information, have a higher discount rate and thus a shorter-term planning horizon, and have less capacity to mobilize resources (Hoekstra, 1985; CIMMYT, 1993). In fact, most adoption studies find strong correlations between wealth and adoption. Results from Zambia confirm that the higher the wealth status, the greater the use of improved fallows. But, on the other hand, about 20% of the poor and very poor households in four sample villages planted improved fallows during the first 4 years of testing, which suggests that there are no absolute barriers preventing low-income farmers from doing this. Moreover, low-income farmers are more likely to adopt improved fallows than mineral fertilizers because the fallows require no cash input.

Female farmers provide most of the labour for African food production (Quisumbing *et al.*, 1995) and the percentage of households that are female-headed ranges from 18% in central Kenya, to about 30% in Zambia and 50% in western Kenya. One would expect that females' use of agroforestry practices would be lower than that of males, for two reasons. First, female household heads tend to have lower incomes than male household heads (Quisumbing *et al.*, 1995). Thus, females would be less likely to test and adopt improved fallows for the reasons mentioned above concerning poor households. Secondly, those choosing participants for experiments and distributing planting material, usually extension staff, tend to select men. Thus, even if the technology itself is gender neutral, adaptive research and dissemination programmes are often biased towards males (CIMMYT, 1993).

Data from Zambia indicate that 32% of the males and 23% of the females in the sampled villages were planting improved fallows, and that there was no significant difference between the two proportions. In fact, in one of the villages where womens' groups were particularly strong, the proportion of females using improved fallows was higher than that of males. Moreover, whereas single females are often disadvantaged relative to female heads of household whose husbands live away (Bonnard and Scherr, 1994), the Zambia data showed that the same proportions of these two groups were testing the technology. Available data thus suggest that improved fallow practices are suitable for poor and female farmers.

Policy Support for Agroforestry Adoption

A conducive policy environment is important for the adoption of any agricultural technology, but there are several reasons why policies are particularly critical for agroforestry practices. First, the production and distribution of planting material for trees is more complicated than for crops, because trees often require nurseries and because most countries have few mechanisms for the production and distribution of tree germplasm. Moreover, agroforestry practices tend to be more complex than many agricultural practices, because they involve mixing trees with crops and because several years are often required before they generate returns. Agroforestry practices thus may rely on supportive policies for their development and diffusion to a greater extent than do other agricultural practices.

The case studies in this volume suggest that germplasm policy must focus more on reducing the cost of planting material, especially important for technologies such as improved fallows, which require large numbers of seedlings per unit area and over time. Small-scale tree nursery promotion is needed for improved fallows in Zambia and for timber, pole and fodder trees in Kenya. Whereas centralized, village-level nurseries offer some advantages for training, seed dissemination and quality control early in the extension process, individual farm nurseries appear to be more viable over the longer term.

While the case studies suggest that an improved policy environment can help facilitate agroforestry adoption, they do not suggest that subsidies and other direct incentives are needed. Similarly, the provision of production credit for agroforestry should not be an important priority for policy makers.

For the practices studied, there was little observed effect of tenure and regulatory policy factors on agroforestry adoption or farm profitability. In southern Africa, free-grazing livestock damage trees during the dry season but this problem is being addressed by using non-palatable tree species. Moreover, some exploratory work on changing community-level norms and regulating grazing appears to be promising.

Increasing the Effectiveness of Technology Development and Dissemination

The case studies described in this book reflect the evolution of a new approach to accelerate the process of technology development and dissemination. This approach has promise not only for the development of agroforestry practices, but also for other types of agricultural and natural resource management innovations in highly heterogeneous environments such as those found in Africa. The key elements of this approach are:

- on-farm trials, with differing levels of researcher and farmer involvement, as a central locus for collaborative technology development;
- farmer participation, adaptation and innovation as key inputs in technology development; and
- adaptive research and dissemination networks.

On-farm trials as a central locus for technology development

On-farm trials greatly expand the potential contributions of research to technology development. The case studies confirm the importance and complementarity of the three types of on-farm trials: type 1, type 2 (trials designed by researchers and managed by farmers) and type 3 trials (trials designed and managed by farmers), which are suited to different objectives. Where biophysical data are needed, type 1 trials are generally best, because conditions can be controlled between treatments and across farms. For data on farmer assessment and innovation, type 3 trials are preferred, because farmers plant and manage technologies in these trials as they wish. Type 2 trials are useful for economic analysis, because farmers manage the trials and because plot sizes are standardized, facilitating the measurement of labour use and other inputs. The optimal sequencing of trial types depends on specific circumstances. For example, in Zambia, in the early 1990s, type 1 trials were used to assess the effect of improved fallows on crop yields, and type 3 trials to monitor farmers' assessments and innovations. In the mid-1990s, other type 1 trials were conducted across four countries to assess biophysical constraints to adoption. In addition, type 2 trials were carried out to estimate yield response and economic returns to a range of options under farmers' management.

It is not always necessary to conduct all three types of trials, or to always begin with type 1 trials. In three of the case studies, researchers started with type 3 trials, for different reasons. In the agroforestry tree trials in western Kenya, much information was already available from on-station trials on the performance of the five species under consideration; thus type 3 trials were started in which farmers tested whether the species could be grown in different niches of the farm. For calliandra in central Kenya, researchers started with type 3 trials as much was known about growing the tree. Several years later, a type 2 trial was conducted to assess the effect of calliandra on milk yields. In western Kenya, a type 2 sesbania improved-fallow trial started before any work on the technology's performance had been conducted on station or on farm. Researchers were particularly interested in understanding farmers' constraints to adoption, and feeding this information back for further research. The trial demonstrated the potential for the technology to increase returns and the main constraint fed back to research was the problem of establishing sesbania when direct seeded. Type 1 trials were instituted to screen new species and, 2 years later, promising species were introduced in type 2 and type 3 trials.

The case studies also highlight the complementarity of different research and assessment methods. No single type of assessment, such as crop yield increases or profitability, can alone explain farmer preference for an agroforestry practice. Rather, an integrated assessment of biophysical performance, profitability and acceptability is usually needed to explain farmers' uptake of a practice. Assessments of acceptability are particularly challenging because of agroforestry's complexity, that is, the length of the cycle of technologies (3+ seasons as opposed to single-season cycles) and the number and diversity of components (intercropping trees and crops, as opposed to crops in pure stand). A range of different methods were found to be effective for assessing farmers' preferences during and following on-farm trials, including monitoring farmers' use of technologies, risk assessments, matrix ranking and decision trees (Chapter 2).

Finally, the case studies show that although farmers have a greater degree of control in type 3 trials, all three of the trial types need to be participatory. For example, at farmer workshops to design the type 2 hedgerow intercropping trials in western Kenya, farmers made important decisions on such experimental factors as the spacing between trees, spacing between lines of trees and crops, and the crops to grow between the hedges (Chapter 5).

Fostering farmer participation, adaptation and innovation

Indeed, the case studies demonstrate the importance of the participatory research approach for improving the effectiveness of the design, implementation and evaluation of on-farm research. Participatory research involves giving farmers control over the research process, as in type 3 trials, in which farmers test new technologies as they wish, adapting them to their specific needs and circumstances. Participatory research also strengthens researcher–farmer partnerships, as when farmers and researchers collaborate in the design, implementation and evaluation of a type 1 or type 2 trial. Researchers contribute their scientific knowledge and farmers contribute their indigenous technical knowledge and information about their needs, preferences and circumstances.

A key lesson from the case studies is that farmers do not adopt practices as initially introduced; they adapt them to their needs and circumstances. Simply stated, in agroforestry, researchers can rarely get a technology ‘right’ tinkering with it in on-station research or even in type 1 and type 2 trials. In Zambia, for example, farmers in type 3 trials made two important modifications in the improved fallows they planted in the early 1990s, these modifications were then tested together by researchers and farmers. One of the farmer modifications, bare-rooted seedlings, was first used by a female farmer who obtained some left-over potted seedlings from a type 1 trial and removed them from their pots so she could pack them in a basin, which she carried on her head to her farm. Bare-rooted seedlings, grown in raised beds, have now completely replaced the higher-cost alternative, potted seedlings. A second modification was to intercrop trees with crops during the year of establishment, instead of planting them in pure stand. This method economizes on land and labour use relative to planting trees in pure stands and, by 1997, was used by about 42% of farmers planting improved fallows.

Similarly, in central Kenya, farmers determined the best niches for calliandra on their own, in type 3 trials. Whereas researchers had expected that farmers would plant calliandra in small plots, few did. Rather, farmers planted in other niches, on internal and external boundaries, around the homestead, and intercropped with napier grass.

The importance of farmer adaptation and innovation has several implications for an effective technology generation programme. First, researchers need to establish a partnership with farmers in which the latter understand that their role is to innovate, not simply to follow instructions, or worse, pretend to follow instructions while innovating in secret! In many areas, farmers are accustomed to working with change agents who have a top-down, we-know-what-is-best-for-you attitude; they are generally not used to working as partners with research and extension staff. Thus, a great deal of time is required to establish effective research partnerships with farmers.

Secondly, researchers need to present farmers with different options to test. For example, in the type 2 trials on improved fallows in Zambia, farmers chose among three tree species and two planting methods: pure stand and intercropping. In addition, many farmers also conducted type 3 trials in which they planted as they wished, modifying operations such as spacing, timing of planting, or crop planted after the fallow. The rationale for testing multiple options is fourfold. Some options may not work; thus it is better to introduce several. Even if all work, farmers appreciate diversifying as a means for coping with the risk that one of the options may fail at some future time; for example, when a species succumbs to disease. An additional reason for testing multiple options is that different farmers have different preferences, resource constraints and circumstances that lead them to choose different options. For example, some farmers in Zambia prefer tephrosia, which economizes on labour but gives a lower crop yield response than sesbania. Others prefer sesbania and are willing to invest the extra labour required in order to get a higher return. Finally, the option approach is important for enhancing biodiversity at the landscape level for ecological reasons, as well as at the household level for economic reasons.

Thirdly, involving farmers early on in type 3 trials is important for encouraging modification and for providing feedback to researchers. Many researchers prefer testing technologies on research stations and releasing them to farmers only when they are ‘proven’. But the experiences in this volume show that what is optimal to researchers may not be optimal to farmers and, indeed, in the above-mentioned case of sesbania and tephrosia in Zambia, different farmers in the same villages may find different technologies to be optimal. Farmers should thus be encouraged to test new technologies on their own before, or at the same time as, they are tested on research stations. In western Kenya, a type 2 improved fallow trial was started before the technology was tested on station. Following planting, it evolved into a type 3 trial, as farmers modified the technology in several ways, changing such operations as spacing, the length of fallow and the crop planted after the fallow. Several farmer modifications, such as increasing the plant density, led to new researcher-designed trials. At the end of the on-farm testing period, the technology was not deemed fit for disseminating. Nevertheless, the lessons learned were critical and fed back to on-station research, where new species were identified and a successful on-farm research and dissemination programme was launched several years later.

Fourthly, a monitoring system needs to be in place so that researchers, extensionists and other farmers can learn from innovating farmers. Our experience is that questionnaires are of little value in identifying innovation. Rather, informal interaction between researchers and farmers, and farmer-to-farmer visits, are much more useful. Monitoring surveys involving questionnaires do have a role – they are useful for determining the extent to which different farmers use different practices. For example, monitoring surveys in Zambia have documented the increased use of tephrosia, relative to sesbania, and the increase in intercropping, relative to planting trees in pure stand.

Building adaptive research and dissemination networks

The on-farm research experiences in Zambia demonstrate a new paradigm of research–extension collaboration, as explained in Chapter 2. An interactive, rather than linear, sequential mode of on-farm experiments exploits the complementary strengths of farmers, extensionists and researchers at a reasonable cost. Building a coalition of organizations to conduct on-farm research and dissemination together appears to be more effective and efficient than leaving each to work independently.

Whenever a farmer tests a new technology, dissemination can be said to take place as neighbouring farmers are exposed to it and take it up. Similarly, in a dissemination programme, farmers using a technology for the first time are conducting research to see if new practices work effectively for them. That adaptive research and extension represent points along a continuum, rather than distinct activities, suggests that integrating research and extension efforts should receive high priority. The case studies show the importance of integrated approaches to on-farm research and dissemination. In eastern Zambia, for example, representatives of research, extension, NGOs and farmer groups meet twice a year to plan, implement and evaluate on-farm research, training and dissemination activities. There the network has already had important impacts, including (Cooper, 1999):

- reduced cost of conducting on-farm research, as field-based extensionists and NGOs establish and monitor on-farm trials;
- enhanced breadth of input into and relevance of the research;
- expanded range of sites under experimentation with relatively little additional cost;
- partners increasingly well-informed on key aspects of technology options and better placed to disseminate technologies and respond to farmer feedback; and
- partners have developed a sense of involvement, enthusiasm and ownership of promising innovations.

The most suitable institutional arrangements to foster useful interaction between agroforestry research and extension will vary, depending upon the density and type of existing extension and farmers' organizations and the commitment to field-based operations by research organizations. The principle of linking research and extension efforts by working together in specific sites around core on-farm research activities, rather than through centralized bureaucratic mechanisms, is strongly endorsed.

Some of the lessons learned from the case studies for developing a successful adaptive research and dissemination network are that:

1. Needs and responsibilities of each actor must be clearly defined.

2. Testing should begin with a few (five) pioneer farmers who are risk-takers. Numbers can be greatly increased in the following seasons, based on the experiences of the initial testers.

3. A range of options within and across technologies should be tested, to minimize the risk of any single option or technology failing.
4. The network can begin informally, without a leader or host organization, and should evolve naturally. But participants should meet regularly (twice a year) to review progress and plan activities.
5. On-farm trials should be jointly planned by research, extension and representatives of farmer groups.

These lessons about adaptive research and dissemination networks, highlighted in the Zambia case study (Chapter 3), can be applied to all of the technologies studied. To promote this new paradigm on a larger scale may require policy makers to effect institutional changes in programme structure and staff incentive and performance evaluation systems in both research and extension organizations. Staff training is also required in participatory on-farm research and dissemination methods adapted to agroforestry.

Future Directions

The experiences reported in this book demonstrate the importance of assessing the adoption potential of agroforestry practices and suggest that more such studies are needed in the future, for several reasons. First, such assessments improve the efficiency of the technology development and dissemination process, by feeding back information on farmers' problems, modifications and preferences to research, extension staff and policy makers. The importance of feedback was especially critical in the case of improved tree fallows in western Kenya, where assessments of adoption potential helped guide a research programme that has been successful in developing improved fallow practices for thousands of farmers (Chapter 4). Secondly, the assessments help document the achievements in developing and disseminating new practices, demonstrating the impact of investing in technology development and dissemination. For example, Chapter 7 shows that the potential benefits from adopting calliandra as a fodder tree amount to US\$139 million year^{-1} in Kenya's smallholder dairy sector. Thirdly, because the activities are conducted with partner-institutions, they facilitate interdisciplinary and inter-institutional cooperation. The adaptive research and dissemination network in Zambia is an excellent example of such cooperation (Chapter 3). Finally, the assessments help to identify the factors contributing to successful technology development programmes as well as the constraints limiting their achievements.

Several critical research themes emerge from all of the case studies examined in this volume. Future assessments of adoption potential need to take advantage of farmers' increased experience with agroforestry practices. Whereas the analyses in this study are primarily at the plot and household level, increased adoption will permit assessment of impacts on community and regional scales. Moreover, whereas most of the assessments in this volume concern economic and crop productivity gains, more information is needed on social and environmental impacts. There is a particular need to examine the environmental impacts of agroforestry practised on a landscape scale, for example, on hydrological flows or patterns of sedimentation.

Research also needs to continue to establish the boundary conditions of different agroforestry practices, focusing on the main biophysical and socioeconomic conditions that influence uptake. Improvements in the development of spatially explicit databases and models should permit the use of geographical information systems for assessing the boundary conditions of new technologies. Guidelines based on such systems can be useful for helping change agents decide which technologies should be offered to farmers in specific areas and with particular features and circumstances. Recommendations need to be prepared, documenting not that a particular technique is 'best', which is an oversimplification, but, rather, what the advantages and disadvantages are of different options in differing biophysical and socioeconomic circumstances. Moreover, technologies always need to be adapted by farmers to suit local needs and circumstances, and change agents need to document these modifications for feedback to researchers and possible dissemination to other farmers.

In all of the case studies, the main agroforestry products were substitutes for purchased inputs, such as mineral fertilizer, dairy meal concentrates or timber. Agroforesters need to follow closely the price and availability trends for these substitutes, and understand how these will affect farmer adoption. More studies still need to be done on farmer nutrient management strategy under different price and risk regimes, and on the biophysical interactions of tree-derived nutrients and chemical fertilizers. A similar focus and studies are needed for the dairy meal input market and farmer use.

Finally, research is needed on approaches to scaling up the benefits of agroforestry across large areas; once participatory research succeeds and hundreds of farmers adopt a practice, how can these benefits be spread? Cooper and Denning (2000) highlight key elements of scaling up the impact of agroforestry research, and the need to compare systematically different options. For example, access to germplasm was a common constraint in the case studies; more research is needed to assess ways of developing decentralized, village-level germplasm production and distribution systems. Research is also needed to increase the number of tree species used in each practice, as a means of enhancing biodiversity as well as helping farmers to diversify in order to reduce risk. Scientists also need to reduce the costs of establishing trees, such as through direct seeding and bare-root seedlings as substitutes for potted seedlings.

Research on dissemination pathways is critical, and should focus on the functioning of farmer information networks and community group learning and diffusion mechanisms. Such information, at subregion or local levels, should be used to guide decisions about the content and balance of extension communication efforts among individuals, groups and across communities. Efforts are also needed to hand over many of the activities in assessing adoption potential to local institutions, such as farmer groups and community-based, non-governmental organizations. The greater control farmers have over assessing adoption potential, the more responsive technology generation activities will be to their needs.

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Glossary

adoption potential: The feasibility, profitability and acceptability of a practice, as viewed from the farmers' perspective.

agroforestry: A dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users.

biomass: The weight of material produced by living plants. It is expressed in terms of dry weight or fresh weight.

boundary conditions: The biophysical and socioeconomic circumstances that affect the adoption potential of a practice. The boundary conditions of using calliandra as a fodder tree may include secure land tenure, altitudes between sea level and 1900 m in the tropics, and rainfall above 1000 mm.

break-even analysis: The calculation of the increase in net returns required to cover the costs of establishment and maintenance of a practice. In practices aimed at increasing crop yields, the break-even yield increase may be calculated, that is, the yield increase required to cover costs.

contour: A line joining all places at the same altitude.

coppice: Cutting certain tree species close to ground level to produce new shoots from the stump. Not all trees may be coppiced.

crown: The canopy or top of a single tree that carries its main branches and leaves at the top of a stem.

direct seeding: Sowing seeds directly where they are to develop into mature plants.

discount rate: The rate at which 1 unit at a future date is converted to assess its value today. Discount rates are usually applied to monetary values but can also be applied to other values, such as units of labour.

economic analysis: Analysis of costs and returns from the perspective of society, as contrasted with the perspective of the individual farmer. Inputs and outputs are valued at prices society incurs. For example, if the government subsidizes the price of fertilizer to farmers, then its price in economic analysis would be the unsubsidized price.

exotic: A plant growing anywhere outside its natural range.

fallow land: Land that is temporarily uncultivated.

financial analysis: Analysis of costs and returns from the perspective of the individual farmer. Inputs and outputs are valued at prices farmers face and profitability measures represent the returns farmers would earn.

hedgerow intercropping: The practice of growing annual crops in the spaces between rows of trees or hedgerows. This is sometimes called alley cropping or alley farming.

herbaceous: A plant that is not woody.

improved tree fallow: Enrichment of natural fallows with trees or shrubs to improve soil fertility.

indigenous: Native to a specified area, not introduced.

intercropping: Growing two or more crops in the same field at the same time in a mixture.

net present value: A criterion for evaluating alternative investments that uses the discounting formulae for a stream of costs and returns over a specified time period to value the projected cash flows for each alternative at one point in time. In this fashion, the net present value criterion directly accounts for the timing and magnitude of the projected cash flows.

niche: A place on a farm or in the landscape that is suited to a particular plant.

nitrogen fixing: Having the ability to convert nitrogen in the air into a form that can be used by plants.

provenance: The place in which any stand of trees is growing or from which a stock of seed originates.

pruning: The process of cutting back the growth of plants.

returns to labour: Returns (that is, earnings) expressed per unit of labour, such as per work day or per hour. This measure is especially relevant for farmers whose most scarce input is labour.

returns to land: Returns (that is, earnings) expressed per unit of land. This measure is especially relevant for farmers whose most scarce input is land.

rhizobia: Type of bacteria with the capacity to invade the roots of certain species of leguminous plants and to fix atmospheric nitrogen that is subsequently taken up by the host plant.

root collar diameter: The diameter at the root collar, that is, the transition zone between the root and the shoot of a plant.

shrub: A descriptive term, not subject to strict definition, referring to a perennial plant with wooden stem or trunk. It may be distinguished from a tree in that it is smaller and usually divided into separate stems from near the ground.

tree: A perennial plant with wooden stem or trunk.

type 1 trial: A trial that is designed and managed (implemented) by researchers on farmers' fields. It is similar to an on-station trial except that it takes place on farmers' fields.

type 2 trial: A trial that is designed by researchers, in consultation with farmers, and implemented or managed by farmers.

type 3 trial: A trial that farmers design in order to test a new practice as they wish. The trial may not include a control plot, or uniform plots laid out side-by-side, unless the farmer wishes.

zero grazing: A livestock production system in which the animals are fed in pens or other confined areas and are not permitted to graze.

Index