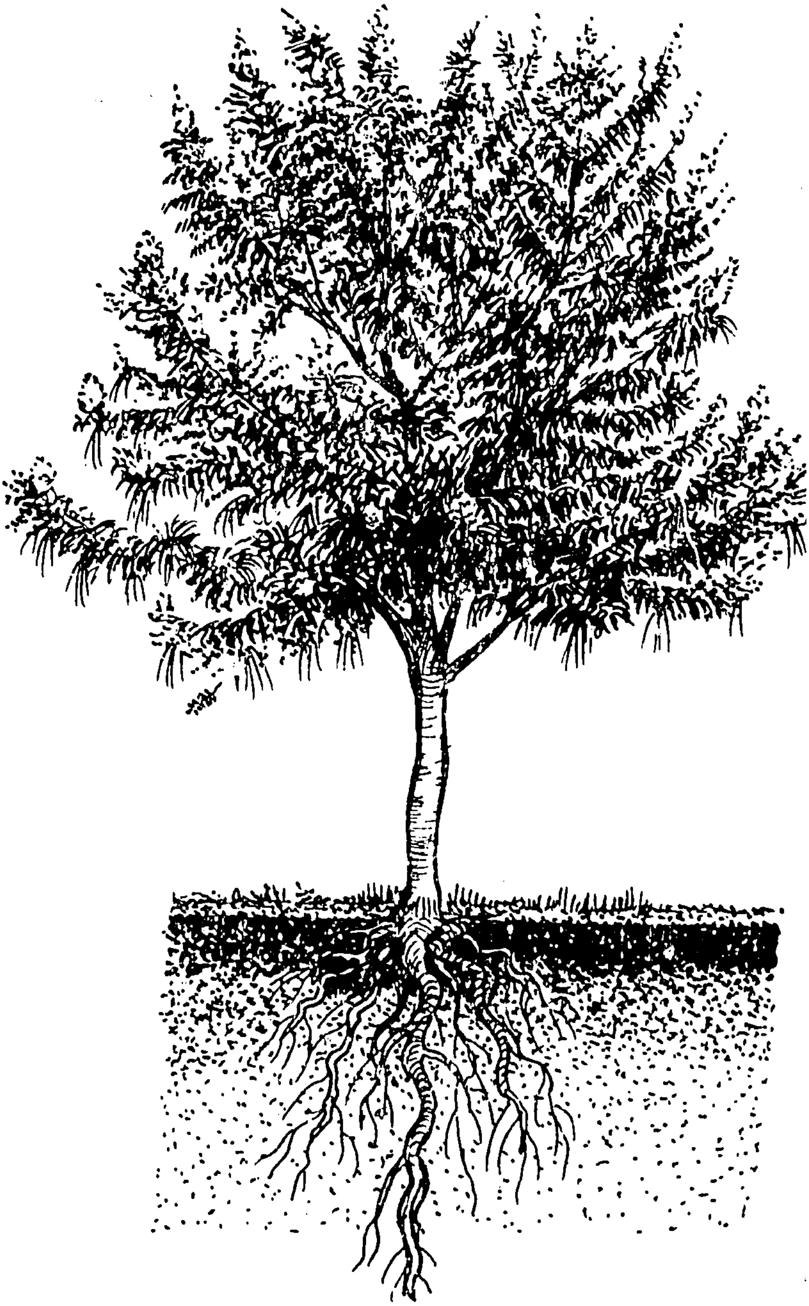
MULTIPURPOSE TREES

selection and testing for agroforestry



Peter A. Huxley and Sidney B. Westley, editors

MULTIPURPOSE TREES: SELECTION AND TESTING FOR AGROFORESTRY

Multipurpose trees and shrubs for specified agroforestry technologies and land-use systems—the ICRAF approach

Peter A. Huxley and
Sidney B. Westley,
editors

The International Council for Research in Agroforestry (ICRAF) was established in 1978 with headquarters in Nairobi, Kenya. ICRAF is an autonomous, non-profit international research council governed by a Board of Trustees with equal representation from developed and developing countries. The mandate is to initiate, stimulate and support research leading to more sustainable and productive land use through the integration or better management of trees in land-use systems.

The Council derives its operational funds from voluntary contributions by several bilateral, multilateral and private organizations. In 1989, these included the World Bank (International Bank for Reconstruction and Development—IBRD), the African Development Bank, the International Fund for Agricultural Development (IFAD), the International Development Research Centre (IDRC), the Swedish Agency for Research Cooperation with Developing Countries (SAREC), the Ford Foundation and the Governments of Australia, Canada, Finland, France, the Federal Republic of Germany (BMZ/GTZ), The Netherlands, Norway, Sweden, Switzerland and the United States of America (USA).

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FOREWORD

Well over 2000 woody species have been identified and listed as useful 'multipurpose trees' – using this term in its broadest sense. A few are well known and have become widespread, others are so far only of local importance and their potential have yet to be fully explored. Early in ICRAF's development, initiatives were taken to collect information about these useful species and about the land-use systems and agroforestry technologies in which they were being used. But how do we match the potential of these species with the needs of the technologies, the land-use systems and the land users? At ICRAF we have focused on developing methods and 'tools' to achieve this match.

This collection of papers was presented at a two-day technical seminar on the occasion of ICRAF's 10th Anniversary. The objective was to indicate the extent of work on multipurpose trees at ICRAF and the integration of this work within ICRAF's 'research-for-development' process. The contributions cover the steps required for the selection and testing of woody species for particular biophysical settings, agroforestry technologies and land-use systems.

If the outcome of the methodologies described here do not provide all the answers, it is because we still do not have a great deal of information about multipurpose trees and their uses. The challenge for us all in the next decade of agroforestry research is to acquire and exchange present and new information, and to learn how to use multipurpose trees as effectively as possible as components in appropriate agroforestry technologies.

We would like to thank all those donors and organizations that funded participants in the technical seminar, and in particular the International Development Research Centre (IDRC), the Canadian International Development Agency (CIDA) and the Government of The Netherlands for their financial support.

Bjorn O. Lundgren
Director-General
ICRAF
July 1989

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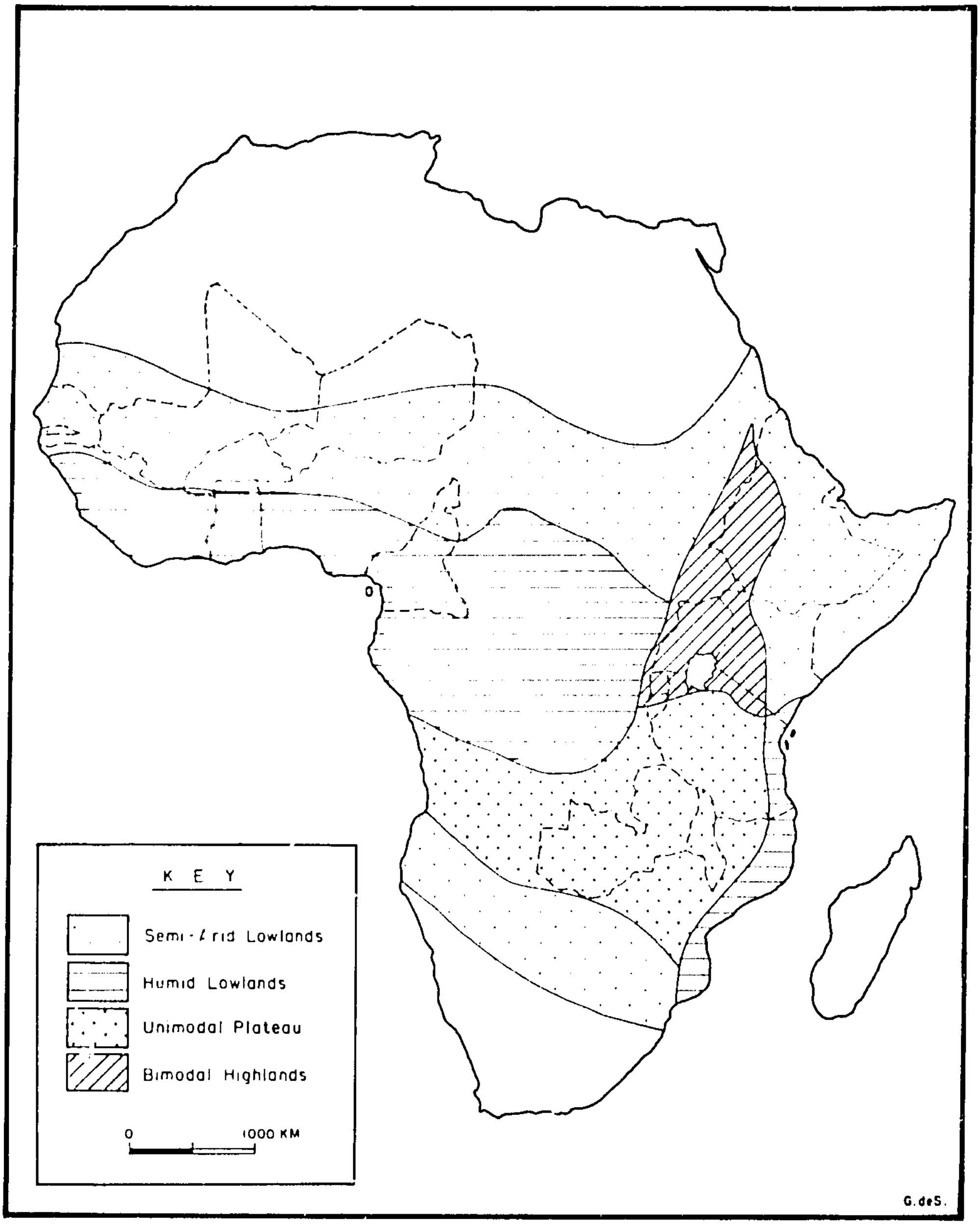

ICRAF in Africa: agroecological zones and countries where ICRAF is planning and/or implementing agroforestry research projects. As of mid-1989, projects are in progress in Burkina Faso, Burundi, Cameroon, Ethiopia, Ghana, Kenya, Malawi, Mali, Niger, Rwanda, Senegal, Tanzania, Uganda and Zambia. All projects are conducted in collaboration with national institutions through the Agroforestry Research Networks for Africa (AFRENA).

INTRODUCTION

This set of papers describes the position reached at ICRAF in 1987 after something less than 10 years of active scientific work related to a central part of the Council's programme – multipurpose-tree research. It represents a statement of the progress made up to that time.

From the start of research activities, it became clear that agroforestry research differed in some essential respects from research in agriculture or related disciplines. This volume helps to indicate what some of these differences are.

When work started, precise information about the woody components of agroforestry systems was scanty and/or mainly botanical or ecological in nature, with just a few notable exceptions such as the information available on *Leucaena leucocephala*. At ICRAF, the priority was to obtain information about potential uses and appropriate management practices for species suited to particular agroforestry technologies and ecological situations. This was undertaken primarily through two major projects – the 'Agroforestry Systems Inventory' and the 'Multipurpose Tree and Shrub Database'. Specialists in other areas also made important contributions.

Establishing useful knowledge bases on multipurpose trees was clearly not enough. Another major problem for agroforestry research was the limited understanding of the constraints affecting the land-use systems under study and of precisely in which ways, and to which extent, any agroforestry intervention could help remedy these. Thus, a major activity at ICRAF has been the development of a methodology for the rapid appraisal of land-use systems – ICRAF's 'diagnosis and design' methodology. Improving our knowledge of multipurpose trees and gaining an understanding of how they might be incorporated into land-use systems – these became two closely integrated activities.

Accompanying all this was the development of a logical approach to agroforestry experimental research. How could the wide range of research tasks be structured and prioritized to promote relevant research programmes that could produce the required information in a cost-effective manner? In most cases, initiating this process has meant starting research on the introduction and testing of multipurpose trees.

Finally, field experimentation in agroforestry inevitably encounters problems originating from the inherently different dimensions of space and time required for agricultural crops and for woody perennials. The complexities of managing trees and shrubs in order to provide different outputs and services also create problems. Important work at ICRAF has led to better understanding of appropriate field designs for agroforestry experimentation and suitable methods for data analysis.

To summarize work completed is often a useful way to establish where to go next. In planning the technical seminar, we soon realized that the completion of a holistic 'research-for-development' process involved several essential components. Some needed to be carried out in parallel (e.g. technology testing through 'prototype systems' design), others were part of the interactive cycle (e.g. research monitoring and evaluation procedures). Summing up progress at the time of the 10th Anniversary was thus of considerable value for the future development of ICRAF's programmes. This exercise resulted in a major emphasis on on-farm agroforestry research – again with its own set of essential components and procedures.

Hopefully, the reader will discern not only an account of the past in this volume, but glimpses of what the future can bring. In most cases, we have attempted in the sections that follow to introduce the issues and then to show how research procedures have been developed, using practical field examples from some of ICRAF's collaborative programmes. The material covered has been drawn from the work of many ICRAF staff, and is the result of a great deal of interdisciplinary interaction. The outcome, we hope, is not just an account of the results of ICRAF's activities, but informative material for others involved in planning and implementing agroforestry research.

Peter A. Huxley
Filemon Torres,
Seminar Organizers

Session 1: Analysing the problems and defining the solutions

ICRAF's 'diagnosis and design' methodology exposes the constraints of a land-use system and helps research planners choose agroforestry technologies to help overcome them.

THE DIAGNOSIS AND DESIGN METHODOLOGY

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The potential contribution of agroforestry to sustainable, integrated land use can only be realised if appropriate agroforestry technologies can be matched with specific land-use situations. ICRAF has developed a diagnosis and design (D&D) methodology to help achieve this goal. The D&D methodology can be used at the initial planning stage of an agroforestry project–for example by a multidisciplinary team charged with formulating research plans for national agroforestry programmes on the basis of rapid appraisal. The methodology can also be used iteratively throughout the implementation of agroforestry projects to refine the match between technology and land-use system.

The author discusses the procedural aspects of the D&D methodology (asking the right questions) in relation to macro- and micro-level applications. Initial diagnosis leads to the identification of 'best-bet' prototype designs which are refined through testing and relevant on-farm and on-station research. The methodology is then used iteratively to help keep the research and development process on track towards the eventual optimization of the agroforestry design for the target land-use system.

The substantive aspects of D&D (arriving at the right answers) depend on building up a knowledge base on agroforestry. Sources of information for agroforestry design are briefly discussed.

BACKGROUND

Agroforestry has great potential as an approach to rural development through integrated land use. There are many potentially useful ways to grow trees together with crops and/or livestock. However, there is a dearth of scientifically validated information on which to base the choice of suitable agroforestry practices and systems for specific land-use situations or the selection of promising agroforestry technologies for further research.

For any applied science, it is axiomatic that research and development efforts should focus primarily on technologies that hold promise for addressing important problems. Following this principle, and in order to avoid squandering scarce resources on ad hoc, piecemeal research projects, ICRAF set out in 1981 to develop a methodological tool to help agroforestry research and extension workers identify relevant research goals and formulate sound recommendations for agroforestry development. This tool–the diagnosis and design, or D&D, methodology–is nothing more, or less, than a systematic approach to agroforestry planning based on the common-sense principle that 'diagnosis should precede treatment'.

The D&D methodology was first developed in response to a need for a coherent interdisciplinary procedure, to be used by multidisciplinary teams on rapid appraisal missions charged with the task of formulating research plans for national agroforestry programmes. This was the original *operational context* of the D&D methodology and is still the most common application, although it is now also used by extension and rural-development workers as well as by planners and research staff. Indeed, the methodology is now supported by an extensive body of literature and practice, with variations covering a range of different needs, objectives, levels of skill and resources. The key to successful use of the D&D methodology is *flexibility* in adapting the basic approach to the needs and resources of particular users.

This brief introduction will not cover the operational details of any of the variants of the methodology. Rather, the aim is to give a general overview of the main aspects of D&D and to set the stage for the presentations to follow. This will be done by focusing first on the *procedural aspects* of the methodology and then going on to discuss some of its more *substantive aspects*.

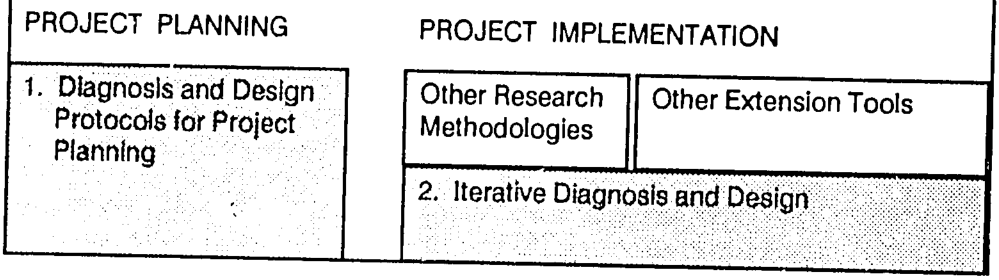
It should be clarified from the outset that the D&D methodology, as used by ICRAF, has two very different levels of meaning and application. The first deals with specific procedures for the planning stage of an agroforestry project, i.e., the use of D&D to identify what research is required in order to develop agroforestry technologies appropriate for the problems and potentials of a given land-use situation. The second level is more general and far reaching – the use of the basic D&D logic throughout the implementation phase of a project.

It is also helpful to define two terms used frequently in discussing the D&D methodology:

Land-use system: a distinctive combination of land resources, technology and land-user objectives. For many purposes, 'land-use system' may be considered synonymous with the more specific 'farming system', but the broader term covers a variety of tree- and livestock-based production systems. The user perspective is integral to the definition of the system for the purposes of the diagnosis and design exercise.

Technology: used in a broad or narrow sense. This term can refer to a *general type* of agroforestry technique, such as hedgerow intercropping, improved fallows, fodder banks or living fences. More narrowly, 'technology' may refer to *specific variants* of an agroforestry technique, for example maize-*Leucaena* alley cropping with specific upperstorey fruit and pole trees, at a specific spacing, under a specific management regime and for specific production and service functions. Finally, 'technology' may refer to an established *technical practice*, such as pruning or pollarding.

Figure 1. Two levels of diagnosis and design in a research-for-development project.



PROCEDURAL ASPECTS OF DIAGNOSIS AND DESIGN

Although several variations of the D&D methodology have been developed for planning different aspects of agroforestry projects, the underlying logic is fundamentally the same. The core of the methodology is the process of diagnosis and design. What comes before and after this process – the 'prediagnostic' preparation and the planning of follow-up activities – varies according to specific resources and goals.

For example, to design a project for a specific site where the researcher already has considerable experience, much of the 'prediagnostic' work will be unnecessary. An in-depth diagnostic survey can be undertaken immediately that leads to a detailed, site-specific agroforestry design. By contrast, in planning an agroforestry research programme at the national level, a broad approach is needed, emphasizing 'prediagnostic' surveys to describe the relevant land-use systems of the country and to set priorities for later, more detailed D&D field surveys.

Table 1. The basic logic of agroforestry diagnosis and design.

BASIC QUESTIONS	KEY FACTORS TO CONSIDER
Prediagnostic stage	
Which land-use system?	Distinctive combinations of resources, technology and land-user objectives
How does the system work?	Production objectives and strategies, subsystems and components
Diagnostic stage	
How well does the system work?	Problems in meeting objectives, causal factors, constraints, leading to intervention points
Design and evaluation stage	
How to improve the system?	Specifications for problem-solving or performance-enhancing interventions
Planning stage	
What to do to develop and disseminate the improved technology?	Research and development needs, extension needs
Implementation stage	
How to adjust the plan of action in the light of new information?	Feedback from research and extension trials

These two approaches correspond to the micro- and macro-level D&D exercises that Professor Ngugi describes in his case study from Zambia. This work is itself part of a larger zonal project within ICRAF's Agroforestry Research Networks for Africa (AFRENA). On a smaller scale, meso-level D&D methods have been developed to deal with landscape-design problems related to a local community or small watershed. Unfortunately, it will not be possible to dwell on this interesting level of application (but see Rocheleau and van den Hoek, 1984; Buck, 1989).

At any level, once the focal land-use systems have been identified and described, the logic is straightforward. The diagnosis of land-management goals, problems and potentials leads to the identification of *systems specifications*, which then suggest possible interventions, or 'candidate technologies', suitable for the land-use system. Detailed *technology specifications* are then formulated, describing the 'nuts-and-bolts' of the envisaged agroforestry practices, such as the desired characteristics of multipurpose trees and other plant components, the appropriate spatial arrangements and the management practices required to achieve designated objectives. This stage of the design process requires detailed knowledge of component characteristics, interactions and responses to management, combined with an overall understanding of the production system.

However, in many cases, the information required to design an agroforestry system in detail is not available in a scientifically validated form. We often do not know the best species, let alone the best provenance, for a given function in a given location, we do not know the best plant arrangement and espacement, and we may have an idea but we do not really know the best management regime to achieve our objectives. At this stage, there is usually an urgent need for further research.

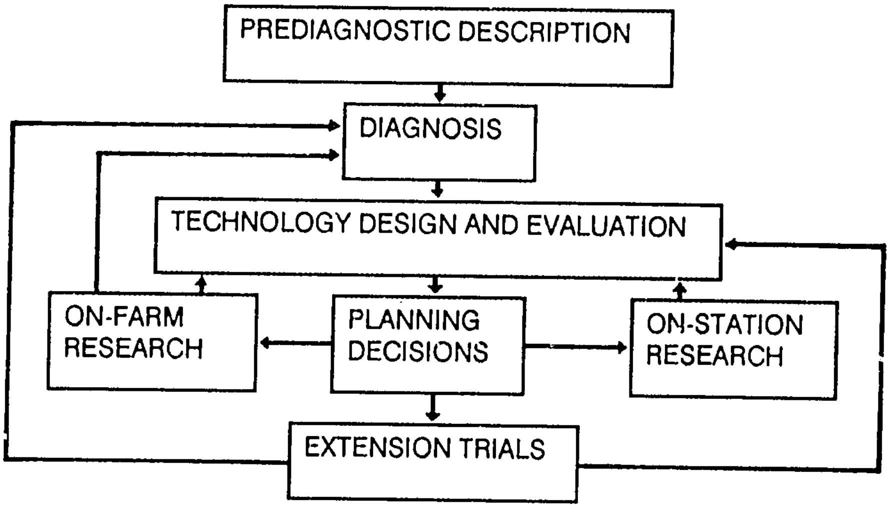
An important feature of the D&D methodology is that research priorities are derived from an attempt to design an agroforestry system for a specific situation. The effort to develop a detailed agroforestry design leads to the identification of gaps in the available information and thus to the clarification of research requirements. Any research programme formulated in this way is likely to be relevant to the actual needs and potentials of the land-use system.

Diagnosis and design is an iterative process. The basic idea is to formulate a 'best bet' prototype design for an agroforestry system, and then to refine the design as research results become available. This might entail adding improved components, altering the spacing or modifying the management regime until the system is more-or-less optimal, or until further refinements are deemed not worth the additional research cost.

The initial D&D exercise, undertaken at the planning stage, is intended to get the research and development process moving in the right direction. The initial design is simply a reference point for further research. Once research is in progress, the D&D methodology is used iteratively to help keep the research and development process on track towards the eventual formulation of an optimal agroforestry design for the target land-use system.

A further guarantee of relevance is the involvement of local farmers in the research and development process through on-farm trials. Prototype-technology trials involving a small number of experimentally oriented farmers are useful at the earliest stages in order to obtain important farmer input throughout the research and development process. Figure 2 shows the feedback linkages between on-farm and on-station research in an agroforestry project, using the self-corrective logic of *rediagnosis and redesign* as part of the project's internal guidance system.

Figure 2. The iterative logic of diagnosis and design as part of the 'internal guidance system' of a research-for-development project. Note feedback linkages.



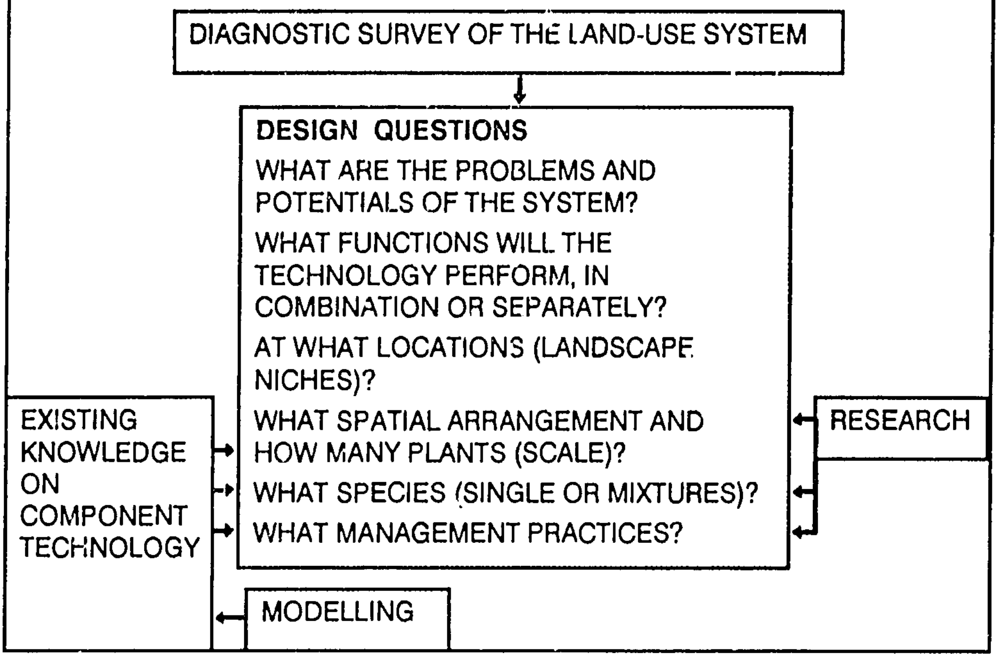
SUBSTANTIVE ASPECTS OF DIAGNOSIS AND DESIGN

The procedural side of D&D helps us to ask the *right questions* in the right sequence. The substantive side of D&D is concerned with arriving at the *right answers* to these questions.

When the D&D methodology was first formulated, the knowledge base on agroforestry was extremely sparse. In these circumstances, there was little choice but to follow the D&D procedures on the assumption that the process itself would lead to a better-than-average agroforestry design. The first interdisciplinary D&D teams, in effect, set forth into an unknown land-use system armed with their separate technical backgrounds, an intuitive grasp of agroforestry and a faith that the logic of the procedures would lead from the description of relevant aspects of the land-use system, through the diagnosis of problems and potentials, to the design of an appropriate agroforestry system. The approach worked well enough in retrospect and, with the procedural refinements that have since been made, we can now recommend it as a reliable method for designing agroforestry systems and projects when applied by a competent multidisciplinary team.

Nowadays, however, the knowledge base on agroforestry is more substantial, so we no longer have to rely exclusively on a procedural approach. From the growing body of literature on agroforestry and from ICRAF's two databases – the Global Agroforestry Systems Inventory and the Multipurpose Tree and Shrub Database – more complete and systematic knowledge of existing agroforestry systems and component species is now available. Also, D&D exercises have now been conducted at a wide range of sites around

Figure 3. Information for the selection of agroforestry species.



At the micro level, a number of questions must be answered before an agroforestry system can be designed and implemented on the ground. The main objective of agroforestry research and development is to provide increasingly detailed and reliable answers to these questions. The D&D methodology contributes a concrete focus for the integration of diagnostic, design and research activities around a concrete, goal-driven process. As shown in Figure 3, the main source of information is the initial diagnostic survey of the land-use system. This provides the basis for specifying development goals, functions of the agroforestry technologies to be introduced and the location of these technologies within the landscape. The initial survey of the land-use system also provides information for deciding on spatial arrangements, local species that might be suitable for agroforestry and management practices that will be feasible in terms of available skills and labour.

Information obtained in the survey is then combined with existing knowledge of potential agroforestry technologies and possibly supplemented by modelling and other methods of ex-ante evaluation. Out of this process, 'best bet' prototype agroforestry technologies are selected. In most cases, field research will be required to evaluate the prototype technologies and to provide the quantitative information needed to refine the prototype designs.

The technology specifications obtained at the early stages of this process must be regarded as *provisional*. These may be modified or overturned by research results obtained at a later stage. We may expect, indeed even hope, that the research results obtained will enable the agroforestry planner to improve, or even completely redesign, the prototype technology.

the world: there is a substantial body of case material to inform our expectations about the kinds of problems we are likely to find associated with different land-use systems and the kinds of agroforestry solutions that are likely to be relevant.

ICRAF is now working to analyse and synthesize all this material into a coherent set of 'recommendation domains'. This should provide a more systematic basis for matching candidate agroforestry technologies with land-use systems during the initial D&D exercise at the macro level.

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A CASE STUDY FROM ZAMBIA

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This paper describes the application of the diagnosis and design (D&D) methodology at the macro level in the upland plateau region of Zambia. The project was undertaken within the collaborative research programme of the Agroforestry Research Networks for Africa (AFRENA).

The prediagnosis phase resulted in the description of six land-use systems, including an inventory of constraints and the possible role of various agroforestry technologies within each system. A micro D&D exercise focused on one land-use system for maize and livestock production. The author describes the major constraints and potentially useful agroforestry technologies identified. As an example, the detailed design of one of these technologies – living fences – is presented, along with some final comments on the value of the process.

INTRODUCTION

Zambia is a large country, occupying an area of 750,600 square kilometres (km^2) in southern Africa. The Southern Africa programme of the Agroforestry Research Networks for Africa (AFRENA) is conducting research in Zambia's upland plateau area, at an altitude of 600 to 1600 metres (m) above sea level and a unimodal pattern of rainfall, ranging from 600 to 1500 millimetres (mm) per year. Agricultural production is dominated by small-scale farming, combining both crop and livestock production. The key crops are maize and pulses and livestock production includes cattle, sheep, goats and pigs.

DESCRIPTION OF LAND-USE SYSTEMS

Using material available at ICRAF and information gathered during a land-use assessment field survey (macro D&D), the research team described six land-use systems in the area. These were:

1. the Chitemene system
2. the grass mound system
3. the maize/cattle system
4. the maize cropping system in the drier part of the zone
5. the Barotse agropastoral system
6. the maize/smallstock system.

The macro D&D exercise included an inventory of the constraints to agricultural production and sustainability in the area and an assessment of possible development strategies for each land-use system, including the potential role of agroforestry technologies. As a result, the maize/cattle and the maize/small stock systems, centred in the Chipata/Katete area of Eastern Province, were selected as priority systems for research. Among the factors considered in this decision were:

- the high potential for agriculture, especially maize growing
- the high population density
- the declining crop yields, notably for maize, due to declining soil fertility.

Table 1. Main characteristics of the maize/livestock production system in the upland plateau region of Zambia.

Biophysical	
Rainfall	800–900 mm, November/April
Altitude	600–1400 m above sea level
Soil type	Sandveldt (acidic parent rock)
Landscape Organization	
Settlement pattern	Nucleated homesteads
Grazing area	Uplands and *dambos* (depressions), crop residues in off season
Cropping area (average farm size)	1.5–3.0 hectares
Uplands	Food and cash crops
Lowlands (depressions)	Livestock and vegetable gardens (*dimbas*)
Land-Use System Components and Practices	
Subsistence crops	Maize, groundnuts, beans
Cash crops	Maize, sunflower
Livestock	Cattle, sheep, goats
Herd size	2–40 (majority 4–8)
Soil fertility maintenance	Intercropping maize/beans/groundnuts, short grass fallows, crop rotation, limited fertilizer use
Soil and water conservation	Contour ridging
Land preparation	Ox-plough and hand hoe
Weeding	Hand labour
Livestock management	Herding
Socioeconomic Conditions	
Population density	Human: 26/km^2; Cattle: 5/km^2
Labour	Family, limited hire, shortage particularly at weeding and harvest time
Land Tenure	Communal
Marketing	Fairly well organized (government and parastatal assistance with marketing and input supply)

THE MAIZE/LIVESTOCK SYSTEM

After the initial field survey, a micro D&D exercise was conducted – focusing on the maize/cattle and maize/smallstock production systems – in order to confirm or modify the findings of the macro D&D and to refine the specifications for proposed agroforestry technologies. This work revealed that differences between farm types in the two systems were not significant. For example, farmers who owned oxen were cultivating holdings of approximately the same size as farmers without oxen who borrowed or hired oxen from the owners. The amount of land cultivated was determined primarily by the availability of labour for weeding, which was virtually all done by hand. The main characteristics of the maize/livestock system are depicted in Table 1.

Identification of constraints

The micro D&D exercise identified a shortage of cash as one of the main constraints to agricultural production – cash for the purchase of farm inputs and household essentials. This shortage resulted from prevailing low crop yields which, in turn, were partly the result of low soil fertility. Farmers made very little use of inorganic fertilizers due to their high cost compared with the prices obtained for farm products, and little use of manure due to concern about exacerbating the weed problem. Poor husbandry practices such as late planting and inadequate weeding, partly caused by the shortage of draught power and labour, were another factor contributing to low crop yields. Livestock production was also low due to lack of cash, poor animal nutrition (especially in the dry season) and disease. This, in turn, limited the availability of draught power for timely ploughing at the beginning of the planting season. Consequently, many farmers who depended on hired oxen prepared their land late, with serious adverse effects on crop yields.

Table 2. Agroforestry technologies for the maize/livestock production system in the upland plateau region of Zambia.

Problem	Development Strategy	Agroforestry Technology	Ecological Niche
Shortage of cash, food	Integrate crop, livestock around soil management to improve land productivity, sustainability, cash income, food supply	Hedgerow intercropping	Upland
Declining soil fertility		Fruit trees	Upper parts of *dimbas*
Fodder shortage		Fodder banks	*Dambo*, upland
Shortage of wood products		Boundary planting	External,internal boundaries
		Living fences, hedges	*Dimbas*, farms near villages

The major source of domestic energy was fuelwood. Overall, there were adequate forested areas on uncultivated hillsides to supply fuelwood and other wood products. However, fuelwood was becoming increasingly expensive and difficult to obtain as trees were cut for fuel and to make way for expanding cropland. Only a few farmers owned carts, which they used to transport wood from distances of often more than 5 km. Construction poles were also in short supply. These were needed primarily to fence *dimbas* (gardens in seasonally flooded depressions) for important dry-season production of vegetables and other crops. Fencing was necessary to protect these crops from livestock damage: farmers spent several person-days each season repairing fences.

Selection of agroforestry interventions

One feasible development strategy for the maize/livestock system would be to integrate crop and livestock production focused around soil management (see Table 2). Improvement of livestock, especially draught animals, would contribute to improved crop production. Reciprocally, improved crop production would benefit livestock through an increased fodder availability from crop residues.

Thus, based on the production constraints and development strategy identified for the system, the following agroforestry technologies were proposed:

- hedgerow intercropping
- fodder banks
- boundary planting
- living fences/hedges
- fruit trees.

These technologies should address the main problems identified: poor soil fertility and shortages of cash, wood for fencing and fodder for livestock. Trees planted on the boundaries of fields might also enhance crop production by acting as windbreaks. Fruit-tree planting on the edges of *dimbas* and/or on upland sites was recommended both to improve human nutrition and as an alternative source of cash. Other technologies, such as rotational hedgerow intercropping, were considered but found unsuitable, since land fallowing was not widely practised. Likewise, the promotion of dairying based on leys of grass and leguminous shrubs was rejected due to the poor local market for milk.

Table 3. Questions arising during the design of an agroforestry technology for a specific land-use system.

- What problems and potentials will the technology address?
- What specific functions will the technology perform, in combination with other technologies or separately?
- At what locations (landscape niches)?
- What spatial arrangements?
- What species, singly or in combination?
- How many plants and on what scale?
- What management?

Technology design and specification

The design specifications for each recommended technology took several factors into account. The questions addressed are listed in Table 3. These relate to environmental conditions, such as rainfall, soil type, drainage and topography; land management, including intensity of land use and management practices; specific constraints; and socio-economic conditions, such as labour, marketing and land tenure. As an example, the specifications for the introduction of living fences are shown in Table 4.

CONCLUSION

This application of the D&D methodology demonstrated that scientists could design a more appropriate and more focused agroforestry research programme by working closely with farmers. The prediagnostic work and the macro D&D provided information about land use which made it possible to define a number of specific land-use systems, to assess their relative importance and to identify the kinds of research and development needed for each. The micro D&D exercise provided a more detailed analysis of the priority system or systems and facilitated the selection and design of appropriate agroforestry technologies. After the design and introduction of a prototype technology, the iterative D&D process offered an opportunity for refining the technology, based on the farmers' evaluation under prevailing, and possibly changing, circumstances.

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Table 4. Specifications for living fence/hedge technology for the maize/livestock production system in the upland plateau region of Zambia.

Functions	Target Locations	Output	– Specifications –	
			Species	Management
Reduce crop losses due to animal damage	*Dimbas*	Higher crop yields	Thorniness/ impenetrable to livestock	Ease of establishment
Improve labour efficiency of crop and livestock components	Upland cropland near villages and roads	Building poles, fodder	No allelopathy	Low labour requirement
		Better cattle performance due to longer grazing	Providing useful by-products	
			Withstanding temporary water logging	

DISCUSSANT'S COMMENTS

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During the past five years, there has been impressive progress in developing a methodology for analysing land-use problems and suggesting designs for appropriate agroforestry technologies. The development of this diagnosis and design (D&D) methodology stemmed from the objective of improving the conceptual understanding of the nature and scope of agroforestry. Agroforestry, in this context, was defined as a set of land-management technologies and the early emphasis was on the formulation of research programmes to develop new or refined technologies. Later, attention also focused on the formulation of agroforestry extension programmes.

Considerable effort has been devoted to developing and publishing the conceptual and operational aspects of the methodology. The present emphasis on enlarging the empirical foundation for the methodology through the comparative analysis of field-trial results and case studies is strongly endorsed.

The D&D methodology focuses primarily on possibilities for developing and introducing improved land-use technologies. This has both merits and limitations. The merits derive from its clear focus on the need to develop agroforestry as an appropriate form of resource management and on what should be done to improve land use. However, this technological approach implies a narrowing of the choice of interventions to stimulate agroforestry-based rural development. It pays less attention to the development of implementation tools (other than research and extension) or to the institutional arrangements required to stimulate the adoption of agroforestry practices (see Table l). In this respect, a clear distinction should be made between agroforestry-implementation projects and projects concentrating on the development of agroforestry technology.

The focus of the D&D methodology on developing appropriate land-use technologies also implies that diagnosis is based on land-use units. It would be worthwhile to investigate if and to what extent the outcome of the diagnosis exercise would significantly change if land users and their decision-making processes were the focal point. This approach would seems particularly relevant at the meso scale.

The D&D methodology uses as basic diagnostic criteria for land management the parameters of productivity, sustainability and adoptability. Other similar methodologies have included additional criteria (see Table 2). These different parameters need to be further conceptualized and put into operation.

The D&D is a diagnostic and planning methodology which has gradually been extended from the micro scale (farm level) to the meso and macro scales. It is important that the concepts and terms used are consistent for each level of application and that they reflect the different planning scales and levels of detail. It is suggested that the term *design* should be used only to refer to the precise description of agroforestry technologies at micro or meso level. At the macro level, the term *strategy* seems more appropriate. In other words, to develop D&D into a methodology that is too all embracing could endanger its clarity and consistency.

Table I. Conceptual planning model for social-forestry development.

Resource-Management Actions	Implementation Tools	Institutional Arrangements
Forestation Management		
Fuelwood lots	Usufruct rights on land	Tenure systems
Fodder lots	Extension and education	Economic policies
Communal forests	Technical help with inputs (seedlings, fertilizers, etc.)	Legal codes
Commercial farm forestry		Reorganize public agencies: forest service
Private multipurpose tree growing	Financial incentives (loans, grants, subsidized inputs, reduced taxes, food-for-work)	Extension service
Subsistence agroforestry	Regulations and licenses	Credit agencies
	Marketing cooperation	
Natural Forest Utilization		
Range management		
Wood harvesting		
Wood collection		
Minor forest products		
Main Managers		
Rural people	Professional foresters in public forest service or non-governmental organizations	Forestry policy-makers and other decision-makers
Village organizations		

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Table 2. Parameters for evaluating land-management systems.

D & D (ICRAF)	Agro-ecosystem analysis (Conway)	Farming-system properties (Harwood; Wiersum)
Productivity	Productivity	
Stability	Stability	Ecological stability
Sustainability	Sustainability	Production sustainability (maintenance of production capacity and level)
Adoptability		Management resistance
	Equitability	Economic reliability

Session 2: Preselecting multipurpose tree and shrub species for particular agroforestry technologies

ICRAF's Multipurpose Tree and Shrub Database is combined with technical specifications obtained through the 'diagnosis and design' exercise.

MATCHING TREES WITH TECHNOLOGIES USING ICRAF'S MPTS DATABASE

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This paper describes the process required to shortlist candidate multipurpose tree and shrub (MPTS) species for specific agroforestry technologies and land-use systems, using ICRAF's computerized MPTS database. The database contains more than 2200 detailed descriptions of over 1000 species, obtained from literature searches and questionnaires completed by field workers. However, the need to draw on additional resources is emphasized. The diagnosis and design exercise should clarify the role and function of any required tree or shrub species. Species can then be preselected by matching sites, uses and tree characteristics using this database.

The problems of collecting, collating and arranging this information in a computerized database are briefly described. This is followed by an example of a search for candidate MPTS species based on climate, soil and tree characteristics. The current level of information available on MPTS species is discussed and the paper finishes with comments on the issue of germplasm supply.

INTRODUCTION

The selection and design of agroforestry technologies for specific land-use systems emerge from the diagnosis and design (D&D) exercises. This paper explains and demonstrated the process of shortlisting candidate multipurpose tree and shrub (MPTS) species for use with these technologies, using ICRAF's MPTS Database. Among other functions, the database has been designed specifically to facilitate the preselection of MPTS species according to the requirements of any particular agroforestry technology.

The database comprised approximately 2200 descriptions of over 1000 species. Although this constitutes a substantial body of knowledge, there are still gaps in the available information. Moreover, no single database can cover all aspects of the wide range of MPTS species. Thus, there will always be a need to draw upon additional sources of information.

A preselection of MPTS species, based on the computerized matching of sites, uses and tree characteristics, cannot provide a guarantee of success. Rather, shortlists of candidate species emerge from a set of sorting and discounting processes. The aim is to focus further research on the species most likely to succeed in a given environment, technology and land-use system.

PRINCIPLES AND APPROACHES

If MPTS species are selected only according to their potential ability to grow and perform intended functions, then most often too many species will be listed. Research resources could be wasted in testing them all. Thus, production objectives have to be clear from the outset if we are to select species which will have the best possible economic and ecological effects as components of specified agroforestry technologies. The definition of these objectives should be derived from:

- a scientifically based consideration that a land-use system can, in fact, be improved by the introduction of an agroforestry technology using trees or shrubs
- an adequate specification of the agroforestry technology that is considered likely to improve the system
- a clear perception of the expected role of the selected woody perennials: i.e. their spatial and sequential arrangement in the system, management requirements and, especially, their functions and expected outputs.

We must, therefore, understand what tree characteristics relate to the functions and requirements of woody perennials in a specific agroforestry technology. The information contained in the computerized database must be categorized and arranged so that it will be available in a meaningful form to assist species selection and research decision-making.

This role has been taken into account in the establishment and expansion of ICRAF's MPTS Database. As outlined in earlier publications (von Carlowitz, 1984; 1986a; 1986b; 1987), a range of literature and field sources has been used to acquire information on:

- environmental requirements and tolerances of trees and shrubs
- important tree characteristics, such as phenology, morphology, and reproduction
- tree services, products and yields.

This information is stored in separate files in an easily accessible form to allow searches through the database according to a variety of criteria, singly or in any required combination. The organizational structure is well suited to match the requirements of ICRAF's technology and systems research. The database can, of course, also be used to assist many other research and development-oriented activities involving woody perennials.

As previously mentioned, ICRAF's Multipurpose Tree and Shrub Database is an important instrument for the preliminary selection of MPTS species, but it cannot always be sufficiently comprehensive in its content and scope to satisfy every demand. Although the process of expanding and adjusting this database is continuous, it should be used together with additional information sources such as, for example, other specialized databases, species monographs and research results (von Carlowitz, 1985).

METHODS AND LIMITATIONS

Basically, four sets of information are required for the preselection of MPTS species suitable for specified agroforestry technologies at specific sites. These are:

- a sufficiently detailed description of the climatic and soil conditions of the site
- the biophysical range of different MPTS species with regard to climate and soil
- a clear definition of the chosen technology and of the precise functions the MPTS species is supposed to perform
- a listing of tree characteristics, products and services required to fulfil the designated functions in the sequence of importance.

Those tree uses and characteristics which are relevant to a specific function are expressed in terms of standardized descriptors which can be used, in combination with climate and soil parameters, to search the database. If, for example, the objective is to make a shortlist of species suitable for hedges in arid to semi-arid zones, the computer search formulation could read as follows:

BSk (Koeppen Class) *plus* bimodal rainfall *plus* 400–600 millimetres (mm) rainfall *plus* 5–6 months dry period *plus* 22–26°C annual mean temperature *plus* sandy soils *plus* acid soils *plus* multi-stemmed *plus* spiny/thorny *plus* pollarding *or* trimming.

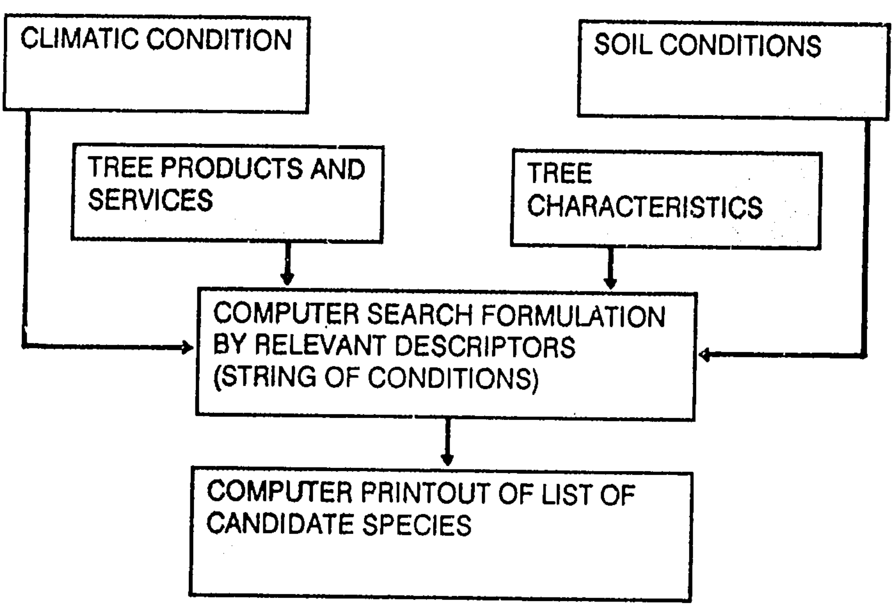
From such an all-embracing string of concurrent conditions, only those species emerge which match an unbroken and complete combination of all the specified conditions (see Figure 1). The absence of one parameter (descriptor) out of the string may eliminate a large number of species that might otherwise be suitable. However, the computerized search process allows the identification of under-represented or missing parameters.

If, for example, information on annual mean temperature proves to be unavailable for most species, this parameter can be removed from the conditional string. Once this is done, more candidate species should emerge from the search and these may then undergo further scrutiny supported by other information sources.

PROBLEMS

Several problems emerge in the preselection of multipurpose tree and shrub species for specific agroforestry technologies at specific sites. For one thing, there are many

Figure 1. ICRAF's Multipurpose Tree and Shrub Database: preselection of species for specific technologies.



specific agroforestry technologies at specific sites. For one thing, there are many potentially useful species. The ICRAF MPTS Database contains over 1000 species, all of which are reportedly used in agroforestry production systems. ICRAF has listings of 1600 species, and even these are patently not complete.

The second problem is the fragmentary information available on the majority of species. Until recently, most of these species were not of particular interest, either to foresters or to agriculturists. Many only received a mention from ecologists or plant taxonomists. Except for a few, such as *Leucaena leucocephala*, *Gliricidia sepium*, *Acacia tortilis*, *A. nilotica and A. mangium*, almost nothing is known about genotype-environment interactions since comparative species/provenance trials at different sites have not been conducted. Again, almost nothing is known about rooting structure or behaviour, an important issue when investigating environmental resource sharing between trees and crops.

Due to these gaps in the information available, it is often not possible to obtain a complete set of data on each species for entry into the database. As a consequence, computerized searches cannot always be expected to provide comprehensive results.

A third problem is the complexity of selecting species with multiple traits. The more traits required from any particular species, the less are the chances of finding one that is satisfactory in *all* respects. Furthermore, researchers must be careful not to specify particular traits that are, in fact, mutually exclusive. For example, species used for hedgerow intercropping and managed by coppicing or pollarding at regular intervals to produce mulch cannot normally produce timber at the same time. Within the ICRAF database, the selection criteria for these two functions are disparate and the same species would not emerge as a candidate for both.

GERMPLASM SUPPLY

One source of information on germplasm supply is ICRAF's *Multipurpose Tree and Shrub Seed Directory* (von Carlowitz, 1986c). Species selection for both research and development activities must be linked to the availability of germplasm – otherwise efforts to preselect suitable species for particular situations will be wasted.

If species are selected that are indigenous to the target area, or have been introduced there earlier, it may be appropriate to collect seeds locally, rather than relying on an outside source that may not be able to provide seeds of the required provenance. Furthermore, the local collection of seeds allows an *ideotype-oriented*, phenotypic selection of mother trees that improves the chances of introducing trees with characteristics closest to those specified for a designated technology.

Guidelines for formulating a particular ideotype are readily derived from a catalogue of tree characteristics appropriate for specific technologies. In the process of defining an appropriate ideotype, the problems of multiple-trait requirements must be considered and functions and desired outputs must be ranked in order to avoid conflicting demands.

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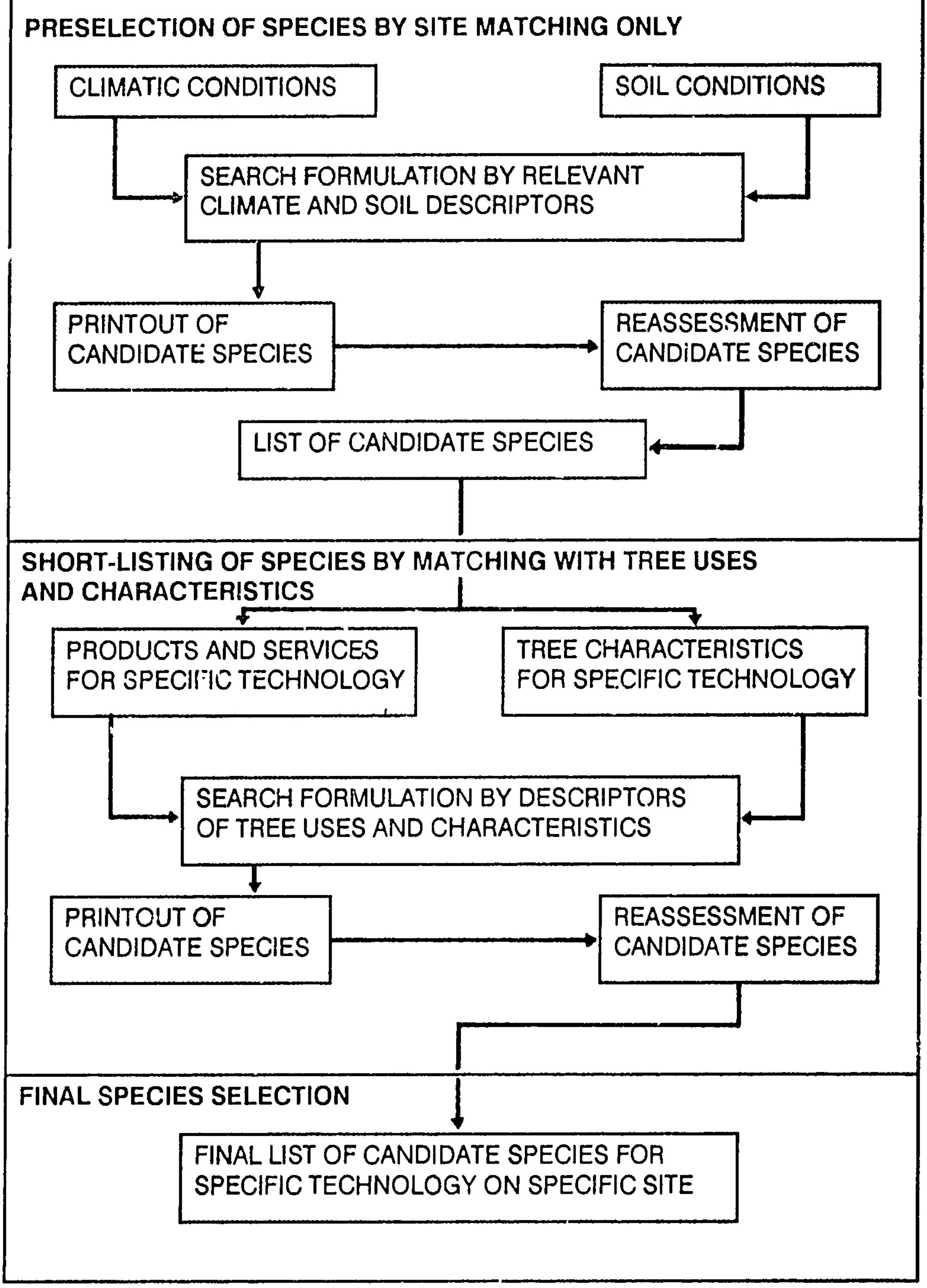
Figure 2. Preselection of species for specific agroforestry technologies.



SPECIFYING TREE CHARACTERISTICS: A CASE STUDY FROM BURUNDI

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This paper describes how multipurpose-tree (MPT) species were selected for hedgerow intercropping and upperstorey wood production in food-crop plots in the central plateau region of Burundi. The region is characterized by small farms concentrating on subsistence food crops and coffee production. Through a collaborative project under the Agroforestry Research Networks for Africa (AFRENA), research began with a diagnosis and design (D&D) exercise. Two major problems were identified requiring the introduction of agroforestry technologies in the area. These were declining soil fertility and declining wood resources, especially fuelwood and timber for construction.

SELECTION OF THE TARGET LAND-USE SYSTEM

The Eastern Africa programme of the Agroforestry Research Networks for Africa (AFRENA) covers the highland areas of Burundi and parts of Kenya, Uganda and Rwanda. To identify appropriate agroforestry technologies for introduction in Burundi, five land-use systems were identified, each with different agroforestry potentials. These were:

- the banana-based system on the eastern escarpment
- the livestock-based system on the Zaire-Nile crest
- the tea- and forest-based system on the Zaire-Nile crest
- the foodcrop-based system on the arid eastern plain
- the coffee- and foodcrop-based system on the central plateau.

This discussion will concentrate on the selection of multipurpose trees for the last of these land-use systems: the coffee- and foodcrop-based system on the central plateau.

DESCRIPTION OF THE LAND-USE SYSTEM

The coffee- and foodcrop-based system in Burundi's central plateau region is characterized by small-scale crop and livestock farms, with cropped areas ranging from 0.5 to 1.0 hectare. The region can be divided into western and eastern areas. These differ considerably in terms of population density, estimated respectively at 350 and 150 persons per square kilometre (km^2). This difference is reflected in land-use patterns. The proportion of non-cultivated land, including marginal and fallow land, is much larger in the eastern area – close to 70%.

In the uplands of the eastern area, the soils are predominantly ferrasols, with smaller areas of luvisols, cambisols and lithosols. In the western area, cambisols predominate, but ferrasols and lithosols are also represented.

Rainfall ranges from 1000 to 1500 millimetres (mm) annually, with slightly higher rainfall in the west than in the east. The distribution of rainfall is also less favourable in the east, with a dry season of 5 to 6 months, whereas in the west the dry season lasts for 4 months.

In both areas, altitudes range from 1700 to 2000 metres (m) above sea level, with the western area generally slightly higher than the eastern. The ambient temperature averages around 22°C. Because temperature is related primarily to altitude, the western area tends to be slightly cooler.

Cropping systems are similar in both areas. Subsistence crops include bananas, cereals, tubers and legumes, while coffee is the main cash crop.

Most farmers practise intercropping in banana and other food-crop plots. Coffee is not normally intercropped. To maintain soil fertility, farmers rely mainly on compost and manure, though quantities are insufficient to affect crop yields substantially. Chemical fertilizers are expensive and thus little used. In the less densely populated eastern area, food-crop plots are usually fallowed for short periods, ranging from one season to two years. In the more densely populated western area, fallowing has disappeared completely.

For soil and water conservation in coffee plots, farmers practise mulching with banana leaves and stems and other crop residues. Soil conservation in food-crop plots takes the form of grass strips along the contours and cut-off drains.

Other than coffee, crops are grown primarily for home consumption. Bananas are used mainly to produce the local beer. Beer may be sold for cash, although primarily among the local people.

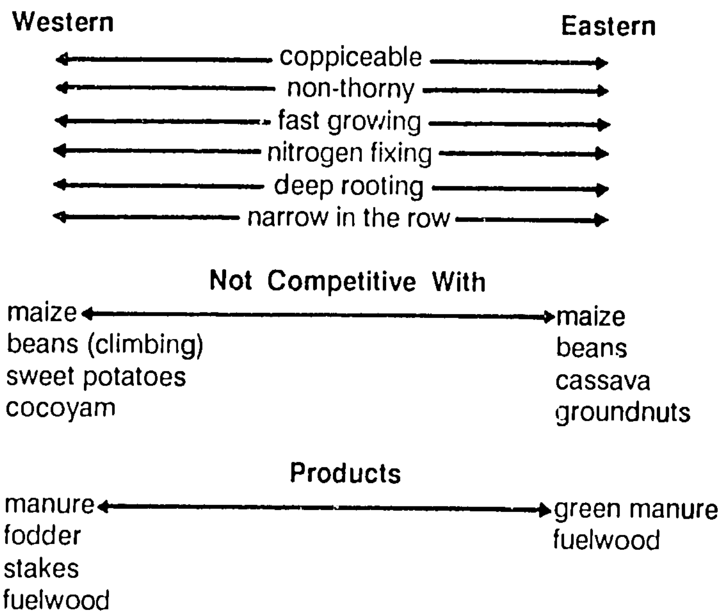
Animals are kept in small numbers, but in recent years the livestock population has decreased and there has been a shift from large to small animals. An exception to this pattern is the eastern area, especially the southern part, where the cattle population is 3 to 4 times higher – at 0.28 cattle per person – than in the rest of the region.

Livestock management in the western area can be described as semi-intensive, with animals feeding on crop residues, planted grasses, fallow land and roadsides. In the less densely populated eastern area, natural grazing lands are an additional source of fodder. While livestock provide a source of milk and cash income, many farmers consider manure the most important output.

DIAGNOSIS OF THE MAIN LAND-USE PROBLEMS

The main problem encountered in this land-use system is the ever-decreasing crop area per household due to population growth, averaging 2.7% annually. In the past, this trend was countered by converting grazing land into cropland. However, the scope for such conversion is now limited since the agricultural potential of most of the remaining grazing land is low due to shallow and acid soils. For this reason, more intensive cultivation of the existing cropping area is unavoidable, leading to a complete disappearance of fallow periods. Although the use of compost and manure may compensate to some extent for the outflow of nutrients from the system, the amounts available for this purpose are insufficient. These may decrease further if the animal population continues to decline and no alternative methods to produce more crop residues are developed. The outflow of nutrients is further aggravated by soil erosion, despite measures put into practice to prevent this problem.

Figure 1. Requirements of hedgerow-intercropping species for the central plateau region of Burundi.



In spite of the efforts of farmers to manage in this situation, the productive capacity of farms in both areas is low and may be declining. There is, therefore, an urgent need not only to improve the existing production system through the improvement of soil-fertility and soil-conservation measures, but also to diversify the production system through the introduction of components which require only small amounts of land. Another major problem is the rapid decline of wood resources, especially fuelwood and poles and timber for construction.

PROPOSED AGROFORESTRY TECHNOLOGIES

Several agroforestry technologies could contribute to the alleviation of these problems. Two of these will be discussed in terms of the selection of multipurpose trees.

The first proposed technology is hedgerow intercropping, with hedgerows planted along the contours and lopped regularly to provide green manure for the crops grown in the alleys in between. Fuelwood sticks are a possible by-product, as well as protein-rich fodder for livestock. The need for supplementary livestock fodder is greatest in the eastern area because of the long dry season, but land tends to be available there where paddocks or fodder banks could be established. In the western area, an important by-product from the hedgerows could be stakes for climbing beans.

The second proposal is for upperstorey trees mixed in cropland, either in hedges, on boundaries or as single trees interspersed with crops. These could yield a variety of products, such as timber, poles, fuelwood and fruit.

DESIRED TREE CHARACTERISTICS

Appropriate tree or shrub species for both these agroforestry technologies should not only match the environmental conditions of the region, but should also match the technologies selected for introduction. For example, the ability to coppice is an essential characteristic for any hedgerow-intercropping species. A summary of tree characteristics for the two technologies is given in Figures 1 and 2.

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Figure 2. Requirements of upperstorey tree species for foodcrop plots in the central plateau region of Burundi.

Western ... **Eastern**

General Specifications

← light/narrow crown →
← deep rooting →
← nitrogen fixing →

Non-Competitive With

Western	Eastern
maize ←	→ maize
beans (climbing)	beans
sweet potatoes	cassava
cocoyam	

Timber Specifications

← single stem →
← straight stem →
← self-pruning →
← coppiceable →

Fruit Specifications

← edible fruits and nuts →

PRELIMINARY MPT SELECTION FOR BURUNDI'S CENTRAL PLATEAU REGION: AN EXAMPLE

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This paper gives an example of the process of preselecting multipurpose tree and shrub (MPTS) species using ICRAF's MPTS database. Species were selected according to environmental conditions in Burundi's central plateau region and in terms of characteristics related to hedgerow intercropping and upperstorey trees in cropland. These two agroforestry technologies were chosen for introduction into a production system based on food crops and coffee.

SPECIES PRESELECTION PROCESS

The biophysical conditions characteristic of the central plateau region of Burundi are reformulated in Table 1 as a set of descriptors recognized in ICRAF's Multipurpose Tree and Shrub (MPTS) database. Table 2 gives descriptors related to the two agroforestry technologies chosen for introduction in the coffee- and foodcrop-based production system – hedgerow intercropping and upperstorey timber trees in cropland. The database can be searched using these descriptors to produce a list of species likely to be suitable in this region and for these technologies.

Table 1. Biophysical site conditions and associated search descriptors used to select species from ICRAF's MPTS database suitable for the western and eastern area of Burundi's central plateau region.

Site Condition	Search Descriptor
Western	
1236 mm annual rainfall	Aw* or Cw*, 1000–1400 mm, unimodal
1500–2000 m altitude	1400–2000 m
20°C mean annual temperature	no descriptor
cambisols, lithosols, gleysols, fluvisols	clayey, loamy or neutral soils
Eastern	
1048 mm annual rainfall	Aw*, 1000–1200 mm, unimodal
1500–1700 m altitude	1400–1800 m
21°C mean annual temperature	no descriptor
ferrasols, lithosols, gleysols, fluvisols	clayey and acid soils

*refers to Koeppen climate classes.

Certain tree characteristics required for different sites and agroforestry technologies have not been transiated into descriptors for searching the database for one of two reasons. In some cases, such as temperature, there is inadequate information in the database; in other cases, such as tree response to spacing, descriptors were omitted deliberately due to lack of confidence in the credibility of this type of information.

RESULTS

Tables 3 and 4 list the species which emerged from searches based on the biophysical conditions of the western and eastern parts of the central plateau. Out of 834 species subjected to the search process, 63 were found to be suitable for the western area. Only 32 were suitable for the eastern area, due to the higher altitude and limitations of clayey and acid soils.

Table 2. Requirements related to specific agroforestry technologies and associated search descriptors used to select species from ICRAF's MPTS database suitable for the western and eastern area of Burundi's central plateau region.

Requirement	Search Desciptor
Hedgerow intercropping	
green manure	mulching
fodder	fodder leaves/shoots
stakes	no descriptor
fuelwood	fuelwood
coppiceable	coppicing or pollarding
non-thorny	not spiny/thorny
fast growing	no descriptor
nitrogen-fixing	nitrogen fixation
deep rooting	no descriptor
narrow in-row spacing	no descriptor
non-competitive with crops	no descriptor
Timber trees	
timber	timber/poles
light, narrow crown	light crown
deep rooting	no descriptor
nitrogen fixing	nitrogen fixation
straight stem	no descriptor
single stemmed	single-stemmed
self-pruning	pruning
coppiceable	coppicing
Fruit trees	
edible fruits and nuts	edible fruits or nuts

Tables 5 to 7 show, in sequence, the results of further selection. This was conducted by exposing the site-matched species to an elimination process on the basis of tree use and products. For hedgerow intercropping, only 9 species were found to be suitable for the western part of the region, and 10 for the eastern part. Among upperstorey timber species, 23 were suitable for the western area and 9 for the eastern. Seven species of fruit tree were suitable for the western area and three species for the eastern area.

Table 3. Species from ICRAF's MPTS Database that match biophysical site conditions for the western part of Burundi's central plateau region.

Acacia albida Del.
Acacia mearnsii de Willd.
Acacia nilotica (L.) Willd. ex Del.
Acacia senegal (L.) Willd.
Acrocarpus fraxinifolius Arn.
Albizia lebbeck (L.) Benth.
Alnus nepalensis D. Don
Azadirachta indica Adr. Juss.
Bauhinia variegata L.
Butea monosperma (Lam.) Taubert
Carissa edulis Vahl
Casuarina cunninghamiana Miq.
Casuarina oligodon L. Johnson
Cordia alliodora (Ruiz-Lopez & Pavon) Cham.
Erythrina poeppigiana (Walpers *Cook)*
Eucalyptus globulus Labill.
Eucalyptus tereticornis Sm.
Gleditsia triacanthos L.
Grevillea robusta A. Cunn. ex R.Br.
Inga edulis Mart.
Juniperus procera Hochst. ex Endl.
Liquidambar styraciflua L.
Mimosa scabrella Benth.
Parkinsonia aculeata L.
Pinus radiata D. Don
Populus ciliata Wall. ex Royle
Prosopis juliflora (Sw.) Dc.
Psidium guajava L.
Robinia pseudoacacia L.
Toona ciliata M.J. Roem.
Vitex doniana Sweet
Acacia decurrens (Wendl.) Willd.
Acacia melanoxylon R. Br.
Acacia saligna (Labill.) H. Wendl.
Acacia tortilis (Forsk.) Hayne
Albizia chinensis (Osbeck) Merrill
Alnus jorullensis Kunth
Artocarpus integer (Thunb.) Merrill
Bambusa guadua H. & B.
Bursera simaruba (L.) Sarg.
Calliandra calothyrsus Meissn.
Cassia siamea Lam.
Casuarina equisetifolia J.R. & G. Forst.
Cedrela odorata L.
Cupressus lusitanica Mill.
Dalbergia sissoo Roxb. ex Dc.
Eucalyptus camaldulensis Dehnh.
Eucalyptus saligna Sm.
Ficus auriculata Lour.
Gliricidia sepium (Jacq.) Walp.
Grewia optiva Drummond ex Burret
Inga jinicuil Schlecht.
Leucaena leucocephala (Lam.) de Wit
Melia azedarach L.
Morus alba L.
Passiflora edulis Sims
Pithecellobium dulce (Roxb.) Benth.
Prosopis chilensis (Molina) Stuntz
Prunus africana (Hook. f.) Kalkm.
Quercus leucotrichophora A. Camus
Sesbania grandiflora (L.) Poir.
Trema orientalis (L.) Blume
Ziziphus mauritiana Lam.

A number of upperstorey species that emerged from the computerized selection process were eliminated manually in a rapid reassessment process. Until current editing of the programme is completed, this procedure will remain necessary in order to separate 'timber' as a broader use of trees from the more specific descriptor 'timber of saw-log quality'.

Table 4. Species from ICRAF's MPTS Database that match biophysical site conditions for the eastern part of Burundi's central plateau region.

Acacia albida Del.	*Acacia mearnsii* de Willd.
Acacia nilotica (L.) Willd. ex Del.	*Acacia polyacantha* Willd. subsp. *polyacantha*
Acacia senegal (L.) Willd.	*Albizia lebbeck* (L.) Benth.
Acacia tortilis (Forsk.) Hayne	*Alnus nepalensis* D. Don
Albizia odoratissima	*Butyrospermum paradoxum* subsp. *parkii* (G. Don) Hopper
Bambusa guadua H. & B.	*Casuarina equisetifolia* J.R. & G. Forst.
Calliandra calothyrsus Meissn.	*Erythrina poeppigiana* (Walpers) Cook
Cassia siamea Lam.	*Eucalyptus camaldulensis* Dehnh.
Cordia alliodora (Ruiz-Lopez & Pavon) Cham.	*Gliricidia sepium* (Jacq.) Walp.
Eucalyptus tereticornis Sm.	*Leucaena leucocephala* (Lam.) de Wit
Inga jinicuil Schlecht.	*Mimosa scabrella* Benth.
Melia azedarach L.	*Pithecellobium dulce* (Roxb.) Benth.
Parinari excelsa Sabine	*Psidium guajava* L.
Prosopis juliflora (Sw.) Dc.	*Strychnos innocua* Del.
Sesbania grandiflora (L.) Poir.	*Vitex doniana* Sweet
Trema orientalis (L.) Blume	
Ziziphus mauritiana Lam.	

Table 5. Species from ICRAF's MPTS Database that match biophysical site conditions for the eastern or western part of Burundi's central plateau region plus requirements for hedgerow intercropping.

Eastern	Western
Albizia odoratissima	*Albizia chinensis*
Albizia lebbeck	*Albizia lebbeck*
Calliandra calothyrsus	*Calliandra calothyrsus*
Cassia siamea	*Cassia siamea*
Erythrina poeppigiana	*Erythrina poeppigiana*
Gliricidia sepium	*Gliricidia sepium*
Leucaena leucocephala	*Leucaena leucocephala*
Pithecellobium dulce	*Pithecellobium dulce*
Sesbania grandiflora	*Sesbania grandiflora*

Table 6. Species from ICRAF's MPTS Database that match biophysical site conditions for the eastern or western part of Burundi's central plateau region plus requirements for upperstorey timber trees.

Eastern	Western
Albizia lebbeck	*Albizia chinensis*
Albizia odoratissima	*Albizia lebbeck*
Alnus nepalensis	*Alnus jorullensis*
Cassia siamea	*Alnus nepalensis*
Casuarina equisetifolia	*Azadirachta indica*
Cordia alliodora	*Butea monosperma*
Eucalyptus camaldulensis	*Cassia siamea*
Eucalyptus tereticornis	*Casuarina cunninghamiana*
Melia azedarach	*Casuarina equisetifolia*
Cedrela odorata	
Cordia alliodora	
Dalbergia sissoo	
Eucalyptus camaldulensis	
Eucalyptus globulus	
Eucalyptus tereticornis	
Gleditsia triacanthos	
Grevillea robusta	
Grewia optiva	
Melia azedarach	
Pinus radiata	
Populus ciliata	
Prunus africana	
Sesbania grandiflora	

Table 7. Fruit-tree species from ICRAF's MPTS Database that match biophysical site conditions for the eastern or western part of Burundi's central plateau region.

Eastern	Western
Butyrospermum paradoxum	*Artocarpus integer*
Parinari excelsa	*Butea monosperma*
Psidium guajava	*Carica papaya*
Strychnos innocua	*Ficus auriculata*
Ziziphus mauritiana	*Gleditsia triacanthos*
Morus alba	
Psidium guajava	
Ziziphyus mauritlana	

DISCUSSANT'S COMMENTS

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ICRAF has been fostering a science now accepted worldwide under the name of *agroforestry*. This term replaced a number of others, all of which evolved in different parts of the world to describe production practices which involve growing trees, food crops and sometimes grasses and livestock together on the same piece of land.

The important role of trees and other woody perennials in certain agricultural land-use systems is no longer an issue – they are accepted as valuable components. The issues now are the selection of the correct tree genotypes for specified systems and the design of appropriate mixtures of trees, crops and livestock in different ecological situations and for different purposes. Another important issue is the quantification of the interactions between components of such systems in order to devise appropriate management schemes for maximum economic, ecological and environmental benefits.

MULTIPURPOSE TREE SELECTION – SOME DIFFICULTIES

Anyone who has been involved in species selection for afforestation will appreciate the problems posed by the large number of potentially useful woody species. The situation is made worse by the paucity of scientific information on most species: the limited information that is available tends to be rather general.

In the species-selection process, the first step is usually the matching of site and tree characteristics. This is followed by years of introductory trials and the evaluation of provenances before species can be selected with any degree of certainty. ICRAF's system for preselecting multipurpose trees and shrubs (MPTS), supported by a computerized database, has the potential to assist with species selection for a variety of land-use systems.

Whether preselection is based simply on matching species with biophysical site parameters or on a step-by-step sequential process, it should help shorten what was, traditionally, a long period of preliminary selection and field trials. It also has the potential for greater accuracy than the traditional process – a factor particularly important for agroforestry interventions in agricultural production systems.

Conventional afforestation schemes normally cover extensive areas, with one or two species catering sufficiently for any site differences that may exist. By contrast, in agroforestry systems trees are required for much more specific ecological conditions and for more complex and demanding purposes. They are grown with crops that command priority because of their direct food value; for this reason the trees must not be too competitive. ICRAF's step-by-step selection process using the MPTS Database is a powerful tool for selecting appropriate tree species for given sites and objectives in this complex situation.

GERMPLASM AVAILABILITY

A major problem in agroforestry is the limited availability of germplasm for a large number of tree species, relatively unknown and little studied. The ready availability of seeds of selected species, of high quality and in adequate quantities, is indispensable for good agroforestry programmes. ICRAF's *Multipurpose tree and shrub seed directory* is an excellent guide to the few, if as yet inadequate, MPTS germplasm collections in existence. Without this document, it would be even more difficult to follow up species selection with the implementation of research and development programmes.

OPPORTUNITIES FOR COOPERATION

It is not surprising that national and international research institutions now seek ICRAF's guidance on MPTS selection. If ICRAF's MPTS selection programme continues to develop, external requests for this type of assistance will undoubtedly increase with the expansion of global efforts to improve agricultural production systems. There are also opportunities for ICRAF to collaborate with the International Union of Forestry Research Organizations' (IUFRO) Special Programme for Developing Countries. Some of the projects in this programme deal with provenance evaluation and the biology and breeding of selected tree species. If such efforts are concentrated on correctly chosen species, a substantial increase in productivity will be achieved.

SOME CONCERNS

At this point, it is useful to mention a number of concerns. The first relates to the information available in the MPTS Database. This is based on experimentation and field observation, but it comes from various sources and naturally differs in terms of quality, coverage, degree of detail and accuracy. Gaps and discrepancies in the information included in the database will result in weighted judgements and defective selections. For this same reason, some of the information derived from field observations needs experimental validation. This may be particularly important when the observations were made in regions far removed from areas where agroforestry interventions are to be introduced. Experimental testing will ultimately improve the accuracy of species selection and enhance the confidence with which recommendations are made.

Who should conduct the additional research required? This is an open question for ICRAF because of the obvious implications of cost. It seems to me, however, that ICRAF's role must be central for two reasons. First, the additional research is a logical extension of ICRAF's present tree-selection programme. Second, ICRAF's position in agroforestry research demands leadership in this area, which could provide a foundation for other agroforestry research efforts.

One other possible weakness of the MPTS Database in its present form is the limited extent to which it includes an assessment of economic values of tree products in the species selection process. The capacity of trees for ecological and environmental improvement has general appeal, but farmers, who are usually poor, will certainly want assurances of satisfactory economic returns before including trees in their production systems. At the policy level, some government departments may recognize the need for ecological considerations, but in practice they formulate their policies and programmes largely in economic terms.

For these reasons, there is a need to collect more economic information for the database, as economic factors are an important consideration in MPT selection. This is all the more important because environmental benefits may take years to become apparent – whereas farmers are concerned primarily with immediate results in terms of food-crop yields.

Another concern relates to the comprehensiveness of the database. ICRAF's work is no doubt stimulating the expansion of existing databases and the establishment of new ones. However, I think ICRAF's agroforestry mandate demands that the MPT database in Nairobi should be as large and comprehensive as possible to serve as a world reference, at least for the tropical multipurpose trees. Descriptions of 1700 items for 830 tree species is an average of only two descriptions per species! This is hardly adequate if the database is to cover tree biological and morphological characteristics, growth and yield – all related to biophysical parameters. Considerable expansion of the database should, therefore, be an urgent priority.

There is also a concern about categorization of the tree species. Systems are as good as the components which constitute them. Agricultural scientists can provide detailed information on most food crops and animal scientists can do likewise for livestock. Comparable information is needed on multipurpose trees, but little is yet available. Multipurpose trees introduced into agroforestry production systems must be suited for given objectives, as well as genetically, morphologically and physiologically efficient within a given set of biological conditions. Selection should therefore aim to go beyond the identification of suitable species to include the more exacting characterization of provenances. This requires systematic, long-term research. Unless this is done, trees will remain the weak link in the development of otherwise well-conceived, multidisciplinary land-use systems.

ICRAF's field station at Machakos is generating useful scientific information, but basic studies on multipurpose trees need to be expanded further. Additional research should make it possible to exploit the biological potential of these species more fully with the aim of maximizing their contribution to agroforestry systems.

Lastly, existing germplasm collections are of varying quality and offer varying levels of service. The development of these collections, particularly for tropical species, requires stimulation through appropriate international support. ICRAF is in a unique position to contribute in this area by establishing a programme of multipurpose-tree germplasm collection and storage or by promoting a network of existing germplasm-collection activities.

Session 3: Formulating agroforestry research programmes

Choosing and then testing candidate multipurpose-tree species takes into account their arrangement and management for particular agroforestry technologies. This involves choosing priorities and fitting the research plan to the resources available.

FORMULATING AGROFORESTRY RESEARCH PROGRAMMES

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The process of planning research programmes in agroforestry differs in some respects from research planning in other disciplines, not least in regard to the choice of institution to carry out the research. Identifying research problems in agroforestry, setting research priorities and applying research results—all these activities are facilitated by the diagnosis and design exercise, focusing on land-use systems. Research questions in agroforestry refer basically to the choice of species, their arrangement and their management. Objectives can be exploratory (i.e. general) or specific. The technologies developed must be feasible and capable of being extended to farmers.

INTRODUCTION

The process of planning research programmes in agroforestry differs in some respects from research planning in other disciplines, not least in regard to the choice of institution to carry out the research. This is because there are, as yet, very few research organizations that concentrate specifically on agroforestry. Frequently, problems arise in allocating agroforestry research activities between institutions focusing on forestry, agriculture, horticulture, animal husbandry or range management. In fact, one of the important outputs of a macro diagnosis and design (D&D) exercise is to evaluate the national capability and identify the organizations appropriate for agroforestry research.

Other differences include the limited resources, up to now, usually allocated to agroforestry research. Finally, the study of the ecological and economic interactions between plants and animals in deliberately created mixtures is still unfamiliar to many scientists. Table 1 outlines some of the major functions of research planning in agroforestry.

DIAGNOSIS AND DESIGN: A CONTINUOUS PROCESS

ICRAF's D&D procedure is a continuous process, beginning with problem identification and leading through to developed technologies applied on farms. The design phase can be compared with engineering design, with a rural-development or agroforestry 'engineer' designing technologies for certain specified situations (see Huxley and Raintree, 1989).

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Table 1. Functions of research planning – is agroforestry different?

Research Function	Factors Specific to Agroforestry
Stating clear research objectives	Agroforestry involves the study of complex interactions between plants and animals that are often unfamiliar.
Planning and allocating work schedules	Which institutions should undertake agroforestry research? Agriculture? Forestry? Other?
Allocating scarce resources	The different ministries involved are in competition for land, skills, training, finance
Financial control	How many financial controllers?
Use of results	Which extension services?

The research phase is needed to fill gaps in the engineer's knowledge; it includes the design and testing of prototype systems which, in agroforestry, will become an important part of the research process. The design of research programmes, therefore, follows logically from the identification of problems and potentials in the land-use system. It includes the following elements:

- *Formulating research objectives in detail* in line with the problems identified at the diagnostic phase plus subsequent evaluation and systems modelling
- *Planning experimental work* in line with the priorities identified at the diagnostic phase
- *Putting the elements of the research programme in priority* according to the availability of human resources, land, finance and time
- *Planning the dissemination and utilization of information* to be obtained from the programme.

The formulation of research objectives is a particularly complex process in agroforestry where there are so many alternative possible interventions and technologies and, within technologies, so many interactions between components. Indeed, a major problem in planning agroforestry research is setting priorities among the great array of possible experiments that could be done and that are relevant to the problems identified.

Similarly, choosing species for any intervention can be a difficult task. There is a confusing number of possible, and often little-understood, tree and shrub species identified as 'multipurpose' in some way (see von Carlowitz in this volume).

Research planning must rely on a wide-ranging study of what is already known – for example, from databases and field experience both within the country and in overseas and international institutions (Huxley, 1981). Specific studies may also be carried out as a result of the outcome of diagnostic work. All this leads to a decision on what needs still to be learnt – in other words, the overall research objectives. There is an important distinction between what needs to be known and what is merely not known, some of which is irrelevant to the design of any chosen agroforestry technology. Figure 3 in the paper in this volume by Raintree shows the relationships between the diagnostic stage, technology-design considerations and the research which follows (see Huxley and Wood, 1984; Huxley, 1985).

TYPES OF AGROFORESTRY RESEARCH: THE QUESTIONS TO BE ANSWERED

Research to develop workable agroforestry technologies may be classified according to the questions addressed, as follows:

- Which species or mixture or species should be used?
- How many trees should be incorporated into the system and in what arrangement?
- What management practices will be needed – for the trees, for the other components of the system, for the human population and for the institutions concerned? (see Huxley, 1985)

To these first questions should be added:

- What will be the economic performance of the new technology?
- What are the implications of the technology for extension?

From the point of view of planning, the research needed to answer each of these questions could be based on individual trees, on the performance of trees in groups or communities or on trees in mixtures with other components of the system. Livestock are important components in this context, although few studies incorporating animals are currently in progress at ICRAF.

Table 2 indicates the framework within which research topics can be classified under each of these headings. Planned research activities are listed within each 'box', as will be demonstrated in a case study from the humid lowland of Cameroon.

THE LOCATION OF RESEARCH WORK

An important decision that has to be made at each stage of research is *where* the research is to be carried out – on-station, on-farm or even in the forest. In agroforestry, much will be gained from simple observations and field experiments conducted on-farm. Often, the same experiment could equally well be conducted on-station, albeit with slightly different objectives and with different management implications. However, there is a definite leaning, in these early days of agroforestry experimentation, towards on-farm studies. The farmer's participation makes possible a better and more integrated evaluation of the complex interactions involved than would be achieved by a researcher alone. On-farm studies can also give important information on extension aspects and may give economic information not available from on-station trials.

Table 2. Examples of topics for agroforestry research.

Research Objective	Topic	Experimental Approach: Single Trees	Trees in Groups	Trees in a Mixture
Which species or combination?	Morphology/ideotype studies	X	X	X
	Life cycle and size	X		
	Size/yield	X		
	Environmental resource sharing		X	
	Genetic/environmental interactions	x		
How many plants and in what arrangements?	Population and age		X	X
	Intimacy of mixtures			X
	Spacing/rectangularity		X	
	Rooting patterns	X		X
	Litter production/utilization	X	X	
	Nitrogen fixation	X		
What management practices?	Coppicing ability	X	X	
	Pruning/lopping/pollarding responses	X	X	
	Fruiting response	X		
	Fodder-production characteristics	X	X	X
	Environmental stress management		X	X
	Components of yield in mixtures		X	X
How does the technology perform?	Economics of production			
	Seasonal labour use			
What extension aspects?	Seed source and distribution			
	Training needs			
	Input/output characteristics			
	Markets			

On the other hand, on-station trials can be controlled more closely and can facilitate instrumentation or other technological inputs required for some studies of plant-environment interactions. Trials should obviously be on-station if there is any risk of failure.

In agroforestry research, a critical choice also often centres on whether to undertake investigations that are site specific or that can be extrapolated to wider areas. There is certainly much to be said for farmers as research partners, especially since a crude 'lab-to-land' extension approach is rarely applicable to agroforestry technologies.

RESEARCH STAGES

Two stages of agroforestry research can be summarized as:

- Exploratory: What is happening in the system?
- Definitive: How do the components interact (Huxley et al., in press)?

At both stages, two types of research can be conducted, as shown in Table 3:

- Prototype systems: Is the technology feasible?
- Extension: How best can the technology be disseminated?

Prototype systems trials and extension investigations lend themselves particularly to on-farm research partnerships.

Table 3. Examples of agroforestry research stages.

Type of Research	MPT Evaluation	Technology Development	Prototype Evaluation
Exploratory research	Data collection on-farm	Initial management	Central performance of system
	Selection trials	Environmental resource sharing	Seed availability
	Phenology studies	Yield/product studies	Needs for farmer skills
	Seed/propagation studies		Market opportunities
Definitive research	Provenance/progeny tests	Intensive management studies	Detailed system performancey
			Extension needs
	Biochemical studies	More complex yield assessments	Training needs
	Heritability studies	Genotype/site/ management /yield relationships	Land-tenure issues
	Genotype/site interaction evaluation		National policy

Exploratory research

What we regard as exploratory research has two main features. First, it is concerned to a large extent with the acquisition and preliminary testing of multipurpose trees – work that has to precede their more detailed testing in any particular technology. It includes introduction or selection trials for species and provenances, observations on phenology and vigour, early management trials, simple nursery and establishment tests and essential work on seed collection, handling, storage, pre-treatment and germination.

Second, exploratory research tends to occupy limited areas of land for relatively short periods of time, and therefore may often represent all that can be done within a limited budget. In addition to field trials, exploratory research can also include biophysical and socio-economic studies on components which have already been introduced to farms, according to the individual farmer's assessment of needs.

Definitive research

Definitive research includes the proving trials that establish the place of multipurpose trees in a specific technology and how they function in a designated system. This stage of research can include studies on the ways in which trees and crops (or grasses) interact, spacing trials, detailed management investigations (for instance, of lopping, pruning, pollarding, coppicing, age at harvesting) and accurate yield estimations. Research of this type is often more expensive in terms of land and other resources and is of longer duration than exploratory research.

The research workplan

The workplan for an agroforestry research programme will not differ markedly from a plan for agriculture or forestry research. The plan should designate the main topics for investigation, together with the objectives. A special feature of the ICRAF approach is that experiments can always be related back to actual problems identified in the diagnostic stages of the D&D process, i.e. they are 'customized' and directly relevant to the land-use system under investigation.

The design chosen for each experiment will, of course, be related to specific experimental objectives. In many cases, agroforestry research does not demand unique experimental designs, but existing designs certainly have to be adapted. New designs and approaches are also being proposed for specific research topics, as discussed in Huxley's paper in this volume.

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AGROFORESTRY RESEARCH FORMULATION: A CASE STUDY OF THE INITIAL STAGES FROM CAMEROON

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ICRAF's collaborative work in the humid lowlands of Cameroon illustrates the development of a research programme that is derived from and relevant to the problems and constraints of a selected land-use system. The dominant production system in the southern plateau region of the country was selected for research. The farmers in this system commonly manage three types of plot—food-crop plots based on shifting cultivation, permanent cocoa plots and homestead plots. The characteristics of these three subsystems are described, as well as the procedures and reasons leading to the selection of food-crop production under shifting cultivation as a focus for research. This subsystem is managed on fairly infertile, mainly acidic, soils under conditions of declining fallow length and serious labour constraints.

Four agroforestry technologies were proposed for the food-crop fields—simple improved fallows, continuous hedgerow intercropping, rotational hedgerow intercropping and mixed intercropping with soil-fertility improving multipurpose trees. This paper describes the process followed to design the initial research programme on hedgerow intercropping, including further evaluation of local farming practices, literature review, selection of 'best bet' technology designs for early evaluation and selection of priority objectives for experimental trials.

INTRODUCTION

An agroforestry research project initiated in 1986 in the humid lowlands of Cameroon illustrates the initial stages of agroforestry research planning. The project was undertaken jointly by ICRAF and national scientists working with the Institute of Agronomic Research (IAR) under the Agroforestry Research Networks for Africa (AFRENA). This paper reviews the research planning procedures, beginning with a diagnosis of land-use systems and design of appropriate agroforestry technologies, followed by the selection of priority technologies, research topics and experimental trials.

SELECTING PRIORITY LAND-USE SYSTEMS

The AFRENA project in Cameroon focuses on the humid rain forest in the southern part of the country. An initial reconnaissance of the region—called a macro diagnosis and

Table 1. Description of the southern Cameroon plateau.

Annual rainfall	1500–2000 mm
Altitude	200–850 metres above sea level
Soils	Orthic ferralsols (pH 4.0–5.0)
Base production system	Fallow-based (shifting cultivation) food-crop production plus permanent cocoa plantations
Average farm size	1 hectare (ha) under food crops, 1–2 ha under cocoa
Principal food crops	Groundnuts, cassava, plantain
Secondary food crops	Cocoyams, bananas, yams, maize
Principal cash crops	Cocoa, food crops, oil palm, coffee
Use of chemical fertilizers	Minimal
Settlement pattern	Permanent homesteads along roadways
Population density	3–6 head per square kilometre (km^2) in frontier zones; 25–100 per km^2 near Yaounde
Food markets	Rising demand for urban food supplies not met by local producers

design exercise (D&D) – led to the identification of three major smallholder land-use systems:

- the coastal system (low, humid, volcanic soils, well-developed infrastructure)
- the smallholder system interspersed among large-scale commercial tree-crop plantations (low, humid, acid soils)
- the southern plateau system (high, less humid, acid soils, predominance of cocoa).

The southern plateau was selected as the target system for research for technical, economic and policy reasons. Some key characteristics of the southern plateau system are listed in Table 1. There are three major production niches within this system:

- food-crop plots
- cocoa plots
- homestead plots.

Small food-crop plots, consisting mainly of groundnuts, cassava and plantain, are managed under shifting cultivation, typically with fallows of three to eight years. The fallow is longer in isolated forest areas and shorter in the more densely populated areas around Yaounde and in fields near homesteads.

Permanent cocoa plots are also usually located near homesteads. Small ruminants and home gardens are commonly found in the homestead itself. Figure 1 illustrates the typical arrangement of different plots. This pattern is not typical of most shifting-cultivation systems in that homesteads are permanent, clustered along the roadways, leading to intensified production in nearby fields, even in areas of low overall population density.

SELECTING PRIORITY AGROFORESTRY TECHNOLOGIES

In planning the research programme, it was essential to keep in mind the modest resources of the project. The project is staffed only by two senior scientists, a research technician and several casual labourers. Resources are available to carry out major field trials initially at only two sites.

Table 2 summarizes the findings of the initial diagnostic surveys. The most serious challenge identified was to increase food-crop production on fairly infertile, mainly acid, soils under conditions of declining fallow length and serious labour constraints. The decision was made to concentrate on this set of problems in the research programme. A modest level of activity was also planned to focus on the introduction of fodder banks with multipurpose trees to feed goats. The animals could be tethered or penned to prevent crop damage in home gardens and nearby fields. Cocoa researchers at IAR were encouraged to pursue research on diversification of cocoa plantations using multipurpose trees.

Figure 1. Landscape organization in the southern plateau region of Cameroon (Source: Beauvilain et al., 1983).

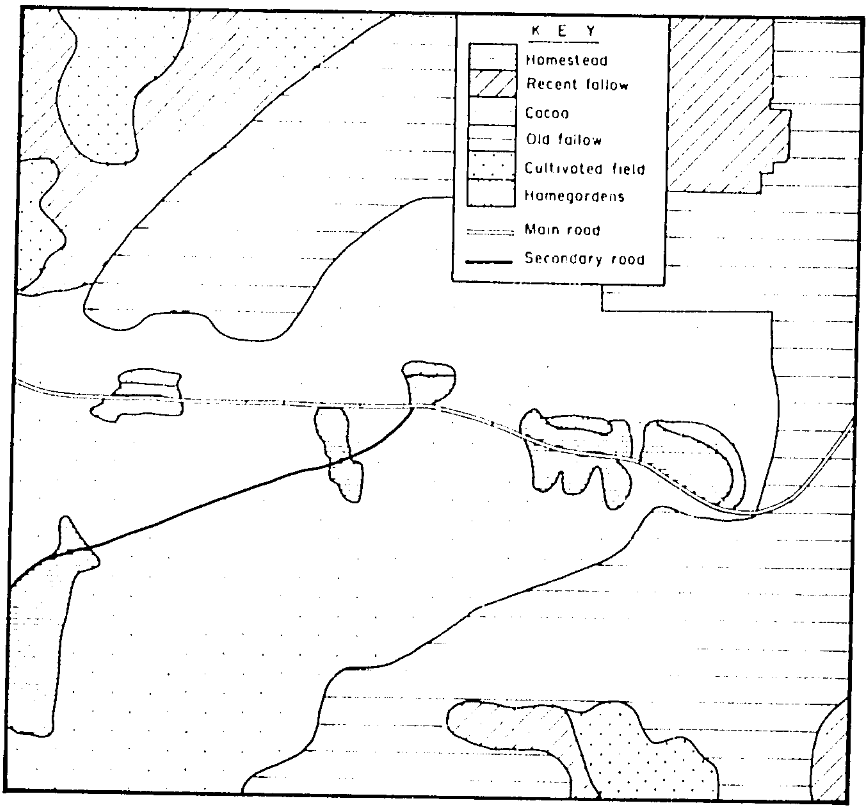

Table 2. Land-use evaluation for the southern plateau region of Cameroon.

Niche/Land-use Problems	Development Strategies	Proposed Agroforestry Systems
Food Plot		
Declining production/ productivity of food crops due to: reduced fallow, low fertility, high acidity, weed competition, pests/ diseases	Increase food production by improving soil fertility for producers with 2–5-year fallows and producers with less than 2-year fallows	Simple improved fallows Hedgerow fallows Mixed intercropping Continuous hedgerow intercropping
Home Compound		
Underdeveloped niche Crop damage from free-ranging livestock	Intensify production	Fodder banks for small stock Living fences for home gardens Multistoreyed home gardens
Cocoa Plot		
Low yields Limited diversification of cash income	Diversify cocoa plantations	Incorporate trees for soil fertility and products for home use/cash income
Labour constraints		
High non-farm employment High labour requirements for cocoa, forest clearing, weeding	Introduce labour-saving tools	Identify labour-saving tools for agroforestry technology

Four agroforestry technologies were proposed to improve soil fertility in this system:

- simple improved fallows
- continuous hedgerow intercropping
- rotational hedgerow intercropping
- mixed intercropping with soil fertility-improving multipurpose trees.

Simple improved fallows are intended to replace existing fallow vegetation with easy-to-establish, fast-growing multipurpose trees with superior soil-regenerating capability. Under rotational hedgerow intercropping, several years of hedgerow intercropping alternate with several years during which hedges are allowed to grow out and the land in the alleys allowed to fallow. In mixed intercropping, multipurpose trees are interspersed in cropland to improve soil fertility through below-ground interactions, leaf fall, and/or pollarding prior to cultivation.

Research priority was given to the two hedgerow-intercropping systems. Rotational hedgerow intercropping could be widely relevant – given current pressure on land – and amenable to intensification. Continuous hedgerow intercropping could be attractive for intensively cultivated food-crop plots near homesteads. Because of serious labour constraints, new tools to improve labour efficiency needed to be identified and evaluated, such as improved machetes or shears for pruning, hand-held or rolling injection planters and hand-held, petrol-powered weeders.

Simple improved fallows could be useful on farms where fallow periods are longer than three years. This technology is also potentially of low cost due to low labour inputs. However, at this time simple improved fallows could only be introduced on an experimental basis due to the lack of proven species for this function. Mixed intercropping might require quite long-term research, although it could be integrated later into a hedgerow system. Thus this part of the research plan called for screening a few multipurpose trees for simple improved fallows and mixed intercropping plus one exploratory prototype trial for simple improved fallows.

DESIGNING A HEDGEROW-INTERCROPPING TECHNOLOGY

A more in-depth field diagnostic exercise led to a set of technology specifications for hedgerow intercropping, clearly defining priority functions and sites. The principal functions of the proposed technology were:

- to increase soil fertility, build up soil organic matter and buffer soil acidity
- to reduce fallow periods without soil degradation
- to increase production of major crops (groundnut, cassava, plantain) in terms of yields per unit of land or labour time
- to reduce labour required for land clearing and preparation and for weeding.

Hedgerow intercropping would be developed for the following site conditions:

- plots averaging one-half hectare with mixed intercrops of groundnuts, cassava, plantain, bananas, cocoyams, yams and maize
- undulating terrain, with crop plots on slopes or tops of hills
- land at an altitude of 600 to 850 metres above sea level
- annual rainfall of 1500 to 2000 millimetres with bimodal distribution
- insolation about 1841 hours a year
- average temperature 25°C, with mean annual variation of 2°C
- relative humidity averaging more than 70%
- well drained, orthic ferralsol soils with a pH of 4.0 to 5.0
- soil-nutrient status varying with length of fallow and cropping history; principal target is soil under one to three years' fallow during cropping cycle.

The micro D&D exercise also identified key criteria for the selection of multipurpose-tree species, spatial arrangements, management and extension. Multipurpose-tree characteristics required included:

- compatible with soil and climate conditions

- leaves moderately slow-decomposing, or different species with slow- and fast-decomposing leaves
- competitive with the principal weed that occurs in fallow periods, *Eupatorium odorata*
- high production of leafy biomass
- not harbouring cocoa/coffee/groundnut pests
- not thorny
- fire resistant.

The required management characteristics included:

- management as continuous or rotational hedgerow intercropping

Table 3. Information needed to develop a hedgerow-intercropping technology for the southern plateau region of Cameroon.

Information Needed	Technology Variables	Determined by System	'Best Bet' Information Available	Research Needed
Which species/ combinations?	**Multipurpose trees:**			
	Climatic/soil suitability		X	X
	Seed characteristics		X	X
	Growth rates/patterns			X
	Farmer use/knowledge			X
	Leafy (woody) biomass production			X
	Mulch characteristics		X	
	Phenology/morphology/ life cycle			X
	Rooting patterns		X	X
	Methods of propagation		X	
	Genetic variation		X	X
	Crops:			
	Interaction with trees			X
	Tolerance of shading		X	X
How many trees, in what spatial arrangements?	Orientation of hedges	X		X
	Number of rows within hedges		X	X
	Between-row spacing within hedges	X		X
	In-row spacing of trees in hedges	X	X	
	Nutrient cycling			X
	Arrangement of associated crops	X		

Table 3, cont. Information needed to develop a hedgerow-intercropping technology for the southern plateau region of Cameroon.

Information Needed	Technology Variables	Determined by System	'Best Bet' Information Available	Research Needed
What management practices?	**Tree establishment:**			
	Method, time, land preparation	X		
	Density of planting, thinning, hedge formation		X	
	Tree management as fallow		X	
	Coppicing height, method, time, frequency		X	
	Mulch requirements/ management for key crops	X		X
	Harvest of by-products	X		
	Weed/pest/disease control in trees and crops		X	
	Control of tree flowering		X	
	Modified crop management	X		
How does the technology perform?	Expected costs and return			X
What extension requirements?	Seed availability, quality			X
	Infrastructure for seed distribution	X		X
	Infrastructure for training			X
	Implications for input and output markets, land use, tenure policy			X

- minimum tillage requirements
- easy tree establishment (direct seeding?)
- minimum labour requirements for hedge management
- careful arrangement of hedges to minimize shading of groundnuts
- time and frequency of hedge cutting linked to crop resource requirements (especially groundnuts)
- consider hedge establishment after the first groundnut crop
- biomass to be cut and burned when managed as fallow

- incorporation of mulch in soils limited by labour constraints
- facilitate use of improved hand-held tools and equipment.

Extension considerations in designing the hedgerow-intercropping technology included factors such as:

- the extensive experience of farmers with tree planting and management
- good existing infrastructure services
- weak crop-extension services
- minimal seed-storage facilities
- limited soil-testing facilities
- limited access to inorganic fertilizers.

Table 4. Hedgerow intercropping: prototype technology trials and extension research for the southern plateau region of Cameroon.

Exploratory Prototype Technology Trials	
Objectives	Explore feasibility of hedgerow intercropping with 'best bet' prototype systems Test different tree species and mulching ratios Obtain farmers' design input
Assessments	Crop yields Biomass production Farmers' evaluation
Location	On-station and on-farm
Start-up year	1: on-station 2: on-farm Set up improved prototype technology trials as new data become available
Extension Research	
Objective	To ensure adequate institutional support for dissemination of hedgerow intercropping
Assessments	Infrastructure for distribution of exotic tree seed to farmers Infrastructure for extension/training in technology management Testing and distribution of new tools for pruning, planting, weeding, clearing
Start-up year	5: with prototype technology validation trials

Within these specifications, the team attempted to design an appropriate hedgerow-intercropping technology for the Southern Plateau land-use system.

In conventional agricultural research, it is common to postpone development of integrated technologies for farmers until all of the major components and their management have been thoroughly evaluated. In the case of agroforestry, however, a linear approach to research – moving from screening and selecting multipurpose trees to testing management systems, then to designing and testing technologies – is untenable, due to the length of time involved.

ICRAF has modified this approach to encourage parallel lines of research on multipurpose trees, tree-crop management and technology development. Long-term evaluation of multipurpose trees is initiated at the start of a project, but management trials are also initiated immediately with the most promising species. Design of integrated technologies is initiated as soon as enough information on the trees and their management is available to justify the hypothesis that such a technology would perform as well or better than the farmers' current system. In some cases, such a 'best bet' technology can be proposed before initiating experimental work. This approach is reflected in the research programme developed for the Cameroon humid lowlands project.

Table 3 lists the basic types of information required by a farmer considering the adoption of hedgerow intercropping. The research team reviewed each variable to see whether (a) it was determined by the land-use system and/or farmer preferences; (b) information could be used from the literature, existing agroforestry systems, standard farmer practices or modelling to find a 'best-bet' solution; or (c) technical surveys or experimental trials were required.

The third column in the table indicates variables which are heavily influenced or determined by the land-use system. For example, the basic parameters of multipurpose-tree spacing and the timing and frequency of coppicing both have to reflect the intolerance of groundnuts to shading. The fourth column gives variables for which we have 'best-bet' information, principally from experience with hedgerow-intercropping trials elsewhere in the humid lowlands.

PROTOTYPE TECHNOLOGY DESIGN AND EVALUATION

Based on the above information, the team judged that it would be possible to design a prototype hedgerow-intercropping system for this zone. Exploratory on-station trials were initiated during the first year of the project (see Table 4). Such exploratory prototype trials allow scientists to identify technology constraints early on and to plan new experimental work to address those constraints in a timely way. The first year's on-station trials looked at the performance of prototypes using different multipurpose-tree species and the effect on crop production of applying different levels of mulch. Exploratory on-farm prototype trials on a few selected farms are planned for the second year to permit early design input and evaluation from farmers. As more research results become available, improved versions of the prototype systems will be designed and tested through replicated on-farm validation trials. These trials can also test improved tools to reduce labour requirements.

As validated prototype systems become available, research will be needed to evaluate the available infrastructure for dissemination of the technology and to arrange collaboration with relevant institutions. Large-scale adoption of hedgerow intercropping requires networks to distribute exotic multipurpose-tree seed to farmers and possibly new tools, as well as an infrastructure for extension and training in technology management. Survey activities to explore these issues are planned for the fifth year of the project.

Table 5. Hedgerow intercropping: multipurpose-tree (MPT) selection trials for the southern plateau region of Cameroon.

Objective	Select best MPTs for hedgerow intercropping (note: larger-scale screening trials to be conducted in Nigeria)
Original list of species to test	Species already growing locally: *Cassia siamea* *Erythrina milbraenii* *Erythrina excelsa* Exotic species already introduced: *Albizia falcataria* *Leucaena leucocephala* *Samanea saman* New introductions: *Inga* spp. *Acioa barteri* *Erythrina poeppigiana*
Assessments	Survival Vigour Root development, phenology Signs of nutrient deficiency Pest attacks Establishment success with and without inorganic fertilizer at planting Growth rate Litter decomposition Soil changes Response to coppicing Response to controlled burn Biomass production
Start-up year	1: Yaounde 2: Sangemelima
Location	On-station

Table 6. Hedgerow intercropping: rotational hedgerow fallow and mulch trials for the southern plateau region of Cameroon.

Rotational Hedgerow Fallow Trial	
Objective	To evaluate performance of different fallow:cropping ratios on crop yields, using typical farmer practices
Assessments	Soil changes Labour use Crop growth/yields Biomass production Fallow species composition
Start-up year	2
Location	On-station
Mulch Trial	
Objectives	To evaluate effect on different crops of mulching with different quantities and application of mulch (microplots)
Assessments	Crop yields/growth Soil changes Weed control
Start-up year	4
Location	On-station

SELECTING EXPERIMENTAL RESEARCH PRIORITIES

The last column in Table 3 indicates the variables that require further experimental research. The first question in technology design is: 'Do we have the components?' We are familiar with some good multipurpose trees for hedgerow intercropping but their performance in improving soil fertility on acid soils has yet to be established – especially for groundnut/cassava/plantain production. Large-scale multipurpose-tree screening for acid soils will be carried out in a joint project at Onne, Nigeria, conducted by ICRAF with the International Institute of Tropical Agriculture (IITA). For this reason, the team working in Cameroon decided to concentrate initially on evaluating nine promising multipurpose-tree species – three local species, three exotic species already being tested in Cameroon and three newly introduced exotic species. Table 5 lists the major assessments needed to evaluate the potential of these species for hedgerow intercropping. A survey is now in progress to ascertain the knowledge and experience of local farmers with different multipurpose trees; this should result in the identification of additional locally growing species, which will be added to the trials.

The second question is: 'Do we know the numbers and spatial arrangements required?' This is fundamentally determined by the quantity and quality of biomass that will be available to improve soil fertility and also by the nature of the environmental resource-sharing characteristics of particular trees and crops. Only limited information in this area is available from the literature; provisional data will be forthcoming from the prototype systems trials. The conduct of more elaborate 'tree-crop interface' trials will have to await the establishment of zonal research projects within the AFRENA programme for the humid lowlands of West Africa.

The third question in technology design is: 'Do we know how to manage the technology?' From experience with hedgerow intercropping on non-acid soils in the humid lowlands, it was judged that 'best-bet' approaches were available for most of the important management variables not already determined by the system. Serious information gaps related to optimum fallow:cropping ratios and pruning practices for rotational hedgerow intercropping and also to the management of leaf mulch with different intercrops. The team thus initiated two trials to explore these questions (see Table 6).

Two sites were selected for major experimental activities: the Nkolbisson Central Research Station near Yaounde, representing the forest-savannah transition zone of neutral to moderately acid soils, and a substation in Dja-et-Lobo, representing the zone of higher rainfall and more acid soils. The initial stage of strategic planning for the research programme, as described in this paper, was followed by preparation of a more detailed work plan and acquisition of multipurpose-tree seeds by the senior scientists in charge of the project.

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AGROFORESTRY RESEARCH FORMULATION: A CASE STUDY OF PROJECT IMPLEMENTATION FROM CAMEROON

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This paper describes practical aspects of the start-up of an agroforestry research project in the humid lowlands of Cameroon. Key issues of multipurpose-tree germplasm acquisition and nursery establishment are discussed, followed by a brief account of initial field trials testing multipurpose-tree introduction and management and hedgerow intercropping.

INTRODUCTION

ICRAF and the Cameroon Government's Institute of Agronomic Research (IAR) began implementing a collaborative agroforestry research project in March 1987. The project was originally planned for two locations: Dja-et-Lobo, in an area of low population density, and Leke, with a relatively high population. However, activities are currently concentrated at the main IAR research station at Nkikolbisson, near Yaounde.

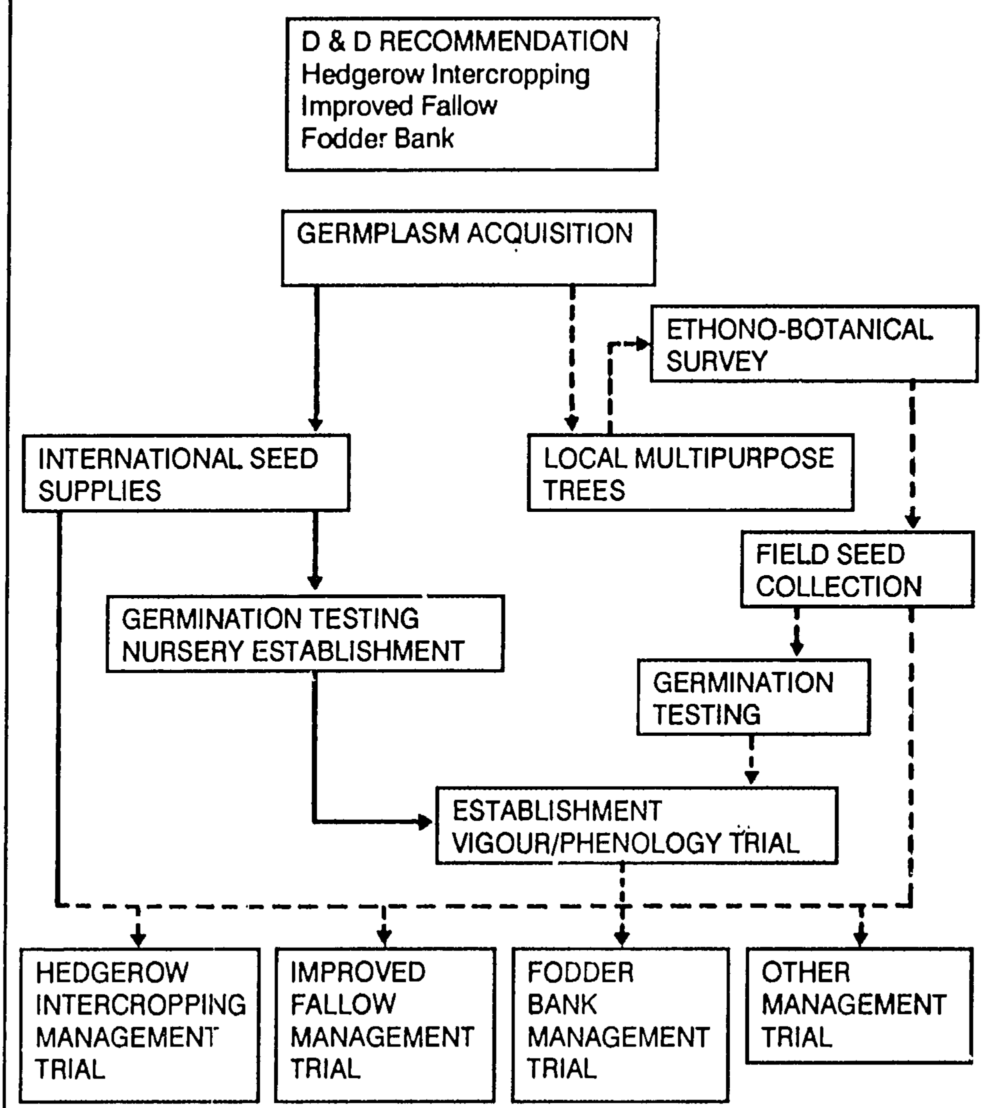
The primary aim of the project's first phase is to design and test three agroforestry technologies identified as priorities for the region. These are hedgerow intercropping, improved fallows and fodder banks. Most of the work in progress or about to begin is exploratory research.

The research strategy is shown in Figure 1. Key research areas include germplasm acquisition and testing, nursery establishment, vigour/phenology trials and management trials.

GERMPLASM ACQUISITION

Project scientists identified a list of multipurpose trees and shrubs with good potential for the region during the diagnosis and design (D&D) exercise. Eighteen exotic species were ordered from 16 suppliers in different parts of the world. Several local species were also obtained and more will be identified during an ethno-botanical survey. As of September 1987, seven of the suppliers had provided only 10 of the species ordered. In addition, the project obtained several species from the International Institute of Tropical Agriculture (IITA) in Nigeria, including *Crotalaria anagyroides, Alchornea cordifolia, Psophocarpus palustris* and *Flemingia congesta* (see Table 1). The International Livestock Centre for Africa (ILCA) in Addis Ababa provided nine species, but in quantities too small to be used in the trials.

Figure 1. Stages of research in the IAR/ICRAF Collaborative Agroforestry Project in humid lowlands of Cameroon.



GERMINATION TESTS AND NURSERY ESTABLISHMENT

Most of the species obtained from international sources lacked detailed information on their germination potential or requirements for pretreatment of seeds. Therefore, they were tested for germination potential before sowing. The project established a nursery to raise seedlings as planting stock for subsequent trials. Among the seeds obtained, *Acacia mangium*, *Albizia falcataria* and *Cassia javanica* showed poor germination, even after scarification by acid treatment.

VIGOUR/PHENOLOGY TRIALS

An initial vigour/phenology trial is not, strictly speaking, a complete elimination or screening procedure. Plans include a larger-scale screening procedure later in the high-rainfall areas of Nigeria. The research team is conducting the present trials primarily to assess the adaptability of multipurpose-tree species to local conditions under environmental stress, with and without crops. Information on tree vigour, phenological stress patterns and response to management (pruning and/or pollarding) should help determine which species are most promising for the proposed agroforestry interventions.

Ten species were included in the trials, eight established from seedlings and two by direct sowing. Different species were established by different methods because seed batches were not all obtained at the same time.

MANAGEMENT TRIALS

Some of the multipurpose-tree species under consideration in Cameroon have been tested in other places. However, full management trials for specific agroforestry technologies are only possible once the potential and adaptability of the tree components have been established under local conditions. While this work is in progress, the research team is conducting trials to assess crop-yield responses to various mulch ratios under hedgerow intercropping. The tree species used in the study are *Cassia siamea*, *Calliandra calothyrsus*, *Sesbania grandiflora*, *Sesbania sesban*, *Leucaena leucocephala* and *Gliricidia sepium*.

Researchers are conducting improved-fallow trials to assess the establishment of selected multipurpose-tree species and the viability of this technology under local conditions. Fodder-bank and mixed-cropping experiments are at the planning stage.

KEY ISSUES

Four key issues were identified during the initial stages of this project:

- It is essential to ensure that germplasm is obtained well in advance to ensure the timely and uniform implementation of trials. If seed arrives well in advance, researchers can avoid using both direct seeding and seedlings in the same experiment.
- The initial diagnosis and design exercises need to assess local economic and other conditions that can facilitate or hinder the implementation of field research – for example, the availability and cost of labour, cost of inputs and the general cost of living. This information is vital for proper research budgeting.
- In collaborative projects, it is important to ensure that the contributions expected from national institutions are in fact feasible. Plans should include alternative ar-

rangements, in case any participating institution is unable to meet its commitments, before the decision is taken to implement a field research programme.

- Based on the size of the project, an adequate level of support staff should be provided for and appointed early in the implementation phase.

Table 1. Multipurpose tree and shrub species suggested, ordered, obtained and tested by the IAR/ICRAF Collaborative Agroforestry Project in Cameroon.

Species	Suggested	Ordered	Obtained	Tested	Considered for: HI	IF	FB	MC
Acacia auriculiformis		X	X	AB				X
Acacia mangium		X	X	A				X
Acacia retinoides			X				X	
Acacia barteri			X			X	X	X
Albizia glaberrima	X					X		X
Albizia falcataria	X	X	X	A	X	X		X
Albizia ferruginea	X					X		X
Alchornea cordifolia	X					X		X
Anthonotha macrophylla	X				X		X	
Calliandra calothyrsus		X	X	AB	X			X
Cajanus cajan	X	X	X		X	X		
Cassia javanica		X	X	A	X			X
Cassia siamea	X	X	X	AB	X	X		X
Codariocalyx gyroides			X				X	
Crotalaria anagyroides		X				X		
Desmanthus virgatus			X				X	
Desmodium cinereum			X				X	
Desmodium discolor			X				X	
Desmodium distortum			X				X	
Dialium guineense	X					X		X
Erythrina excelsa	X					X		
Erythrina poeppigiana	X				X	X		
Flemingia congesta		X	X		X	X		
Gmelina arborea		X	X					X
Gliricidia sepium	X	X	X	AB	X	X		X
Leucaena leucocephala	X	X	X	AB	X	X		X
Pithecellobium dulce			X				X	
Psophocarpus palustris			X			X		
Samanea saman	X				X	X		
Sesbania grandiflora		X	X	AB	X			
Sesbania sesban		X	X	A	X			
Trema orientalis	X					X		
Inga spp.	X	X			X	X		X

HI = Hedgerow intercropping; IF = Improved fallow; FB = Fodder bank; MC = Mixed cropping; A = Vigour/phenology trials; B = Management trials.

DISCUSSANT'S COMMENTS

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INTRODUCTION

ICRAF's approach to multipurpose-tree research has been reviewed in four sections: problem analysis, mult'purpose-tree selection, research programme formulation and experimental design. Speakers in Session 3 have focused our attention on the following as significant issues:

- the diverse institutional base, limited funding and relative novelty of multipurpose-tree and integrative agroforestr" research
- the challenge of setting prioriti s amongst the many options of agroforestry systems; e.g. the species and combinations to evaluate, the choice of management and harvest methods, the diversity of product uses
- the location of research trials: i.e. the search for a balance between on-station and on-farm activities, while continuing to satisfy both applicability issues and statistical demands for extrapolation
- the power and limitations of exploratory versus definitive research.

We have been provided with an excellent illustration of ICRAF's approach to the design of an agroforestry programme and a candid appraisal of its limitations.

SOME CONCERNS

Among my preliminary reactions and concerns on these issues are the following, allowing for the inherent biases of a plant breeder:

- **We must not design programmes that are too inflexible:** Multipurpose trees are versatile, often easily convertible from one use to another, and one experiment can serve many research objectives.
- **We must not overestimate the tenure of tropical scientists:** Long-term career scientists with long-term support are rare; for this reason, long-term multipurpose-tree breeding programmes are almost unknown.
- **We should not underestimate the power of genetic improvement:** Most multipurpose trees are barely domesticated, based on narrow germplasm sources with no selection for yield, let alone ideotype.
- **We must not overestimate the duration of multipurpose-tree trials:** Many multipurpose trees reach mature height in two years, so time in planning should not exceed time in execution; sets of evolving exploratory studies are useful, each based on results of its predecessor.
- **We must not separate researchers too far from their research:** Tree/crop interactions can change daily, and impromptu, empirically derived data can be a most powerful source of inspiration.

- **We must not categorize agroforestry research solely as problem solving:** Basic research is needed, for example, on taxonomy, ecological diversity and the physiology of even the most popular multipurpose trees; basic understanding is lacking in areas such as allelopathy and root interactions, to name but two.
- **Multipurpose-tree research must be published:** Programme planning must include regular progress reports, avoiding any tendency to postpone publication until 'after the next set of data'.

Session 4: Experimental designs for multipurpose-tree research

We need to understand the combinations of tree, crop and livestock components in an agroforestry technology, but reduce them to simple categories and choose appropriate field designs and assessment methodologies in order to investigate them.

EXPERIMENTAL DESIGNS FOR MULTIPURPOSE-TREE RESEARCH

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This paper describes ICRAF's approach to designing field experiments for multipurpose-tree research. It highlights the need to simplify the potential number of experimental situations and proposes a scheme for doing this.

The paper begins with a brief discussion of the particular constraints on experimental design arising from the complexities of agroforestry research. It gives three examples and makes suggestions on how to overcome various design constraints for multipurpose-tree introduction and testing, for experiments with tree/crop associations and for rotational experiments in time. In discussing problems of field assessment, phenological recording is emphasized as a tool for understanding adaptability. The paper also mentions ICRAF's Datachain – a computerized data-capture and data-handling facility.

Proposals follow to reconsider the approach to on-farm agroforestry experimentation and the need for single-tree investigations and biophysical surveys. There is a clear need for innovation and elaboration of existing agricultural approaches to field experimentation for agroforestry research.

INTRODUCTION

The preceding papers have presented, with examples, a logical process to arrive at well-focussed proposals for *relevant* agroforestry research. I now want to give a brief account of some considerations and suggestions for field experimental designs that have been found useful at ICRAF for agroforestry investigations of different kinds, with some examples and comments to illustrate the points made.* A 'diagnosis and design' exercise can answer the question: 'Experiments for what?' We now address the problem: 'What kind of experiments?"

REDUCING THE NUMBER OF EXPERIMENTAL SITUATIONS

The first task is to reduce the seemingly innumerable experimental situations arising from the study of multipurpose trees (MPTs). Experiments are needed to select appropriate

*Extensive discussion on the basis of agroforestry experimentation is found in ICRAF's series of booklets on 'Source materials and guidelines for research methodology for the exploration and assessment of multipurpose trees', (P.A. Huxley, editor, 1983–) and in a number of other ICRAF publications.

Table 1. Simplifying the number of experimental situations (source: Huxley, 1986a).

Categories*	Sets of Experiments Required
1. Species selection and testing (for all types of agroforestry)	Multipurpose-tree introduction and assessment trials; assessment methodologies and data analysis need careful review and, in some cases, development
2. Investigations concerned with promotion of *mixed* agroforestry systems	Tree/crop interface effects; simple phenology studies aimed at providing information about tree management; investigations into ways of optimizing environmental resource sharing; land sustainability
3. Investigations concerned with promotion of *zonal* agroforestry systems	Tree/crop interface effects; simple management trials (lopping, spacing); land sustainability
4. Investigations concerned with promotion of *rotational* agroforestry systems	Tree-planting density; early management; harvest removals in relation to 'trade-offs' in terms of outputs removed versus land sustainability
5. Special subject areas (according to pro-blemsassociated with particular agroforestry systems)	For example, nitrogen fixation, honey or gum production, fodder value, timber or fuelwood quality; these will mainly use well-tried research methodologies where available

*1 is likely to be common to all programmes; 2,3 and 4 will be selected according to type or types of agroforestry system; and 5 may be necessary in particular cases.

MPT species for various niches, to understand the kinds and complexities of their association with other plant components and to discover the best ways of arranging and managing them. Fortunately, considerable simplification is possible, at least during the initial stages of research. Table 1 indicates an approach that has been found useful.

EXPERIMENTAL DESIGN CONSTRAINTS AND THEIR IMPLICATIONS

Once an experimental focus has been formulated, the general framework within which the design of *any* agroforestry field experiment can be considered will conform to the following requirements:

- it will address the appropriate stage of the investigation
- it will have strictly limited objectives
- it will aim to provide rapid results, with high cost-effectiveness.

This suggests that we are more likely to be looking at an array of small, simple trials, rather than large, complex experiments – at least in the first instance.

The very nature of agroforestry land-use systems imposes increased levels of complexity on any field investigation. An agroforestry experiment may well have to incorporate several of the following concerns into the plan and design:

- a requirement for multiple products and 'service' outputs: Which of these are to be accommodated in the experiment, and which standardized?
- a need to explore useful variability (both biological and environmental), which may be far greater than that found, for example, in many agricultural crop situations: To what extent is this variability to be contained or exploited?
- the possibility to study the woody component as single plants, as a community of a particular species or as woody/non-woody plant mixtures: To what extent can the structure and assessment methodologies adopted maximize the kinds of information obtained for each of these?
- an awareness of spatial constraints and opportunities – i.e. planting densities, species ratios, plant arrangements and the level of intimacy of different plant associations: How best can we explore an adequate range of possible combinations of these factors?
- an appreciation of the temporal limitations imposed, on the one hand, by the nature of woody perennials (length of life cycle, juvenile/mature phases, dependence on preceding season's influences) and, on the other hand, by the need to investigate the possible beneficial effects of trees on soil with time: In what ways can a design achieve a compromise between maximizing information and limiting both the size and duration of experiments?

In practical terms, and depending very much on the specific objectives of any particular investigation, these issues greatly effect experimental design. This occurs through:

- the choice of kind and number of experimental units; this reduces to considerations of plot number, plot size and internal guard areas
- the choice of how experimental units are best combined, i.e. aggregation (blocking) and external guard areas.

Agroforestry field research demands considerable skill in order to resolve conflicting requirements. These are, basically, to keep the experiment from becoming too large and unwieldy whilst, at the same time, taking into account the number of potential treatments and the space needed to test each effectively without interfering with the others or introducing bias. The plot size must be large enough to achieve a reputable biological test, yet block size must be small enough to maintain environmental homogeneity. Partial replication is a powerful tool in balanced or unbalanced designs (Huxley and Mead, 1988). On tropical sites, regularly shaped blocks may be quite inappropriate (especially as what is occurring underground at tree-root depth may be only partially known). Thus an agroforestry experimental 'block' may often be irregular in shape, or even fragmented, in order to fulfil the basic requirements of environmental homogeneity (Figure 1).

Figure 1. Fitting an appropriate experimental design to a specific site is essential for any kind of field research programme, but special care is required in agroforestry because trees and crops (or grasses) may be affected differently by particular site characterisitics. Spending time to establish appropriate blocking schemes is well worth the trouble. Here is a hypothetical case where differences in soil depth on an otherwise fairly homogeneous site make it impossible to have normal contiguous plots in each of the three blocks (I-III). Treatments are not yet assigned.

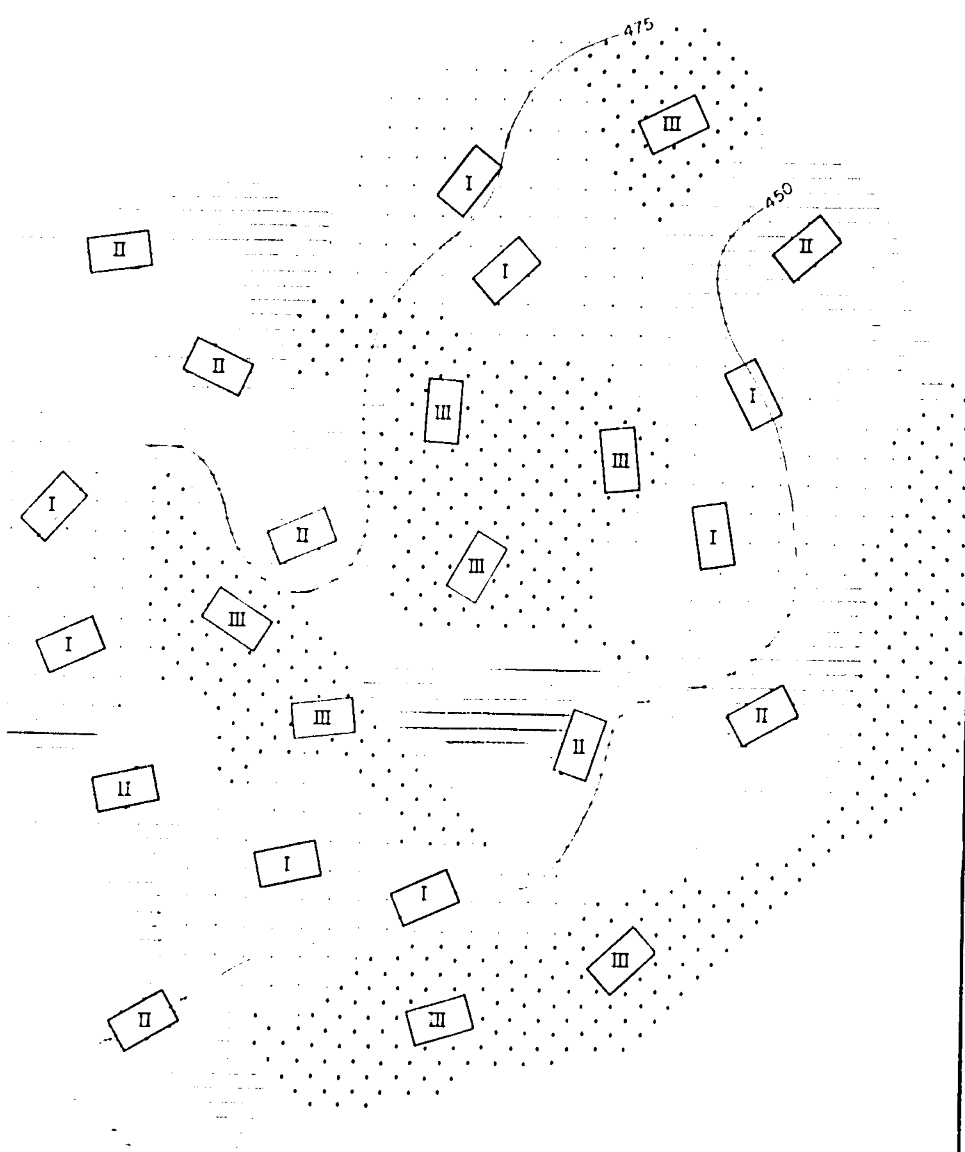


Table 2a. Example of a layout for species and provenance proving trials: 30 entries, using blocks of 5 plots (modified design from a semi-balanced lattice) (source: as suggested by R. Mead in Huxley et al., 1987).

Blocks	– Entries –				
1	1	2	3	4	5
2	6	7	8	9	10
3	11	12	13	14	15
4	16	17	18	19	20
5	21	22	23	24	25
6	26	27	28	29	30
7	1	12	17	22	27
8	2	7	18	23	28
9	3	8	13	24	29
10	4	9	14	19	30
11	5	10	15	20	25
12	6	11	16	21	26
13	1	8	20	21	30
14	2	9	15	22	26
15	3	10	11	17	28
16	4	6	12	18	24
17	5	14	16	23	29
18	7	13	19	25	27
19	1	6	15	19	28
20	2	11	17	21	29
21	3	9	20	23	27
22	4	10	13	16	22
23	5	7	12	24	30
24	8	14	18	25	26

SOME DESIGN EXAMPLES

Despite the simplifications proposed in Table 1, the nature of agroforestry experimentation and the need to address precise objectives for each experiment preclude the feasibility (or, indeed, the desirability) of producing 'recipes' for experiment design. We can, however, draw up guideline proposals. I propose to present three, relating to the appropriate sets of experiments outlined in Table 1.

Multipurpose-tree introduction and testing trials

Assuming that all entries have been pre-selected for a whole range of needed characteristics, the scope of multipurpose-tree introduction and testing trials will cover the

Table 2b. Example of a layout for species and provenance proving trials: 27 entries, using blocks of 6 or 7 plots (source: as suggested by R. Mead in Huxley et al., 1987).

Blocks	–		Entries	–			
1	1	2	3	4	5	6	7
2	8	9	10	11	12	13	14
3	15	16	17	18	19	20	21
4	22	23	24	25	26	27	
5	1	5	9	13	17	21	15
6	2	6	10	14	18	22	26
7	3	7	11	15	19	23	27
8	4	8	12	16	20	24	
9	1	7	10	12	17	19	22
10	2	5	8	13	15	20	27
11	3	9	14	16	21	23	24
12	4	6	11	18	25	26	
13	1	6	11	13	20	24	
14	2	8	12	14	17	13	15
15	3	5	10	16	19	19	27
16	4	7	9	15	18	21	22

following three stages of investigation, either separately (in trials overlapping in time) or amalgamated in some way:

- species/provenance elimination trials (to test entries for likelihood of survival in the environment at the site)
- vigour/phenology assessments (to test entries for biological suitability, i.e. how closely they are adapted)
- early-management trials (suitability for the intended system).

Progressively fewer entries (50 or more down to 10 or 12) will be required. The last two stages – vigour/phenology and early-management trials – may, perhaps, be most readily combined.

Two types of design for this kind of trial are now so well established among crop scientists that they need no elaboration. These are lattices (Table 2a) and, more recently, 'alpha' designs (Table 2b). They seem equally well suited for the assessment and selection of woody species as long as species which have very different growth rates and habits are kept to separate experiments.

Another approach used extensively for testing multipurpose trees is 'augmented blocks' (see Table 3). Professor James Brewbaker and the Nitrogen Fixing Tree Association have considerable experience with this form of rotational design.

Table 3. Augmented randomized complete block design (source: J.L. Brewbaker).

Block	Treatments (not yet randomized) Replicated						Unreplicated	
1	A	B	C	D	E	F	G	H
2	A	B	C	D	E	F	I	J
3	A	B	C	D	E	F	K	L

- Use estimated error variance from anova containing replicated treatments only.
- Adjust replicated treatment means for the effect of the replication in which it occurs before comparing means
- Use appropriately calculated SEs of differences between means.

Separating the elimination stage

There is an important reason for separating the elimination stage experimentally from the other two stages of investigation. Some entries are possibly going to fail (i.e. prove non-adapted to the site; see Figure 2a). Then missing plots, irregular sample sizes, increased error variance, non-homogeneous treatment variances and possibly non-normal sample distributions may undermine the statistical evaluation of the results – or at least make it more complicated and less reliable. However, agroforestry research planners may wish to avoid the time delay consequent on first completing at least the initial stage of an elimination trial before proceeding. How might this be resolved?

Thinning: an experimental tool

A compromise solution could be to establish larger plots than would be needed in a dedicated elimination trial and to undertake sequential thinning so that, eventually, for the early-management studies, only a few specimens are left on each plot (see Figure 2b). This procedure will help safeguard against a situation where large numbers of missing plots occur, although the method of selecting plants to be removed could introduce considerable bias. Failures must be eliminated before the start of the experiment proper, according to a strictly laid down protocol. Thinning would have to be carried out at random among those plants remaining. Thinning must also be carried out without causing below-ground disturbance to the remaining trees.

Using the system's constraints to help eliminate

Another demand on design ingenuity arises because of the requirement to eliminate multipurpose-tree entries – and also to examine their vigour/phenology attributes – against conditions of competing weedy vegetative growth, and not just in terms of general eco-climatic suitability as would normally be done. As all who have conducted weed-competition experiments know, the problem of establishing standard levels of weediness across a set of experimental plots is seldom an easy one. Therefore, the proposal here is to substitute a standard crop species, chosen for an established level of 'competitiveness' and sown at an appropriate planting density and time in the growing season, in order to simulate the 'weed stress' required. The level of competition of the standard crop and of the actual weed situation could be compared in separate trials, if need be. Thus a rather complicated combined elimination-vigour/phenology-early management trial could be carried out which also incorporated a 'simulated weediness' treatment. This would use a robust, randomized block arrangement with either a fully factorial set of treatments or a split-plot arrangement, depending on the statistical sensitivity of the tests required.

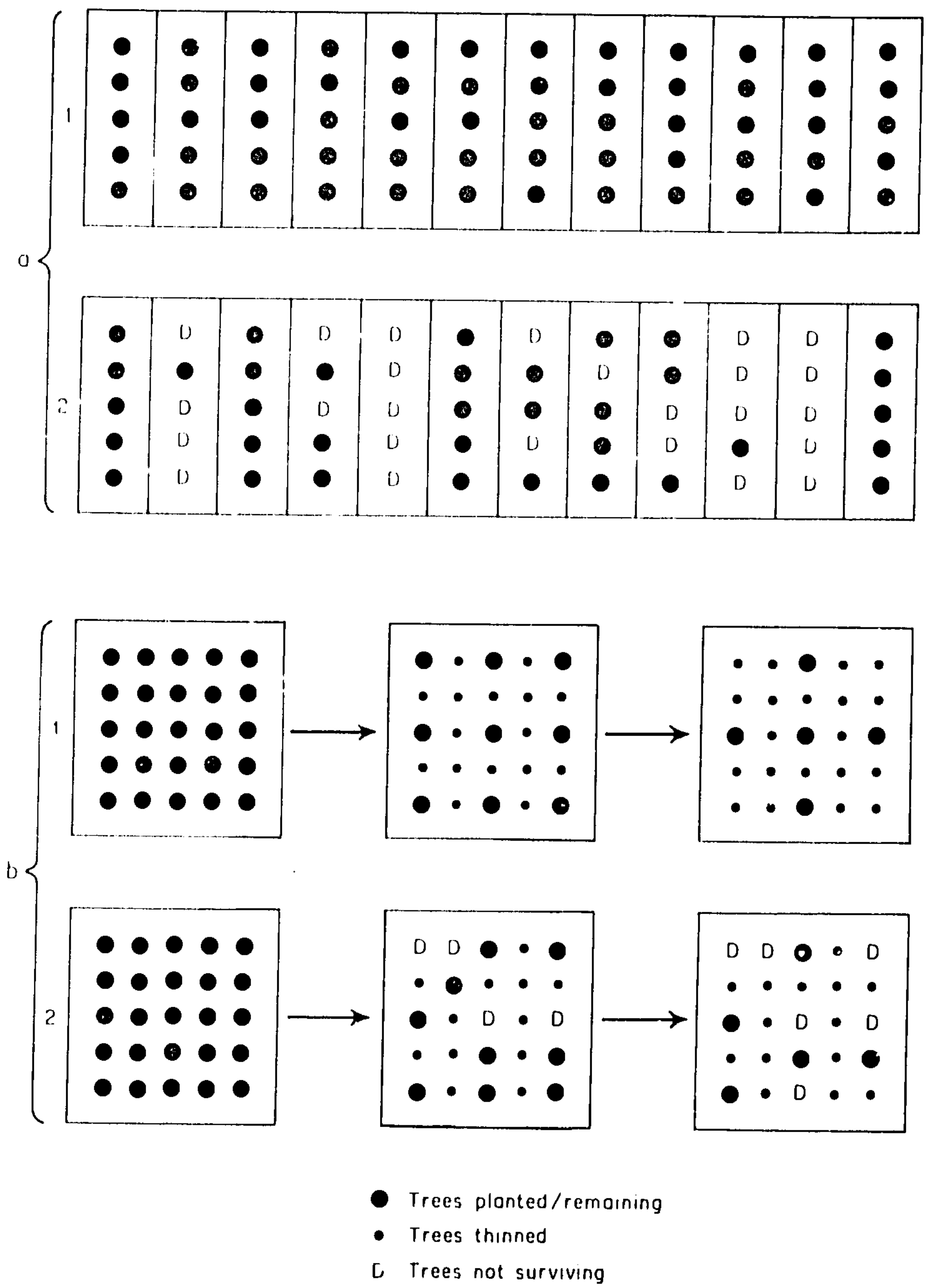
Conclusions

The design problems raised so far are relatively simple. They mainly encompass some dimensional considerations, plus additional demands for compressing what would normally be a series of sequential trials into either an overlapping series or some combination of the required tests -- all without jeopardizing the investment of relatively large amounts of research resources through ill-conceived designs. In the next two examples we meet some considerably greater complications.

DESIGNS FOR THE STUDY OF TREE/CROP ASSOCIATIONS

Designs for the study of tree/crop associations can be divided into investigations of 'mixed' or 'zonal' systems, where the intimacy of the woody and non-woody plants is either encouraged or restricted, respectively. In parallel with field experimentation, some prototype systems testing may be required (best-bet observation, with many treatments confounded). However, from a strictly experimental point of view, the more advanced investigations represent a formidable array of possibilities, and hence design opportunities and requirements. Nevertheless, in the initial stages a high degree of 'simplification' is possible. How can this be?

Figure 2. a: One block of an MPT introduction/testing trial showing small (12 x 5-plant) linear plots of different species (or provenances), when planted out (1) and after the first season (2). Clearly, there is little point in including any longer-term management treatments in an experiment where survival rates may be as poor as shown here. b: Example of larger individual plots which can be successively thinned. These might be more suitable for combining a test of survival after planting out with longer-term vigour/phenology or early-management trials. In (1) survival is complete and a regular thinning pattern can be imposed; in (2) some early and mid-term losses can be accommodated, even though final within-plot spacing is somewhat irregular, as long as the trees are not to be grown on to a stage where mutual interference becomes an important factor. At any stage, it is important that the surviving young trees are thinned according to pre-defined criteria and so as not to introduce bias for size.


a
1
2
b
1
2
Trees planted/remaining
Trees thinned
Trees not surviving

The questions

On examining the problem, we see that we are first going to ask questions relating to productivity (production per unit land area per unit time) and to the way in which the woody and non-woody plant components share available environmental resources – either intrinsically or under some designated form of management. Second, there will be questions of sustainability (i.e. sustainable production with time) and potential, including possible soil changes. An experimental programme may require answers to questions about both productivity and sustainability.

Now, if we design a field experiment that resembles the system for which precise answers are needed, then we are very likely to have too large a range of factors under study. It will be impossible to deal with all of these factors as experimental variables and the extent and degree of confounding will be high. This means that interpretation of the processes and interactions will be difficult and the experimental results may well not be repeatable if carried out under circumstances where even one factor is changed. In other words, the experiment has become highly site specific.

Tree/crop interface – the basic unit

How can we resolve the problem of complexity and make experiments small enough so that we can easily repeat them at different sites? Is there one common feature, which lends itself to experimentation, that can be the key to understanding *any* agroforestry system? I believe that there is.

The fundamental feature of any agroforestry land-use system is the presence of woody and non-woody plant associates. If we can designate a unit on which to experiment, it is just this association at its simplest level. At ICRAF we have been working for a number of years on the design and assessment methodologies of, for want of a better term, the 'tree/crop interface' (Huxley, 1986b).

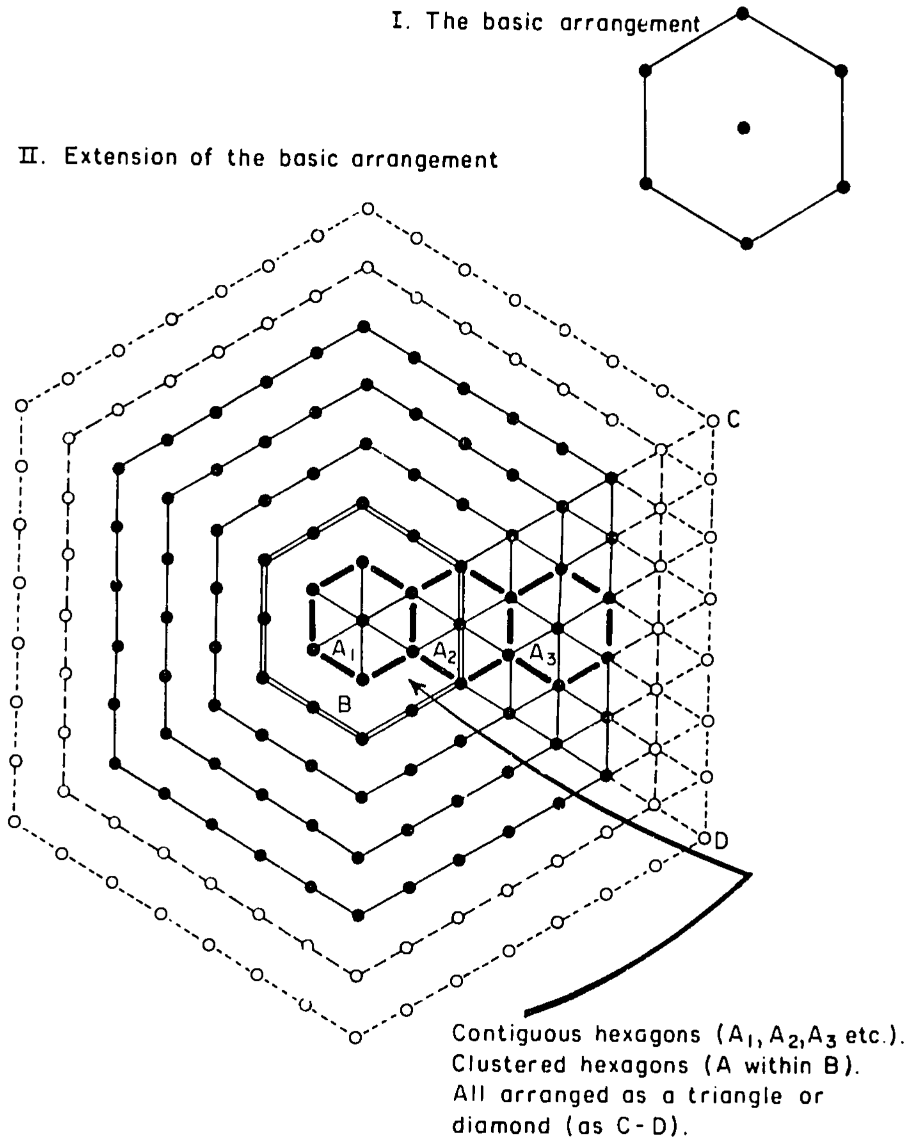
What and how?

The first practical question that any agroforestry research project needs to answer is '*What woody/non-woody components go best together?*' (treating the problem only bio-physically at this stage). This is followed by '*How does that result come about?*' Answers to the second question are needed in order to extrapolate to other environmental conditions. Because *any* system can be structured from the tree/crop 'units', a knowledge of the production potential (and sustainability aspects) of such units would seem to be a priority.

Designs

Research on tree/crop mixtures or zonal associations can beneficially start with investigations on the 'tree/crop interface'. Indeed, the work at ICRAF has resulted in a general acceptance that relatively small experimental units are sufficient. For example, these might consist of a short length of hedgerow and some parallel rows of crop, which will suffice to

Figure 3. Hexagonal arrangements for testing MPT species and/or MPT/crop associations – conceptual framework.



explore fully the component parts of any hedgerow-intercropping scheme, i.e. the hedge, the crop and the interaction between the two.

On theoretical grounds, the orientation of zonal arrangements can have an influence on the outcome – through shading, rainfall redistribution or shelter by one plant component on another. This aspect can be incorporated if it is thought to be relevant. If it is not

Table 4. Example of a layout for a rotational hedgerow-intercropping trial in six blocks. Each block has four cropping:rotational tree-fallow ratios, but they have been arranged in different ways at the start so as to provide different sequence x season comparisons. Because these are replicated in pairs of blocks, statistical tests can be applied both within and between blocks at any one time as appropriate. Hedgerows are established in all plots during the season (0) preceeding Year 1. Thereafter, different patterns of managing the hedgerows are adopted, either by cutting them back at the start of (and perhaps during) the designated cropping season (C) or ceasing to crop and letting hedges grow untouched (T). This table shows the first 13 years of an experiment: these can be repeated as required (source: Huxley et al., 1987).

Ratio of Cropping in Alley to Tree Fallow (non-cropping period)	– Year –													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Blocks 1 and 2														
1:1		C	T	C	T	C	T	C	T	C	T	C	T	C
1:2		C	T	T	C	T	T	C	T	T	C	T	T	C
2:1		C	C	T	C	C	T	C	C	T	C	C	T	C
2:2		C	C	T	T	C	C	T	T	C	C	T	T	C
Blocks 3 and 4														
1:1		T	C	T	C	T	C	T	C	T	C	T	C	T
1:2		T	C	T	T	C	T	T	C	T	T	C	T	T
2:1		T	C	C	T	C	C	T	C	C	T	C	C	T
2:2		T	C	C	T	T	C	C	T	T	C	C	T	T
Blocks 5 and 6														
1:1		C	T	C	T	C	T	C	T	C	T	C	T	C
1:2		T	T	C	T	T	C	T	T	C	T	T	C	T
2:1		C	T	C	C	T	C	C	T	C	C	T	C	C
2:2		T	T	C	C	T	T	C	C	T	T	C	C	T

C = cropping phase; T = rotational tree-fallow phase.

to be included as an experimental factor, it might still be wise to confound orientation with blocking, just in case.

In fact, researchers can study a tree/crop interface wherever it is found, for instance in other types of experiment. Otherwise, simple randomized block, 'geometric' or systematic spacing designs are suitable, depending on the resources available and the specific objectives of the experiment. There are numerous suggestions for experimental units and layouts (e.g. Huxley, 1986a, 1986b and 1987). Tree/crop-interface experiments have to be thought of as similar to biological assays in that, because of the large number of biophysical factors, those to be considered experimentally need to be defined and controlled precisely and all others have to be standardized.

I have indicated that such field experimentation can form a useful part of the *initial* stages of an investigation. Later experimental stages may use the same approach, but also test management factors at various levels of detail. These may require more robust, standard (e.g. randomized block) designs, possibly with partial replication in order to contain the size of the experiment. Eventually, we will need to consider layouts for more advanced prototype systems trials. Yet by that time, enough exploratory experimental work will have been completed to make possible a carefully planned and relevant prototype design.

Intransigent problems

Some design problems seem particularly intransigent – especially those relating to intimate tree/crop mixtures, which may often contain numerous species. Current investigations simulate appropriate species mixtures but in some ordered arrangement (e.g. Flores Paitan, 1986). Useful as these investigations are, assessment possibilities can result in an incredible amount of data for which a rigorous statistical analysis still needs to be devised. In many cases, some form of 'nearest-neighbour' technique might be useful, and appropriate designs need to be elaborated (e.g. 'beehive' designs; see Figure 3).

Sustainability experiments

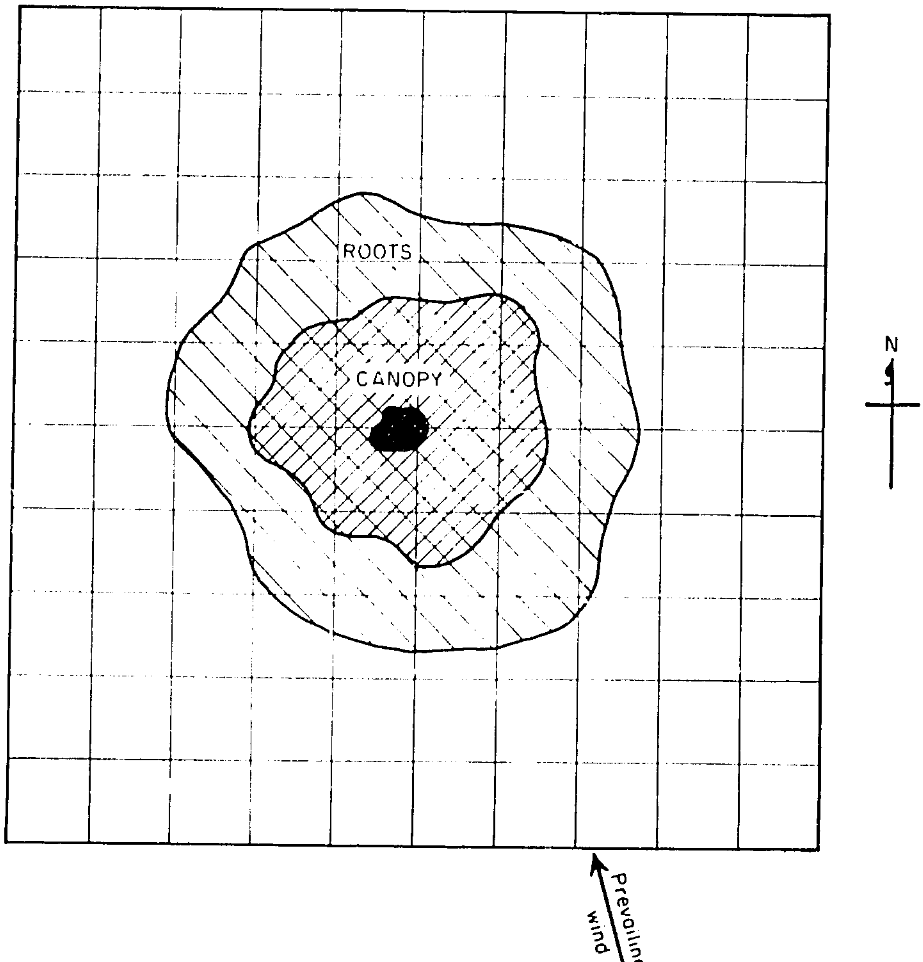
In many cases, data on sustainability are acquired through a programme of soil (and plant tissue) analysis for the appropriate characteristics. We may need to know something about the 'rates' at which things happen, and not just the 'states' (the 'what' and 'how' again). Much of the required information will be found by adding the appropriate assessment methodologies to existing experimental situations and, of course, by surveying appropriate situations on-farm and in natural vegetation. The implication for existing experimental designs is, perhaps, mainly to increase the dimensions. On the other hand, the use of micro-plots (or containers) for examining the effects on soil of factors such as plant residues is an obvious instance of conserving experimental resources and focusing on the fundamentals, i.e. chemical changes in plant residues and chemical and physical changes in soil.

Designs for rotational experiments

Rotational experiments pose some special design problems unique to agroforestry. First, experiments involving a sequence of land occupancy by different crop species, or species mixtures, pose the usual design choice – either different species can be sown or planted in different years (or seasons) so that plots are examined/harvested in the same year after their respective rotation times, or they can be sown or planted in the same year and examined/harvested in different years as each rotation runs its course. The first alternative entails delays that may be unacceptable in what will, in agroforestry, in any case be a lengthy experiment. The second involves making between-season comparisons of crop components that are subject to the high season-to-season variability commonly found in tropical and subtropical areas. Indeed, as trees are very much influenced by what has happened in *preceding* seasons, it is, again, necessary to consider comparative measurements on trees between rotation sets only after these have been concluded and 'converge' at a particular time. All in all, this presents something of a challenge to the experimentalist.

There is probably no one solution to this quandary. A compromise will be chosen depending on the resources available, the time that can be allocated to the experiment (not less than 12 to 15 years with fast-growing multipurpose trees), the precise objectives

Figure 4. Hypothetical single-tree environment interaction study: stem, root and canopy as at 15 years. Dimensions of individual grid squares will depend on the degree of discrimination required. The total number of grid squares, and thus the overall size the measured plot, will depend on the dimensions of individual squares plus the number of samples that it is practical to handle, e.g. 8 x 8 1.5-metre squares for a medium-sized tree (source: Huxley and Mead, 1988).



and the priority assigned to crop comparisons versus tree comparisons. Another consideration is that very young trees are unlikely to influence adjacent crops or, certainly, to change soil characteristics to any extent. Some delay is inevitable until trees reach a reasonable level of maturity.

To help limit the size of such an experiment, the design approach is, again, to establish sets of rotational treatments that are assembled in blocks with partial replication (Huxley et al., 1987). Table 4 presents an example with comparisons of various sets of appropriate treatments at selected years. The structure of such a design requires a good deal of thought and its analysis requires the assistance of a competent statistician.

ASSESSMENT PROBLEMS AND DATA ANALYSIS

Introduction

Agroforestry experiments require many more kinds of assessment than agricultural experiments, and assessment methodology will also influence experimental design in several ways. Clearly, there are additional considerations in determining plot size if factors such as litter fall have to be measured or if assessments can damage a plot, as in soil sampling over many years. Most assessment problems call for a common-sense approach and a thorough appreciation of what to measure, how and when.

Phenological records

One important assessment that should be included in every agroforestry experiment is the phenological behaviour of the components, especially the woody perennial species. These can display many different types of growth and development, leading to practical conclusions concerning management strategies and – especially important – the opportunities for growing them in association with crops (or grasses). The techniques of measurement are extremely simple and the cost-effectiveness of the information obtained is high (Huxley et al., 1989).

Data analysis

Existing techniques for data analysis are likely to be adequate for all experiments with multipurpose trees except, as already indicated, for studies of highly complex experimental layouts with multi-species, multi-storied treatments. Currently, the most urgent need is much simpler: We have to analyse and evaluate agroforestry field experiments without delay and communicate the outcome as rapidly as possible.

To do this, we must help with the analysis of experimental data generated by national research projects, where sophisticated computer hardware and/or software may not be available and where staff may not necessarily be familiar with the use of currently available computerized statistical programmes. ICRAF is preparing a user-friendly software package called Datachain (A. Pinney and P. Muraya, personal communication). This will, ultimately, provide a facility for each research collaborator to design forms and collect field data, using inexpensive, hand-held equipment, which will load directly onto a micro-computer. A capability for data quality control will be included, as well as modules of appropriate forms for statistical analysis and plotting facilities.

APPROACHES TO ON-FARM EXPERIMENTATION

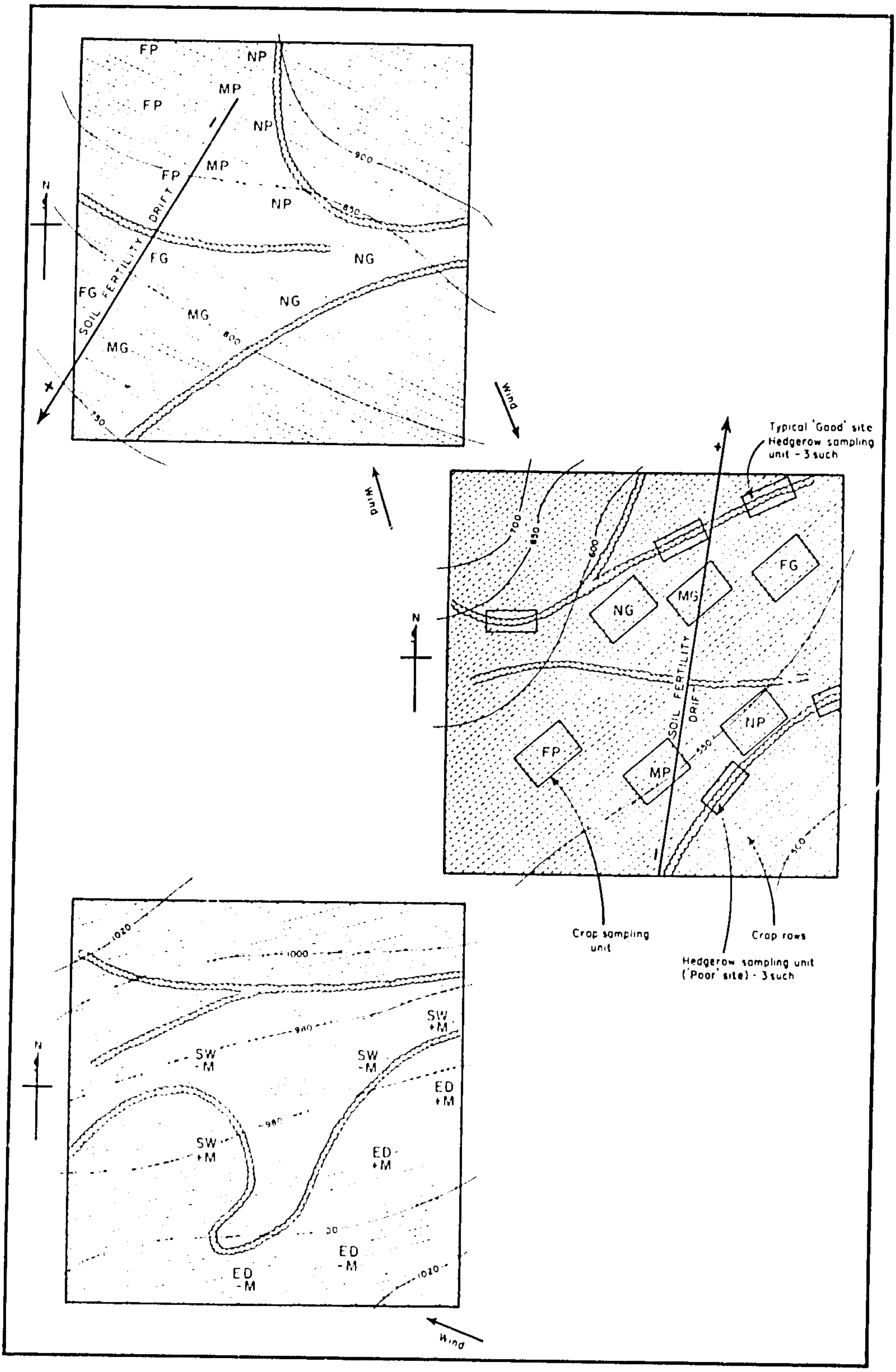
A reconsideration needed?

To design on-farm experiments with multipurpose trees, we have to reconsider normal agricultural approaches because of the particular constraints of tree-based experimentation and the farmer's possible reluctance to make any kind of investment in trees. Classical experiments, as we know them in agriculture, were originally designed for work in temperate regions on large, flat, relatively uniform experiment stations. The concepts and techniques of agricultural field experimentation have been modified for on-farm circumstances mainly in two ways: they have been miniaturized (fewer treatments, smaller plots) and modified to take account of the high level of locational variability. This has been done by adopting the concept of a 'block' as an environmentally uniform unit, but with all parts not necessarily contiguous. Despite these modifications, the outcome is often startling to the farmer and experimentally (biologically and statistically) inefficient and/or inadequate. A more ecological approach to on-farm investigations for agroforestry seems appropriate (Huxley and Mead, 1988). Two examples will be outlined.

Biophysical surveys

A large amount of information lies waiting to be uncovered concerning the interaction of trees with crops or grasses and trees with soil. This information can be discovered either from natural stands of vegetation or from farmer's fields. One approach could be by collecting appropriate data from selected single trees (or small stands of single species) for which a valid history is known or can be found (Figure 4). What constitutes 'appropriate data' and how can we obtain it most cost-effectively? ICRAF has recently initiated a project to investigate such assessment methodologies.

Figure 5. Location of hedgerows and crop sampling units at three hypothetical on-farm sites (fields). An ecological approach to on-farm experimentation sets out to *exploit* the existing variability. Plots/quadrats can be selected with the farmers' help, and a range of conditions established that reflect relevant existing situations – these would represent large differences. 'Interference' (e.g. management) treatments could be imposed on a random sample of each. The diagram shows three such 'fields' in which quadrats (ecological treatments) represent two levels of fertility (G = relatively good; P = relatively poor) and three levels of proximity of the crop to a hedge (N = near; M = moderately near; F = far). This gives six combinations, NG, MG, FG and NP, MP, FP. An even simpler comparison could be to measure crop and hedge production in an 'exposed/dry' site (ED) and a 'sheltered/wet' site (SW) (see Huxley and Mead, 1988, for more information).


FP
NP
MP
FP
NP
FP
MP
NP
FG
NG
FG
NG
MG
MG
SOIL FERTILITY DRIFT
900
850
800
750
Wind
Wind
Typical 'Good' site
Hedgerow sampling unit - 3 such
700
650
600
FG
NG
MG
NP
FP
MP
SOIL FERTILITY DRIFT
Crop sampling unit
Crop rows
Hedgerow sampling unit ('Poor' site) - 3 such
1020
1000
980
SW +M
SW -M
SW -M
ED +M
SW +M
ED +M
ED -M
ED -M
Wind

The 'quadrat' approach to on-farm experimentation

In order to compare different treatments on-farm, we could discard attempts to manipulate and miniaturize the classical experimental design and, instead, adopt a more ecological approach. This would entail examining 'quadrats' rather than conventional experimental plots. Such 'quadrats' could consist either of available on-farm agroforestry situations ('ecological' treatments) or manipulated situations ('imposed' treatments) or both. Sets of each would be chosen at random from all those available at any one site (Figure 5). Treatments (or situations) should be markedly different from one another because such experiments are normally only concerned with establishing large differences.

Appropriate sets of on-farm 'ecological' situations could also be achieved by planting and managing new agroforestry interventions, which will be assessed – and the comparative outcomes evaluated – only after a suitable time. Results from sets of plots would be compared using relevant statistical methods, which might include appropriate forms of regression or multivariate analysis.

With such an approach, the validity of each 'cluster' of plots forming any single treatment would need to be established at the start. The practicality of the 'ecological' approach will depend on the amount of effort, resources and skill required to achieve this.

Obviously, in theory, the two types of approach ('conventional' and 'ecological') are not completely dissimilar. However, addressing on-farm situations in an ecological context will promote designs that are more exploitive of natural heterogeneity. Furthermore, the experiments can be clearly focused on a set of relevant and limited objectives and the farmer can more easily be made a participant. This is because she will not only be concerned with the selection of treatments and the design of the trial, but can also be allowed to manipulate all those residual areas in the 'design' that are not specifically set aside as researcher-assessed plots. At present, ICRAF is initiating a programme to establish the feasibility of this approach with on-farm multipurpose-tree research.

CONCLUSIONS

As agroforestry research becomes increasingly experimental, there is a need to structure, prioritize and simplify research approaches – designs and assessment methodologies must be both efficient and cost-effective. Many of the conventional designs used in agricultural research are suitable for situations involving multipurpose trees, but often some innovations or extensions to existing concepts are needed. ICRAF has made a start – both in consolidating what is already known to be useful and in opening up new areas of experimental thought.

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DISCUSSANT'S COMMENTS

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THE RESEARCH STRATEGY

ICRAF staff members are obviously aware of the problems posed by the large number of variables and interactions inherent in agroforestry experiments, and hence the need to limit the number of questions to be answered from a single experiment. They also recognize the need to keep experiments as simple as possible in order to minimize the cost and workload. ICRAF has therefore proposed the following steps for an agroforestry research strategy:

1. diagnosis and design studies to identify agroforestry needs in support of various farming systems
2. selection of tree species that have characteristics appropriate for the particular needs of a given agroforestry system
3. elimination and provenance trials to select a smaller number of species that appear well suited to the given ecological and management conditions
4. field experiments with even fewer selected tree species that perform suitably under specified conditions, including tree/crop interface situations.

The first two steps should help focus the objectives of an experiment and hence reduce the number of variables to be measured. The third step can be achieved through standard forestry experimental techniques and would further reduce the number of species to be incorporated in the actual agroforestry experiments.

GENERAL CONSIDERATIONS IN DESIGNING EXPERIMENTS

The fourth step is the subject of this session's discussions, with the emphasis on how to obtain valid results from agroforestry experiments. The first consideration is how to determine whether a given species of tree is appropriate and beneficial, either as single trees or in stands (woodlots, shelterbelts, hedgerows). Eventually, the main interest here is to determine optimum spacing in relation to management for required outputs. The designs suggested seem equally appropriate depending on site characteristics. The question of spatial orientation could, however, be played down since in actual practice small-scale farmers are especially constrained in space allocation, aspect and orientation. Careful observation of trees within a stand may be adequate to detect whether mutual shading or other aspects of spatial orientation are causing significant systematic effects.

The second consideration is the behaviour and nature of interactions between plant species in close proximity or mixtures. Of special interest is the productivity and interactions of woody and non-woody (agricultural crop, pasture) species. The problems in tree/crop-interface experiments are somewhat similar to those encountered in intercropping with agricultural crops but they are much more complex due to the large differences in characteristics and behaviour between woody and non-woody plants. The design of agroforestry experiments is also further complicated by the absence of basic information on the physiology of many tree species, particularly the indigenous tropical species, and hence our inability to predict the nature of interactions in a tree/crop interface situation. The fact that the tree or shrub species included in agroforestry experiments are also intended to be multipurpose – either in terms of the nature of their products or the possibility of 'managing' them in different ways to achieve different products or services – further complicates the design of even the simplest experiment.

THE NEED FOR DETAILED STUDIES OF BIOPHYSICAL AND AGRO-CLIMATIC CHARACTERISTICS

While complex experimental designs and careful visual observation can be used to test plant compatibility and enhance the productivity of agroforestry systems, the cost-effectiveness and information yield of such experiments is limited by insufficient knowledge of the characteristics of individual species. For this reason, a parallel effort is required to search, analyse and compile all available information on a wide variety of tree species, especially their physiology, phenology, growth and yield under different environmental conditions. Of particular interest is information on rooting patterns in relation to soil moisture availability, on canopy structure and light interception and on nutrient requirements and nutrient recycling characteristics. For species of particular interest in existing agroforestry systems, it will also be possible and highly desirable to study some of these characteristics *in situ* in mature trees. This information would facilitate a certain degree of theoretical modelling, a technique which is playing an increasingly important role in improving the design, and hence the cost-effectiveness, of agricultural experiments.

THE CHOICE OF EXPERIMENTAL DESIGN

The presentation and various reports prepared by ICRAF staff members on the subject of experimental design recognize the special problems of experimentation in agroforestry research – especially problems caused by site heterogeneity and the requirement for large plots to accommodate trees, as well as the long maturation period of most woody species. In most cases, these problems preclude the option of repeating experiments over time. Experimental designs must also accommodate the possible loss of experimental plants and the changes such losses may cause in the behaviour of the plants remaining.

The choice of experimental design is influenced mainly by the factors to be investigated, together with site characteristics. In addition, at the present stage of development of research capacity, especially in the field of agroforestry at the national level, experiments should be kept as simple and small as possible and the quality of observations should take precedence over the number of replicates. It is also essential to ensure that facilities exist for the continuous collection and analysis of data. An important feature of ICRAF's collaboration with national programmes will be to assist collaborators, as necessary, with facilities for rapid data analysis and evaluation.

Site heterogeneity is particularly serious in low-potential areas and on sloping ground. These happen to be the areas of greatest need and they also have the largest number of problems that must be overcome in order to best use their natural resources for sustainable production. A normal practice in agricultural experiments is to test the homogeneity of the site using a seasonal cover crop. However, such tests may fail to reveal variations in the soil profile that could become increasingly significant with time as tree species develop deep rooting systems. A careful survey of the soil profile will undoubtedly help in site selection and 'blocking' of experimental layouts, but experimental designs should also incorporate the possibility of superimposing stratified sampling if major problems of this nature are noticed as the tree crops mature.

ROTATION EXPERIMENTS

Rotation experiments appear to introduce complex interactions that are difficult to sort out until main effects in each system are well documented and their mechanisms understood. Some effort in this area seems justifiable at ICRAF collaborative sites, using the suggested incomplete block design – if only to test the approach. However, rotation experiments may unduly complicate work at the national level if introduced at this early stage.

PHENOLOGICAL OBSERVATIONS

Trees are known to respond phenologically to environmental (seasonal) variations in soil moisture, temperatures and other factors, as well as to management practices such as fertilization, pruning, coppicing and flower removal. Since all agroforestry practices involve some form of tree management, prior knowledge of the phenological responses of multipurpose trees to different management practices and ecological conditions would be very useful – not only in the choice of species, but also in deciding what factors are to be varied or standardized in experimental designs.

A coordinated programme of phenological observation on a number of multipurpose-tree species could be initiated by ICRAF with national programmes with minimal resource requirements. However, the interpretation of such data depends heavily on the standardization of observations and careful training of observers. In terms of priority, phenological studies rank alongside biophysical measurements as a prerequisite for ensuring cost-effective experimentation with multipurpose trees and shrubs.

ASSESSMENT PROBLEMS – DATA ANALYSIS

Recognizing the difficulties of analysing large quantities of data at project level, ICRAF staff have produced a Datachain facility, starting with electronic data recording at field level and including data quality control and eventual analysis and plotting. Such a system should work well provided it is available to field staff at every stage of experimentation.

Field researchers should be able to identify problems of data quality promptly so that observations can be repeated if possible or an assessment technique improved. They should also be able to carry out some analytical manipulation and preliminary analysis.

ON-FARM EXPERIMENTATION

One important purpose of on-farm experimentation is to test the validity of conclusions reached through well-controlled on-station experiments when such controls are relaxed in actual farming situations. Another purpose is to observe any additional factors that may emerge at farm level through the introduction of proposed technologies. If farmers are to participate in research on their farms, then the proposed designs and procedures must not impose significant expense or inconvenience on them. This condition is rightly recognized to be particularly relevant to agroforestry experiments because these are usually long term.

Considering the present state of knowledge of biophysical interactions in existing agroforestry systems and the difficulties involved in on-farm experimentation, the proposal to initiate on-farm research with studies of existing systems appears appropriate. This would be through a procedure of identifying and analysing quadrats containing features such as single trees, hedges or shelter belts.

Some multipurpose-tree species have already been identified that provide benefits recognized by farmers. A limited network of on-farm testing could certainly be developed, especially with well-selected, innovative farmers or in isolated sites, in order to build up information on the appropriateness of these species for various agroforestry systems.

A SUMMARY OF QUESTIONS AND ISSUES

1. The very limited knowledge of the biophysical characteristics of tropical woody species and of their phenological behaviour in various environmental conditions means that experimental designs, however sophisticated, may raise more questions than they answer. In this case, should not the proposed research effort be more strongly supported by a vigorous programme to compile information on individual species and to supplement this information with further studies of phenological behaviour in relation to environmental conditions? Such investigations would include studies of rooting patterns in relation to soil moisture, of canopy structure and light interception and of nutrient demands and nutrient recycling.

2. In spite of the efforts being made to simplify experimental designs, there will still be difficult problems of site selection and layout in view of the inevitable site heterogeneity. It may, therefore, be desirable to incorporate in the design the possibility of stratified sampling and analysis should serious systematic differences occur as trees mature. Will tests of site heterogeneity with an annual crop reveal those differences occurring throughout the soil profile that may increasingly affect a woody perennial as it matures?

3. At this stage, it may be unnecessary to complicate experiments by introducing questions of orientation. Some of the influences of orientation can probably be inferred

from routine observations and existing knowledge, for example of the effects of shelterbelts and windbreaks on microclimate.

4. The difficulties of organizing rotational experiments are recognized. Are these experiments of sufficient priority at this stage, considering the scarcity of knowledge on the main species characteristics? Incomplete block designs appear appropriate, but they complicate experiments unduly unless a certain degree of modelling can be carried out to define the main effects to be observed.

5. The phenological responses of multipurpose-tree and -shrub species to environmental and management factors are important indicators of adaptability and suitability for different types of agroforestry practice. However, the value of phenological data depends on the availability of a standard set of observations and trained observers. ICRAF could play a leading role in initiating international or regional programmes in this area.

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