A TREE FOR ALL REASONS

The Introduction and Evaluation of Multipurpose Trees for Agroforestry

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J. Burley
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The idea of producing a source book at ICRAF on the early stages of multipurpose-tree research was proposed in 1986, and partial funds for undertaking this task were kindly provided by the Federal Republic of Germany. Mr Peter Wood, then Senior Forestry Advisor in ICRAF’s Research Development Division, undertook responsibility for compiling material for the book, and Dr Jeffrey Burley, Director of the Oxford Forestry Institute, joined him for the month of April 1987 as a consultant.

This source book is the result of their collaboration. It is intended to help field workers who may be planning experiments on multipurpose trees or establishing prototype systems trials using best-bet agroforestry species and technologies to bring about improvements in land-use systems as quickly as possible. This book is part of an expanding range of publications aimed at supporting ICRAF’s own collaborative programmes and assisting all who are concerned with the study and development of agroforestry.

B.O. Lundgren
Former Director-General
ICRAF
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The authors acknowledge the participation and help of many colleagues in the preparation of this book. In particular, Peter Huxley of ICRAF maintained a close interest at all stages, commenting on several drafts and contributing substantially to Chapters One, Two and Three. Also at ICRAF, Till Darnhofer, John Raintree and Anthony Young contributed information on climatology, sociology and soil science, respectively. Howard Wright and Trudy Watt of the Oxford Forestry Institute kindly read and made valuable suggestions for Supplement Three. Janet Stewart of the same institute made valuable comments on Chapter Eight. Sidney Westley of ICRAF edited the text and shepherded the book through the production process. Terry Hirst designed the book and Gerlinde Darnhofer was responsible for typesetting and layout. Kathy Stephen worked with Peter Wood in London to produce the illustrations and cover design. Her quick grasp of the experimental principles and landscapes contributed greatly to the finished drawings.

We hope that this book will be a help to agronomists, foresters and other scientists, and especially to those in the field who are actively concerned with improving our knowledge on the use of woody perennials—multipurpose trees and shrubs—in rural development generally and in agroforestry in particular.

Responsibility for the final text and any errors or omissions lies primarily with the first author, who will be grateful to hear from readers on how the book might be improved.

P.J. Wood
J. Burley
This book provides guidance for the introduction and evaluation of woody perennials for use in agroforestry. By woody perennials we include not only trees, shrubs and bushes, but also palms, woody grasses, such as bamboos, and climbing plants, such as rattans. Throughout the book all these are referred to as MPTs—multipurpose trees. Many plants of this kind are already well known in agriculture, horticulture and forestry, but others are little known outside quite restricted areas. This book is primarily concerned with guidelines for evaluating these less well known species for introduction into agroforestry systems.

In this context, introduction means taking a species to an environment where it is not well known or established. Evaluation refers to the process of determining the suitability of a particular species, either for use in an agroforestry system or for further research in combination with other plant or animal components. The evaluation process seeks, first, to determine the adaptation of the species to the site, as demonstrated by its survival and early growth, and, second, to study its phenology and morphology as a guide to its suitability for a specific agroforestry production system.

Agroforestry is defined here as ‘all practices that involve a close association of trees with crops, animals and/or pasture. This association is both ecological and economic. Agroforestry may involve a combination of practices in the same place at the same time (intercropping and related practices), or practices in the same place but at different times (rotational practices). The “place” may be as small as a single garden or cropland plot or as extensive as a small watershed or a vast stretch of communal grazing land’ (Rocheleau et al., 1988).

In some instances, it may be possible to include MPTs in prototype trials of agroforestry systems, without a prior stage of MPT species evaluation. The objective of such trials is to evaluate the performance of an agroforestry system as a whole. However, there is some danger of wasting research effort if mixtures of woody and non-woody plants are tested together before enough is known about the suitability of each to the site under study. Thus, before prototype systems trials are conducted, research is often required on the MPT species. It may be possible to save time by testing a species in light of the requirements of a particular agroforestry technology—for example, a species that is to be used for hedgerow intercropping could be tested from the start as lopped hedges.

The objectives of this book may be summarized as follows:
- To give basic principles for MPT evaluation, rather than ‘recipes’, helping the research scientist to design and develop appropriate research programmes to meet specific objectives.
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- To present a logical, chronological sequence of the stages of MPT research, including the early study of possible responses to management
- To give guidance for the preparation of simple, robust experimental designs
- To recommend simple and easily measured assessment procedures.

The book is organized in four sections and four supplements. The four sections are:
- The background to species selection for agroforestry
- Research planning and design
- Assessment and evaluation
- Important areas of research work.

The supplements are intended to amplify the information contained in the main text. They include a checklist of principal characteristics of MPT species and their products, a list of assessments for the evaluation of MPTs with sample formats, experimental designs for the introduction and evaluation of MPTS, summary plans for 10 types of experiment on MPT species, a reference list, a glossary of terms used, a list of acronyms and a list of names and addresses of useful organizations.
SECTION ONE

The Background to Species Selection for Agroforestry
CHAPTER ONE

MULTIPURPOSE TREES:
THEIR SELECTION AND ROLE
IN LAND-USE SYSTEMS

HOW DO WE DEFINE 'MULTIPURPOSE' TREES-MPTs?
We have already noted in the introduction that the term 'multipurpose trees', as used in this source book, covers all woody perennials used in agroforestry. From many attempts to arrive at an agreed definition, we have selected the following as most appropriate for understanding the multiple functions of woody perennials in an agroforestry technology:

Multipurpose trees are defined as all woody perennials that are purposefully grown to provide more than one significant contribution to the production and/or service functions of a land-use system. They are so classified according to the attributes of the plant species as well as to the plant's functional role in the agroforestry technology under consideration (after Burley and von Carlowitz, 1984).

Any woody perennial species can be 'multipurpose' in one situation and 'single-purpose' in another.
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AT WHAT SCALE DO WE USE MULTIPURPOSE TREES IN THE LANDSCAPE?

Agroforestry can be applied at different scales in a landscape. The smallest scale is the individual farm, where trees might be grown around the homestead or as boundary markers. At the macro scale, agroforestry practices may be applied to whole watersheds or to large expanses of open cereal farms, where the trees may be used to control water or wind erosion, as contour barriers or shelterbelts.

The fundamental roles of the woody perennials can vary greatly in relation to the needs of the system, as indicated in Table 1.1. Many examples are described in ICRAF’s Agroforestry Systems Inventory (see Nair, 1989). Supplement One is a checklist of MPT characteristics, their possible productive and service roles, and also some important management characteristics. In the context of experiments on agroforestry, the smallest unit can be regarded as the zone of interaction between the multipurpose tree and the individual crop plant—the 'tree-crop interface' (Huxley, 1983a).
Table 1.1. The service and production roles of woody perennials in land-use systems.

**Forestry Applications**
- Protection forestry, land reclamation and rehabilitation
- Management of natural vegetation
- Industrial plantations
- Community woodlots
- Farm woodlots

**Agroforestry Technologies**
- Trees in cropland, mixed intercropping
- Hedgerow intercropping
- Contour strips in farmland
- Trees in home gardens
- Live fences and hedges
- Trees on borderlines and boundaries
- Trees on terraces and earthworks
- Trees on waterways, gullies and flood plains
- Fodder lots
- Windbreaks and shelterbelts
- Improved fallows
- Trees in pastures and rangelands

**MATCHING MULTIPURPOSE TREES TO A SITE**

Where little is known about a species, research is largely exploratory. As more information is gained, research becomes more definitive, or technology oriented; it also becomes more site specific. The exercise of matching the site where a species is planted with the site where it originates is termed homoclimal comparison. As the name suggests, this is based largely on climatic matching. Yet this exercise should not relate solely to climate, but should also incorporate soil and land-use information.

Homoclimal comparisons permit a considerable reduction in the number of MPT species to be tested for introduction from the initial possible choices, which may number several hundred. However, they cannot completely replace the actual comparative testing of potential species on the ground.

Several databases on MPT species have been prepared in different parts of the world. These can be used to make homoclimal comparisons for initial MPT selection. Three of these will be mentioned. ICRAFs MPT database includes information on the climatic and soil features of sites where over 1000 species are actually being grown. These features are also the basis of the INSPIRE database.
(Oxford Forestry Institute; see Webb et al., 1984), created for the selection of over 200 species suitable for woodlots. For Australian species that have a wide application in tropical agroforestry systems, the Commonwealth Scientific and Industrial Research Organization (CSIRO) at Canberra has established a database called TREDAT.

Booth et al. (1987) have made improvements in site-matching procedures for Austrahan species using two quantitative techniques. Both make use of modern interpolation methods to estimate meteorological variables at sites that may be some considerable distance from recording stations, and both are aimed specifically at comparisons involving Austrahan sites and species. The first technique requires no biological information, but simply compares mean climatic conditions
Multipurpose Trees

at a trial site outside Australia with conditions at 2795 locations in a regular half-degree grid across Australia. The second method uses information from the natural distribution of a species, plus information on its performance in trials, to develop a detailed description of its climatic requirements. This use of trial-performance data has not yet been included in ICRAFs MPT database and is only included in the Oxford Forestry Institute's INSPIRE system to a limited extent.

Within a species, seed collected from one location belongs to that particular provenance, as discussed in more detail in Chapter Six. Provenances of the same species can be so different that they warrant treatment as different species. However, the question of provenance variation within a species is difficult to incorporate into a workable database. This problem is well catered for in the methods described by Booth.

MATCHING MULTIPURPOSE TREES TO PEOPLE'S NEEDS: THE IMPORTANCE OF SOCIOECONOMIC FACTORS

The role of a woody perennial is not confined to its service and production functions; it must be acceptable in all respects to the farmer and to the local community. Tree characteristics that are particularly important to many local communities include smokiness of fuelwood, odours and flavours imparted by fuelwood or charcoal, and thorniness. However, the overriding factors for farmers are perceived economic benefits and the reduction of risk. A new species or technology will not be adopted by local farmers if it cannot be shown to be superior in these respects. For this reason, long-term research programmes must include the collection of appropriate economic data.

Other, 'social', factors have to be taken into account when planning research, although they are more difficult to quantify than economic benefits. These include personal and community preferences, tastes, and cultural and religious behaviour;
there are many examples of species that grow well on a particular site but are not favoured by farmers for such reasons. Many of these factors can be identified during diagnostic surveys of rural areas (see Chapter Two for more details). A research programme must eventually investigate these preferences, attempt to put values on community preferences and provide factual information on growth characteristics and uses of trees to help local communities and development planners in decision making.

THE ROLE OF INDIGENOUS SPECIES

In many countries, an important point of discussion is whether MPT species used in agroforestry should be indigenous or exotic. The most important factor in all cases is to make the best choice for the farmer and for the site. As in modern farming and also in plantation forestry, there may have been an overemphasis on exotic tree species for agroforestry, mainly because they were thought to be easier to manage than indigenous species and their products more saleable.

However, indigenous MPT species also need to be evaluated—not only those that are common locally, but also those that are less well known or that have specialized uses. Many of these species can be identified during diagnostic exercises, ethnobotanical surveys or specialized marketing studies. Although the fact that local farmers currently utilize a particular species does not necessarily imply that it will be suitable for a specific agroforestry technology, such information at least suggests that the species should be examined since it is known to survive and to be acceptable under local conditions.
CHAPTER TWO

DIAGNOSING LAND-USE PROBLEMS
AND DESIGNING AGROFORESTRY TECHNOLOGIES

The farmer or other land user makes the final decision on whether or not to adopt an agroforestry technology for use in a particular land-use system. Yet the enormous variety of potentially useful ways of using trees together with crops and/or animals makes it difficult to decide which agroforestry technologies to adopt in any given situation.

Similar problems confront the researcher who has to decide which of many possible agroforestry experiments should be conducted, especially when resources for research are scarce. The priorities for research and extension should always be those technologies that have the greatest potential for solving problems, and not necessarily those that are easiest to carry out.

In order to help agroforestry researchers and extension workers to identify these priorities and arrive at sound agroforestry recommendations, ICRAF has developed a tool known as the diagnosis and design (D&D) methodology. This is simply a systematic approach for applying to agroforestry the common-sense medical principle that 'diagnosis should precede treatment'.
In any field of endeavour, the ability to solve a problem depends on being able to define exactly what that problem is. A clear statement of the problem is often all that is needed to suggest the nature of a possible solution. This is the core of the logic that the D&D methodology uses to identify relevant agroforestry technologies for a given set of land-use problems and potentials. This same logic is followed to ascertain the desirable attributes of MPT species to be used in a particular land-use system.

THE DIAGNOSIS OF PROBLEMS AND POTENTIALS

Following this approach, the diagnosis of land-management problems and potentials leads to a set of specifications for agroforestry interventions, i.e. what an agroforestry technology is expected to do for the system and, to some extent, how it should do it (see Table 2.1). These system specifications suggest general agroforestry technologies from the list given in Table 1.1. To design an appropriate prototype technology, detailed specifications are required. These specifications must include the characteristics of suitable MPT species and other plant components, plus detailed plans for spatial arrangements and management practices. This step requires a knowledge of the component species, the ways in which they interact with each other and their responses to management, so that they can be combined into a workable system.

Because each distinctive land-use system has a different set of problems that call for different solutions, each system requires a separate D&D exercise. Thus, there is a need for a prediagnostic reconnaissance survey, during which the land-use systems that are to be the focus of a particular exercise are delineated and described. Detailed D&D field surveys then examine each distinct land-use system.

The ultimate objective of the D&D process is, of course, to encourage the use of selected agroforestry technologies by farmers and other land users. However, available knowledge on the precise ways in which species interact is still rudimentary. At the same time, many agroforestry technologies are still of a 'notional' character, while others, known to exist as traditional farmer practices, have yet to be subjected to systematic scientific scrutiny. For this reason, most D&D exercises point to requirements and priorities for further research.

SETTING RESEARCH PRIORITIES

The most important feature of the D&D methodology is the manner in which research priorities are derived from an attempt to design an appropriate agroforestry system. We say 'attempt' because in the beginning, before the needed research is done, it may not be possible to specify with any degree of confidence all the characteristics of a desirable technology. For example, it may be clear that hedgerow intercropping is needed for a given land-use system, but using which
Table 2.1. Sequence of steps for the design and introduction of agroforestry technologies.

**Macro D&D**
Identify promising agroforestry interventions for an entire watershed

**Example**
Living fences for barriers and fuelwood and fodder production

**Micro D&D**
Develop specifications for what the interventions are to do in the farming system

**Technology Design**
Draw up detailed specifications for on-farm and on-station prototype evaluation

**Research Operation**
Develop and test the technologies

**Test**
performance of the technology: Does it meet the needs?

**Information for Extension Service**
Teach extension workers for wider dissemination

**Prepare**
guidelines for training courses
tree species? At which in-row and between-row spacing? Under which specific management regime? These are all questions for research.

To sum up, by trying to develop a detailed agroforestry design and by finding that the requisite information is lacking, the research needs are clearly exposed. Moreover, any research programme derived in this way is known to be relevant to the actual problems of a real land-use system. Once the research programme is being implemented, the iterative D&D process (Figure 2.1) helps to keep its focus on the optimization of agroforestry designs for the target land-use system.
The design of an agroforestry system should be based on the diagnostic and design (D&D) exercise. One of the most important outputs of this phase of work is a description of the role that an ideal tree would play in the new agroforestry system. Of course, most farmers and other land users would like to have one type of tree that meets all their needs at the same time. Few actual species can achieve this, but a definition of the ideal species is an important baseline for evaluating the MPT species that are actually available. This 'ideal' tree is called an ideotype.

**IDEOTYPES**

An ideotype is a model in morphological and physiological terms of the ideal agroforestry species for a particular purpose. It is expected to perform predictably, leading to greater quantities and higher qualities of crop yields in defined environmental conditions.

Three categories of plant ideotype have been defined by Donald (1968). These are:

- **isolation** ideotypes characterized by wide branches and broad leaves and by other 'aggressive' growth attributes; these generally grow best as freestanding specimens
- **competition** ideotypes, which grow well in a community of their own kind with a tendency to dominate less aggressive varieties
- **crop** ideotypes with the ability to share environmental resources in a community of their own kind.

For agroforestry plant components, Huxley (1984b) has added a fourth category:

- **associative** ideotypes contributing to the fulfilment of the agroforestry system's designed objectives, whilst maximizing environmental resource use in both space and time. Such types of trees would essentially be capable of positive interaction with crops.
Table 3.1. MPT attributes in relation to production and service functions (adapted from von Carlowitz, 1986b).

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Effects</th>
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<tr>
<td>Breeding pattern, outcrossing or inbreeding, pollination method</td>
<td>Related to production and service functions; variation found in populations of seedling origin</td>
</tr>
<tr>
<td>Dioecious or monoecious</td>
<td>Distribution of sexes within and between individual plants: important for seed and fruit production and pollen flow</td>
</tr>
<tr>
<td>Tree height</td>
<td>Ease of harvesting leaf, fruit, seed, branchwood; shading effects</td>
</tr>
<tr>
<td>Stem form</td>
<td>Suitability for timber, posts, poles; shading effects</td>
</tr>
<tr>
<td>Crown size and form</td>
<td>Quantity of leaf, mulch and fruit production; shading effects</td>
</tr>
<tr>
<td>Multi-stemmed habit</td>
<td>Fuelwood production; shading effects</td>
</tr>
<tr>
<td>Rooting pattern (deep or shallow; spreading or geotrophic)</td>
<td>Competitiveness with other components, particularly resource sharing with crops; suitability for soil conservation</td>
</tr>
<tr>
<td>Leafiness; physical and chemical composition of leaves and pods</td>
<td>Fodder and mulch yield and quality; soil nutritional aspects</td>
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*Acacia tortilis* trees offer shade (a service) and fodder pods and timber (products).
<table>
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<tr>
<th>Trait</th>
<th>Description</th>
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<tr>
<td>Thorniness</td>
<td>Suitability for live fencing or hedgerow intercropping</td>
</tr>
<tr>
<td>Wood quality</td>
<td>Acceptability for fuelwood and various wood products</td>
</tr>
<tr>
<td>Phenology: leaf flush, leaf fall, flowering and fruiting cycle; seasonality</td>
<td>Timing and labour demand for fruit, fodder, seed harvest; ability to withstand extreme conditions</td>
</tr>
<tr>
<td>Deciduousness</td>
<td>Seasonal or permanent leaf fodder availability; suitability for live fences, hedges and shelter-belts</td>
</tr>
<tr>
<td>Pest resistance; vigour</td>
<td>Major requirements, irrespective of function</td>
</tr>
<tr>
<td>Site adaptability and ecological range</td>
<td>Suitability for extreme sites or reclamation uses</td>
</tr>
<tr>
<td>Response to pruning and cutting</td>
<td>Use in hedgerow intercropping or for pollarding, lopping, coppicing</td>
</tr>
<tr>
<td>Possibility of nitrogen fixation</td>
<td>Use in hedgerow intercropping, planted fallows, rotational systems</td>
</tr>
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In hedgerow intercropping, also known as alley cropping or alley farming, the hedgerows are cut back and the prunings are applied to the crops in between as mulch.
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Table 3.1 provides a list of MPT attributes in relation to different production and service functions. These can be used to characterize MPT ideotypes for particular purposes, although specific research is always required to evaluate the characteristic of 'associativeness'.

Of course, no single species or individual tree can exhibit all the traits that may be desirable for an agroforestry application. Indeed, some of these traits may be mutually exclusive—such as fruit and wood production—as they may often represent competing sinks for photosynthates. The very fact that trees are needed for multiple objectives emphasizes the need for precise and reasoned definition of desired ideotypes. As the trees are often to be grown in association with plants of the same type and also with others of different morphology and phenological behaviour, a much wider range of attributes and tree characteristics has to be considered in determining appropriate ideotypes that would be the case, for instance, with trees for forestry plantations or horticultural orchards.

GENETIC ASPECTS

Taxonomic families, genera and species differ widely in morphological and physiological characteristics, and there is also much visible variation within populations of a single species. Considerable individual variation can therefore be expected at levels below the species—the provenance, variety or progeny. This variation will be a resource for future genetic selection and improvement, provided, of course, that the desired ideotypes can be adequately described.

Phenotypic variability is related to the breeding pattern of a species and, through various processes, to the spatial segregation of different subspecific taxons within populations. High variability is common in outcrossing species, such as many forest trees. This is visible, for instance, in many species of *Acacia* and *Prosopis*, which are widely used in agroforestry.

The genetic constitution of an MPT species is the result of complex evolutionary forces and cannot be fundamentally changed, except possibly through genetic engineering. Such characteristics as the ability to form nitrogen-fixing root associations or to resprout after coppicing are either present or absent. Evolutionary development also affects genetic traits such as the ability to withstand drought, which may be present in varying degrees in different individuals or populations of individuals (provenances). It is important to determine which MPT characteristics can potentially be improved through selection and breeding, and which cannot.

DIFFERENT IDEOTYPES FOR DIFFERENT SITUATIONS

The full ideotype description, listing the preferred morphological and behavioural characteristics of the tree, will differ for each specific agroforestry situation. For instance, requirements for hedges or hedgerow intercropping are clearly different from those for mixed intercropping or woodlots. A definition of the requirements
Table 3.2. Example of an ideotype specification for *Acacia tortilis* for agroforestry use in semi-arid zones.

**DESIGN NEEDS**

Products and services required

( in order of importance): fodder, fuelwood, food, windbreaks, poles/posts, shade

General selection criterion: vigour

Ancillary information required: whether nitrogen-fixing, chemical composition (fodder value) of leaves and pods

**IDEOTYPE DESCRIPTION**

- **Stem:** as straight as can be found in a population; multi-stemmed phenotypes acceptable, but long boles important
- **Crown:** fairly rounded, medium diameter (crown/bole ratio 25:1 or less) with many branches and positioned high up the stem; foliage medium to dense
- **Roots:** geotrophic angled rather than horizontally extending lateral roots
- **Pods:** large, averaging 10 cm long and 8 mm wide, in large quantities
- **Thorns:** as few and as small as can be found
- **Response to management:** prolific regrowth after pollarding and individual branch pruning; reliable coppicing response
- **Deciduousness:** short period of dry-season leaflessness compared with population average
of an agroforestry system, and of its tree components, may also require research at the social and institutional levels. Some socioeconomic factors are included in the types of MPT assessment listed in Supplement Two. However, it is difficult to give numerical values to these factors or to rank them in order of importance. An example of an ideotype for specific systems and products is given in Table 3.2.

DISCUSSION

With fodder as a priority, pod and leaf production is of foremost importance. Consequently, the modelling of an appropriate ideotype and the subsequent phenotype selection should concentrate on tree attributes that support this. A fairly rounded crown with a large surface area exposed to light is likely to increase flowering and fruit setting. Dense foliage, together with delayed leaf drop, will increase leaf fodder production for an extended period. Prolific regrowth of shoots, with fewer and smaller thorns, in response to pollarding will provide a large quantity of digestible fodder for a prolonged period during the dry season. Straight stems, at least 4 m long, will favour the production of poles and posts of good quality without losing the opportunity to collect fuelwood as a by-product. Fuelwood production would also be increased by selecting intensely branching crowns. A deep root system is less liable to cultivation damage and is likely to be less competitive with adjacent grass or crops.
SECTION TWO

Research Planning and Design
The fundamentals of planning are similar for all research concerned with land use. However, research planning for agroforestry differs in several respects from that familiar in agriculture and forestry.

In the first place, there are few specific agroforestry research institutions. Thus, research planners must choose which ministry or research organization should carry out the necessary work. Secondly, mixtures of crops, livestock and multi-purpose trees and shrubs can only be designed and managed effectively with a thorough understanding of a wide range of effects and interactions that have not been a part of traditional agricultural or forestry science in the past. Thirdly, the sheer complexity of the systems—number of possible combinations of species and timings—necessitates the development of new research approaches in order to reduce the number of experiments to be carried out and to make the best use of land and other limited resources.

In trying to give guidance to farmers on the best ways to use multipurpose trees in an agroforestry system, researchers must provide answers to three basic questions:

- Which species or mixtures of species?
- How many trees and in what combinations?
- How should the trees and crops be managed?

Table 4.1. Summarized functions of an overall research plan.

- Clear statement of the research objectives
- Plan and allocation of work schedules: a calendar of all activities
- Allocation of resources according to work schedules
- Management and financial control
- Use and publication of results
The first of these must include the evaluation of multipurpose trees and shrubs — the subject of this sourcebook. Experiments on mixtures and combinations of trees and crops provide the basis for the development of agroforestry technologies. The design and implementation of experimental prototype systems test the performance and acceptability to farmers of a number of 'best bet' specifications.

PLANNING RESEARCH IN RELATION TO AVAILABLE RESOURCES

Agroforestry research, like any other, depends upon the availability of the fundamental resources of land, labour, skills and capital. Research planning is concerned with the development of a design and management plan that takes into account both the research objectives and the resources available. Table 4.1 provides a general checklist of the functions of an overall research plan.

In agroforestry, there is nearly always a wider range of research questions to be answered than there are resources available. Moreover, the research questions are often rather broad: these may need to be narrowed down and arranged according to priority in order to design workable experiments. In addition, high-priority questions may be of short-term or long-term importance. Benefit-cost comparisons from the point of view of the target group may also be needed.

The selection of research priorities is based primarily on the findings of rural appraisal surveys. A numerical ranking of priorities can provide a useful basis for discussion and decision making by the research team.

Land

The land used for field trials must be representative of the land currently used or likely to be used for the agroforestry systems under study. In addition, tenure must be secure for the length of time required for the research programme, a factor of special importance for on-farm agroforestry trials. Land is also inherently variable and the more complex agroforestry research designs, in particular, must take account of this variability.

Labour

Labour, or human resources, includes not only adequate manual labour for the establishment and maintenance of field experiments but also sufficient, adequately trained, professional and technical staff to plan, manage and interpret the research. The lack of persons trained in agroforestry research methods may present a constraint.
Research Objectives and Planning

Capital

Capital includes not only the finance required for buildings, equipment and running costs, but also the cost of acquiring information and genetic resources. One aspect of the use of capital in agroforestry research is the shortage of relevant published information. The evaluation of MPTs for agroforestry is likely to be constrained by insufficient knowledge of the fundamental biology of the species, as well as of the agroforestry technologies to be introduced. The lack of adequate germplasm may also be a constraint.

SOURCES OF INFORMATION ON MULTIPURPOSE TREES AND SHRUBS

Research should not be initiated without an exhaustive study of what is already known, to avoid 're-inventing the wheel'. A great deal of help may be obtained from international library and documentation services, such as those listed in Table 4.2. The primary source of information on agroforestry species selection is ICRAFs MPT database, which contains information on over 1000 species, focusing on the functions of trees. Other important sources of information include the Nitrogen-Fixing Tree Association (NFTA) in the USA, CSIRO in Australia and some of the centres in the Consultative Group on International Agricultural Research (CGIAR).

<table>
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<th>Table 42. Major information sources for agroforestry research</th>
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<td><strong>ICRAF</strong></td>
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<td><strong>USDA/AGRICOLA</strong></td>
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PREPARING THE RESEARCH PLAN

The basic information to include in an agroforestry research plan is as follows:

- **The objectives of the programme and the target groups for whose benefit the research is being planned**: these are identified from rapid appraisal surveys (diagnosis and design—see Chapter Two). They should be identified in the context of national research programmes and priorities. In some cases, it may be advisable to carry out a 'prototype systems' trial (see Chapter Two), rather than a more formal experiment, in order to reduce costs, especially when not enough is known to design trials that test all the important variables. In most cases, fundamental work is required, including germplasm acquisition and storage, information handling, botanical surveys and nursery research.

- **A short statement of the current state of knowledge**: there is often a large body of literature not directly referring to agroforestry that has to be sifted through to gain guidance on what is already known and what can be achieved.

- **The proposed programme of work for specified periods**: this normally includes a detailed programme for 1 year and a programme for 5 to 10 years in outline. Aspects of the proposed research should be ranked in order of priority in case an unexpected cut in funding or other emergency necessitates a reduction in activity.

- **Estimates of requirements for resources**: these should include finance, land and labour requirements for skilled staff and unskilled workers.

- **Details of how the information obtained is to be written up, distributed and used**: agroforestry research, like forestry but unlike agricultural research, may require many years before conclusive results are produced. Attention must therefore be given to the handling and distribution of interim data.

An agroforestry research plan, as outlined here, may be a lengthy document. It forms the essential framework for the individual experimental plans that must be prepared for each separate trial.

PREPARING THE EXPERIMENTAL PLAN

Having clarified the research objectives and defined the ideal MPT species, or ideotype, to meet these objectives, the researcher comes to the selection of an experimental design and preparation of an experimental plan, as outlined in Table 4.3. This should be prepared within the framework of the overall research plan. The experimental plan is most important for the continuity of management and assessment of each individual trial; the research plan is needed for the control of the entire research programme.
Table 43. Checklist of points to be considered in making an experimental plan
(not all of these may be needed for every trial).

TITLE (heading of the overall programme or research section):

Title of trial: Experimental reference number:

Date of establishment:

Name or title of officer responsible for executing the plan:

DESCRIPTION:
Briefly, what the experiment is, its background, references to other similar trials, relevance to the overall programme of research.

OBJECTIVES:
A clear statement of the objectives of the trial, including the type of information required, the expected duration and the date for writing up the results.

METHODS:
1. Location of the trial, details of how to find it and a location map
2. The entries involved, details of origin, provenance and germplasm source
3. Location of nursery and details of nursery techniques
4. Design layout, plot size, size of surrounds, including a site map and plot charts if necessary
5. Details of any treatments to be superimposed on the basic trial
6. Weeding, thinning, pruning, fertilizing, irrigating etc. to be done
7. Statistical information: degree of accuracy required and the probability level to be used in testing (95 or 99% are most usual, but may also quote the level of probability actually achieved)
8. Analysis of variance
9. Assessments to be made and when
10. A note on how the results will be analysed.

RESOURCES:
1. Details of land, seed and nursery requirements
2. Specifications of fencing and internal/external demarcation
3. Organization of machinery, if required
4. Staff requirements, with timetable if possible
5. Estimates of costs.
There are many textbooks on experimental design and statistical analysis, including several books and working manuals aimed specifically at forestry research. Useful background information and details are also presented in ICRAF’s series of booklets, *Source materials and guidelines for the exploration and assessment of multipurpose trees*, and in various other ICRAF publications. This chapter gives only a brief summary of the basic principles of experimental design, with illustrations of alternative approaches to some research problems. Several useful publications are listed in the references: these provide more details on the theory and practice of experimental design.

**SOURCES OF VARIATION**

Each experimental set of biological material—that is, germplasm of a multipurpose-tree species—is unique in its variability. There may be considerable differences between populations, between plants of the same population growing in different sites, or even between plants of a single population growing together. The characteristics of the growing plant, taken all together, are known as the

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**Individual PHENOTYPE = GENOTYPE + ENVIRONMENT**

Variation of one clone with site change

Genetic variation of seedlings on uniform site

The observed phenotype is based on the genotype as modified by the environment.
Designing the Experiment

phenotype. The reasons for differences between phenotypes are partly genetic and partly environmental, for even plants of a single clone—which are genetically identical—will differ according to the circumstances in which they are grown.

Plant growth rates and other characteristics are the result of the interaction of genotype and environment. The environment, in turn, consists of climate, soil and biological factors that have an impact on the plant. These factors include competition from other plants, the influence of pests and diseases and the impact of people and animals.

The objectives of species and provenance research are to assess the differences in phenotypic performance between different genotypes in a given environment and—in some cases—to observe whether these differences are the same in two or more varying environments. These differences in performance are known as genotype-environment interaction (GEI). Most of the problems encountered in meeting research objectives arise because:

- The environment in which trees are grown cannot be controlled perfectly.
- No two tree seedlings of the same provenance are genetically identical, nor are they necessarily representative of their class.

In experimentation with MPT species and provenances, five sources of variation may be identified. These are:

- Known genetic differences between the populations being compared
- Environmental differences within a site or between two or more experimental sites; such differences may be controlled and measured best in a controlled-environment experiment where young plants are being evaluated
- Uncontrolled genetic variation among the experimental plants and between those plants and the populations they represent
- Uncontrolled environmental variation, including factors that vary from plot to plot or tree to tree and can be observed, but not controlled—such as differences in soil, microclimate or aspect—and also factors that cannot be observed or assessed
- Experimental error arising from inaccuracies of assessment and recording or from random variation within a plant, such as the difference in essential-oil content between two adjacent leaves; a further and more serious source of experimental error is undetected mistakes in the management of an experiment, such as planting trees of the wrong provenance in a given plot.

Uncontrollable genetic and environmental variation are generally difficult or impossible to separate in experimental work. For this reason, their combined effects are termed sampling variation. This, in turn, is often difficult to separate from experimental error. The two combined have often been wrongly called 'error'. A better term for the combination of sampling variation and experimental error is residual variation.

SETTING UP THE EXPERIMENT

Introduction and evaluation trials of MPT species or provenances should ideally be conducted using the best seed available and the best possible nursery and establishment methods. Any extra costs entailed in ensuring the highest possible standards are minor in view of the long-term nature of the research and the importance of the information to be obtained.

The factors affecting plant production from seed to establishment in the field are numerous, interact with each other and are expensive to evaluate. Optimum nursery and establishment methods also differ between species. It is possible to save both time and money by doing some simple preliminary research to help evaluate the technical feasibility (as opposed to the biological feasibility) of introducing MPT species for particular agroforestry technologies. Such research should be carried out with a small number of known and promising species (see Chapters Ten to Twelve for a more detailed discussion). This work can be conducted in parallel with genetic evaluation (Chapter Thirteen), which itself has nursery, planting and management components. This phase of experimentation is often called the proving stage.

A good example of a topic deserving preliminary testing for technical feasibility is the choice of *Rhizobium*, the symbiotic bacterium found in the root nodules of nitrogen-fixing leguminous trees. If a germplasm entry shows a high specific demand for a particular strain of *Rhizobium* and this strain is difficult to obtain or to inoculate, then the entry may have to be rejected, although in other ways it may be particularly well adapted to the site.
EXPERIMENTAL DESIGNS FOR SPECIES AND PROVENANCE TRIALS

The primary objective of a species or provenance trial is to make precise and accurate estimates of differences between populations, between environments and, where appropriate, between management treatments. The design chosen should be described in the experimental plan for each experiment. It should take into account the following factors:

- Choice of experimental site
- Adequate replication
- Blocking
- Randomization
- Overall simplicity.

Choice of experimental site

The choice of experimental site affects the planning and design of the experiment in several ways. Chapter Six refers to the influence of landforms and other factors such as the proximity of buildings or trees. The area of land available obviously has an influence on the size of experiment possible. Microclimatic and soil characteristics have a considerable influence on the orientation and arrangement of blocks in randomized complete block designs, lattices and related designs. Steep slopes, proximity of stands of trees and similar major features may necessitate the use of latin squares.

Adequate replication

Increasing the replication of each population — that is, the number of plots of each entry — reduces the residual variation associated with any comparison of population means. Theoretically, the precision of such comparisons is proportional to the
square root of the number of replications. However, in practice, other factors may slightly reduce the gain in precision. Chief among these is the fact that, for any given plot size and number of populations, increased replication means a larger experiment and, consequently, a greater likelihood of encountering site heterogeneity.

There are several different methods for determining the number of replications required to achieve a given level of precision. Some are outlined in Burley and Wood (1976). If many populations must be tested, it may be impossible to achieve replication sufficient for a given level of precision because of lack of experimental resources. In such a case, there is a choice between reducing the number of populations tested or accepting a lower level of precision. Note that precision may also be improved by using a complex design such as a lattice (see Supplement Three).

**Blocking to control external influences**

If an experimental site is reasonably uniform, with only random variation from plot to plot, then a completely randomized arrangement of, say, 5 plots (replicates) of each of 12 populations would be as efficient as any other design. However, such an ideal site is rare. Field trials of MPTs frequently cover a large area, with variations in soil, microclimate, topography, aspect, site history (i.e. previous vegetation and land use) and other factors. Such variations can be systematic or unsystematic. Even in greenhouses, there are often considerable differences in the environment from side to side, end to end or side to centre. In the nursery, there may be variation in shading, irrigation patterns, soil or exposure to wind. In all these cases, the simplest way to avoid confounding population differences with systematic site variations is by blocking, that is, designating site areas that include one plot of each entry.

*Confounding* refers to the situation in which the effects of two or more experimental treatments or site factors are always in combination and cannot be separated. To avoid this, the experimental site should be divided into blocks, each.
Designing the Experiment

corresponding to the most important environmental subdivisions. For most types
of design, blocks should be of similar size, each having the same number of
experimental plots. This restriction, plus the frequent existence of several different
sources of systematic variation, means that simple blocking rarely gives a perfect
control of external influences. More complex blocking methods may be used to
monitor two or three independent sources of systematic variation. Two types of
design—latin squares and graeco-latin squares—are particularly suitable for ex­
periments in greenhouses and other controlled environments.

Blocks need not consist of physically adjacent plots. On the contrary, a block
may be a collection of separate plots having an important environmental feature
in common, such as soil type. Their layout is frequently affected by physical
obstructions, such as roads, rock outcrops or streams, or determined by the shape
of the experimental site (see Supplement Three, Figures 1 and 2).

A further advantage of blocking arises from the fact that it is often difficult or
impossible for one person, or a single team, to plant a whole trial in a single day.
Similar difficulties may exist in applying other experimental treatments or making
assessments. Systematic differences between individuals or between days (for
instance, due to intervening rain) can be confounded with block differences by
ensuring that each person or team manages one block at a time. This increases the
amount of variation attributable to known causes.

In all experiments, blocks should be kept as homogeneous as possible. In order
to reduce their size, the size of the whole experiment must be limited and, for this
reason, it may also be appropriate to set up blocks with only partial replication.

Randomization

If it is assumed that residual variation among plots is random, there will still be
extreme plots. For example, some plots will be relatively fertile and others will be
relatively infertile. Each species or provenance should be assigned to plots at
random, as this is the best way to avoid bias in the estimation of population
differences, for instance if a particular population is planted on all 'good' or all
'bad' plots. In addition, random assignment of the population ensures an unbiased
estimate of residual variation and, consequently, makes it possible to use tests of
statistical significance—tests that are based on independent random distributions.

The arguments are strong against the systematic or subjective assignment of
plant populations to experimental plots, but systematic designs may be useful for
certain types of agroforestry experiment. The non-random assignment of some
variables (such as planting time, weeding or lopping time) to separate blocks will
combine—confound—any effects of these variables with the effects of all other
block characteristics. This will prevent the researcher from testing the effects of
these particular variables statistically, but they can be standardized and/or treated
as non-statistically testable observations.
A Tree For All Reasons

The assignment of plant populations to plots can be randomized using tables of random permutations or numbers. Computers or hand calculators are also increasingly used. These give sequences of ‘pseudo-random’ numbers that may be regarded as random for all practical purposes.

If a randomization is produced which is obviously exceptional, having, say, the same or nearly the same plot sequence in several replicates, the design should be rerandomized. This advice is controversial, but has been justified by Cox (1958).

Simplicity

Simplicity of experimental design promotes accuracy by minimizing the possibility of mistakes at all stages of the experiment. For this reason, an experiment should be as simple as possible in design, execution and analysis.

CHOOSING AN APPROPRIATE DESIGN

Some well-known experimental designs, such as randomized complete blocks, are both simple and efficient (i.e. they provide a high degree of information for a given expenditure of resources) as long as the number of species or provenances to be compared is fairly small. These are described in Supplement Three. As the number of populations increases, these simpler designs often become less efficient because both random and systematic variation within blocks tend to increase. This is frequently the case in agroforestry research, where large numbers of entries are to be tested.

Two main approaches have been developed to reduce within-block heterogeneity:

- Plots are arranged in blocks that are smaller than a complete replicate, in other words, in incomplete blocks
- Plot size is reduced.

All these approaches—randomized complete blocks, incomplete blocks and reduced plot sizes—are discussed in the the references listed at the end of this chapter. Supplement Three also includes a discussion of these approaches plus illustrations of systematic designs.

The design methods commonly used to increase precision in factorial experiments, involving two or more treatments, include confounding, fractional replication and split plots. These are not generally applicable to introduction and evaluation trials. However, confounding may be used to superimpose managerial treatments, such as lopping, on genetic evaluations of MPT species.
Any agroforestry research programme aims at finding the optimum tree or shrub for each proposed intervention. Thus, the introduction and evaluation of species is an essential aspect of the first stages of research. As mentioned in Chapter Five, introduction and evaluation trials of MPT species or provenances should be conducted using the best seed available and the best possible nursery establishment methods. Propagation material—whether seed, cuttings or sprouts—from all available sources should be tested early in the research programme, and enough material should be obtained from appropriate sources for further testing and evaluation at later stages of research. Chapter Ten gives details on seed collection in the field, as well as on seed handling, storage and testing.

In practice, most trees that are planted are raised from seed in nurseries. However, for the purposes of this chapter, other propagules—such as cuttings or root suckers—are also regarded as 'seed'.

GERMPLASM AND GENETIC RESOURCES

Germplasm is the hereditary material that is transmitted to offspring through the germ cells. Essentially, this is the fundamental genetic information carried in the
DNA of chromosomes. Germplasm does not only include sexually produced material (i.e. seed) — plants that are grown by vegetative propagation also contain the same type of genetic information; these can be used to produce seed in future phases of breeding programmes. Vegetative parts of plants are therefore also a vital part of the germplasm of a species.

Two other terms commonly used in this connection are *genetic (or gene) resources* and *gene pools*. These describe the total genetic information possessed by all reproductive members of a population of sexually reproducing organisms.

**ORIGIN OR PROVENANCE?**

Species that are naturally distributed over a wide geographic range have been subjected to natural selection by environmental factors that may differ throughout the range. Therefore, genotypes (the genetic constitution of individual plants) and gene frequencies vary in local populations of the same species. These differences are transferred when plants are introduced as exotic species elsewhere. The natural origin of a plant population, i.e. the location where the population evolved, is termed the *origin or provenance*. More specifically, provenance is the location of the parent trees from which the germplasm was collected and origin is the location where the tree population evolved.

Some species have been used as exotics or subjected to intensive human selection in their natural range. For these species, the population genotype no longer represents the one that evolved under purely natural selection. Plant populations of this type are approaching the classical concept of a *land race*, a population naturalized and adapted to a new environment. For forest trees, however, these are usually called *provenances*. This confusion is not just a problem of semantics, but presents a practical problem in interpreting the results of population trials or of past research work. The definitions given here are simple and are recommended for general use.
Identifying Suitable Germplasm

Jones and Burley (1973) distinguish 'natural' from 'derived' provenances and present as illustrations a range of genetic histories that have implications for provenance testing and future breeding. They emphasize the need to obtain precise information on the history and genetic origin of each seedlot. This information is required to interpret the results of trials, to interpolate between tested sources and to predict the value of untested sources. It is also vital in order to ensure that the best sources are obtained in future.

SEED CERTIFICATION

Three main sets of information are required for any seedlot. These relate to genetic composition and origin, physiological and physical quality, and health. Several national and international systems exist for the provision of this information, but many countries do not follow these systems or are unable to enforce their rules on seed suppliers and traders.

A seed-source certificate contains information on the genetic composition and origin of a seed sample. This information is essential for several reasons:

- To identify currently optimum populations
- To avoid currently inferior populations or those with high risks of future unsuitability
- To devise appropriate strategies for future breeding or eugenic management.

Existing schemes for certification of seed origin are described in Burley (1985) and Jones and Burley (1973).

Whatever the genetic composition of a seedlot, it is also important for the purchaser or user to have information on its purity, viability, collection and storage methods and dormancy. This is to ensure that expensive seed is not wasted.
Seedlot Identity Number: 45/85, 52/88

Species: *Leucaena collinsii*
Subspecies: *collinsii*
Common Name: Guash

Collection Site Location
Country: Mexico  State: Chiapas
District: Tuxtla Gutierrez  Site: Narcisco Mendoza
Latitude: 16°36'N  Longitude: 93°00'W  Altitude: 400-550m

The collection site lies in the Central Depression of Chiapas which is formed by the broad terraced valley of the Rio Grijalva. Seed was collected from trees scattered over a wide area centred on the town of Narcisco Mendoza which lies about 20km south of the state capital Tuxtla Gutierrez.

Climate

Location of Meteorological Station: Tuxtla Gutierrez
Lat: 16°45'N  Long: 93°07'W  Alt: 536m
No. of years of observations: 35
Mean annual rainfall: 948.2mm  Mean annual temperature: 24.7°C

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<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
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<tr>
<td>Mean monthly rainfall (mm)</td>
<td>0.5</td>
<td>0.6</td>
<td>2.0</td>
<td>8.7</td>
<td>81.6</td>
<td>228.3</td>
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<td>207.1</td>
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<td>Mean monthly temp (°C)</td>
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<td>26.1</td>
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<td>25.7</td>
<td>25.3</td>
<td>24.3</td>
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Soil

The geological strata in the area are mostly marine limestones and slates. Soils are derived mainly from alluvial material and vary from heavy black clay vertisols in the hollows to freely drained gravelly soils on the higher slopes. Soils are generally highly degraded through loss of forest cover, over-grazing and fire.

Vegetation

Extensive cultivation and grazing have led to the destruction of the original tropical deciduous forest and in some areas this has been replaced by thorn scrub or savanna. Grazing pressures are severe and fires occur frequently across the area. *Leucaena collinsii* in common with most of the woody vegetation has been largely cleared and now occurs only as small remnants and in fence lines.

Associated woody species include:

- *Acacia farnesiana*, *Acacia penna. *Acacia collinsii*, *Acacia pringlei*, *Albizia carinata*, *Albizia plurijuga*, *Caragalia eriostachys*, *Enterolobium cyclocarpum*, *Gliricidia sepium*, *Humamayylon brasiliense*, *Piscidia sp.*, *Pithecellobium duke*, *Prosopis laevigata* and *Senna atomaria*.

Tree Characteristics

Trees are generally open grown with wide spreading crowns and an open branching system. Stem gum exudation is common. Trees are generally 6-7m in height with some individuals to 12m. Trees are completely deciduous losing all their leaves during the prolonged dry season. The species is highly favoured amongst local farmers and is used for a range of products including fence posts, firewood, food (edible seeds), posts and cattle fodder. The firewood is of excellent quality and requires little drying.

Seed Collection Details

**Ident No. 45/85**
Date of Collection: 1st-3rd April, 1985
Collector: C.E. Hughes, OFL
Material collected: Phenology is quite variable, the first trees ripening in mid February and some still unripe in early April. Seed was collected from 25 parent trees and partially bulked after extraction. Seed extraction was carried out by manual threshing.
Botanical vouchers: C.E. Hughes 527, 530-539 (leaves and pods) 662 (leaves, flowers and pods) MEXU, FHO, K

**Ident No. 52/88**
Date of Collection: 4th-5th April, 1988
Collector: C.E. Hughes, OFL
Material collected: Seed was collected from 20 widely scattered parent trees and bulked after extraction.
Botanical vouchers: C.E. Hughes 527, 530-539 (leaves and pods) 662 (leaves, flowers and pods) FHO, K, MEXU.
Identifying Suitable Germplasm

and the highest possible number of young trees are obtained for planting out. A set of rules for testing seed has been developed by the International Seed Testing Association (ISTA, 1976). The results of such tests are presented on a standard seed quality test certificate.

International certificates are issued by competent authorities in the exporting and importing countries respectively. They were developed originally for agricultural and horticultural crops but are equally important for trees. The standard document is the Phytosanitary Certificate, which gives details on the results of seed inspection and on any treatment carried out. Existing systems are described in Ivory (1984).

SEED TESTING AND RECORD KEEPING

The internationally based systems of certification are particularly important for seed that is to be transferred between countries. However, most MPT species have not been tested extensively. For these species, simple, replicated germination trials in a laboratory or nursery would provide practical information, even if they do not conform precisely to the plant health and quarantine certification process set out by international regulations. See Chapter Ten for more information on simplified seed-testing methods.

It is equally important to maintain records on the treatment and use of all seedlots within a country and within each research or development programme. For the researcher, proper record keeping is necessary in order to interpret the results of trials; for the manager, it is important in order to monitor the future performance of germplasm collections. As individual farmers become self-sufficient in seed or propagule supply, it will become increasingly difficult to maintain complete records, yet it is important if future genetic variability is to be maintained and viable breeding programmes initiated.

RELIABILITY OF SEED SUPPLIES

It is one thing for the researcher to recommend the use of a particular provenance, but it is often another for the manager to obtain reliable, bulk supplies. For multipurpose trees and shrubs, it is frequently difficult to obtain viable propagation material from an identified supplier. A major source of information on possible seed suppliers is ICRAFs *Multipurpose tree and shrub seed directory* (von Carlowitz, 1986a). This lists the uses and climatic or site requirements of many species and gives the names and addresses of suppliers. The directory cannot endorse the reliability of any of the suppliers listed, but at least it helps researchers and managers begin their search for seed supplies.
Three major aspects must be considered in choosing an experimental site for the evaluation of multipurpose trees and shrubs. These are:

- To ensure as far as possible that the site is representative of the area in which agroforestry is to be developed
- To assess the site in order to design the experiment in the most effective and statistically valid way
- To ensure that the results of the experiment can give the most information possible about the relationship of the trees with their environment — the GEI referred to in Chapter Five. This makes it possible to extrapolate the results of the experiment to different sites.

The first stage in choosing a site for an MPT introduction or evaluation trial is the diagnosis and design exercise discussed in Chapter Two. This exercise results in suggestions for promising agroforestry interventions and indicates which sites will be suitable for testing them.
It is not always possible to choose an ideal site for an agroforestry experiment. Land may not be available or there may be other compelling reasons for choosing a less-than-ideal site, such as proximity to a research station. However, the site for an MPT trial should, as far as possible, match the climate and soil characteristics of the area for which the agroforestry intervention is planned. Climate and soil maps may be used to compare the majority of the farms with the available research sites. The availability of resources and the accessibility and convenience of the trial site are also important. Once resources are allocated, the next step is to plan the experiment in relation to the selected trial site.

The evaluation of a proposed trial site begins the moment the researcher sets foot on it. The site should be as representative and as uniform as possible.

Some knowledge of the climate is essential, both for the selection of MPT species to be tested and as a guide to the conditions to be expected during the trial. Three major aspects of climate must be considered: macroclimate, topoclimate and microclimate.

The macroclimate consists of the average climatic conditions on the trial site in the past. These may not be easy to ascertain if there are no previous records. In such cases, the best plan is to estimate climatic parameters from nearby sites for which representative records are available. The macroclimate is normally uniform over large areas, but may be modified locally. Figure 7.1. shows an example of a climate diagram that includes information on average monthly values of various climatic parameters.
The topoclimate (from the Latin topo — a place) results from local modifications of the macroclimate caused by landforms, such as hills or valleys. In research planning, it might be important to avoid frost hollows or particularly windy places, for instance.

The microclimate generally refers to the fine climatic structure of the atmospheric layer close to the surface of plants or other obstacles. It is influenced by small-scale effects, such as plant interactions or the proximity of buildings. Important microclimatic features include shading, frost hollows, and wind-funnel effects. These should be examined carefully when planning an experiment.

Soil, along with climate, is a major factor in plant growth. Important differences in soil over the experimental area may be detected from:

- Variations in the vegetation, whether natural or introduced, already existing on the site; the use of 'indicator' species to show waterlogging or acid soils is an example
- Variations in the topography, for instance indicating patterns of drainage or likely sites of shallow soils over pans
- Rock outcrops, if present, indicating fundamental geology and soil depth.

Much of this information can be mapped using very simple survey techniques, such as a chain and compass, plane tabling or even pacing. A good way to investigate the top soil is to plant a uniform agricultural crop, such as maize, across the whole site and note differences in growth.
Choosing the Experimental Site

For the growth of multipurpose trees and shrubs, the major soil characteristic of importance is soil depth, which provides some measure of rooting volume. This can be gauged on a grid of about 10 x 10 metres, using a simple soil augur or even a crowbar or stick. The soil depths measured are then plotted on a larger-scale map of the area, and, if necessary, further samples are taken to fill in more details.

Other important soil characteristics with a direct effect on plant growth are chemical and physical features such as pH, nutrient levels, texture and bulk density. An agricultural crop may be grown on the site before planting trees to indicate soil variability, but this does not test the important characteristic of soil depth.

Several other features of the site should be taken into account during the research planning process. These are the basic geology of the site, its physical geography, including landforms and hydrology, and the prevalence of pests or diseases in the area.

This initial examination of the research site will normally give guidance for blocking the experiment (see Chapter Twelve for further information on experimental layout). Variations over time must also be considered: soils do not change rapidly, but substantial variations in climate can, and usually do, occur between years in tropical and subtropical regions.
Figure 7.1. Climate Diagram.
Mean monthly values of meteorological parameters, from nearby observation stations provide basic information about the climatic conditions at proposed research sites (Data in Diagram are from Nairobi Dagoretti station).
SECTION THREE

Assessment and Evaluation
CHAPTER EIGHT

ASSESSMENT
AND RECORDING

ASSESSING MULTIPURPOSE TREES AND SHRUBS

In measuring trees to be used mainly for timber production, the characters of interest are well known and standard assessment techniques have been developed. The most common are height, diameter at breast height (1.3 metres above ground) and diameter at selected points along the stem. Together, these indicate the total volume of stem wood. Some information on wood quality is obtained from assessments of straightness, branching (number, size and angle) and some structural characters of the wood such as density and fibre dimensions.

By contrast, multipurpose trees and shrubs are required to supply a much wider range of products and services than just timber. Supplement Two lists some of the principal groups of characters that may be studied in assessing these species. This chapter only describes some general features that are essential at the stages of species elimination and vigour/phenology trials. Some sampling and measurement procedures are suggested, but these should not be considered as mandatory or applicable to all types of experiment.

If research begins with a diagnostic survey (D&D), many of the most important characters for assessing the tree species in a particular situation will already have been identified. Thus, fodder yield will be of primary importance if the major need is for improved animal nutrition.

In general, important characters for MPT species to be used in agroforestry technologies are:

- Survival
- Form, including crown form and width
- Phenology
- Height, or length of stem if not vertical
- Stem diameter(s)
- Forking and bole characteristics
- Utilization characteristics, including suitability for the production of poles, posts and stakes; suitability for fuelwood; and fodder and mulch characteristics, including foliage density
- Responses to management
- Susceptibility to pests and diseases, and whether the trees have an effect in terms of pests and diseases on nearby crops.

These characters will be described in more detail. Table 8.1 gives an example of a programme of assessments for an MPT trial.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>At Planting</th>
<th>2 Weeks</th>
<th>6 Months</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td></td>
</tr>
<tr>
<td>Phenology</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Height</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Stem diameter</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Forking</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Utilization</td>
<td>X</td>
<td>as needed</td>
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<td></td>
</tr>
<tr>
<td>Management</td>
<td>X</td>
<td>as needed</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pests and diseases</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Soil monitoring</td>
<td></td>
<td>X</td>
<td>X</td>
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</tr>
</tbody>
</table>

Survival

With the highest possible standards of nursery and field management, survival rates for multipurpose trees and shrubs under trial should be at least 80%. In fact, survival rates are often much lower for a variety of unexpected or uncontrollable reasons, such as drought. The survival rate is clearly an important parameter at the elimination stage of research and is usually recorded for every experiment, of whatever type. It can be recorded as a count of trees per plot if plots are small, or as a percentage if plots have more than 25 trees.

Survival is not always a clear-cut parameter, but it should be taken to refer to the presence of the living tree, even if it is not completely healthy. Often a sapling may appear lifeless but sprout again from the base when climatic conditions improve, so it is important to establish whether death has actually occurred.

Survival should be recorded two weeks after planting and then quarterly or annually, depending on the treatments and objectives of the experiment. Trees that are dead or missing two weeks after planting may be replaced, with their locations in the plots recorded, but for experiments of short duration no replace-
Assessment and Recording

ments are recommended. Whenever possible, the cause of death or disappearance should be noted. Survival of plants in establishment trials is considered in Chapter Twelve.

Form or habit and crown characteristics

Form or habit is an important characteristic of a tree or shrub and a primary factor in determining the appropriateness of a species for any particular agroforestry technology. Most MPTs, including such diverse species as palms and vines, can be classified according to one of three distinct forms:

- Erect and tree-like, normally with a single bole
- Leaning and often multistemmed
- Shrubby, prostrate or climbing.

Crown size can be assessed by measuring two diameters at right angles, plus the depth of the crown. A quantitative description of the form of an individual plant can be obtained by calculating various ratios between different measurements. A particularly useful ratio is that of the stem or bole diameter to the crown diameter, often referred to as the 'd/k ratio'.
Phenology

The study of plant growth and development in relation to climatic sequences and other environmental factors, including management, is termed phenology. We can observe broad within-season changes ('phenophases'), such as vegetative growth ('flushes'), flowering, fruit ripening/maturation and leaf fall. These occur within the life cycle of the plant from germination/emergence to the juvenile vegetative stage, maturation and senescence.

For crop plants, we need to match duration of growth and the various phenophases with expected environmental sequences. However, woody plants in the tropics not only respond to climate in very diverse ways, but are also affected by what happened to them in previous seasons. For example, drought, over-wet periods, excessive fruiting and pest damage, as well as lopping and pruning, can markedly displace any 'normal' pattern. Similarly, woody species that are moved into new, unsuitable environments often respond by over-frequent or obviously mis-timed sequences of vegetative growth, indicating, quite early on, their inability to adapt. Later, they may flower and fruit at unsuitable times.

We need to observe and understand these patterns if we are to choose new, well-adapted MPT species and design appropriate management regimes. We can make phenological observations at regular intervals, either as descriptive comments and/or photographs of whole trees, or on sample branches of replicated trees. Using the latter procedure, it is possible to mark and measure increases in branch length, to count leaf numbers, and to record at which nodes flowers and fruits occur, as shown in Figure 8.1.
Figure 8.1. Changes in length, leaf number, flowering and fruiting on a primary branch over three seasons (A-C). Arrows show ‘base’ marks. Source: Huxley et al. (1989).

Primary Branch Phenology
Whole-tree descriptions can be displayed diagrammatically and branch phenology provides measurement data that can be shown either in tabular or graphical form. All phenological studies need to be supported by baseline meteorological data from the actual site, or nearby. Information on field procedures and examples of the results of applying the two methods are contained in Huxley and van Eck (1974) and Huxley et al. (1989).

**Height**

Height should be measured at the highest point above ground attained by any part of the tree if the tree is erect, or, if not, in terms of the length of the largest stem. The ratio of height to length of longest branch is an indicator of habit: values near one indicate a tree type of habit while lower values indicate shrubbier species.

**Stem diameter**

Neither height alone nor the habit ratio is a reliable indicator of biomass production. Some measurement of stem cross-section is also required to estimate stem wood content, and often this can be used to predict total biomass yield. Some destructive sub-sampling is needed to compile prediction equations that link height and stem diameter, but this usually requires larger numbers of sample trees than are available in small trial plots. It is useful to plant some larger blocks of the most promising populations for this purpose, and also for other observations or destructive sampling. An alternative is to sacrifice a whole block of the experiment for such measurements.
Assessment and Recording

The location of the diameter measurement is a major problem with many MPT species that have multiple stems that are often very thin at the traditional breast-height measurement point (1.3 metres above ground level). A common approach to this problem is to measure at the root collar. One advantage is that this is the point used for measurement in nursery work, but, because of the steepness of taper close to the ground, measuring at this point could result in an exaggerated estimate of diameter. A general recommendation would be to count the number of stems that are more than 1 centimetre in diameter at 10 centimetres above ground, and to record the diameter of each of these at this height. However, different approaches could be more appropriate, depending on the overall objective of the trial. For example, a recent international hardwoods trial organized by the Oxford Forestry Institute suggested that a useful compromise height might be 30 centimetres above ground and that all stems should be measured at this point. The usual way of marking the point of measurement is by a paint spot; alternatively, aluminium nails or tags may be used.

A prediction of total biomass may be obtained from some form of basal area calculation. Basal area is the horizontal area of the stems at a particular height; in order to obtain some measure of area, it is based on the diameter squared. The biomass equations will not be the same for all species, but will have to be calculated for each species individually or for groups of related or similar species.

For a more precise calculation of biomass, it is important to obtain dry biomass weights by drying in an oven. This is a fairly easy process for leaves, but longer periods and greater care are needed for woody material. It is advisable to carry out simple trials on samples of different materials — leaves, twigs, branches and stems — that are to be dried. The material should be placed in an oven, usually at a temperature of 105°C, and the weight loss should be checked hourly. When there is no further loss, the sample is oven dried.
Forking and bole characteristics

The **frequency and height of forking** may not be easy to separate from branching in multipurpose trees and shrubs, but it is an important character for those species intended for poles and saw timber. If saleability of the bole for cash income has been identified at the diagnostic stage as a major objective, then a single straight stem may be essential — as usually required for forest plantation species. For this purpose the **minimum length of usable bole** should be measured.

Utilization characteristics

**Poles, posts and stakes.** Multipurpose trees and shrubs that are to be used for poles, posts and stakes need to be straight, strong, flexible and resistant to decay or amenable to preservative treatment if preservatives are available. Minimum bole length and diameter are the most important measurements.

**Fuelwood.** Estimation of fuelwood production and quality depends primarily on woody biomass production. Calorific value is directly related to dry weight, although wood of high density is generally preferred for fuel. However, many other factors are involved in the acceptability of fuelwood, including the sizes of pieces available, ease of cutting and splitting, thorniness, type and amount of smoke produced, rate of burning, temperature of burning, tendency to produce sparks and suitability for charcoal production. These factors are somewhat subjective and should be assessed in terms of a particular set of socioeconomic conditions. As noted above, the main criterion is dry-matter production.
Assessment and Recording

Fodder and mulch characteristics. In addition to assessments of biomass, it is desirable to make a preliminary evaluation of the fodder quality of the leaves of a multipurpose tree or shrub. This includes standard laboratory chemical analyses of mineral and protein contents and also feeding trials to determine palatability and toxicity. At the initial evaluation stage, this analysis need only include the major elements (nitrogen, phosphorus, potassium, calcium and magnesium), crude protein content, energy content, fibre content and the presence of tannins. These laboratory tests only require small quantities of material. Once a species has been selected as a major component to supply fodder in an agroforestry prototype system, more detailed analyses may be needed, including feeding trials.

Sufficient material for these analyses—of the order of one tonne or more—may not be obtainable from small species-evaluation trials and it may be necessary to establish larger plots for this purpose. Furthermore, while standard analyses exist, there are no clearly defined standards for sampling, which must take into account the natural variation between leaves at different positions in the tree crown and at various seasons of the year. It is essential to record carefully the following information on all material taken for analysis; otherwise the information obtained will be of very little use:

- The part of the plant taken
- The date of sampling (season of the year)
- The phenological state of the tree.

A chemical analysis will also help to indicate the value of leaf materials as mulch. In addition, a specific test should be conducted on the rate of litter decomposition under defined conditions.

The accurate evaluation of MFTs for use as fodder demands vigorous and well-defined analyses. For more detailed information, see van Soest (1983).

Responses to management

Once a species is introduced into an agroforestry system, its response to management becomes important. For hedgerows or live fences, for instance, thorniness, dense branching, tolerance of cutting and unpalatability to livestock are valuable characteristics. For hedgerow intercropping, a species should be able to withstand repeated lopping and produce a vigorous growth of nutrient-rich foliage.

In the preliminary trials discussed in this book, it is not possible to generate precise information on all of these characteristics, but some useful guidance may be obtained. Sampling of some features, such as thorniness or density of foliage, does not usually require that trees be destroyed. Such features may be evaluated through simple field observations, noting particularly any marked variation between trees.
More quantitative features, such as the estimation of potential yields of leafy material for mulch and fodder, require destruction, or at least lopping. In order to obtain comparative estimates of the amount of stemwood, branchwood and leaves produced, it is often advisable to harvest a complete replication of a trial. The trees, having been cut, can also provide an indication of coppicing ability.

The accurate determination of yields under specific management regimes will require long-term experiments.

MEASURING AND RECORDING THE MACROCLIMATE

Unless the trial site is on a research station, resources are bound to be limited for meteorological measurements. The most important parameters to measure, in order of priority, are:

- Precipitation—measured and recorded daily
- Temperature — maximum and minimum recorded daily
- Evaporation—while fundamental to the calculation of the water balance, this can only be measured by setting up an evaporation pan. Otherwise, it must be estimated by calculation or extrapolation from the nearest meteorological station.

Guidelines for setting up a standard meteorological station and for taking detailed meteorological observations are given in Darnhofer (1985).
SOIL MONITORING

Interpretation of the results of early MPT trials may require some detailed soil analyses. The extrapolation of these results to other sites may also require additional information on soils. A guide to sampling of soil characteristics will be found in the site-description forms given in Raintree (1983). However, detailed soil analyses are not usually necessary for the selection of MPT species for subsequent phases of agroforestry research.

The soil changes that occur under specific combinations of trees and crops in agroforestry systems are best studied by means of long-term experiments designed specifically for this purpose.

RECORDS AND DATA HANDLING

The need for a careful research plan for each experiment has already been stressed. Equally important are the design and maintenance of experimental record forms to record the managerial and environmental history of each experiment and plot as well as the data collected on the growth and properties of the plants. To minimize the opportunities for error, data should be copied as infrequently as possible, and then, if possible, by electronic means. Several methods are being used in different parts of the world for collecting field data by direct entry to hand-held computers. ICRAF is developing a system called Datachain, using PSION hand-held computers to collect data in the field and transferring these data directly to a personal computer. Details of this sophisticated approach are available from ICRAF.

The use of computers does not diminish the importance of proper recording formats for all experimental assessments. Examples of simple recording formats are given in Supplement Two.
CHAPTER NINE

FARMER PARTICIPATION IN RESEARCH AND EVALUATION

For most agroforestry research, the ultimate target group of users and beneficiaries is the farmers. For this reason, some of the research questions mentioned in Chapter Eight call for the participation of farmers, as well as scientists, in the assessment process.

The evaluation of MPT species leads to further testing of the most promising species in agroforestry mixtures and in prototype systems trials. The participation of farmers becomes particularly valuable at these stages. Moreover, many of these kinds of experiment are ideally situated on farms, and are therefore under the observation and control of farmers.

In this discussion, however, we are concerned with the involvement of farmers in the preliminary stages of MPT research, using farmer assessments to help decide which species are worthy of further trial. A small group of interested, innovative farmers is likely to provide better information at this stage than a completely random cross-section of the rural population.
Farmer Participation

FARMERS AND THE SPECIES EVALUATION STAGE

The selection of MPT species for initial trials is based on the identification of problems and potentials during the diagnostic phase of research. These choices are made in close consultation with farmers and other land users. Thus, at the earliest stages, researchers have the opportunity to discuss with farmers the species selected as a result of the diagnostic surveys, along with the reasons for these choices.

For species that were hitherto unknown, farmers should only be called in to see the trials once the final form, habit and other characteristics of the trees are beginning to become apparent. If there is already some confidence about the usefulness of a species on-farm, small numbers of seedlings may be distributed to selected farmers in parallel with the trial programme. Each farm can be treated as an experimental plot, and missing plots may be expected to be common.

![Image: A group of farmers view a plot of planted *Acacia tortilis* of good form.](image)

FARMERS AND PROTOTYPE SYSTEMS TRIALS

Although they are strictly different types of experiment, prototype systems trials and species evaluation trials may often be started at the same time. During the implementation of an on-station prototype systems trial, researchers should organize regular field days for neighbouring farmers. On these occasions, the researchers may explain the objectives of the trial and invite the farmers to comment freely on what they see.

When a prototype systems trial is conducted on farms, the researchers give guidelines to participating farmers on how the system should be managed. The
A Tree For All Reasons

researchers then monitor and evaluate the trial on a regular basis. Any modifications to the original design introduced by the farmers will prove to be particularly instructive.

MODIFICATION OF EXPERIMENTAL DESIGNS FOR ON-FARM RESEARCH

It may be necessary to modify standard research layouts for on-farm experimentation—for example, by splitting up blocks on to different fields or even on to different farms. In these circumstances, the risks of missing plots are greater, so the research design must be robust enough to continue to yield valid results. Treatments may not be adhered to rigidly, and slight modifications of the original design may be expected. In situations where little-known species are introduced, a great deal may be learnt from the different ways in which the farmers manage the trees.
SECTION FOUR

Important Areas of Research Work
Detailed research on seed is normally not a part of initial research on MPT introduction, although seed research maybe important in later phases of agroforestry research. Every nursery raising trees for experimental or operational planting should seek to produce the best planting stock possible, and this means regular trials to improve performance and to solve problems as they arise. This chapter will consider briefly some of the principles involved in seed collection, storage and testing, as specifically related to the introduction of multipurpose trees. More detailed information, although primarily covering coniferous species, is given in an excellent FAO manual (Willan, 1985) on the collection, processing, storage, pretreatment and testing of tree seeds.

COLLECTION FROM THE FIELD

Flowering and fruiting seasons for tropical trees and shrubs are frequently not well known. If seed (or other propagules) have to be collected for experimental work, tree phenology must be observed and the collection exercise organized well in advance. The researcher is rarely able to make the collections personally; for this
reason, reliable field teams must be recruited. Once the locations of the desired parent trees are determined, along with the dates when seed will be ready for collection, the teams should be sent promptly to the collection areas with all the tools and equipment needed, including vehicles.

In general, seed should not be collected from less than about 25 parent trees. The actual number of parent trees should always be recorded. If possible, the seed collected from different individual trees should be stored separately, and used in the research programme as individual progenies. The advantages of this approach are as follows:

- Biosystematic study is permitted within and between populations
- Parents can be balanced in a provenance 'mix' of seeds
- Hybrid-bearing parents can be detected.

These points are discussed in more detail by Turnbull (1975).

In any collection, it is natural for the scientist to wish to collect from the most promising-looking phenotypes. However, for unsupervised collection crews, there is an even stronger temptation to collect from the 'easiest' and most heavily seeding specimens. This often leads to an increase in the planting of badly formed, heavily seeding trees, whereas heavy seeding is often related to reduced vegetative growth and can therefore be undesirable.

The selection of 'good' phenotypes in the field is a useful practice if seed is to be planted near its point of collection, where it can be expected to result in a population of improved ideotypes. Such a collection will not, of course, be typical of the whole population. For first-time collections of exotic seed, it is better to collect a broad spectrum of all phenotypes in the source population, so that the fullest possible range of genetic variation is represented in the trial programme.
SEED HANDLING AND STORAGE

Normally, seed should be obtained as needed and sown soon after receipt. If it is to be kept for more than a few weeks, advice on its storage should be sought from the supplier, from the literature or from organizations with databases on seed handling, such as the Danish International Development Agency (DANIDA), CSIRO, the Oxford Forestry Institute or ICRAF. In general, seeds are best air- or sun-dried and stored in sealed containers in cold (about 4°C) conditions. They should not be frozen.

SEED PRETREATMENT

The seed of many woody species requires special pretreatment before satisfactory germination can be obtained. This may involve inducing a physiological change in the embryo, sometimes by chilling (often referred to as 'stratification'), or by making alterations in the seed-coat to enable the seed to imbibe water. Seed-coat
treatments range from soaking in water for 24 hours to immersing in boiling water or sulphuric acid. For some seeds, mechanical scarification of the seed coat may be all that is necessary. An interesting variation, effective with the seed of many MPTS species, is the use of a heated wire touched lightly on the seed-coat. This method is particularly useful with many species of *Acacia*.

For all seedlots, advice should be obtained from the supplier and from the literature on methods of pretreatment. In virtually all cases, soaking before sowing is a good practice. If the seed of any species proves to be particularly difficult, research may be required to determine optimum methods for germination.

**SIMPLIFIED SEED TESTING**

Having used an appropriate pretreatment, the main objective of testing a seedlot is to obtain a good estimate of the likely production of healthy planting stock. For standard tests, the rules laid down by the International Seed Testing Association (ISTA) should be used. However, very few MPT species are listed in then-publications (see ISTA, 1976). The methods recommended by the ISTA involve the use of standard laboratory equipment, and their recommendations should be followed by most suppliers of MPT seed for research. For the researcher, it is important that any seed used for testing should be a representative sample of the whole seedlot.

In any experiment, it is advisable to carry out a seed test prior to sowing so that the sowing rate can be adjusted accordingly and, if a seedlot is found to be non-viable, further supplies can be sought. The small-scale, practical tests referred to in Chapter Six can be conducted with, for example, 4 replicates of 25 seeds each in Petri dishes or in plastic containers with lids. Such tests could also be carried out in well-protected boxes of sand in the nursery. A seed laboratory should be used if available, but the absence of an elaborate seed-testing laboratory is no reason for failing to carry out germination tests, as these can be done effectively even in nursery beds.

For further information, the Danish Forest Tree Seed Centre in Humlebaek, Denmark, produces useful seed leaflets, circular letters, technical notes, seed-handling notes and books.
The best possible nursery practice should be used to raise MPTs for field trials because experimental seedlots are usually expensive and not easily replaced and also because sturdy plants with good root systems are essential for optimum survival. Trials of MPTs in the field are not trials of the standard of nursery work.

In most cases, plants should be raised in polythene sleeves or pots. Seed is either sown directly into pots or germinated first in a seedbed and later 'pricked out' into pots. If there is any doubt about nursery techniques, an expert (often a local nursery technician) should be called in to advise or nursery trials should be conducted, such as those described in Supplement Four.

Different nursery practices may need to be tested and evaluated in order to:

- Facilitate the production of suitable nursery stock for evaluation trials
- Investigate the potential of a species or provenance under trial in terms of operational production of nursery stock for planting or direct sowing, including the long-term prospects for large-scale propagation.
Table 11.1. Some standard measures of plant quality.

Morphology index: height x diameter at root collar x root/shoot ratio
- Applied as an average value based on samples of a population
- The root/shoot ratio is obtained by weighing the separate parts

Sturdiness index: diameter at root collar x height
- Applied to individual plants
- Plants are then grouped according to height classes

One experiment listed in Supplement Four (NUR/G) is designed to test fruit-tree grafting in the nursery, another (NUR/C) to determine whether MPT species may be propagated from sprouts or cuttings and a third (EST/S) to test direct sowing as an alternative to raising seedlings in nurseries.

RAISING STOCK FOR HELD EXPERIMENTS

In raising planting stock for field experiments, it is important to keep nursery conditions uniform. The principle is to make the planting stock as uniform as possible by giving different groups of seedlings the same treatment in the nursery.

The field trial should always be designed before the seed is sown in the nursery. Then, if it is not possible to provide completely uniform nursery conditions, at least plants to be used in a single block or replicate are kept as uniform as possible.

Poor germination and survival often result in shortages of planting stock of some entries, so that adjustments have to be made to the field design, or even a new design drawn up. To prevent this, seedlots should receive the best possible treatment, as determined from the literature and consultation with specialists as well as the personal experience of the nursery specialist. Good records must be maintained of exactly what treatments are applied to each group of plants in the nursery, along with regular evaluations of nursery stock. Notes on simple ways to classify nursery stock into quality classes are given in Table 11.1.

Estimating the number of seedlings required

The number of seedlings raised should be calculated taking into account possible rejections because of poor quality and possible replacements in the field. As a rough guide, seedlings should be produced at two to three times the estimated number required. Enough seedlings should be produced to:

- Make it possible to select uniform and healthy planting stock
- Obtain enough plants to replace any casualties at the planting site without delay.
Nursery Practice

Certain entries — species, provenances or seedlots — may germinate poorly, making it difficult to plant out the full proposed design. In addition, it is sometimes desirable to carry out destructive sampling of nursery seedlings for chemical or other analysis. Finally, it is often desirable to plant additional, unreplicated, plots in which to carry out management trials. For these reasons, some deliberate over-estimation may be justified when planning the production of nursery seedlings.

Germination

Suggestions for seed germination are as follows:

- If a field experiment is to be replicated, sow enough seed for each replicate at one time
- Whether sowing into containers or into a seedbed, keep all entries rigorously separated and labelled; use boards, bricks, polythene sheets or other materials to ensure that seed of one entry is not confused with that of another
- Investigate appropriate pregermination treatments in advance and apply just before sowing
- If sowing directly into containers, adjust the rate of sowing according to results of germination tests.

As a rough guide, to be modified in the light of experience, sow two seeds per container if germination is below 80% and transplant surplus seedlings into spare containers; sow one seed per container if germination is over 80% and after about 15 days resow any containers that do not have seedlings. If seeds are very small, it is not possible to sow single seeds. In this case, it is better to allow seeds to germinate in seedbeds and then prick out seedlings into containers if necessary.
Desirable features of a soil mix include the following:

- Good moisture-holding capacity, provided by a good content of humus or well-rotted farmyard manure
- Good drainage, provided by a small proportion of small gravel or sharp sand
- No surface caking; silt content contributes to caking, whereas humus and sand have a beneficial effect
- Retention of nutrients, requiring a small clay content;
- Fertility; for most MPT species, a small initial application of nitrogen, phosphorus and potassium is all that is needed
- A pH about neutral or slightly acid.

Transplanting

If sown in a seedbed, seedlings will have to be transplanted when they are ready for planting out—generally when they are about 3 to 5 centimetres tall. The seedlings should be held gently by the cotyledons, not by the stem, and handled with great care. Not all species transplant easily. For those that do not—such as some of the leguminous species—direct sowing is preferable.

At the transplanting stage, it is easy to mix up different entries and special care is needed to keep the identities of similar-looking plants distinct. Particular care is also needed to avoid heavy casualties through mishandling. Seedlings should be watered with very fine water droplets, such as are obtained with a 'Hawes' watering can. In addition, better results are obtained if seedlings can be pricked out on a cloudy day.

Soil and water

Local practice should be followed or adapted for soil mixtures, the use of beds or pots and the levels of watering to be used. In all cases, the best technology available should be used to avoid wasting time and valuable seedlots, which are often difficult to replace.

Root pruning

Whether seedlings are raised in beds or in containers, root pruning is usually required. Polythene bags, i.e. tubes sealed at one end, are not recommended, as they do not allow effective root pruning, whereas polythene tubes allow only undercutting. In beds, root pruning should be done at two-week intervals, alternately pruning side roots and vertical roots. Open containers should be moved weekly to break emerging long roots.
Shade

Full sunlight and frequent watering are generally the best combination to produce robust planting stock, although shades may be necessary to protect the nursery in areas where hailstorms are prevalent. Heavy shade reduces moisture loss and protects from frost, but tends to produce etiolated, weak seedlings. It should only be used where the watering regime cannot be assured, and not as an alternative to proper and regular watering. However, light shade is valuable for seedbeds and for a few days after pricking out. Where desiccating winds are common, hedges or artificial barriers may be needed to protect the sides of seedbeds. In permanent nurseries, high shades may be desirable, allowing through about 60% of light. This gives protection from heavy rain and hail, as well as from wind.

Root inoculation

Many MPT species require the presence of symbiotic bacteria or fungi for healthy and vigorous growth. For most leguminous —nitrogen-fixing—species, the associated bacteria are of the {\textit{Rhizobium}} type. For \textit{Casuarina} species, which are also nitrogen-fixing but not leguminous, actinomycete fungi, known as \textit{Frankia}, are
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needed. Other fungi, usually of the group known as *Basidiomycetes*, are necessary to form mycorrhizal associations. Some trees require more than one such microorganism.

The identification of species and strains of these microorganisms is a job for specialists, but if a tree species has already been grown successfully in an area, then it is usually safe to assume that suitable microorganisms are present in the soil. If not, specialist advice from one or more of the major international centres for MPT research should be sought (see Supplement Eight).

These microorganisms are most effective in enhancing tree growth when soil fertility is low or moderate. For this reason, large quantities of inorganic fertilizer should not be applied to nursery soil. Experiments to determine appropriate levels of fertilizer application are outlined in Supplement Four (EST/F).

**ASSESSING THE QUALITY OF PLANTING STOCK**

Nursery plants do not always grow continuously: if nutrients or water is limiting, they may stop growing at any stage and go into 'check'. This should be avoided by ensuring good soil conditions, adequate water, adequate plant nutrients—either in the soil mixture or in the irrigation water used—and the presence of symbiotic microorganisms if necessary.

If young trees are to withstand the shock of being transplanted to a new environment, they must be not only vigorous, but tough. This means that the aerial parts of the plants should be woody and not soft or green. The process of attaining this state, called 'hardening off, involves reducing the water supplied to seedlings during the last few weeks before planting out.

The root system of seedlings depends in part on the species and in part on management in the nursery. Good, regular root pruning is necessary to produce a fibrous root system that is not straggling, and thus liable to damage or bending during planting. A fibrous root system can be planted whole with the minimum of damage to fine roots. By contrast, root systems produced in polythene bags are frequently coiled and unsatisfactory.

Some standard measures for evaluating the quality of planting stock are given in Table 11.1. These can be used to classify plants used in MPT field trials. As a rough guide, the goal should be to produce a plant 30 centimetres in height and 8 to 10 millimetres in diameter at the root collar, but an experienced nursery technician or supervisor usually has an 'eye' for quality root stock.

**NURSERY EXPERIMENTS**

Experimental profiles for three types of nursery trial are included in Supplement Four. These are trials for the production of quality planting stock (EST/Q), fruit-tree grafting (NUR/G) and vegetative-propagation trials with cuttings (NUR/C).
CHAPTER TWELVE

TREE ESTABLISHMENT

The chief objective of research on tree establishment is to investigate the characteristics of a particular germplasm collection in relation to its planting and management in agroforestry systems. Clearly, germplasm cannot be tested in all possible agroforestry situations. Establishment research should concentrate on general principles and on ensuring good survival of plants in the field. Summary plans for different types of experiment will be found in Supplement Four.

Establishment research focuses on the survival and growth of tree seedlings in the field. Seedlings should be spaced so that they do not compete with each other during the first few months, when their survival is being assessed. A square spacing of about 1 x 1 metre should be suitable.

Important research questions are as follows:
- The feasibility of direct sowing to economize on labour and other resources
- Optimum planting dates in relation to operational planning and seasons
- The response of seedlings to different degrees of ground preparation and weeding
- The use of fertilizers and/or pesticides
  Early protection methods, for instance against browsing.

Each of these topics will be discussed in more detail.

DIRECT SOWING (EST/S)

Direct sowing is particularly suitable in humid or subhumid conditions and where seed is cheap and abundant. It becomes progressively more difficult in drier climates. If successful, direct sowing eliminates the nursery phase and produces plants with well-developed root systems. However, problems associated with direct sowing include sporadic germination, damage by predators—both to the
seed and to the young plants—and uncertainties over the timing of operations. Experiments should investigate the variables involved, including timing, depth and density of sowing, pregermination of seed and protection from pests.

DATE OF PLANTING (EST/D)

The importance of determining the effects of planting trees at different dates lies partly in finding the planting date that results in the best survival rates and partly in finding other dates that result in acceptable survival rates. The reason for investigating alternative, acceptable, planting dates relates to information on the timing of labour demand obtained during the initial diagnosis and design stage of research. Peak demand for agricultural labour is almost always at the beginning of the rainy season, which coincides with the optimum date for tree planting. For this reason, tree-planting trials should begin about one month before the onset of rains and should continue throughout the rainy season.

The researcher should record the wetted front, the depth to which the soil is wetted, as the rains progress. This is an easy parameter to measure, requiring only a spade and a ruler. The objective is to be able to tell farmers that is safe to plant when the wetted front reaches a certain depth, say 10 to 15 centimetres. The actual depth is determined by research.

GROUND PREPARATION AND WEEDING (EST/W)

The interaction between different plants and their environment is the core of the scientific study of agroforestry. The relationship between weeds, soil preparation
Tree Establishment

and planted trees should thus be regarded as an interaction, and not merely assessed in terms of the effects on trees. Ground-preparation methods used in trials should be those normally used by the local farmers, but clean weeding should always be included as a control. This makes it possible to compare the growth of trees with little or no competition to tree growth under conditions more similar to those likely to occur in an agroforestry system. In some cases, instead of testing the competitiveness of trees against naturally occurring weeds, it may be more useful to test them against the stress imposed by an interplanted crop.

FERTILIZER AND PESTICIDE TRIALS (EST/F)

It is unlikely that farmers will use fertilizers solely to enhance the growth of trees, but trees will respond to fertilizers applied to interplanted agricultural crops. Information on tree responses to fertilizers could be useful for agroforestry technologies such as woodlots or fodder banks.

Trials should be designed to assess the effects of different levels of fertilizer application on tree survival, growth, phenology and yield. In most agroforestry situations, fertilizers will not be necessary to ensure survival. The pattern of tree response to fertilizer is unlikely to be linear, so research is needed to make it possible to estimate the level of fertilizer required to achieve a specific response, for instance the minimum amount of nitrogen, phosphorus and potassium fertilizer needed to produce tree growth sufficient to suppress weeds or to pass browsing height in the shortest possible lime.

Fertilizer trials with multipurpose trees and shrubs will involve mainly nitrogen, phosphorus and potassium application in systematic or factorial designs on a small
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scale, plus other nutrients, such as boron, calcium and manganese, if necessary. Known nitrogen-fixing trees would not normally need to be supplied with additional mineral nitrogen, but they do usually require inoculation with the appropriate bacteria or fungi. Simple fertilizer experiments could be superimposed on almost all other experiments.

Clean weeding is essential on at least some plots to avoid complex nutrient/weed interactions. The expense of clean weeding is a major reason for keeping experiments small, both to keep down costs and to ensure that all plots are weeded as far as possible at the same time. In systematic trials designed to test the extremes of fertilizer application, it is expected that some trees will die as a result of toxicity. However, in trials with factorial arrangements of variables and levels, the amounts of fertilizer applied would be limited to a range of possible field applications.

It should be re-emphasized that fertilization for the exclusive benefit of trees is not widely applicable in agroforestry. In practice, any expenditure on fertilizer is likely to be for the benefit of both the tree and crop components. Proposals for fertilizer trials with multipurpose trees and shrubs therefore relate primarily to a few specific agroforestry technologies, such as woodlots or fodder banks.

The effects of pesticides could be tested initially as a superimposed treatment on an early trial, although a recommended standard treatment applied over the whole experiment would be better. If factorial trials are needed to test different levels and combinations of pesticides to solve particular problems, then they are best conducted as subsequent experiments on a limited number of entries, and not at the introduction stage.
The agroforestry approach to evaluating population genetics is similar to standard plantation-forestry practice, with some important differences, as indicated in Table 13.1. The screening stages are similar: The main differences are in the applied research stages. In agroforestry, selected entries from screening or elimination trials are not put into larger plots. They may even be tested in single-tree plots, but under systems more closely related to the actual designed agroforestry technology. In forestry, the designed technology is usually a well managed, productive plantation.

Generally, the final stage of testing in agroforestry is a prototype systems trial. This is a field trial of a designed system, with the objective to provide information and feedback on the operational aspects of that system.

This sourcebook concentrates on the first two stages of testing—elimination and vigour/phenology trials. Several types of trial that might be conducted at this stage will be described. In all cases, differences between closely related provenances will be much less than between widely differing species, and experiments must take this into account. It must also be emphasized that there is no standard procedure
Table 13.1. Comparison of agroforestry and forestry species evaluation research terms.

<table>
<thead>
<tr>
<th>Agroforestry Terminology Term</th>
<th>Description</th>
<th>Standard Forestry Terminology Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elimination</td>
<td>Mass screening: small plots/lines</td>
<td>Species elimination trial, range-wide provenance trial</td>
<td>Mass screening: small plots/lines</td>
</tr>
<tr>
<td>Vigour/phenology</td>
<td>Reduced number of entries in any size of plot, including single-tree and hedgerow studies</td>
<td>Species testing, restricted range provenance trial</td>
<td>Reduced number of entries in larger (25-49 trees) plots</td>
</tr>
<tr>
<td>Performance/management</td>
<td>Even fewer entries in any size of plot, including single-tree and hedgerow studies</td>
<td>Species and provenance proving trial</td>
<td>Up to 5 entries in large plots incorporating some field experiments</td>
</tr>
<tr>
<td>Prototype systems trial</td>
<td>Designed system or subsystem under study</td>
<td>Pilot forest plantation study</td>
<td>Small operational plantation for yield studies and management feasibility</td>
</tr>
</tbody>
</table>

or time schedule for passing through successive stages of testing, nor is there always a need to conduct tests at every stage.

**TWO SETS OF TRIALS: ELIMINATION AND VIGOUR/PHENOLOGY**

We will now consider the two major phases in the evaluation of multipurpose trees and shrubs — elimination or 'adaptability trials, and vigour/phenology or 'proving' trials.

*Elimination trials* are intended to identify seed sources that can survive the nursery and the initial, and most traumatic, stages of establishment in the field. Conversely, the objective is to exclude from further study those seed sources that cannot survive establishment. Elimination trials examine the adaptation of the seed source to the natural conditions of the site, primarily the soil and climate.
**Genetic Evaluation**

*Vigour/phenology trials* evaluate the initial productivity and phenological behaviour of populations and make a start in examining responses to imposed management conditions. They do not attempt to evaluate all populations under all conditions, but seek to identify suitable seed sources for further research on particular agroforestry technologies.

The genetic evaluation of multipurpose trees and shrubs must address four underlying criteria:
- The population must be suited to the local environment
- It must be responsive to management
- It should be able to share resources with intercrops
- It should sustain or improve the soil.

The main objective of an elimination trial is to assess the suitability of a population of woody perennials to the local environment. If the trees are responsive to management, this means that positive benefits are obtained, for instance from coppicing, pollarding, lopping, pruning or bud manipulation. The specific management treatment varies according to the agroforestry technology. For example, any species used in hedgerows must withstand the stress imposed by close in-row spacing.

Environmental resource sharing is the essence of agroforestry: the woody species must share finite environmental resources with agricultural crops or domestic animals or both, resulting in positive ecological and/or socioeconomic benefits. Research in this area covers such questions as the spacing of trees, shrubs and crops; weediness and competitiveness; the effects of tillage, fertilizer and other inputs; the use of plant residues; and the influence of the layout, density and orientation of intercropping on light and water budgets and microclimatic factors.
Soil sustainability and improvement are a major objective of most agroforestry interventions. Yet, the evaluation of effects on soil chemistry and structure, nutrient retrieval from lower soil layers and recycling within the rooting zone requires considerable long-term research. These effects cannot be assessed in short-term introduction and evaluation trials.

In this section, we shall mention several different types of experiment that can be modified in the light of local conditions. These will be described in more detail in Supplement Four. The exact type and design of an experiment can only be determined after examining the experimental objectives, the resources available, and the experimental site. No single experiment can answer every question: a compromise is always required. Generally speaking, it is best to use simple, well known experimental designs and analyses to yield—in a short time—information on the productivity of multipurpose trees and shrubs and their suitability for further research. All experiments should be repeated after at least two years (or pairs of blocks planted in different years) to allow for differences in seasonal climatic conditions.

The choice of experiment often depends on which factor is most limiting, for instance time, space or staff. The six major experiment types outlined here for species/provenance elimination and early vigour/phenology studies are intended particularly to optimize the use of time.

These are as follows:

- **Elimination trials in small plots (ET/S):** limited land, many entries, few superimposed treatments, close spacing and short duration
- **Elimination trials in large plots (ET/L):** few entries, plentiful resources, wide space, long duration and superimposed treatments possible
- **Vigour/phenology (proving) trials in large plots (VIG/L):** few entries, accurate estimates of biomass production and fodder quality, long duration
- **Vigour/phenology (proving) trials in single-tree plots (VIG/S):** single trees in completely random designs for observations on phenology
- **Vigour/phenology (proving) trials combined with spacing (SPACE)**
- **Proving trials in hedgerows (PROV/H):** small trials with the specific objective of selecting entries according to their response to hedgerow management.

The coding after the names of these experiments refers to the summary plans given in Supplement Four.

**ELIMINATION TRIALS IN SMALL PLOTS (ET/S)**

Elimination trials in small plots of less than 10 trees are designed to provide valid information on the principal trait—survival—for a limited investment of land,
Genetic Evaluation

Plants, labour and time. Plot interactions are obviously significant in single- or double-row plots. Vigorous species will dominate slower-growing species and exaggerate the genetic differences. For this reason, plots should be maintained free of weeds and protected from interference by people or animals. Close spacing between plants is acceptable — as little as 1 metre for experiments with a duration of one to three years.

Given the limited plot size, there is little opportunity for superimposing additional treatments, but early phenological behaviour and habits can be studied. The entire experiment can be coppiced after two to five years to determine the response to this treatment.

**ELIMINATION TRIALS IN LARGE PLOTS (ET/L)**

Elimination trials in large plots (up to 36 trees) are intended to compare a large number of entries — species or provenances — in terms of survival under the best available conditions of management and protection. The primary objective is to determine which entries are worthy of further trial.

Clean weeding is advised generally for elimination trials, and particularly if the entries are to be used principally for woodlots. However, if the proposed agroforestry technology includes weed competition or intercropping, then a standard cereal intercrop could be planted to simulate the expected conditions.

Each plot should contain about 16 trees. This will allow an estimation of vigour and phenology for several years and an indication of wood or pole production. A space of 3 to 4 metres should be allowed between trees if the trial is to last more than about five years.

This type of trial is suitable to produce material for preliminary analysis of fodder quality, wood density or calorific yield. For estimates of performance in stands, where between-tree competition is considerable, square plots of trees are
recommended. Otherwise, line plots—2 x 8 for example—are often easier to handle, especially if other treatments are to be included in the trial. If a trial includes coppicing or lopping, these management treatments may be superimposed on selected individual trees or confounding with replications.

Plots of this size allow some estimation of the extent of individual genetic variation within species. However, the information obtained is probably less reliable in species trials than in provenance trials because of the difficulty of obtaining certified seed with genetic information at the species-evaluation level. If the trials are planted on a number of sites, this type of design will give valuable information on the extent of species/site interaction effects.

In forestry research, no thinning would normally be done in elimination trials. However, with fast-growing species in 16-tree plots, sequential, systematic (i.e. not selective) thinning could be done to lengthen the life of the trial and to facilitate some early management studies.

**VIGOUR/PHENOLOGY (PROVING) TRIALS IN LARGE PLOTS (VIG/L)**

Vigour/phenology trials are the most important stage in the introduction and improvement of species for new sites or agroforestry systems. For species with a wide natural distribution, there can be variations in productivity between sources of as much as 100% of the mean. Land races have developed in species that have been widely introduced and manipulated by man, and these also show large differences. In these cases, all available sources should be compared.

Comprehensive, well-documented provenance collections are seldom available from commercial seed suppliers. It is best, where possible, to make use of existing international species and provenance seed collections such as those of CSIRO in Australia for Australian species, especially of *Acacia* and *Eucalyptus*, the NFTA in the USA for *Leucaena* species and the Oxford Forestry Institute in the UK for Central American dry-zone species, and particularly for provenances of *Gliricidia sepium*. 
Genetic Evaluation

The objective of trials in large plots (up to 100 trees) is to determine the optimum provenance for a given site and technology in terms of the desired products or services. They provide information of particular relevance to technologies based on trees in pure stand (woodlots) or trees planted densely over crops or pasture (fodder banks). Stem and crown form are determined, patterns of phenology assessed and total biomass production estimated. Fodder yield and quality can also be studied. An important consideration is to decide in advance the level of differences that the trial is intended to detect.

VIGOUR/PHENOLOGY (PROVING) TRIALS IN SINGLE-TREE PLOTS (VIG/S)

Researchers accustomed to studying trees for forestry purposes tend to use designs with large numbers of trees per plot, as exemplified by several of the trials described above. This is usually because of the high degree of inter-tree variation and the need to have many samples in order to estimate mean values for species or treatments. In addition, trees in pure stands have to grow in competition with each other. However, a great deal of information can be obtained by observing and measuring individual trees, with considerable saving in space and funds. Single-tree studies are particularly relevant to agroforestry interventions in which trees or shrubs are likely to be managed individually.

The design of a vigour/phenology trial using single trees could include replicated single-tree plots but, for the majority of characteristics to be assessed, a large degree of replication is probably not important. It is necessary only to assemble a small number (up to 10) of individuals from all available germplasm sources and plant them out at random on a uniform site. The objectives are to study seasonal
phenology in detail and, for a sub-sample, to examine responses to various pruning and bud-management techniques.

For several tropical hardwood species, there is evidence of substantial individual variation in growth habit and phenology, which is likely to result in different responses to management and therefore in different degrees of suitability for specific agroforestry systems. The results from this type of experiment will indicate whether further research on infra-specific variation is needed.

PROVING TRIALS IN HEDGEROWS (PROV/H)

The objective of proving trials in hedgerows is to determine the optimum seed sources for widespread species that are intended for linear planting and tree management such as lopping. As with trials in large plots, these experiments should concentrate on a small number of well-known species, attempting to cover the range of natural origins and land races or derived provenances. The literature from international trials should be referred to as a starting point.

Trees should be planted at close spacing within rows and wide spacing between rows and with three rows of a standard cereal crop planted in the alleys. The hedgerows should be lopped after one year and thereafter at appropriate intervals. The fresh weights of all lopped biomass, and dry weights of sub-samples, should be recorded together with standard measurements of stems and branches. After fresh weight is recorded, the lopped material may be spread on the adjacent alley. These trials provide an opportunity to study soil changes under hedgerow intercropping and to evaluate differences among provenances in foliage nutrient content and mulch and fodder value. It is not necessary to measure the production of the cereal plants as these are included only to exert stress on the hedgerow.
Hedgerow trials can be expected to yield information for a long time—they should certainly be planned to continue for at least five years. If they are conducted after the results of large-plot provenance trials are known, there should be no need to repeat them over several years. However, if they are conducted at the same time as—or instead of—larger trials, they should be repeated in order to take account of annual variations in the effect of climate on early establishment.

**VIGOUR/PHENOLOGY (PROVING) TRIALS COMBINED WITH SPACING (SPACE)**

In all the preceding types of trial, the spacing between trees has been virtually the same between rows and often within rows, with the exception of the hedgerow trials in which the within-row spacing is reduced. Yet for many agroforestry interventions, the ideal spacing is not known. For living fences and protective hedges, it may be crucial to obtain information on the behaviour of trees at very wide or very close spacings early in the evaluation programme.

Considerable research has been undertaken on the design of spacing trials, for both large perennials and for small annual plants. Systematic spacing designs often have problems of layout and statistical analysis. For the initial selection of multi-purpose trees and shrubs to be included in further research, a more simple and robust layout is proposed. This is intended to be used for a small number of proven or promising species identified from species-selection trials, or, better still, for the promising provenances identified in provenance trials. However, if the spacing trial is to be carried out at the same time as other selection and proving trials, it should incorporate seed sources that are already known and in use locally.

Three spacings are proposed to cover the range of likely management requirements for hedges or fences—0.5, 2.5 and 5.0 metres. Trees are planted in row plots 30 metres long, so the three treatment plots have 60, 12 and 6 plants respectively. Rows are 4 metres apart with three rows of a standard cereal as an intercrop. Clean
cultivation is required and tree-management treatments may be superimposed by confounding with replicates. Appropriate treatments might include lopping frequencies or the effect of singling coppice shoots to leave one main pole stem.

In addition to survival, which should be recorded annually, the main characteristics evaluated should be fresh weight of all lopped material plus dry weight and chemical composition of a sub-sample. The cereal yield should be determined by individual rows.

This type of trial allows phenological observations to be made on the seasonal production of leaves. Together with the data on vigour and fodder production, these would indicate the region of inter-plant spacing that should be the subject of detailed research at the site-specific level.
SUPPLEMENTS
SUPPLEMENT ONE

PRINCIPAL CHARACTERISTICS OF MPT SPECIES AND THEIR PRODUCTS:
A CHECKLIST

PRINCIPAL ENVIRONMENTAL TOLERANCES

- Low temperature (extreme and monthly mean values)
- High temperature (extreme and monthly mean values)
- Rainfall minimum (annual and for individual months)
- Length of dry season (months)
- Soil pH (maximum and minimum)
- Alkalinity
- Salinity
- Wind speed (extreme and average kilometres per day)
- Waterlogging
- Resistance to pests and diseases

PRINCIPAL MANAGEMENT TRAITS

Seed storage

- Longevity
- Temperature and moisture requirements

Seed germination

- Pretreatment requirements
- Plant yield

Alternative propagation methods

- Direct sowing
- Vegetative propagation

Plant establishment

- Need for microorganisms (mycorrhizas, Rhizobium, Frankia)
Plant management

Coppicing  Pollarding
Lopping  Pruning

PRINCIPAL TREE PRODUCTS

Wood

Unprocessed
- Fence posts (untreated)
- Building poles
- Stakes
- Transmission poles (untreated)

Processed, solid
- Construction
- Furniture
- Fence posts (treated)
- Transmission poles (treated)
- Flooring
- Boat building
- Railway sleepers
- Wagons/carts
- Wheels/spokes
- Farm tools
- Musical instruments
- Household utensils
- Carving, turnery
- Weapons
- Sporting goods
- Matches

Reconstituted
- Veneers
- Pulp and paper
- Chipboard

Bark

Cork  Fibre
Wrapping  Beverages
Tannins  Spices
Dyes  Pharmaceuticals
Energy

Solid, raw (fuelwood)
Solid, processed (charcoal, wood chips, sawdust briquettes)
Other processed (fluid, gaseous, industrial feedstock)

Chemical (stem, leaf and root extracts)

- Resins
- Oils
- Paints
- Varnishes
- Pharmaceuticals
- Tannins
- Dyes
- Adhesives
- Biocides
- Water purification/clearing agents
- Waxes

Leaf products

- Food and spices
- Fodder for domestic animals, silk worms
- Fibre for rope, clothing
- Thatch, roofing material
- Wrapping material
- Smoking material
- Mulch
- Lac
- Pharmaceuticals
- Biocides

Fruit and seed products

- Food (fruit, seed)
- Fodder (fruit, seed)
- Beverages
- Pharmaceuticals
- Oils and fats
- Spices and cooking additives
- Colouring agents
- Cultural and ceremonial dress
- Seed for planting

Flower products

- Honey
- Pharmaceuticals
- Perfumes
- Dyes
- Beverages
- Food

Root products

- Pharmaceuticals
- Dyes
## SUPPLEMENT TWO

### PRINCIPAL CHARACTERISTICS FOR GENETIC EVALUATION OF MULTIPURPOSE TREES, WITH SAMPLE ASSESSMENT FORMS

<table>
<thead>
<tr>
<th>Sample taken</th>
<th>Scope and Purpose of Test</th>
</tr>
</thead>
</table>

#### LEAVES
- Morphology and anatomy: Taxonomy, response to environment
- Phenology or state: Flushing times, duration; longevity
- Chemical composition: Soil nutrient availability; food, fodder, mulch values; taxonomy; physiological condition
- Physical properties: Weight; temperatures; light reflectance/transmission for physiological studies
- Microbiology: Organisms in phyllosphere
- Pests and diseases: Identification of causal organisms

#### CROWN/CANOPY
- Morphology: Size and shape in relation to species and environment; form in communities
- Phenology or state: Seasonal changes and effects on light distribution, rain throughfall
- Physiology: Water loss and use estimates; radiation (light distribution) measurements; light interception
- Pests and diseases: Position in crown
### BUDS

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology</td>
<td>Type and characteristics</td>
</tr>
<tr>
<td>Anatomy</td>
<td>Position, axillary bud series, in relation to plant form</td>
</tr>
<tr>
<td>Phenology or state</td>
<td>Dormancies and growth flushes; pollination and fertilization; fruit drop</td>
</tr>
<tr>
<td>Physiology</td>
<td>Temperature; water potential; hormones for growth-regulation studies; plastochron/phyllochron for growth and flowering behaviour</td>
</tr>
<tr>
<td>Pests and diseases</td>
<td>Special pests (e.g. thrips); birds; diseases</td>
</tr>
</tbody>
</table>

### STEMS

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology</td>
<td>Total height of tree; diameter at base, breast height (1.3 m above ground) and top to estimate taper and volume for poles and timber; diameter at 30 cm for shrubs and multistemmed species; form (straightness); forking, branching; bark; thorns</td>
</tr>
<tr>
<td>Anatomy</td>
<td>Of wood for taxonomy; fibre length; texture; grain indication; figure; heartwood; sapwood</td>
</tr>
<tr>
<td>Phenology or state</td>
<td>Linear changes; season of bark formation; branch shedding; seasonal production of extractives</td>
</tr>
<tr>
<td>Chemical composition</td>
<td>Extractives and exudates, including quality; carbohydrate reserves; analysis of major and minor elements</td>
</tr>
<tr>
<td>Physical and physical-mechanical properties</td>
<td>Colour/density; calorific value; strength; properties for fuelwood, processing, finishing and preservation, veneer and pulp paper; fire resistance in the field; weight</td>
</tr>
<tr>
<td>Physiology</td>
<td>Water potentials; sap studies</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Epiphytes</td>
</tr>
<tr>
<td>Pests and diseases</td>
<td>Stem cancers, galls, wood borers; resistance to termites</td>
</tr>
</tbody>
</table>
**FRUIT AND SEED** *(flowers may be important taxonomically)*

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology</td>
<td>Size; shape; colour; surface characteristics; variability</td>
</tr>
<tr>
<td>Anatomy</td>
<td>Ovule development; fruit growth (parts); seed characteristics; relation of seed to fruit growth during development</td>
</tr>
<tr>
<td>Phenology or state</td>
<td>Time of flowering, fruit set and pollination; duration of fruit maturation period; site of fruiting points; source/sink relationships and environment; effects of weather; size of fruiting load</td>
</tr>
<tr>
<td>Chemical composition</td>
<td>Nutrient composition; total carbohydrates; oils, fats, fibre, vitamins</td>
</tr>
<tr>
<td>Physical properties</td>
<td>Seed storage requirements</td>
</tr>
<tr>
<td>Physiology</td>
<td>Growth rates</td>
</tr>
<tr>
<td>Microbiology</td>
<td>Mycotoxins</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Permits for movement</td>
</tr>
<tr>
<td>Pests and diseases</td>
<td>Mammalian and avian pests; insects, such as bruchids</td>
</tr>
</tbody>
</table>
ROOTS

Morphology
Habit and type of roots

Phenology or state
Elongation; death and decay

Chemical composition
Carbohydrate analysis of main root tissue; extractives

Physical properties
Weights (but cleaning roots is difficult); distribution of roots of different kinds

Physiology
Root activity by observation of live, fine roots in soil cores; soil water profiles; radioisotope techniques

Microbiology
Seasonal occurrence of root nodules (from soil cores); estimates of nitrogen fixation using ethylene reduction technique; net nitrogen increase/decrease in topsoil (giving only partial balance); total nitrogen balance using radioisotopes, cuvettes; detailed soil/plant nitrogen status; samples for free-living nitrogen fixers; mycorrhizas

Pests and diseases
Sampling for soil-borne pests, pathogens and diseased roots; weeds; allelopathy, termites

* Notes for sample field assessment forms (pp. 94)
1. Fill in one form for each plot.
2. Record for every tree number, even the dead trees.
3. Assess at establishment, 6 months, 1 year, 2 years, 3 years.
4. Record height in centimetres to the nearest 10 centimetres.
5. Under tree form, record whether suitable for timber, poles or firewood.
6. Under observations, record vigour, phenology, pests and, optionally, mean crown width. Measure distance along the ground between poles held vertically at the edges of the crown across the widest and narrowest parts. The mean crown width is calculated from these two diameter measurements.

* Notes for sample phenology assessment forms A,B,C (pp. 95-97)
1. Fill in one form for each plot.
2. The same trees are assessed in Parts A, B and C, as indicated by the tree numbers on the left of the forms.
3. Number trees in the same order as on the field assessment form.
4. Mark date (+) if the characteristic has appeared since the last assessment; date (-) if it has disappeared.
5. Estimate the intensity of flowering or fruiting as:
   1 = light, 2 = moderate, 3 = heavy, 4 = very heavy.
6. Under observations, record damage, pollinators, dispersers, predators.
# SAMPLE FIELD ASSESSMENT FORM*
(adapted from Oxford Forestry Institute)

<table>
<thead>
<tr>
<th>Country:</th>
<th>Trial Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institution:</td>
<td>Date established:</td>
</tr>
<tr>
<td>Nursery:</td>
<td>Species:</td>
</tr>
<tr>
<td>Site:</td>
<td>Date of assessment:</td>
</tr>
<tr>
<td>Block number:</td>
<td>Plot number:</td>
</tr>
<tr>
<td>Assessor:</td>
<td>Assessment number:</td>
</tr>
</tbody>
</table>

* Notes: See page 93.

<table>
<thead>
<tr>
<th>Tree No.</th>
<th>Height (cm)</th>
<th>Diameter (cm) at 1.3 m at 10 cm</th>
<th>Stems at 1.3 m</th>
<th>Thorns</th>
<th>Tree Form</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

Numb. Total Mean S.D. Max. Min.
SAMPLE PHENOLOGY ASSESSMENT FORM (A)*
(adapted from Oxford Forestry Institute)

Country: Species:
Trial site: Date of first assessment:
Block number: Plot number:

Form A:
* Notes: See page 93.

<table>
<thead>
<tr>
<th>Tree No.</th>
<th>Leaves Falling</th>
<th>No Leaves</th>
<th>Buds</th>
<th>New Leaves</th>
<th>Old Leaves</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

95
SAMPLE PHENOLOGY ASSESSMENT FORM (B)*  
(adapted from Oxford Forestry Institute)

Country: 
Species:  
Trial site: 
Date of first assessment:  
Block number: 
Plot number: 

Form B: 
* Notes: See page 93.

<table>
<thead>
<tr>
<th>Tree No.</th>
<th>Buds</th>
<th>Flowers</th>
<th>Flowers Falling with ovary</th>
<th>Flowers Falling without ovary</th>
<th>No Flowers</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>
SAMPLE PHENOLOGY ASSESSMENT FORM (C)*
(adapted from Oxford Forestry Institute)

Country:  
Trial site:  
Block number:  
Species:  
Date of first assessment:  
Plot number:  
Form C:  
* Notes: See page 93

<table>
<thead>
<tr>
<th>FRUITS</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree No.</td>
<td></td>
</tr>
<tr>
<td>Immature Small</td>
<td></td>
</tr>
<tr>
<td>Immature Large</td>
<td></td>
</tr>
<tr>
<td>Mature Fruit</td>
<td></td>
</tr>
<tr>
<td>Fruit Falling</td>
<td></td>
</tr>
<tr>
<td>No Fruit</td>
<td></td>
</tr>
</tbody>
</table>
SUPPLEMENT THREE

EXPERIMENTAL DESIGNS
FOR THE INTRODUCTION
AND EVALUATION OF
MULTIPURPOSE TREES

RANDOMIZED COMPLETE BLOCK DESIGNS

The most commonly used design for the introduction and early evaluation of multipurpose trees for use in agroforestry is the randomized complete block (RCB). With this type of design, the experimental site is divided into a number of blocks of equal area. Each block is split into an equal number of plots, one for each species or provenance. Within the plot, a specific number of trees of a single species or provenance is planted. Each species or provenance tested is called an entry. Thus, each block contains a complete replication of the entries to be compared. The entries are allocated at random—using randomly generated numbers—to the plots within each block. It is important that the area within the block is as uniform as possible. Plots should be grouped into blocks with this in mind.

A recommended sequence of operations for designing an RCB experiment is as follows:

1. Determine the number of entries and the number of replications (blocks). There must be at least two blocks in order to estimate residual variation. In practice, a minimum of three blocks is recommended and up to six are sometimes used. The number chosen will be influenced partly by requirements for precision and partly by practical limitations of resources.

2. Decide on the plot size and the number of trees per plot. The duration of the trial, the expected growth rates of the trees and the need for information on performance of trees in stands will influence these decisions. Depending on the duration of the experiment, the expected degree of interference between different entries and the degree of precision with which differences between entries need to be estimated, you may wish to surround each plot with a number of rows of trees as guard rows. However, guard rows enlarge the area occupied by an experiment and increase the costs of maintenance; they should be used with care.

3. Allocate the populations at random to the plots within each block. If, for example, there are four entries, the numbers 1 to 4 are assigned to them in...
any convenient order. Their sequence in a block can then be determined from a table of random permutations, or 'random' numbers generated by a computer. Separate randomizations should be made for each block. The result can be termed an 'office layout' and may look like the plan in Figure 1.

**Figure 1.** Example of a formal plan or 'office' randomization of a randomized complete block design for four populations with four replicates

<table>
<thead>
<tr>
<th>Block 1</th>
<th>2</th>
<th>4</th>
<th>3</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Block 2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

4. Demarcate the plots in the field or nursery. Blocks should be laid down to be confounded with environmental variation within the experimental site, which should be as uniform as possible. Variations between blocks can be accepted within limits, but the plots within a single block should be similar. Placement should take account of natural obstacles such as rivers, rock outcrops, farms or other stands of trees. Where the site is homogeneous with only random variation, or where information on site variation is not available, the plot layout may closely resemble the office layout in Figure 1. A more typical situation is represented by the example in Figure 2, where there is systematic site variation, such as ground slope (indicated by the arrow), and natural obstacles, in this case rock outcrops or homesteads. The blocks are physically split to avoid the obstacles, while remaining fairly homogenous.

The size and layout of each plot depend upon the expected life of the trial, effects of competition between plots and management practices. Large plots of trees necessitate large blocks, and this leads to more variability from plot to plot arising from the natural variability of the site. However, large plots contain more trees from which to evaluate mean values.

Large plots also lead to higher costs, unless replication is reduced. For agroforestry experiments, very small plots, including lines or even single trees, may provide all the information required to choose entries for the next phases of research.
The advantages of RCB designs are:

1. They are suitable for a wide variety of experimental situations.
2. Analysis is simple and is easily accomplished using a desk calculator. Interpretation of results is straightforward.
3. They are statistically robust. There should be no problem in analysis if one or more populations or treatment groups fails completely or is seriously damaged, because such plots can be omitted from the analysis. However, if these plots are excluded, powerful computing facilities may be required for the analysis.

RCB designs are less suitable for comparisons among many populations, since the blocks become large and the assumption of within-block uniformity becomes harder to sustain. They are also less suitable where systematic site variation is complex. In these cases, other designs based on smaller blocks should be used.

INCOMPLETE BLOCK DESIGNS

Often in population studies, and particularly in MPT provenance trials, the number of entries to be compared exceeds 10 or 12. If there are 20 or more trees per plot, it is difficult to find a site with sufficient uniformity to accommodate a complete replication. In incomplete block designs, the experimental plots are grouped into blocks of less than the total number of entries. Each block usually has the same number of plots and each entry occurs the same number of times
overall (i.e. there is constant replication). The arrangement is such that variation between blocks can be estimated and eliminated from the analysis of differences between entries.

An objective of most incomplete block designs is for each pair of entries to occur in a block together the same number of times (however, see alpha designs below). Such a design is said to be balanced: It allows all population comparisons be to made with the same precision. However, it generally requires a large number of replications. Smaller experiments, with only partial balance, are often used in order to reduce size and expense, although these entail some loss of precision for certain comparisons between entries.

Balanced incomplete block designs are not possible for all numbers of entries. This problem may be overcome by adjusting the number of entries to fit the design — either by eliminating those in which interest is low (because they meet the design specifications for the proposed agroforestry system less well than other entries) or by including one or more additional or ‘dummy’ entries (for instance, local seed collections). Another method is to use unbalanced designs, such as alpha designs, which can be drawn up for any number of entries. Increased replication of standard or control entries is also possible. A comprehensive list of available incomplete block designs is given by Cochran and Cox (1957), who also describe the construction and analysis of the designs in detail.

**LATTICE DESIGNS**

A simple type of incomplete block design is the lattice, in which the blocks are physically grouped in sets that form complete replications of the entries. See, as examples, Figures 3 to 9.

**Figure 3.** Plan for a 3 x 4 rectangular lattice with 12 treatments.
The number of entries must be a perfect square, $k$ squared ($= 16, 25, 36, \text{ etc.}$), or a product of the form $k(k +1)$ ($= 12,20,30, \text{ etc.}$). These designs are known as square or rectangular lattices respectively. In each case, there are $k$ ($= 3,4,5, \text{ etc.}$) plots per block and $k$ (square) or $k + 1$ (rectangular) blocks per replicate. In general, a fully balanced square lattice requires $k + 1$ replicates, each arranged in a distinct way. Balanced designs do not exist for certain sizes of square lattices (e.g. for $k = 36,100$ and $144$), nor for any of the rectangular lattices.

**Figure 4.** Plan for a $4 \times 4$ balanced square lattice with 16 treatments.

<table>
<thead>
<tr>
<th>Block</th>
<th>Replicate 1</th>
<th>Replicate 2</th>
<th>Replicate 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 2 3 4</td>
<td>5 1 5 9 13</td>
<td>9 1 6 11 16</td>
</tr>
<tr>
<td>2</td>
<td>5 6 7 8</td>
<td>6 2 6 10 14</td>
<td>10 5 2 15 12</td>
</tr>
<tr>
<td>3</td>
<td>9 10 11 12</td>
<td>7 3 7 11 15</td>
<td>11 9 14 3 8</td>
</tr>
<tr>
<td>4</td>
<td>13 14 15 16</td>
<td>8 4 8 12 16</td>
<td>12 13 10 7 4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Block</th>
<th>Replicate 4</th>
<th>Replicate 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>1 14 7 12</td>
<td>17 1 15 8</td>
</tr>
<tr>
<td>14</td>
<td>13 2 11 8</td>
<td>18 9 2 16</td>
</tr>
<tr>
<td>15</td>
<td>5 10 3 16</td>
<td>19 13 6 3 12</td>
</tr>
<tr>
<td>16</td>
<td>9 6 15 4</td>
<td>20 5 14 11 4</td>
</tr>
</tbody>
</table>

Unrandomized plans for all the important lattices are given in Cochran and Cox (1957) and in Fisher and Yates (1963). See also Figure 9. Notice in the rectangular lattice in Figure 3 that, although the treatments labelled 1,2,3 and 4 never appear in the same block (Neither do 5, 6,7 and 8 nor 9,10,11 and 12.), the lattice is still balanced, enabling us to compare unadjusted means. In unbalanced designs, we must adjust the means before comparing them. See, for instance, Cochran and Cox (1957), p. 380.
When the required numbers of populations and replications have been determined, the appropriate plan is used to produce a randomized design as follows:

1. When the number of replicates required is less than the number in the selected plan for a balanced design, choose replications from the full set at random. Select the required replications at random. Thus, if four replicates of a 5 x 5 lattice are required, select four randomly from the six given in Figure 6. However, this makes the design unbalanced and therefore more complex to analyse. If more replicates are required than are given in the plan, then two or more of the replicates in the plan must be repeated. If in doubt, always seek the advice of a statistician.

2. Randomize the order (sequence) of the replicates actually used.
3. Randomize the order of incomplete blocks within the replicates.
4. Randomize the plots within each block.
5. Assign the entries at random to the treatment numbers in the plan.

**Figure 5.** Plan for a 4 x 5 rectangular lattice with 20 treatments.
This series of randomizations should be carried out using a table of random numbers and permutations, or one of the programmes available for hand calculators. The result is an office layout analogous to that described above for an RCB design. The principles for laying out the design in the field follow those given for RCB designs: Blocks should be confounded with systematic site variation and plots should avoid obvious extreme irregularities. A possible field layout for three replicates of a $3 \times 4$ rectangular lattice is illustrated in Figure 9. This may be compared with the plan from which it was derived, shown in Figure 3.

**Figure 6.** Plan for a $5 \times 5$ balanced lattice with 25 treatments.

<table>
<thead>
<tr>
<th>Block</th>
<th>Replicate 1</th>
<th>Block</th>
<th>Replicate 2</th>
<th>Block</th>
<th>Replicate 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 2 3 4 5</td>
<td>6</td>
<td>1 6 11 16 21</td>
<td>11</td>
<td>1 7 13 19 25</td>
</tr>
<tr>
<td>2</td>
<td>6 7 8 9 10</td>
<td>7</td>
<td>2 7 12 17 22</td>
<td>12</td>
<td>2 8 14 20</td>
</tr>
<tr>
<td>3</td>
<td>11 12 13 14 15</td>
<td>8</td>
<td>3 8 13 18 23</td>
<td>13</td>
<td>16 22 3 9 15</td>
</tr>
<tr>
<td>4</td>
<td>16 17 18 19 20</td>
<td>9</td>
<td>4 9 14 19 24</td>
<td>14</td>
<td>11 17 23 4 10</td>
</tr>
<tr>
<td>5</td>
<td>21 22 23 24 25</td>
<td>10</td>
<td>5 10 15 20 25</td>
<td>15</td>
<td>6 12 18 24 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Block</th>
<th>Replicate 4</th>
<th>Block</th>
<th>Replicate 5</th>
<th>Block</th>
<th>Replicate 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>1 12 23 9 20</td>
<td>21</td>
<td>1 17 8 24 15</td>
<td>26</td>
<td>1 22 18 14 10</td>
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<tr>
<td>17</td>
<td>16 2 13 24 10</td>
<td>22</td>
<td>11 2 18 9 25</td>
<td>27</td>
<td>6 2 23 19 15</td>
</tr>
<tr>
<td>18</td>
<td>6 17 3 14 25</td>
<td>23</td>
<td>21 12 3 19 10</td>
<td>28</td>
<td>11 7 3 24 20</td>
</tr>
<tr>
<td>19</td>
<td>21 7 18 4 15</td>
<td>24</td>
<td>6 22 13 4 20</td>
<td>29</td>
<td>16 12 8 4 25</td>
</tr>
<tr>
<td>20</td>
<td>11 22 8 19 5</td>
<td>25</td>
<td>16 7 23 14 5</td>
<td>30</td>
<td>21 17 13 9 5</td>
</tr>
</tbody>
</table>

With lattice designs or other incomplete block designs, differences between entries may be estimated with precision at least as great as that obtained using an RCB design with equal replication. The disadvantage is that the designs and their analyses are complex and require good computing facilities. However, a lattice, unlike other incomplete block designs, is arranged in complete replicates so that it can, if necessary, be analysed as an RCB, although with some loss of information.
**Figure 7.** Plan for a 5 x 6 rectangular lattice with 30 treatments.

<table>
<thead>
<tr>
<th>Block</th>
<th>Replicate 1</th>
<th>Replicate 2</th>
<th>Replicate 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 2 3 4 5</td>
<td>7 12 17 22 27</td>
<td>13 7 13 19 25</td>
</tr>
<tr>
<td>2</td>
<td>6 7 8 9 10</td>
<td>8 2 7 18 23 28</td>
<td>14 2 8 14 20 26</td>
</tr>
<tr>
<td>3</td>
<td>11 12 13 14 15</td>
<td>9 3 8 13 24 29</td>
<td>15 3 9 15 21 27</td>
</tr>
<tr>
<td>4</td>
<td>16 17 18 19 20</td>
<td>10 4 9 14 19 30</td>
<td>16 4 10 16 22 28</td>
</tr>
<tr>
<td>5</td>
<td>21 22 23 24 25</td>
<td>11 5 10 15 20 25</td>
<td>17 5 11 17 23 29</td>
</tr>
<tr>
<td>6</td>
<td>26 27 28 29 30</td>
<td>12 6 11 16 21 26</td>
<td>18 6 12 18 24 30</td>
</tr>
</tbody>
</table>

**Figure 8.** Plan for a 6 x 6 square lattice with 36 treatments.

<table>
<thead>
<tr>
<th>Block</th>
<th>Replicate 1</th>
<th>Replicate 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 2 3 4 5 6</td>
<td>7 1 7 13 19 25</td>
</tr>
<tr>
<td>2</td>
<td>7 8 9 10 11 12</td>
<td>8 2 8 14 20 26</td>
</tr>
<tr>
<td>3</td>
<td>13 14 15 16 17 18</td>
<td>9 3 9 15 21 27</td>
</tr>
<tr>
<td>4</td>
<td>19 20 21 22 23 24</td>
<td>10 4 10 16 22 28</td>
</tr>
<tr>
<td>5</td>
<td>25 26 27 28 29 30</td>
<td>11 5 11 17 23 29</td>
</tr>
<tr>
<td>6</td>
<td>31 32 33 34 35 36</td>
<td>12 6 12 18 24 30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Replicate 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 1 12 17 22 27 32</td>
</tr>
<tr>
<td>14 2 7 18 23 28 33</td>
</tr>
<tr>
<td>15 3 8 13 24 29 34</td>
</tr>
<tr>
<td>16 4 9 14 19 30 35</td>
</tr>
<tr>
<td>17 5 10 15 20 25 36</td>
</tr>
<tr>
<td>18 6 11 16 21 26 31</td>
</tr>
</tbody>
</table>
This feature can be very useful if one or more entries fails completely or if there are many missing values. Moreover, it permits the researcher who does not have ready access to a computer to do the initial analyses by hand.

Figure 9. Example of a field layout of a 3 x 4 rectangular lattice design with three replicates.

<table>
<thead>
<tr>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Block 4</th>
<th>Block 5</th>
<th>Block 6</th>
<th>Block 7</th>
<th>Block 8</th>
<th>Block 9</th>
<th>Block 10</th>
<th>Block 11</th>
<th>Block 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>10</td>
<td>9</td>
<td>6</td>
<td>12</td>
<td>10</td>
<td>6</td>
<td>12</td>
<td>6</td>
<td>12</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td>6</td>
<td>12</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>4</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>4</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>4</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Block 11</td>
<td>Block 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Block 11</td>
<td>Block 12</td>
<td></td>
</tr>
</tbody>
</table>

Cubic lattice designs exist for very large numbers of entries which form a perfect cube (e.g. 27, 64, 125). These are suitable where site uniformity is so low that very small blocks (3, 4 and 5 plots respectively) should be used. The use of these designs has been described by Yates (1939).

**ALPHA DESIGNS**

Alpha designs are another type of incomplete block design. They were derived from lattice designs (Paterson and Williams, 1976) to reduce the field work needed for particularly large numbers of entries, in this case for agricultural varietal trials. As noted above, lattice designs are only available for certain numbers of entries, even when cubic lattices are used. Alpha designs can be prepared to cover all numbers of entries in the range 16 to 100, and can do this with high efficiency. They do, however, have some disadvantages compared with normal lattices, including a heavy dependency on computers, both for design and analysis.
Alpha designs can be produced from one of a number of generating arrays held in computer memory, and are generally used with block sizes of 4 to 16 plots. A feature of these designs is that some pairs of entries never occur in the same block, so that the accuracy of comparisons can differ between entries. Alpha designs should only be used with the advice of a competent statistician and with adequate computing facilities.

An example of an alpha design for 20 entries—in 3 replicates, 4 blocks and 5 entries per block—is given as Figure 10, derived from Paterson and Williams (1976). These authors give information for deriving designs with between 20 and 100 entries and 2, 3 or 4 replicates.

**Figure 10.** Example of an alpha design for 20 varieties in 3 replicates with 4 blocks and 5 varieties per block. Source: Paterson and Williams (1976).

<table>
<thead>
<tr>
<th>Replicate 1</th>
<th>Replicate 2</th>
<th>Replicate 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>Blocks</td>
<td>Blocks</td>
</tr>
<tr>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>0 1 2 3</td>
<td>0 1 2 3</td>
<td>0 1 2 3</td>
</tr>
<tr>
<td>4 5 6 7</td>
<td>5 7 6 4</td>
<td>6 7 4 5</td>
</tr>
<tr>
<td>8 9 10 11</td>
<td>10 11 8 9</td>
<td>11 8 9 10</td>
</tr>
<tr>
<td>12 13 14 15</td>
<td>15 12 13 14</td>
<td>13 14 15 12</td>
</tr>
<tr>
<td>16 17 18 19</td>
<td>19 16 17 18</td>
<td>18 19 16 17</td>
</tr>
</tbody>
</table>

OTHER TYPES OF DESIGN

Several other types of design might be considered for MPT species or provenance trials, although they are not necessarily appropriate. These include fully randomized designs, latin squares, family blocks and systematic designs.

Fully randomized designs

The fully randomized design is the simplest type of experimental design. Individual plots of each entry are arranged completely at random with no blocking. The
populations need not be equally replicated—there could, for example, be five plots of one provenance, three of another, four of a third and so on. The analysis is straightforward, but the estimated residual variation may be inflated by systematic site variation. Consequently, comparisons between entries maybe less precise than with a corresponding blocked design. The use of systematically or randomly sited control plots (of a 'standard' population, say) probably makes no improvement to precision (Cochran and Cox, 1957) and the implied adjustments to estimated entry means are complicated.

**Latin squares**

A latin square design makes it possible to estimate, and hence correct for, systematic environmental variation in two directions. Plots are arranged in rows and columns, as shown, for example, in Figure 11. Each entry occurs once in each row and once in each column, and the number of replicates of each entry is equal to the number of rows or columns. These designs are most suitable for moderate numbers of entries, i.e. about four to nine. If there are many entries, a latin square becomes too large, while for very small experiments (three or four populations), residual variation may be imprecisely estimated. A set of latin squares for different numbers of entries is given by Fisher and Yates (1963).

**Figure 11.** Example of a formal latin square design for 5 populations.

<table>
<thead>
<tr>
<th>Row</th>
<th>Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>E</td>
<td>B</td>
</tr>
</tbody>
</table>

Latin square designs may be particularly useful in greenhouse or nursery experiments where the sources of systematic variation are obvious. Latin squares would only be used in agroforestry research if there is a specific need to evaluate
site variation in two directions, such as a fertility gradient across a slope. Otherwise, standard blocked designs should be used.

These are formal designs and before use they should be randomized using the following procedure:

1. For the appropriate number of entries, select a design at random from those given in Fisher and Yates (1963). Cochran and Cox (1957) provide one plan for each number of entries.
2. Arrange the columns at random.
3. Arrange the rows at random.
4. Assign the entries randomly to the letters A, B, C, etc. used in the formal plan.

Randomization should be carried out using tables of random numbers.

Graeco-Iatin squares

Graeco-latin squares are designs in which three different sources of systematic environmental variation can be identified and their effects estimated. For instance, the effects of using different soils in a pot experiment could be estimated as well as the row and column effects of a latin square. The number of levels of the third factor (in the example, the number of soils) must be the same as the number of rows, columns or populations. These designs are consequently limited in their usefulness.

Family block designs

If the populations from which entries are selected divide naturally into a number of groups—for instance according to geographical origin or end-use characteristics—it may be useful to keep the groups together in blocks within each complete replication. Typically, the groups may be separate species or distinct varieties, with several provenances (or progenies) of each. The number of provenances in each group (i.e. group size) need not be constant. The resulting design is analogous to a split-plot layout, with groups corresponding to main plots and provenances to subplots.

In the appropriate circumstances, the advantage of the family block design is that differences between provenances, which are likely to be smaller than those between groups (e.g. species), may be estimated more precisely. Designing a family block layout is straightforward. The groups are assigned at random within each replication and then the individual entries are assigned randomly within each group.
Split-plot designs

An agroforestry experiment may be designed to investigate two or more treatment factors applied to experimental units of different sizes. Using a split-plot design, one treatment factor is applied to large plots and a second factor is applied to smaller plots within the larger ones. An example might be the use of three different agricultural crops under a number of different tree species. Each large plot, planted under a single tree species, would be split into three smaller plots, each planted under one of the three crops. In each replicate (block), the treatment factors applied to the larger units (the tree species in our example) are allocated at random, and then the treatments allocated to the smaller units (crop species) are allocated at random separately within each larger unit.

In a split-plot design, comparisons between the split-plot treatments are generally more precise than comparisons between the main-plot treatments. However, to obtain the greatest amount of information that is statistically valid, an experiment should be designed so that all treatment combinations are randomized together: this is not the case with split plots. Split-plot designs should only be used for practical reasons, when some treatment factors require large plots.

Systematic designs

Systematic field layouts have been used by agriculturists, horticulturists, foresters and forage specialists for many years. In such designs, the treatments are laid out in a systematic fashion, dispensing with randomization. For instance, plots may be arranged so that the fertilizer level increases as one moves from plot to plot. In agroforestry, they have some limited applications, such as in the early stages of a study when researchers may wish to test a wide range of levels of a variable, especially if little information is available on the best treatment levels to use in a more conventional design. Examples are plant spacing and fertilizer and herbicide applications, particularly when these are being tried in a new situation.

Systematic designs such as the Nelder fan (Nelder, 1962) have been used for testing entries over a range of different spacings. However, these designs are not recommended for use in straightforward MPT species or provenance trials. They are applicable in agroforestry, for instance, to test a species over a wide range of spacings in order to estimate its response to different amounts of growing space. In this case, each design should be restricted to a single species or provenance, since a comparison of the response to spacing among species is of little interest and not easy to estimate.

In general, systematic designs may be most useful in the early stages of experimentation in order to survey the responses, such as early growth or flowering, of a small number of entries to a variable, such as fertilization or spacing. Such trials will usually be followed by further field experimentation using replicated, randomized designs, especially where reliable yield data are to be compared.
The one possible advantage of a systematic design is that it sometimes requires less space than a randomized block or other conventional layout. In a conventional design where experimental variables (e.g. spacing) are tested at a wide range of levels, large guard areas must be used between plots. In a systematic design, a broader range of levels can be tested in the same space, so that extremes can be included. The use of a wide range of treatment levels can provide a better understanding of plant responses to density stress or other imposed management factors. Such experiments are also useful as demonstrations because they provide an easily observable response to a treatment. For example, they are particularly useful for exploratory fertilizer trials.

The main disadvantage of systematic designs, as compared with conventional designs, is that, even when replicated, there is no randomization within the replicate, and hence no estimate of variation within blocks or replicates. For example, in a fan design, rows may be confounded with a site fertility gradient. Any regression analysis of yield on spacing would therefore give a biased estimate within a single replicate. It is only possible to estimate the standard error of the the regression coefficients from the replication of blocks. An unreplicated systematic design cannot give any estimate of standard errors. For an analysis of fully replicated systematic designs, see a statistician.

Other drawbacks include the need for a high level of skill to lay out the design in the field, the need for each plot to be sited on an environmentally uniform area and the susceptibility to damage—the loss of one plant can seriously affect the response of several others under different treatments around it. To avoid errors arising from the genetic variability of plant material, systematic designs ideally should use clonal planting stock.

Illustrations of systematic designs are given in Figure 12 (Nelder fan), Figure 13 (parallel row), Figure 14 (superimposed managerial treatments) and Figure 15 (two superimposed parallel designs at right angles).

**PLOT SIZE AND TYPE FOR CONVENTIONAL DESIGNS**

The size of experimental plots is determined by the requirement to provide information at a specified level of precision at minimum cost, subject to practical limitations. These limitations include the availability of land and plant material and the requirement to grow the plants under appropriate management condition-s. Precision refers to the level of differences that the experiment should detect, for example differences of 50 centimetres in height between entries with a mean height of 7 metres.

Large plot sizes minimize the effects on mean values of abnormal individual trees and of tree-to-tree microsite abnormalities. Large plots may also be needed if there are substantial edge effects between plots, for instance if there are considerable differences in growth rate between entries, giving competitive advantage to the faster-growing ones. One or two rows of trees around the edges of
Figure 12. A fan design using 11 radii that can also be extended to fit a rectangle, thus increasing the number of plants per arc for the middle range of spacings.
Figure 13. A parallel row design with equal numbers of plants per row in the centre, extending on either side as necessary.
Figure 14. Experimental treatments (e.g. lopping, pruning etc.) superimposed on a parallel row design. The treatments could also be different crop species at standard spacings, for investigating mixed cropping combinations.
Figure 15. Two superimposed parallel row designs for testing the effects of changing plant density in both a tree and a crop species simultaneously. If the parallel rows of trees are extended, a second crop layout could be fitted in.
each plot are defined as guard rows. The larger the plot size, the greater will be
the number, though not the proportion, of guard-row trees. Edge effects may be
considerable if boundaries are unplanted or are highly variable. If no guard rows
are planted, it is recommended to plant two or three rows of a species similar to
the experimental entries on the boundaries of the trial.

If a trial is to last a long time, it is necessary to ensure that there will be enough
trees left in each plot to provide reliable data after one or more thinning oper­
ations. If plots are small, poor survival, whether or not combined with the effects
of thinning, may result in some plots being inadequately represented. Similarly,
analytical problems associated with missing plot values are more likely to occur
with small plots.

Plot size should not be extended beyond the requirement of ensuring that an
adequate plot remains throughout the life of the experiment. Large plots require
large blocks for any given experimental design and so may give rise to a greater
range of residual variation within blocks due to site variability. As a practical guide
for agroforestry experimentation, it is generally preferable to use the available
experimental material to provide more replications of small plots, rather than a
smaller number of larger plots.

If a trial is of short duration and the plants will not need to be thinned, then plots
may be much smaller than otherwise. This is particularly so if edge effects are
assumed to be small, as is probably the case for young woody perennials in a trial
of fairly similar provenances or if early coppicing or lopping are standard manage­
ment treatments.

Spacing is an important determinant of plot area. A spacing between trees
of 3 x 3 metres is frequently suggested for fast-growing species intended for
woodlots or plantations in the tropics, since this allows easy access for inspection
or weeding, reduces or delays the need for thinning and prolongs the life of the
trial. Assessment of height and branch and crown characteristics is easier in widely
spaced stands, and any inherent characteristics of stem form are easier to see. For
agroforestry experiments, even spacing wider than 3 x 3 metres may be desirable.
Single-tree plots should be used with care, but may be relevant if the performance
of the tree in free growth is under study.

For woodlot species, plot size, replication and the duration of experiments
generally increase through the various stages of species and provenance testing.
In the later stages of MPT evaluation in pure woodlots, plots of 20 to 25 trees are
suggested. If space permits, a single guard row is desirable for short-duration trials,
but not essential.

**LAYOUT AND DEMARCATION OF A TRIAL**

A trial should be laid down carefully and precisely, following a field plan designed
according to the site and the number and type of entries. Each block should be as
homogeneous as possible in terms of soil type and depth, slope, aspect, exposure,
previous land use and natural fertility. The experimental site should be uniformly prepared according to the management prescribed in the experimental plan and the entire trial should be marked out before planting begins.

EXPERIMENTAL DESIGNS IN THE NURSERY

These descriptions of designs refer mainly to field experimentation, but generally apply equally to the nursery stage of species and provenance trials. Since the areas involved in nursery trials are smaller and the environment more controllable, the designs may be simpler. However, since there may be systematic differences between nursery beds, it may be desirable to use a blocked design in which the nursery blocks are confounded with blocks in the field design — that is, plants in any one field block should all come from the same nursery block. This is not always possible, but, in any case, treatment of plants within a nursery block should be as uniform as possible.
SUPPLEMENT FOUR

SUMMARY PLANS
FOR EXPERIMENTS ON
MULTIPURPOSE TREES

INTRODUCTION

This supplement is intended to provide guidance on drawing up research plans for experiments involving multipurpose trees and shrubs. The checklists are to be used together with the main text. Any doubts about statistical designs should be clarified with a statistician.

In general, the kinds of trial proposed for the early stages of multipurpose-tree research should not require the use of complex designs. Randomized complete blocks, lattices and alpha designs will normally suffice, with standard analysis of variance. If the only objective is to observe any major qualitative differences as a guide to further research, then it may not be necessary to use a statistical design at all.

The checklists contain suggestions for the following:
- The main objective: this can be modified according to local needs
- A list of agroforestry technologies to which the research might contribute
- A list of specific objectives: exactly what the experiment is meant to find out
- A note on experimental design: this is not an alternative to consultation with a statistician if in doubt
- An indication of spacing and layout
- An indication of likely management needs during the experiment
- A probable duration for the experiment
- An indication of assessments and their timing: these should always include general plant health, the presence of any pests or diseases, and the presence or absence of features such as thorns that may affect the usefulness of the multipurpose trees for service or productive roles.
Checklist 1: DIRECT SOWING

Reference: EST/S

**Type of research:** Establishment trial.

**Main objective:** To determine whether the species may be directly sown successfully under local conditions.

**Relevant agroforestry technologies:** For many farming systems, including hedge-row establishment, boundary planting, fodder lots, live fences and improved fallows.

**Examples of specific objectives:**
- Protractedness of seed
- Density and arrangement of sowing
- Depth of sowing
- Timing and season of sowing
- Use of insecticides and repellents
- Watering regimes.

**Experimental design:** On uniform seedbeds, unreplicated rectangular grids or lines would be adequate if observation only is required. Lines are especially appropriate for hedges and boundary planting. Otherwise, standard replicated designs.

**Field layout:** No more than 20 to 25 viable seeds should be sown per metre of line, or 400 to 500 seeds per square metre. Such dense plantings are appropriate for emergence. Less dense plantings will be used at establishment. Viability percentage to be obtained from standard nursery or laboratory germination tests.

**Management:** Clean weeding, with protection from birds and rodents by mulch, thorny covering or wire netting.

**Duration:** Normally less than 2 years.

**Suggested assessments:** Survival at 3, 6, 12, 18 and 24 months. Notes on causes of damage such as rodents, drought, wash or termites. Height at 6, 12 and 24 months.
Checklist 2: VEGETATIVE PROPAGATION
BY GRAFTING

Reference: NUR/G

Type of research: Nursery trial.
Main objectives: To evaluate grafting potential of fruit tree species in order to provide improved genetic material for distribution and to facilitate the establishment of grafted seed orchards.
Germplasm entries: Normally trials will not be necessary for standard commercial fruit trees if these are well known in the area, but experiments will be needed for lesser-known indigenous species.
Relevant agroforestry technologies: Fruit orchards including grafted seed orchards, mixed intercropping, trees in homegardens, live fences.
Examples of specific objectives:
- Age of rootstocks
- Age or maturity of scions
- Season of grafting
- Types of grafting and budding.
Design: No specific design, but randomized individual trees would be appropriate.
Duration: The success of the technique would be apparent in less than one year. Grafted trees and rooted cuttings would be planted and assessed over the life of the tree.
Suggested assessments: Survival, vigour, compatibility. For fruit trees, yields and long-term acceptability to target user groups.
Checklist 3: **ROOTING CUTTINGS**

**Type of research:** Nursery trial.

**Main objective:** To determine whether species may be propagated easily from sprouts or cuttings, in field or nursery conditions.

**Relevant agroforestry technologies:** Almost all agroforestry technologies in which nursery plants are planted out in the field, especially for high-yielding woodlots. Direct rooting of vegetative material can reduce the costs of establishment and enable farmers to propagate their own plants, especially those of superior phenotype.

**Examples of specific objectives:**
- Age of shoots or sprouts when taken: cuttings should ideally be taken from seedlings, coppice or managed stock plants; the branches must be erect and vigorous to reduce an unwanted tendency to plagiotropism (oblique growth); the best material is frequently that from the uppermost 10 to 15 nodes, as these are relatively un lignified; avoid taking cuttings from shoots of mature trees.
- Density and arrangement of setting out in the rooting medium: the density does not matter a great deal as long as the leaf area per cutting is controlled at about 50 square centimetres; cuttings of each clone should be set in straight lines and well labelled at both ends.
- Depth of planting: cuttings should be inserted fairly deeply and firmed in without compacting the medium; for multinode cuttings, the lower leaves should be removed; cuttings should be placed so that the base of the cutting is just touching the water-table, for example in a non-mist propagator.
- Timing and season of planting.
- Use of hormones, insecticides and repellents.
- Watering: since water is the most critical stress in cutting propagation, the relative humidity has to be constantly maintained at close to 100%.
- Shading: shading is not too critical if cuttings are raised in a water-tight propagator; otherwise, the balance should be optimized between the advantages of photosynthesis and the disadvantages of transpiration.
- Type of irrigation applied (for instance, mist, overhead or subsoil).

**Experimental design:** No special designs are proposed; for simple tests, unreplicated arrangements may be sufficient.

**Field layout:** No more than 20 to 25 cuttings per metre of line or 400 to 500 per square metre should be planted. Trials of short duration can use dense plantings. Longer trials will be less densely spaced.

**Duration:** 6 to 12 months will be sufficient.

**Suggested assessments:** Survival at 3, 6 and 12 months; timing to production of roots/shoots; response to different levels of hormones; response to different levels of irrigation; notes on pests, diseases and other damage; height growth at 12 months.
Checklist4: DATE OF PLANTING

Reference: EST/P

Type of research: Establishment trial.

Main objective: To determine, in relation to progress of the rainy season and timing of labour demand, the survival of trees planted at different dates.

Relevant agroforestry technologies: All in which nursery plants are planted out in the field. Especially important where labour is critical at planting time.

Examples of specific objectives:
- Results from planting out in every month of the year
- Planting beginning about one month before the onset of the main 'planting' rains and continuing at two-week intervals until the beginning of the dry season
- Relationship of extent of soil wetting to plant survival
- Testing survival of a number of different germplasm entries against climatic parameters.

Experimental design: Simple randomized complete blocks.

Field layout: Plot size of 1 to 25 trees per treatment at a spacing of 1 x 1 metre.

Management: Normally clean weeding/cultivation of the soil surface. If the normal land-use system entails weedy conditions, some information from weeding trials (see EST/G) should be incorporated into the design, using a 'normal' level of weeds or a standard crop as competition.

Duration: 6 months to 1 year. May need to be repeated over several years/seasons.

Suggested assessments:
- These trials are best conducted without weeds because the competitive effects of weeds are difficult to quantify
- Measurements are needed of daily rainfall at the site, plus temperature and wind if available. Depth of soil 'wetted front', as observed by digging and measuring with a 30-centimetre rule daily until planting out. This is a well-tried and simple technique for estimating soil moisture and determining when to plant.
- Other suggested measurements are soil moisture content in the rooting zone and survival at two-week intervals until six months after the end of the rains, then when the plants are one year old.
Checklist 5: QUALITY OF PLANTING STOCK
Reference: EST/Q

Type of research: Establishment trial.
Main objective: To determine optimum and minimum qualities of nursery planting stock for species that are already known, including those that are problematical.

Relevant agroforestry technologies: All technologies in which trees are established from nursery stock.

Examples of specific objectives:
- Container sizes. Locally manufactured containers, of banana fibre for example, should be tested alongside plastic tubes. For trials of plastic tube size, the standard, locally used tube of volume V should be taken and treatments based upon five tube sizes as follows: 0.5V, 0.75V, 1.0V (control), 1.25V, 1.5V. Costs (of soil, labour and transport) should be compared in addition to growth characteristics
- Bare-root trials. Trees should be grown in raised nursery beds, with root pruning both below and between plants at regular intervals. Trees raised in this way should be transported to the planting site well protected in wet sacking
- Stumping trials. Stumps are also called 'root/shoot cuttings'. Trees should be grown in open beds without root pruning and cut back to 'stumps' of about 2 centimetres of shoot and 15 to 25 centimetres of root when the mean root collar diameter is about 2 centimetres.

Experimental design: Appropriate designs would be randomized complete blocks and incomplete blocks. In most cases, 10 to 20 trees per plot would be suitable. Since the duration of the trial will be short, a spacing of 1 x 1 metre would be adequate.

Management: the trials would normally be clean weeded. Tests against competition with other plants (crops or weeds) are discussed under 'Establishment Trials' below.

Duration: Normally only one year should be necessary, but trees can be kept for examination of root systems at different ages.

Suggested assessments: The trees from the nursery will be assessed according to normal practice. Internationally accepted standards include root/shoot ratio, sturdiness index and height. Survival could be assessed at at 1, 6 and 12 months. Evaluation of root systems of casualties. Heights at one year. Records of cause of death.
Checklist 6: GROUND PREPARATION AND COMPETITION TRIALS

Reference: EST/G

Type of research: Establishment trial.

Main objective: To determine the levels of ground preparation and weeding necessary to ensure satisfactory survival of planted multipurpose trees.

Relevant agroforestry technologies: All technologies in which trees are established from nursery stock.

Examples of specific objectives: The normal range of ground preparation methods in the area would be obvious basal treatments if used by local farmers: for example, ploughing, hand cultivation or even ripping, applied uniformly over the entire experimental area.

If weeding is to be tested, 'normal' practice should form the control or median treatment. Other treatments would ideally include weeding at varying frequencies, plus no weeding. Suggestions would be:
- At the end of the rains and then monthly or quarterly
- As needed, depending on the judgement of researcher and farmers
- Weeding annually.

In agroforestry practice, most land will be well weeded; patch weeding should be included only in special situations where trees will not be intercropped, e.g. in the establishment of certain woodlots.

Subsidiary treatments could be superimposed, such as fertilizer applications.

Experimental designs: Factorial and split-plot designs as appropriate. A need for uniform plots of large size would reduce the number of treatments that can be applied in a reasonable space.

Field layout: The spacing in plots should approximate that used in field arrangements, although single-tree plots would be suitable for testing many agroforestry applications. A plot size of 50 to 100 square metres is suggested.

Management: No special prescriptions.

Duration: One to two years.

Suggested assessments: The most important parameter to be assessed is survival at the end of the first and subsequent years. Height and diameter would be measured at the same time if the tree is required for the production of woody biomass; otherwise other products and services should be assessed.

The weight of weeds or the biomass of a standard competitive crop maybe used to assist in interpretation.
Checklist 7: FERTILIZER APPLICATION

Reference: EST/F

**Type of research:** Establishment trial.

**Main objective:** To determine the optimum and minimum levels of fertilizer for satisfactory tree establishment and growth.

**Relevant agroforestry technologies:** Those in which trees are planted for a production objective, such as woodlots and fodder banks. Fertilizer trials for the exclusive benefit of trees are not widely applicable in agroforestry. If a smallholder can afford fertilizer, the first priority is likely to be food production. These proposals are, therefore, directed mainly towards the needs of farm woodlots and fodder banks.

Trials would not normally be necessary unless it were felt that fertilizer use on trees rather than on food crops could be justified by the benefits obtained or where soils were so severely deficient in nutrients that tree-growing would be difficult.

**Examples of specific objectives:** The two main soil nutrients likely to prove deficient are phosphorus and nitrogen, the former more necessary for establishment and the latter for production. Other possible nutrient deficiencies include boron, calcium and manganese. Levels would be decided on consultation with a soil chemist, but suggested ranges are up to 400 grams per plant of phosphorus and up to 200 grams of nitrogen.

**Experimental design:** Small two-way systematic designs using single trees can save space; otherwise standard factorial designs would be used.

**Field layout:** A suitable plot size for factorials would be 9 x 9 trees.

**Management:** A spacing of 2 x 2 metres is suggested. Clean weeding is essential throughout the experiment to avoid complex nutrient/weed interactions.

**Duration:** One to five years.

**Suggested assessments:** In systematic trials designed to test the extremes of fertilizer application, it is expected that some trees will die as a result of toxicity. In all other trials, no deaths would be expected, but rather improved survival and growth. Therefore, recommended assessments are survival at one year and heights and diameters (or other parameters assessing biomass) at annual intervals.

Statistical analysis is only possible with systematic designs when the main plot is sufficiently replicated and the direction of systematic change has been randomized across main-plot units.
Type of research: Species/provenance trial.
Main objective: To compare species for initial field survival, with early indication of tree form and phenology, for wood/pole production and, if required, response to lopping. The trial should include at least one local species and one well-known exotic species as controls to link results with other experiments.
Relevant agroforestry technologies: All.
Examples of specific objectives: Testing of exotic species that are little known other than from homoclimal comparisons in database searches and indigenous species identified through ethnobotanical surveys. For wide-ranging species, two or three provenances should be included. Subsidiary treatments could include response to coppicing or lopping frequency or height, or to fertilizer.
Experimental design: Randomized complete block, lattice or alpha designs are recommended, depending on the number of entries and the amount of site variability.
Field layout: A spacing of 3 x 3 metres would be suitable, except for species expected to grow more than three metres in height in a year, for which wider spacing would be used. Large borders or guards will be needed between plots when species have dissimilar growth patterns.
Management: Clean weeding or a constant-density cereal intercrop is suggested; coppicing or lopping could commence at three years.
Duration: Two to three years for estimation of survival and habit. An additional five to eight years for study of wood/pole production, or two to three years for study of simple coppicing or pollarding, if required.
Suggested assessments: Planting height in centimetres. Survival at end of each growing season (count per plot, percentage per species). Survival at end of each dry season (count per plot, percentage per species). Length of longest branch and height at tallest point annually, in metres. The height:branch length ratio describes the habit of the tree. Number of stems more than 1 centimetre in diameter at 10 centimetres above ground and diameter of each of these annually.
Checklist 9: SPECIES/PROVENANCE TRAILS
IN SMALL PLOTS
Reference: ET/S

Type of research: Species/provenance trial.
Main objective: To compare species for initial field survival and to obtain preliminary information on phenology, habit and response to coppicing. The trials should include at least one local species and one well-known exotic species as controls to link results with other experiments.

Relevant agroforestry technologies: All, but especially planted fallows, mixed intercropping, fodder lots and woodlots.

Examples of specific objectives: To examine exotic species that are little known other than from homoclimal comparisons in database searches and indigenous species identified through ethnobotanical surveys. Two or three provenances should be included for some species.

Experimental design: Randomized complete block, lattice or alpha designs are recommended, depending on the number of entries and the amount of site variability.

Field layout: Five plots of lines of trees or 2 x 5 plots of 10 trees. Spacing recommended is 2 x 2 metres.

Management: Clean weeding is recommended with no thinning, but coppicing after three years.

Duration: Three years for estimation of survival and habit. An additional three years for response to coppicing.

Suggested assessments: Planting height in centimetres. Survival at end of each growing season (count per plot, percentage per species). Length of longest branch and height at tallest point annually, in metres. The height:branch length ratio describes the habit of the tree. Number of stems more than 1 centimetre in diameter at 10 centimetres above ground and diameter of each of these annually.
Checklist 10: VIGOUR/PHENOLOGY TRIALS IN LARGE PLOTS

Reference: VIG/L

**Type of research:** Provenance/species trial.

**Main objective:** To determine the optimum seed source of wide-ranging species for given site types, based on survival, biomass production, form and coppicing ability. Provenances of wide-ranging, well-known species are preferred, with some demonstrated potential under local conditions.

**Relevant agroforestry technologies:** All, but intended primarily for woodlots or tree-fodder lots.

**Examples of specific objectives:**
- Testing up to 20 natural origins plus appropriate local land races from within or outside the region
- Obtaining data on rates of growth or on coppicing or pollarding.

**Experimental design:** Randomized complete block, lattice or alpha designs are recommended, depending on the number of entries and the amount of site variability.

**Field layout:** Suggested planting distance is 2 x 2 or 1.5 x 1.5 metres, with square spacing. Suggested plot size is 25 to 64 trees with one unmeasured border row.

**Management:** Fifty percent thinning at canopy closure of the fastest-growing provenance. Clean weeding is recommended with no thinning and coppicing after three years.

**Duration:** Ten years.

**Suggested assessments:** Planting height in centimetres. Survival at end of each growing season (count per plot, percentage per species). Survival at end of each dry season (count per plot, percentage per species). Length of longest branch and height at tallest point annually, in metres. The height:branch length ratio describes the habit of the tree. Number of stems more than 1 centimetre in diameter at 10 centimetres above ground level and diameter of these annually. Height at thinning and final felling. Diameter of thickest stem at height of 30 centimetres above ground at 12 months, at thinning and at final felling. Chemical and other analyses could be carried out on a sample of two trees per plot at final felling.
Checklist 11: PROVING TRIALS FOR HEDGEROWS

Reference: PROV/H

Type of research: Species/provenance trial
Main objective: To determine the optimum seed source of wide-ranging species for given site types, intended primarily for hedges or hedgerow intercropping, based on survival, coppicing/lopping ability, biomass production and effect on adjacent crops. Wide-ranging species would be used, preferably those that are well known and with demonstrated potential for hedges and foliage production.

Relevant agroforestry technologies: Hedgerow intercropping, hedges.

Examples of specific objectives:
- To examine the potential of 20 natural origins plus appropriate land races from within or outside a region
- To carry out leaf-composition studies.

Experimental design: Randomized complete block, lattice or alpha designs are recommended, depending on the number of entries and the amount of site variability.

Field layout: Ten trees in single row of 10 or double rows of 5, at 0.5 metre between trees in rows, 4 metres between rows of trees, 0.5 metre between crops in rows, and 1 metre between rows of crops. Two border rows of trees around perimeter of whole trial. Alternatively, a systematic spacing design could be used to produce additional information. This would involve closely spaced trees at one end of a line plot to simulate a hedge, increasing to individually growing trees at the other end of the line.

Management: Trees could be lopped at one year or when average height reaches 1.5 metres and lopped every three months thereafter at 0.5 to 1 metre above ground. Lopped material either spread on the adjacent alley after determination of fresh weight production or removed and used elsewhere.

Duration: Five years.

Assessment: Height at planting, in centimetres. Survival as count per measured plot and percentage per provenance after 0.5 month and annually. Weight of fresh biomass at each lopping, separated into whole leaves (including petioles) and stems or woody branches. Dry weight determined from subsample of two trees per plot. Length of thickest branch or stem at first lopping. Number of branches exceeding 1 centimetre in diameter at 30 centimetres above ground, at first lopping. Number of branches sprouted at time of second lopping. Crop yields by individual rows. Analysis of soil structure and chemistry after one and five years.
Checklist 12: VIGOUR/PHENOLOGY IN SINGLE-TREE PLOTS

Reference: VIG/S

**Type of research:** Provenance/species trial.

**Main objective:** To provide examples of free-growing multipurpose trees for phenological observation and study of morphology after various lopping treatments.

**Relevant agroforestry technologies:** Hedges/live fences, hedgerow intercropping, mixed intercropping.

**Examples of specific objectives:** To evaluate pruning or training treatments.

**Experimental design:** Randomized complete block, lattice or alpha designs are recommended, depending on the number of entries and the amount of site variability.

**Field layout:** A spacing of 5 x 5 metres square is suggested, using single-tree plots.

**Management:** Standard planting and cultivation, including cereal intercrop if intended for hedgerow or mixed intercropping. Pruning or training, depending on fence or hedge requirement.

**Duration:** 5 to 10 years.

**Suggested assessments:** Observations on phenology of leaf, sprout and flower production every two weeks. Daily climatic data averaged monthly. General description of morphology of each plant.
Checklist 13: FENCE/HEDGE SPACING

Reference: SPACE

**Type of research:** Species/provenance trial.

**Main objective:** To assess the suitability of multipurpose trees for fences and hedges and to determine spacing levels for further site-specific research. To examine the early phenology of multipurpose trees under competition and free growth. A small number of proven or highly promising species would be chosen.

**Relevant agroforestry technologies:** Hedges, live fences, hedgerow intercropping.

**Examples of specific objectives:** To estimate the effects of lopping at one year and annually thereafter, lopping at one year and then every three months, and singling at one year and thereafter maintaining single stems to post or pole size.

**Experimental design:** Randomized blocks.

**Field layout:** Suggested spacing would be 0.5, 2.5 and 5.0 metres between plants in row (60, 12 and 6 plants respectively), 4 metres between rows with three rows of crops at standard spacing in rows.

**Management:** Optimum land preparation and cultivation, clean weeding is advised. Tree-management treatments could be considered as subsidiary treatments.

**Duration:** Five years.

**Suggested assessments:** Survival annually. Fresh weight of lopped material. Fodder analysis, if fodder requirement. Diameter of branches and stems at 30 centimetres above ground after each lopping or singling. Yield of crops by individual row. Phenological observations of leaf-production time.
A GLOSSARY OF TERMS USED IN AGROFORESTRY RESEARCH

Note: This glossary is based largely on Huxley (1986). Not all the terms in the glossary appear in the text.

A

Albedo: The ratio of reflected to incoming radiation, usually given in percent of vegetation or soil.

Allelopathy: The influence of plants, rather than microorganisms, upon each other, arising from the products of their metabolism.

Alley cropping: Also called 'alley farming' and 'hedgerow intercropping'; an agroforestry intercropping system in which species of shrubs or trees are planted at close in-row spacing, with wide spacing between rows to leave room for herbaceous crops.

Association: A plant community of a particular kind or grade.

Attribute: In statistics, qualities possessed by an individual; see also 'variable'.

B

Block: A set of items or experimental units under treatment or observation that have been grouped to minimize environmental effects or other initial differences between units.

Bole: A tree stem once it has grown to a size to produce poles or timber.

Breast height: By international agreement, the point 1.3 metres from the ground on the bole of a tree.

Browsing: The feeding on buds, shoots and leaves of woody growth by livestock or wild animals. Browse is the material consumed.
**Buffer:** In biological systems, to regulate against sudden change.

**Bulk density:** Of soil, weight per unit volume.

**Bunding:** The arrangement of organic material or soil in lines along the contour of a slope, to control runoff or erosion.

**C**

**Certified seed:** Seed used for commercial production from a registered seed source under the regulation of a legally constituted agency.

**Character:** Attribute of an organism resulting from a genotype/site interaction.

**Check:** A condition in which plant growth is arrested or reduced due to competition, disease or the state of the soil.

**Cline:** Graded sequence of genetically based differences within a species related to environmental gradients.

**Clone:** An organism or organisms descended by mitosis from a common ancestor.

**Collar:** The transition zone between root and shoot in a plant.

**Coppice:** To cut broad-leaved trees close to the ground to produce sprouts and regrowth.

**Cotyledon:** The ‘seed leaf present in the seed that forms the first green leaf in the germinated plant. The cotyledons are often organs for food storage.

**Covariance:** The mean of the product of the deviation of two variates from their individual means. A statistical measure of the interrelation between variables.

**Covariance analysis:** An analysis of variance in which the dependent variable being analysed is a function of one or more independent variables not controlled in the experimental design.

**Crown:** The canopy of a tree or other woody plant, surmounting a more or less clear bole or boles.

**Crown diameter:** A mean figure derived from two or more measurements of the maximum and minimum horizontal spread of the crown of a tree.
Crown height: The vertical distance from ground level to the base of the crown of a tree.

Cultivar: A cultivated variety of plant.

D

Degrees of freedom: The number of independent comparisons that can be made in a set of data.

Diameter class: A grouping of plants having stem diameters falling within a preset range of values.

Direct sowing: Planting seeds to germinate in the site at which the mature plants are to be grown.

E

Etiolation: The condition of a green plant that has not received sufficient light or is attacked by certain diseases, typified by long attenuated stems having insufficient supporting tissue and yellowish or whitish leaves.

Exotic: Strictly, a plant growing anywhere outside its natural range.

F

Factorial: An experiment in which all levels of two or more treatments are applied singly and in all possible meaningful combinations so that the main effects and interactions can be observed.

Fan design: A type of systematic design for plant-spacing studies in which plants are arranged at systematically increasing distances along radii and arcs.

Free growth: A situation in which a tree or other plant is growing with its crown more or less free from competition.

G

Gene pool: The total genetic information possessed by the reproductive members of a sexually reproducing population.

Genecology: A combination of ecology and genetics to study the genetic variation among populations of a species that is correlated with habitat.
**Genotype:** An individual's hereditary constitution, with or without phenotypic expression of the characters it underlies. The genotype is determined chiefly from the performance of progeny and other relatives. Genotype x environment = phenotype.

**Genotype x environment interaction:** When tests are conducted at different locations or under different cultural conditions, the failure of entries to maintain the same relative ranks or levels of differences in the different environments.

**Genus:** A rather arbitrary category in the taxonomic hierarchy between that of family and species. Tree and shrub genera consist of one or more closely related species and are defined mostly in terms of the characteristics of the flower and/or the fruit.

**Geometric design:** A simple type of field layout for examining the tree/crop interface (or transect) and measuring plant-environmental changes brought about by the association of two or more species.

**Germplasm:** The sum total of the hereditary materials in a species, i.e. the genes and cytoplasmic factors governing inheritance; the hereditary material transmitted to offspring through the germ cells.

**Guard row:** A line of plants along the edge of a research plot that is not measured, with the object of minimizing the effects of one treatment plot on another.

**H**

**Herbaceous:** Not woody, dying down each season.

**Hybrid:** Offspring of organisms of dissimilar genotype, often the offspring of a cross between different species.

**I**

**Ideotype:** A conceptual model of a plant type that will be best suited to a particular set of circumstances. Ideotypes can be defined in terms of both form and function. There can be isolation, competition and crop ideotypes.

**Increment:** The increase in girth, height, volume, weight or value of individual trees or crops.

**Independence:** A relationship between variables in which the variation of each is not influenced by that of the other.
Indigenous: Native to a specified area, not introduced.

L

Land race: Genetically variant population originating from selection and propagation by individual farmers or in small areas of geographic isolation.

Latin square: Experimental design that attempts to remove two sources of positional error (row and column effects) from residual variation. A $5 \times 5$ square consists of 25 plots in 5 rows with 5 plots per row and each treatment occurring once in each row and column.

Lattice designs: Incomplete block design for variety or provenance trials. In square lattices, the number of entries must be an exact square—9, 16, 25, 49, 64. Rectangular lattices allow 12, 20, 30, 42, 56 entries. Analysis of lattices is fairly straightforward.

Leaf area index: The area of crop leaf per unit area of ground covered by the crop: can also be estimated for single plants or hedgerows.

Litten Uppermost layer of organic debris on the soil surface, composed of freshly fallen or slightly decomposed materials.

Lopping: Cutting one or more branches of a standing tree for fuel and/or fodder.

M

Macroclimate: The climate of a region.

Mean annual increment (MAI): The total increment up to a given age divided by that age. The MAI for a whole rotation is termed the final MAI.

Microclimate: The climate around a plant.

Model: A quantitative representation which, if complex, may require algebraic and arithmetic manipulation. Such models are essential elements of systems analysis, statistical analysis and many forms of computer simulation.

Monoculture: Repeated growing of the same crop on the same land.

Morphology: The form or outward shape of a plant.
Multiple regression: Relationship between the specified values of two or more ('independent') variables and the expected value of a random ('dependent') variable whose distribution depends on particular values taken on by the investigators.

Multivariate analysis: A loose term denoting the analysis of data that are multivariate in the sense that each observation bears the values of a number of variables, e.g. principle component analysis, canonical correlation analysis.

Multivariate factor analysis: A mathematical method of analysing sets of data to discover which variables are statistically linked, by causative or other factors.

N

Nodules: Nitrogen-fixing root swellings of characteristic shape and size for particular leguminous species, which contain the bacterium *Rhizobium* spp. If effective, atmospheric nitrogen is fixed within nodules and becomes readily utilizable by the plant.

O

Origin: For an indigenous stand of trees the origin is the place in which the trees are growing. For a non-indigenous stand, the origin is the place from which the seed or plants were originally introduced.

Orthogonal: Keeping other factors constant when comparing any particular set of factors.

P

Parallel row design: A type of systematic spacing design in which the area per plant is changed systematically by varying the spacing between and within rows, with all the rows parallel to one another.

Parameter: Characteristic or feature of a population.

Perennials: Plants that continue their growth from year to year.

Pests: Organisms which, in a general sense, damage plants or animals. These may include insects, birds, rodents or other mammals, weeds and fungi or other disease-causing agents.
Phenology. The study of the time of appearance of characteristic periodic phenomena in the life cycle of organisms in nature, for example flowering or leaf fall, especially as influenced by environmental factors.

Phenotype: An organism as it is observed, i.e. as judged by its visual, perceptible characters resulting from the interaction of genotype with environment. Similar phenotypes do not necessarily breed alike.

Phyllosphere: The space immediately adjacent to, and influenced by, a plant leaf.

Phytosanitary certificate: A written statement about the health of plants required when they are exported or imported: usually in an internationally agreed form indicating field inspection, seed treatments etc.

Phytotoxic: Toxic (damaging) to at least some plants.

Plot: Any experimental unit that is uniform in some way.

Plus tree: A tree shown to be superior in terms of phenotype, but not yet proven genetically as an elite tree by progeny testing.

Pollarding: Cutting back in more or less systematic fashion the crown of a tree with the objective of harvesting small wood and browse, producing regrowth beyond the reach of animals or reducing the shade cast by the crown.

Population: In genetics, a community of individuals that share a common gene pool. In statistics, the hypothetical and infinitely large series of potential observations from which the observations actually made constitute a sample.

Precision: The closeness of agreement to be expected between a succession of independent estimates made by a repetition of the sampling procedure.

Progeny: Offspring.

Progeny test: A test of the value of a genotype based on the performance of its offspring produced in some definite system of mating.

Propagule: Part of a plant with the potential for producing a new individual.

Provenance: The place in which any stand of trees is growing. The stand may be indigenous or non-indigenous.
Pruning: The process of cutting back growth of plants, including roots, but more particularly the side branches of trees.

R

Ramet: A propagule.

Range: The limits of magnitude (of a set of data).

Recalcitrant seed: Seeds of certain species that have relatively short viability and will die if not kept in moist conditions.

Regression: A statistical technique for modelling the way that one variate predicts another.

Regression coefficient: A parameter in a regression model, usually the slope of a linear regression.

Replicate: To apply a treatment, or set of treatments, more than once in order to increase the precision of comparisons and to provide an assessment of the variability among experimental units treated alike.

Research: Investigation directed to the discovery of some fact by the careful study of a subject; a course of critical or scientific enquiry.

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

Root zone: Layer of the soil interwoven by plant roots.

Root stock: A root-bearing plant or plant part, generally a stem or root, onto which another plant part is grafted; also, the collective roots in a stand, capable of sprouting.

S

Sample: Part of a population consisting of one or more sampling units, selected and examined as representative of the whole.

Scarification: Abrasion of the coat of seed or fruit by mechanical, chemical or physical (e.g. dry heat) means; often required to improve the germination of 'hard-seeded' species.
**Scion**: A vegetative propagule used for grafting.

**Shrub**: A descriptive term, not subject to strict definition, referring to a woody plant that remains low and produces shoots or trunks from the base, not treelike nor with a single bole.

**Silvopastoralism**: The integration of trees with pasture.

**Singling**: The procedure of removing surplus seedlings or young plants from clusters (clumps) or close-planted lines in order to leave each plant with sufficient space for its future needs. The process of removing coppice shoots to leave one, or a small number, to grow on.

**Split plots**: In an experimental layout in which one or more treatments is applied to whole plots and one or more different treatments is applied to portions of plots, the portions are known as split plots.

**Stand**: A community of trees possessing sufficient uniformity—in terms of composition, constitution, age, spatial arrangement or condition—to be distinguishable from adjacent communities, so forming a silvicultural or management entity.

**Standard deviation**: A measure of the range of variation of a series of observations.

**Standard error**: Standard deviation of an estimator, usually a mean, indicating the precision with which the estimate has been made.

**Stochastic**: Having a probability attached to it. A stochastic process is one in which the next event is probabilistically related to previous events.

**Strain**: A group of similar individuals within a variety.

**Stratification**: 1. A sampling procedure in which a population is divided into strata, each stratum is sampled separately and the results are combined, with the objective of improving precision. 2. In seed handling, the placing of a seed in a moistened medium, such as peat or sand, which is often chilled, in order to maintain viability and overcome dormancy.

**Stump**: Planting stock in which the shoot and root have been cut back (usually to a shoot of 2 to 3 centimetres and a root of 10 to 20 centimetres) to produce an easily transported propagule.
**System**: A number of components linked together for some common purpose or function, hence 'agricultural system', 'agroforestry system' etc.

**Systematic**: Referring to an experimental design in which treatments are applied in a systematic fashion without randomization, such as a fan design or a design in which adjacent plots have gradually increasing spacing or rates of treatment.

**T**

**Taper**: The decrease in thickness, generally in terms of diameter, of a tree stem or log from the base up.

**Taungya system**: Method used in the early stages of forest plantation establishment based on raising forest trees in combination with agricultural crops in order to provide some food and lessen establishment costs.

**Topoclimate**: The climate at a place, such as a field or a slope: usually considered to encompass a larger area than a microclimate, which refers to the climate around plants, but a smaller area than a macroclimate, which refers to the climate of a region.

**Tree form**: The degree and mode of taper in a tree or log; also loosely applied to the general shape of the bole and its desirability for utilization.

**Tree/crop interface**: The spatial extent over which some form of interference occurs between the tree and crop components in an agroforestry system.

**Trial**: An action, method or treatment adopted in order to ascertain a result, usually shorter and/or less significant than an experiment; may be part of an investigation.

**V**

**Variable**: Any quantity or quality able to show variation from one individual to the next in the same population.

**Variate**: A single observation or measurement.

**Variety**: A subdivision of a species; see also cultivar, which means a cultivated variety.
REFERENCES AND FURTHER READING


FAO (1973-). *Forest Genetic Resources Information*. Various issues.


LIST OF ACRONYMS

ACIAR: Australian Centre for International Agricultural Research (Canberra, Australia)

AGRICOLA: database of the National Agricultural Library of USDA

AGRIS: International Information System for the Agricultural Sciences and Technology (FAO, Rome, Italy)

CABI: CAB International (formerly Commonwealth Agricultural Bureaux) (Wallingford, UK)

CATIE: Centro Agronómico Tropical de Investigación y Enseñanza (Turrialba, Costa Rica)

CGIAR: Consultative Group on International Agricultural Research (Washington, DC, USA)

CSIRO: Commonwealth Scientific and Industrial Research Organization (Canberra, Australia)

CTFT: Centre technique forestier tropical (Nogent-sur-Marne, France)

DANIDA: Danish International Development Agency (Copenhagen, Denmark)

DNA: deoxyribonucleic acid

EMBRAPA: Empresa Brasileira de Pesquisa Agropecuária (Brasilia, DF, Brazil)

FAO: Food and Agriculture Organization of the United Nations (Rome, Italy)

GEI: genotype-environment interaction

ICRAF: International Council for Research in Agroforestry (Nairobi, Kenya)
ISTA: International Seed Testing Association (Zurich, Switzerland)

ISTS: Indian Society of Tree Scientists (New Delhi, India)

IUFRO: International Union of Forestry Research Organizations (Vienna, Austria)

KEFRI: Kenya Forestry Research Institute (Muguga, Kenya)

MAI: mean annual increment

MPT: multipurpose tree

NFTA: Nitrogen Fixing Tree Association (Waimanolo, Hawaii, USA)

RCB: randomized complete block

USDA: United States Department of Agriculture (Beltsville, Maryland, USA)
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<td>Commonwealth Scientific and Industrial Research Organization (CSIRO)</td>
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This source book was written to provide guidance to field workers on the introduction and evaluation of woody perennials for use in agroforestry. In this context, *introduction* means taking a species to an environment where it is not well known or established and *evaluation* refers to the process of determining the suitability of a particular species for use in an agroforestry system. The evaluation process seeks, first, to determine the adaptation of the species to the site, as demonstrated by its survival and early growth, and, second, to study its phenology and morphology as a guide to its suitability for a specific agroforestry system.

The authors' objectives may be summarized as follows:

- To give basic principles for multipurpose-tree evaluation that will help scientists who are designing agroforestry research programmes
- To present a logical, chronological sequence of the stages of multipurpose-tree research, including the early study of possible responses to management
- To give guidance on the preparation of simple, robust experimental designs
- To recommend simple assessment procedures.

The book is organized in four sections and four supplements. The sections cover: background to species selection for agroforestry, research planning and design, assessment and evaluation, and important areas of multipurpose-tree research. The supplements include a checklist of principle multipurpose-tree characteristics and products, a list of assessments for multipurpose-tree evaluation with sample formats, experimental designs, summary plans for 10 types of experiment, a glossary of terms, names and addresses of useful organizations, and references.

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