

## Chapter 3

# SELECTION OF SPECIES AND PROVENANCES FOR PLANTING

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The selection of species and provenances for planting is still a very subjective process. It is largely reliant on personal knowledge, judgement and experience augmented by literature reviews. This situation has improved somewhat in recent years with the development of computer-assisted decision support systems. Field surveys of the planting site, assessment of the precise end-use of the trees and a desk survey of the range of potentially suitable species available should be conducted before final decisions are made on species to be short-listed. Ideally this phase should be followed by a research phase involving field tests of short-listed species, seed sources and management options. Only when such steps have been followed can we be confident that we have selected the best species for the site and intended end use. Although there have been some instances where a single species has been chosen and planted widely from the start, one should be aware that new 'miracle' species often have not been adequately tested and may not meet expectations.

Perhaps the most exciting new development in recent years has been the emphasis placed on the selection of non-industrial trees for farm (agroforestry) and environmental use in both developed and developing countries. This has considerably expanded the range of species to be considered and has really tested the capacity of forestry professionals to give accurate advice on choice of species. There has also been an increased call for the greater use of indigenous species to avoid the reliance usually placed by professionals on a small number of well-tried exotics. The problem we all face is that reliable information on ecological, growth, silvicultural and utilisation characteristics of many potentially valuable species is still difficult to obtain. Many lesser-known species with potential for agroforestry, e.g. native fruit trees, have been described by Leakey (1994) as Cinderella species. When detailed knowledge of lesser-known indigenous species is

acquired it may also be possible to trade-off species with rapid growth for those indigenous species with slower growth but with greater resistance to drought, fire and pests. Such species may have lower water and nutrient requirements, or may provide more valuable wood products than common exotics, albeit over a longer time.

The modern development of agroforestry as a scientific discipline has brought with it a very special focus on the use of certain tree species, and their special properties, for use in particular farming systems (see Sanchez 1995). From a species selection viewpoint the objective is to choose species that are compatible with farm crops, produce valuable products and provide environmental services, e.g. improved soil fertility. While it is possible to recommend certain species for certain products we still lack the capacity to quantify the effects of tree growth on the growth of companion crops. In this sense our scientific knowledge of trees and their interaction with crops is still in its infancy and our selection procedures primitive. Moreover, the impact of repeated harvesting of the tree crop itself may differ significantly between species.

Young (1989) took account of much of ICRAF's pioneering work on categorising agroforestry technologies when proposing 19 such technologies (Table 3.1). Most of these technologies are based on information gathered worldwide on existing indigenous agroforestry systems. Categorisation only serves to focus our attention on how trees can be used on farms in a technological sense. One can divide all 19 technologies into two time-related types, viz. simultaneous and sequential agroforestry systems. From the point of view of this book, our long-term vision is to evaluate all lesser-known Australian species for use in each technology. Two technologies of special interest to current agroforestry practice are improved sequential systems such as fallows (e.g. the role of tree species in improving soil

**Table 3.1.** Agroforestry technologies (adapted from Young 1989).

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MAINLY AGROSILVICULTURAL (trees with crops)

*Rotational*

- Shifting cultivation
- Improved tree fallow
- Taungya

*Spatial mixed*

- Trees on cropland
- Plantation crop combinations
- Multistoried tree gardens

*Spatial zoned*

- Hedgerow intercropping (barriers, alleys)
- Boundary planting
- Trees on erosion-control structures
- Windbreaks and shelterbelts
- Biomass transfer

MAINLY OR PARTLY SILVOPASTORAL

(trees with pastures and livestock)

*Spatial mixed*

- Trees on rangeland or pastures
- Plantation crops with pastures

*Spatial zoned*

- Live fences
- Fodder banks

TREE COMPONENT PREDOMINANT

- Woodlots with multipurpose management
- Reclamation forestry leading to multipurpose use

OTHER COMPONENTS PRESENT

- Entomoforestry (trees with insects)
  - Aquaforestry (trees with fisheries)
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chemical and physical properties) and improved simultaneous systems such as mixed plantings of trees and crops where the issues are tree–crop interactions (usually below ground) and competition between or complementarity of components of mixtures. For example, in the context of this book it would be useful to know which Australian *Acacia* species have potential for use in improved fallows and how valuable the contribution from each would be. It would also be useful to know if other *Grevillea* species besides *G. robusta* have

desirable tree–crop interactions and what special characteristics they possess to allow such complementarity. It is only by systematically researching and assembling such knowledge that we can make real progress in the more precise selection of species for agroforestry development. Our databases are only as useful as the information we feed into them.

The aim of this chapter is to provide an historical overview of tree species introduction and then cover traditional and modern techniques for species and provenance selections. Some details are given on social issues that affect species selection and appreciation by people. The qualities required of tree species to provide fuelwood, roundwood (poles and posts), fodder, live fences, windbreaks, shade, soil improvement and protection are briefly examined as these are the major products from or uses for tree species within the scope of this book. These products and uses can be produced within particular agroforestry technologies (as outlined in Table 3.1) or in other systems. The processes used in the selection of species and provenances for traditional forestry and agroforestry are compared.

## HISTORICAL PERSPECTIVE OF SPECIES INTRODUCTION

Much is known of the introduction of new annual crop plants. The introduction and domestication of cereal crops such as wheat from the Old World and fruit crops like tomatoes from the New World are reasonably well known, but the equally long history of tree crop introduction is often overlooked. Food tree crops were initially important. Chestnuts (*Castanea sativa*) and figs (*Ficus carea*) were introduced to Britain by the Romans some 2000 years ago and at least six varieties of figs were grown in Britain before the Christian era (Anon. 1977).

There are similar examples of the introduction of food tree crops in tropical regions. Baob trees (*Adansonia digitata*) were reputedly introduced into India from Africa by either Arab traders or Indian seafarers in the 7th or 8th century (Vaid 1978) while the Makassan trepangers (Indonesian fishermen) brought tamarind (*Tamarindus indica*) to the northern coasts of Australia before European colonisation

(Macknight 1976). The Indonesian clove tree (*Eugenia aromatica*), a food spice whose properties were known from early times (at least 300 BC in China), has been cultivated outside Indonesia for 200–300 years (Cobley 1956). The oily seeded candlenut (*Aleurites moluccana*), *Canarium* spp. and the breadfruit (*Artocarpus incisor*) are examples of species that were probably spread widely by the Pacific Islanders prior to European settlement. Most of these species have been subjected to some degree of domestication.

By comparison, tree introduction for non-food purposes is much more recent. The Romans are believed to have introduced the shrubby plant *Rhus coriarea* into Spain to produce leaves as a tannin source (Gonzalez 1982), while in East Africa Arab dhow captains arranged for the planting of *Casuarina equisetifolia* to mark harbour entrances (Perry and Willan 1957). Though native trees were used *in situ* for a wide range of non-food uses such as shelter, weapons and handicrafts, it was not until the 19th century that scientifically managed industrial plantations of native and exotic species were established. These plantations provided wood products such as sawn timber, fuel for railways and more recently pulp for paper and other products. Extensive areas of exotic pines and eucalypts were planted during the 20th century for industrial wood; this development overshadowed the need, especially among developing nations, to cultivate non-food trees for non-industrial purposes.

By the 1970s there was a growing realisation of the detrimental impact that the exploding world human population was having on the woody vegetation in many countries. Excessive cutting of fuelwood, overgrazing and more-widespread shifting cultivation for agriculture led to the serious degradation of the native tree flora in many parts of the tropics. The emphasis now is on conserving remnant vegetation and revegetating degraded areas with planted material. Social and community forestry became the rallying calls of the time. In these plantings the emphasis was still mostly on a limited number of well-tried exotics.

In the 1970s attention moved to agroforestry as a means of encouraging farmers to plant trees on their own lands rather than relying solely on government planting programs (Bene et al. 1977; Stepler and Nair 1987). This focus brought a realisation that research

was needed in order to explain better the merits of many traditional agroforestry practices around the world and to justify the emphasis placed on this form of land use. This international movement led to the establishment of ICRAF (International Council, later Centre, for Research in Agroforestry) in 1982. In the years since, ICRAF's attention has shifted progressively from agroforestry systems documentation, technology description and categorisation, survey of farmers' practices and prescribing agroforestry interventions and proselytising, to intensive research on pertinent agroforestry research questions (see Sanchez 1995).

The 1970s also brought increased attention to the selection of tree species which could biologically fix atmospheric nitrogen (such as legumes with rhizobia and non-legumes with *Frankia*, e.g. *Casuarina*, *Alnus*). This attention arose in part from the agricultural sector where improved mixed pastures with legumes and legume fallows were common technologies, but also as a result of the rise in oil prices which increased the price of nitrogenous fertilizers. This in turn led to the exploratory work of the International Rice Research Institute (IRRI) on a range of organisms that fixed atmospheric nitrogen, and included work on small shrubs such as *Sesbania rostrata* for improved fallows in rice paddies. In addition the leaves of many legumes, e.g. *Leucaena* and *Chamaecytisus*, were high in nitrogen and hence valuable leaf protein for animal feeds. In retrospect it is not surprising that considerable attention was given to biological nitrogen-fixing plants, but the downside was that other tree species that accumulate nitrogen (e.g. *Cassia siamea*) and other plant elements in luxury amounts have not been well studied.

Given these historical trends, the question to be addressed is how has the science of species and provenance selection kept pace with and adapted to these new demands. Fortunately many of the scientific methods employed in species selection and domestication for industrial plantations can be adapted for selecting trees and domesticating tree species for non-industrial uses. A major difference will be in assessment techniques, which depend on whether we are selecting trees for agroforestry, village woodlots or environmental purposes. It is in the agroforestry

domain that more research is needed, and in particular a better understanding of species characteristics in relation to companion crops is required.

There is no doubt that it is in the non-industrial plantings that the range of species available for selection has increased. This is because of the range of agroforestry technologies and due to the diversity of products that can be produced. In addition, tree size, stem straightness and wood quality are not constraints to selection. Small rapidly growing trees and shrubs are often more suitable than large trees for village or farm planting. The ICRAF MultiPurpose Tree (MPT) database contains information on about 1100 mostly non-industrial species (von Carlowitz et al. 1991), and this number could easily be expanded to 2000. Many of these species are still poorly known outside the areas where they are locally appreciated. It is often impressive to see in the field the skill with which local people have successfully exploited and managed indigenous tree species in their farming systems.

Research involving several scientific disciplines will be required to evaluate lesser-known species for use in various agroforestry technologies. Simple on-research-station field trials should be established to assess basic attributes of new species such as survival, growth rate and form characteristics. There is a real need for rapid tests to assess the competitive and complementary aspects of tree crop interaction. This can be addressed via either genetic or management studies, e.g. pruning and coppicing, or through combinations of these approaches. At the same time it is wise to quickly move promising species to on-farm trials that are farmer-managed to allow some empirical experimentation. This allows farmers to comment on the performance of species. This phase will also benefit from the involvement of social scientists and economists who can document and assess farmers' opinions and needs. There is no point in continuing classical domestication pathways until it is certain that a promising species is worthy of further research investment. Methods for the careful selection of priority species for tree improvement with a focus on farmer opinions have been explored by Jaenicke et al. (1994) and Franzel et al. (1995).

## SOCIAL ISSUES HAVING IMPACT ON SPECIES SELECTION

Despite the benefits that can be derived from planting exotics there exists in some countries a belief, mainly among environmental groups, that only native trees should be planted. Many of these groups are motivated by nationalistic, spiritual and other worthy motives. Sometimes the opposition to planting exotics is not based on accurate information. Examples include general opposition to planting eucalypts in India and Myanmar because of their supposed excessive extraction of soil water, and in Spain because of the putative poisonous effect of leached leaf oils on soil microorganisms. Such criticisms create considerable uncertainty amongst tree-growing organisations and the community in general. The real issue is to find the right species for the product required on the site available for planting. Correct siting of trees on farms to avoid conflict with neighbours, especially on small farms, is essential and is practised in many countries, e.g. in Ethiopia with *E. camaldulensis*.

Criticisms of exotics may be justified on other grounds, especially in cases where a poorly adapted species has been used for large-scale planting. In southern Spain, for example, the drought-susceptible *E. globulus* has been widely planted in dry areas where the stressed plants are attacked by the longicorn beetle (*Phoracantha semipunctata*), causing widespread growth retardation and even death. Black wattle (*Acacia mearnsii*), an otherwise valuable tree for tannin, roundwood, fuelwood and pulp, has escaped from cultivation and become a weed in certain parts of Africa and elsewhere. These examples suggest that species must be chosen wisely by species introduction officers and plantation planners who have a social responsibility for the long-term consequences of their decisions. This fact was stressed by Hughes (1994) in relation to the testing of weedy legumes and the damage that can be caused, especially to indigenous flora on small oceanic islands. While it is highly desirable to promote native trees in cultivation and to include them in trials, the long history of successful exotic introduction suggests that one should not be too timid in searching for and testing a wide range of new and potentially valuable

species. Midgley et al. (1995) also alluded to this in their report of tree species used in three communities in Vietnam, provocatively subtitled 'Do trees need passports?'

Tree and land tenure issues can have a dramatic positive or negative impact on species selection and tree planting. In Kenya *G. robusta*, being an exotic species, was widely adopted initially to mark permanently individual farm boundaries. Landowners also had the right to harvest tree products, and the management of *G. robusta* developed in a surprising way. Farmers adopted management techniques in which trees are treated as 'milking cows', i.e. trees are climbed, pollarded and branches lopped regularly for fuelwood and other products. Leaves are used for mulch and cattle bedding materials and the residual tree stems eventually used for sawlogs. In contrast, tree planting in Ethiopia and Eritrea has virtually ceased on farms as the State now owns most land and controls tree products that grow on them. In this situation there is little incentive for private citizens to plant any tree species. In addition the combination of high population density, small farm size, roving cattle after crop harvest and use of wooden ploughs (for which tree roots are a problem) to cultivate annual crops curtailed the use of agroforestry.

Gender issues are also important in species selection. In much of Africa, tree planting is seen as 'men's work'. One reason for the lack of success of alley farming is that women are reluctant to lop hedges as this heavy work is in the male domain. In some rural surveys in East Africa, ICRAF found that women prefer some tree species more than men if they contain medicines of value to them, e.g. for breast complaints (S. Franzel, pers. comm.). ICRAF staff also pioneered the use of the traditional African Mbaob board game to assist in species selection when dealing with farmers. In a rapid rural appraisal survey of bush mango (*Irvingia gabonensis*) in Gabon, West Africa, Boland et al. (1996) found that women have a better knowledge of genetic variation within the species (as they are major gatherers). They could more accurately predict the fruit properties (really cooking properties of the cotyledons) of closely related species, i.e. the species preferred for cooking were consistently better known to women.

## SITE ASSESSMENT

This section provides an account of the data that are required to assess or characterise a site before species are selected. The larger the area where the site characteristics remain the same, the greater the practical impact of a successful introduction. Greater emphasis is given to traditional forestry approaches, but the modifications necessary for providing species to small-scale, resource-poor farmers are described. In recent years the development of Geographical Information Systems (GIS) has revolutionised rural land-use planning appraisals. Land use planning can be assisted by flexibility of scale and the ability to isolate and mix different maps. The eco-regional approach to species testing can be refined more rigorously and comprehensively when GIS technology is used.

### Procedures for evaluating the planting site

Once the characteristics of the species required have been established, and before species are actually chosen, the specific conditions of the planting site need to be evaluated. This stage involves a description of the physical, edaphic and climatic factors of the site. This stage can be as comprehensive as required and may involve a considerable amount of work. The aim is to divide the area into categories with each category having uniform conditions. The ultimate unit may be termed a 'site' that Coile (1952) defines as 'an area of land with a characteristic combination of soil, topographic, climatic and biotic factors'. This evaluation sets the limits for species selection and also enables a realistic appraisal of where trial sites for particular species should be located so that the results can be extrapolated accurately. Some scientists refer to this process as site characterisation.

#### *1 Physical, edaphic and vegetational factors of the land*

On a large scale it is often useful to have vegetation maps, soil maps and perhaps aerial photographs to determine the overall land patterns. In some countries, e.g. Zimbabwe and the Republic of South Africa, major silvicultural zones based on elevation, climate, vegetation and past experience with exotic trees and crops have been delineated. These broad-scale appreciations are a desirable prerequisite to more detailed mapping.

In the agricultural sector similar maps exist which show 'agro-ecological zones'. Such zones often have colloquial names attached to them such as the 'coffee-based' land-use system.

Maps of the planting area at a scale of at least 1:50 000 or 1:20 000 are essential. These should indicate latitude, altitude and small topographical detail, e.g. aspect, slope, swamps, rivers, rocky hilltops. Other maps showing soil type, native vegetation and land use should be obtained or compiled. Special biotic characteristics, e.g. in South Africa snout-beetle (*Gonipterus*) attack on eucalypts more common at higher altitudes, can be noted. In other areas, the occurrence of termites which eat the roots of newly planted seedlings is a serious pest and should be noted.

## 2 Climatic factors

Meteorological stations are rarely located at proposed plantation sites, and some extrapolation is commonly needed. Burley and Wood (1976) suggest that the following data should be assessed for each site type.

- (1) Mean annual total precipitation.
- (2) Mean monthly precipitation.
- (3) Mean monthly relative humidity percentage.
- (4) Mean annual temperature.
- (5) Mean monthly temperature.
- (6) Mean daily minimum temperature for the coldest month.
- (7) Absolute minimum temperature.
- (8) Mean daily maximum temperature for the hottest month.
- (9) Absolute maximum temperature.
- (10) Mean range of temperature.
- (11) Mean monthly wind speed at 2 m above ground level.
- (12) The number of years of observation for each of the above.

On a broad scale some climatic indices can be applied to indicate climatic types (homoclimes). Thornthwaite and Koppen are the most commonly used homoclimes. In the Thornthwaite system, potential evaporation and transpiration are estimated as a function of mean monthly temperature with a day-length adjustment to account for effects of latitude and for seasonal varia-

tion. The main advantage of these systems is that they can be applied worldwide and hence broad-scale climatic comparisons can be made.

In recent years more complex climatic indices indicating likely or anticipated crop growth have been developed so that more precise matches can be made between a plant in its natural range and its performance in an exotic situation. This has been applied to crops (Hutchinson et al. 1992) to determine suitable areas for cultivation.

## 3 Mapping site types

Once the physical, edaphic, vegetational and climatic factors have been established, the various site groupings can be drawn on topographic maps. Positions for species trials can then be selected in advance of actual species introductions. These positions may be located randomly within each site type, or determined subjectively because of constraints, such as ease of access, availability of land for trials, ease of protection, the fragmented nature of the planting area. These practical considerations are almost always overriding factors in any introductory work.

## Site assessment for agroforestry

Site assessment procedures for forestry are equally applicable to agroforestry. Perhaps the major difference between the two is that foresters are usually looking for uniformity of the site to ensure, if possible, uniformity of production. There is ultimately greater management control in the whole production process in forest plantations than is possible in agroforestry. In agroforestry, greater interaction between the site and the users, i.e. farmers, is necessary.

In an agroforestry context it is also necessary to include a social component in the site characterisation process. This should include census of population, household income, farm size, labour availability and willingness to grow trees. Details of preferred tree species are also vital. Unfortunately it is only in recent times that the value of this kind of preliminary social survey has been fully appreciated. Rapid Rural Appraisals can be used to gather this kind of data.

## TRADITIONAL TECHNIQUES TO SELECT SPECIES AND PROVENANCES

This stage should proceed in a logical and systematic manner once the required species' qualities and site conditions have been determined. The two main problems that impede progress are lack of knowledge of suitable species and availability of seed for planting.

### **Local appraisals of species near the planting site**

Previous native and exotic plantings at or near the planting site should be carefully examined. All relevant local literature should be consulted and knowledgeable people contacted for useful information.

#### *Indigenous tree species*

Suitable native trees should be examined for their potential. Both local and non-local seed sources should be examined for suitability. The best native species should always be included in species trials so that scientific assessments can be made on the relative merits of natives versus exotics.

#### *Local exotics*

It is rare for any country these days not to have some successful exotic trees. Often these may be found in botanic gardens, on farms, alongside streets, in parks and around old established farmhouses. A survey of these trees should be made as early as possible. This should provide information on species to plant, countries where suitable species may be found, or taxonomic groups of species worthy of further study, e.g. if one member of a particular genus is performing well then others should be tried, particularly closely-related species from similar environments. This naturally presupposes that evolutionary relationships amongst species in the genus are known, e.g. by prior cladistic analyses.

### **Selection of exotics**

The method most commonly employed for selection of exotics for introduction is environmental matching. This may involve examining native trees in their home climatic environments and/or their performance in trials as exotics in other countries with similar environmental conditions. It is preferable that this latter step be taken

first. For example, information on exotics can be gathered from Streets (1962) for a wide range of species grown in the British Commonwealth, from Poynton (1979) and FAO (1979) for eucalypts and from NAS (1979) for tropical legumes. For information on specific topics one can consult NAS (1980, 1983) for fuelwood species or FAO (1963) for tree species and planting practices in arid zones. Webb et al. (1980) produced a valuable data set when they compared up to 82 characters for about 125 of the world's most important forest trees.

#### *Climatic matching*

This technique involves comparing the climate of the planting area with other equivalent climatic areas around the world (see Chapter 1). Species are then selected from these areas with adjustments for soil types or special features, e.g. salt tolerance. This technique has been used for many years e.g. by Robertson (1926) when he compared Australian climatic zones with those in South Africa in selecting species. In Brazil Golfari et al. (1978) demarcated climatic zones and matched them with similar zones in Australia in order to select eucalypt species and provenances for trial.

One serious disadvantage of climatic matching is that some species perform well outside their natural climatic range, e.g. *E. robusta* grows well from tropical to near-temperate parts of Brazil. Past events such as fire or climatic squeezes may have severely restricted the current natural range of the species, and thus the natural range may not indicate the full potential of a species.

#### *Information exchange*

Arguably the most practical method is for the plant introduction officer to send environmental data and information on planting objectives to appropriate scientists in other countries having similar climatic conditions requesting their comments on species selection. Special advisers may also be consulted or visits arranged to bring them to the plantation site. Such practices are common in many parts of the world.

#### *Selection of provenances for planting*

The concept that provenance has a genetic and evolutionary basis has dominated forestry thinking for some time; it implies that genetic variation is associated closely

with the ecological conditions in which the species evolved. Application of the concept involves recognition of intraspecific variation in particular characteristics and classification of forest reproductive material according to its geographical origin (Turnbull and Griffin 1985). The term 'provenance' is applied frequently to the original geographic source of seeds or propagules. Most provenances are labelled by locality names but often regions are confused with provenances, e.g. Coffs Harbour *Eucalyptus grandis* covers a huge region and many provenances. There is a definite international need to standardise the nomenclature of provenance.

In arboreta or species elimination phases great care must be taken to get representative seed sources. One view is that seed should come from the part of a species range where growth is optimal. Namkoong (1969) reasoned that outlying populations have evolved conservative survival strategies at the expense of fast growth, while those populations in optimal sites have developed under more intense competition for light and nutrients, thus favouring rapid growth over survival strategies.

A different view for provenance selection has been espoused by Edwards (1963). He suggested for an unknown species that at least three provenances should be used. These are the optimum, the closest climatic match, and one marginal provenance from the boundary of the distribution that extends the range in a given preferred direction, e.g. drought tolerance. Overall this approach is recommended, and it is important that each provenance be treated as a single testable unit for a species.

## NEW TECHNIQUES FOR SPECIES SELECTION (COMPUTER-ASSISTED DECISION SUPPORT SYSTEMS)

The development of computers and database software has made possible the storage, retrieval and comparison of large data sets on individual tree species. This development has gained considerable momentum over the past 20 years and has been helped considerably by the advent of more powerful desktop computers. Most databases on species consist of two main types of data sets. These can be summarised as: (a) documentation of the

physical characteristics of species, and (b) documentation of growth performance of tree species in a range of environments. One advantage of combining such data is that we have the essential components necessary to select species for a particular end-use and then predict their growth response on a particular planting site. This may also involve including additional information on climate and soils and also other environmental factors. The development of these decision support systems has made species selection simpler. Today we are in the fortunate position of being able to assess the value and use of several databases developed in Australia and other countries.

One of the earliest databases to assist in species selection was INSPIRE, developed by Oxford Forestry Institute (OFI) and based on a compendium of tropical species compiled by Webb et al. (1980). INSPIRE made use of the six climatic parameters given for each species in the compendium and searched for species that fulfilled specified climatic conditions. Although valuable, the limitations of INSPIRE were absence of soil data, no ability to predict growth rates or growth performance and no provision for users to add extra datasets.

Many advances in the use of climatic datasets for tree species selection have been promoted by Booth (1985, 1996). Underlying these new approaches has been the ability to interpolate climatic data for sites where no weather station records are available. Climatic surfaces at the country and continental levels have been developed for the continents of Australia and Africa, and for China, Vietnam, Indonesia and the Philippines. The power of this modelling approach has resulted in several new uses. At its simplest level one takes the climate at a particular planting site in, say, Thailand and then circumscribes the part of Australia that best matches the Thai site. This enables selection of species and provenances from that part of Australia for trial in other countries (Booth et al. 1987).

Another approach involves a circumscription of the climatic parameters for a particular species in its natural distribution in Australia and then the interrogation of a climatic database to determine where the species will grow in corresponding areas in, say, Africa (see Booth 1991). This procedure is appropriate when a species has not been widely tried outside Australia. However, it is well known that many species may grow

successfully in plantations in conditions which are somewhat different from those within their natural distribution. The assumption is that factors such as competition with other species and fire and pest and disease problems have limited the natural distribution of species. One can assess this adaptability by examining the planted distribution of an Australian species outside its natural range and then redefining its climatic requirements. For example, *A. mearnsii* is grown successfully in plantations outside Australia in areas that tend to be both wetter and warmer than locations where the species is found naturally in Australia (Booth and Jovanovic 1988).

One facet of climatic modelling that has not yet been well embraced is the concept of climatic region of provenance within species. In papers on *Acacia mearnsii* (Booth et al. 1989) and *Acacia auriculiformis* (Boland et al. 1990), cluster analysis techniques were used to defined subregions of the natural distributions with similar climatic conditions. Artificial limits are usually set for the number of subregions that are required. This has the potential advantage of defining a climatically-based seed collection program so that the whole climatic range of a species is adequately sampled. Alternatively this technique can more sharply define where trees from a region or provenance of a species in Australia can be grown in other countries.

A major limitation of the climatic approach is that other environmental variables (e.g. soil properties) are also important in the species/provenance prediction process. In addition there is no modelling capability for predicting rates of growth of a species at a particular site. This decision support system will also be considerably enhanced once climatic surfaces are available for all countries.

Recognition of the importance of multipurpose trees (MPTs) to resource-poor farmers in tropical ecosystems worldwide brought the accompanying realisation that very little was known of their special physical characteristics, how they could be managed and conditions under which they grew best. Many of these species were shrubs, that occur spontaneously in fallow land, weedy trees and indigenous fruit species and were not well known to foresters, horticulturalists or agriculturalists. The International Centre for Research in Agroforestry (ICRAF) recognised this problem and

sought to address it by developing an MPT database. The first release contained data on about 1100 species (von Carlowitz et al. 1991). The database is largely descriptive in character. A special feature for agroforestry is the coding of species for particular agroforestry technologies and end-uses. The database enables all species to be searched for particular end-uses, soils, agroforestry technologies, climatic regions (using Koppen codes) and other properties. The data are somewhat limited by the small number of field records for most species. Major technical limitations are the lack of modelling capability to predict species growth at particular sites, and the difficulty for users of adding new records. The database is continually being improved and there are hopes for graphic capabilities and electronic data capture techniques for use by field observers. Users of the database are encouraged to send new records to ICRAF to update the database.

Two recent Australian systems of note with predictive capability are TREDAT and PLANTGRO. The former database was developed jointly by Queensland Department of Forestry and Division of Forestry, CSIRO (Brown et al. 1989); work first commenced in 1983. The underlying concept was the recognition that considerable numbers of field trials had been conducted in the past in many parts of Queensland, but often results existed as 'grey literature' that had not been adequately documented. The TREDAT database permits the results from field trials of species or provenances to be stored and selectively retrieved to assist in the choice of planting material for particular sites. The database made early use of relational database technology. Information on species was divided into six categories (files or modules) with links between them. These categories were site description, management history, performance record, botanical identity and project description. A more recent description of TREDAT was given by Vercoe and Clarke (1995). A key advantage of TREDAT is that it allows actual mean values from trials to be included so that comparisons in growth performance for species/provenances across sites are possible.

When TREDAT was initially developed it could only be run on a mainframe computer but now it is possible to run it on desktop personal computers (PCs). While the original purpose was to serve Queensland users, the system has potential to accommodate information

on trials of trees from other Australian States as well as those growing in other countries. Limitations to the database include lack of graphic capability and no real capacity to model plant growth.

MPTDAT is usable on PCs and was developed under the USAID F/FRED project. MPTDAT is based on a minimum dataset which was taken from TREDAT. Its main purpose was initially to underpin the F/FRED fuelwood trials in Asia and to develop the capability of modelling growth responses of trees at any particular site. The main dataset were based on priority species used in the F/FRED field trial program established at several sites in Asia. There was an initial vision that users could network and share data files on species growth in trials within the region. This database has also been used by the Division of Forestry and Forest Products, CSIRO for recording responses of Australian native trees to salinity.

PLANTGRO is a software package on PC for predicting the growth of crops, forest trees, and other species (Hackett 1991). The database comprises plant, soil and climate files, with the soil and climate data being based around widely used descriptors. Each plant file contains quantitative relationships which describe the plant's responses to 11 soil and 11 climate factors. By using a generic prediction engine whose output includes dynamic information about growth rates and water balance, predictions can be made for almost any higher plant and for a very wide range of locations. The current version (V2.1) provides starter sets of files for ca 35 forest trees, 100 crops, 50 soils, and 100 climates, any of which can be upgraded or adapted by use of the editor provided in the package. Programs are provided for making further such files, with the handbook providing expert systems for estimating the relationships for plant files. A recent new additional system called INFER (Hackett 1995) enables starter plant files to be made from records of the conditions a species is known to experience; data in the MPTDAT, TREDAT, and similar databases can be used by INFER to help estimate species' environmental relationships, which can then be improved by making predictions for various combinations of soil and climate conditions. Connections are provided too with GISs and flat-file plant databases, and two special programs enable multi-species systems to be constructed and tested. PLANTGRO passed extensive

testing for crops in 1993 at Wageningen Agricultural University in the Netherlands and was used successfully by international forestry consultants for the recent construction of Indonesia's National Masterplan for Forest Plantations. 'Matching Trees and Sites' (Booth 1996) includes several papers summarising recent forestry work with the PLANTGRO model. Current research with the package is focused on demonstrating formally that the model's predictions for forest trees are reliable for the uses envisaged. Some 80 files exist in all for forest trees, covering many species important in tropical and subtropical regions. It is hoped that all these files will ultimately become publicly available.

Another database of international significance is MIRA developed by CATIE, Costa Rica, to monitor the results of the Madelena project in Central America. This has many of the elements of TREDAT (Ugalde 1988).

One of the major difficulties of all databases is the need for continued funding to upgrade records and improve interface capabilities. There has been a rapid increase in the number of species databases being developed around the world. One must recognise that different organisations require databases for different purposes and may wish to develop their own customised products. It is clear, however, that there is a need to achieve easy access to a range of databases, and the development of platforms to permit this is desirable.

## STAGES OF SPECIES INTRODUCTION AND IMPROVEMENT (THE CLASSICAL APPROACH)

The stages (phases) developed for the selection of species and provenances for industrial plantations are: an arboretum phase, a species elimination phase, a species testing phase, a species proving phase and a species provenance phase. In sophisticated programs a tree-breeding phase involving individual tree selections and controlled crossing can be developed after the provenance phase. Some of the phases can be conducted simultaneously.

### **Arboretum phase**

This is one of the most interesting and stimulating phases of tree introduction but unfortunately it is

usually the most poorly setup and understood. The aim is to test a few individuals of a wide range of species. The demonstration value of arboreta is important, so siting the trial near roadsides or towns is desirable. These trials have long-term value and must be properly maintained for many years. Few new arboreta have been established in the tropics in recent years, despite there being interest in a greater number of species than ever before, and many organisations move straight into the species elimination phase.

### **Species elimination phase**

The aim is to examine a large number of the most promising species in small plots to eliminate unsuitable candidates. These trials are usually of relatively short duration. If several species do well, more tests with a selected few over a wider range of sites may be useful in establishing the most versatile species. Care should be taken to use appropriate and well-documented seed sources.

The main conceptual issues for these trials are trial purpose and trial design. Once thoughts are clear on the former, the latter issue can be determined with assurance. In general the aim is to field-test a wide range of accessions (species and provenance) and assess survival, initial growth rate and species capacity to provide the type of product wanted, e.g. fodder or thorniness for fencing. Duration of the experiment may be as short as three years. Once the best species have been identified we can move onto other related trials. By three years, spacing, competition and gaps through death of accessions are usually a major problem in the trials. Given these potential limitations it is sensible to plant line plots and use incomplete block designs (Williams and Matheson 1994).

Details of trials of Australian species in China, Thailand, Kenya and Zimbabwe are given in Boland (1989).

### **Species proving phase**

This involves examining all possible methods of propagation (e.g. is propagation by cuttings possible if seed is difficult to obtain?), methods of ground preparation, planting techniques, spacing, thinning, pruning, fertiliser, weed control, etc.

Many introductions fail because seed is difficult to collect, hard to store and loses viability rapidly. These

factors can have a dramatic influence on the choice of species. Species that are difficult to germinate, are susceptible to disease in the nursery, are slow-growing or need special inoculation with fungal or bacterial organisms to maintain thrifty growth are seldom included in later plantations. Vegetative propagation can play an important part in providing planting stock of improved varieties of many valuable multipurpose species.

### **Species provenance phase**

Once an important species has been identified a provenance trial can be commenced. This trial may be limited to provenances from a favoured region, or there may be one or more wide-ranging trials involving all possible provenances.

This stage can be considerably enhanced by participation in international provenance trials for a particular species. Such trials have been organised by CSIRO (e.g. *Casuarina equisetifolia* trials), OFI (e.g. *Gliricidia sepium*), IUFRO (e.g. *Eucalyptus grandis*), FAO (e.g. *E. camaldulensis* and *Azadirachta indica*) and DANIDA (e.g. *Tectona grandis*). Such participation can be very rewarding in finding provenances well suited to particular ecozones or, conversely, determining whether there are very significant site–genotype interactions, a situation which makes selection of superior provenances very difficult.

### **Final testing stage**

This stage will vary with the end uses involved. Small pilot plantations, agroforestry plots, etc. can be established.

In all of these stages identifying best seed sources is vital. As the program develops, considerable thought has to be given to establishing seed stands or seed production areas to ensure the production of high-quality improved seed in sufficient quantities to meet current and anticipated demand. Procedures for eucalypts are documented by Boland et al. (1980) and Eldridge et al. (1994).

### **Diffusion of germplasm of selected or improved seed to users**

This phase is probably the most important in getting selected and/or improved seed to users (Turnbull 1984). In industrial forestry the clients traditionally

have been either government organisations or large forestry companies. For these clients it was relatively easy to assess demand and get seed to the user. Social forestry and agroforestry has a more diffuse client base with, in many cases, a very poor appreciation of the value of improved seed. This difficulty has to be tackled through education and careful analyses of the diffusion pathways. Both sociologists and economists are needed for this work.

## STAGES OF SPECIES INTRODUCTION AND TREE IMPROVEMENT

(for simultaneous agroforestry technologies)

The process of selecting species/provenances/clones for simultaneous agroforestry technologies is based mainly on the classical approach with modifications to allow for input from other scientific disciplines and from farmers, the real users of trees in agroforestry. Table 3.2 gives details of the issues involved and sequencing of research activities that must all come together to select species for domestication for simultaneous agroforestry technologies.

## TREE PRODUCTS AND SERVICES

(qualities required when selecting species for use)

This section highlights some of the uses to which species in this book are put. Table 3.3 indicates how these products and services are related to some agroforestry technologies.

### **Fuelwood**

Fuelwood is required by both industrial and non-industrial nations but the need is much greater in developing countries where domestic fuelwood is often essential for cooking and heating. Charcoal has an advantage over wood as a fuel in that larger-diameter logs can be utilised in its production, and that it is much lighter and therefore easy and cheaper to transport long distances to city markets. Charcoal production is, however, wasteful of fuelwood resources and

has been banned in some countries, e.g. Eritrea. Native people, who traditionally obtain fuelwood from indigenous species whose burning and smoke properties are well known, are often extremely reluctant to change to exotic unknown woods. These preferences must be considered in the selection of species for fuelwood.

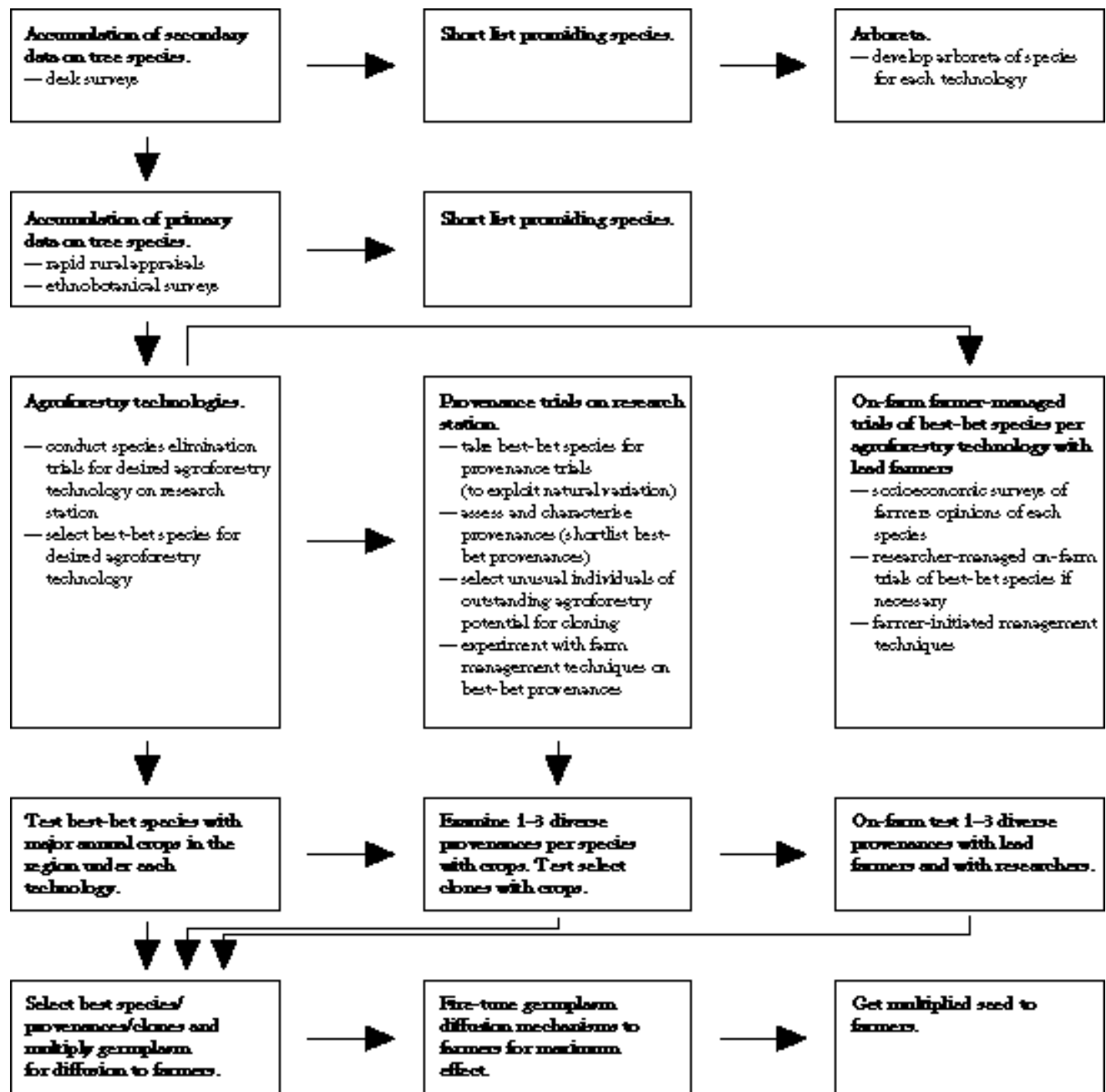
The qualities needed for fuelwood can be divided into the physical properties of the wood and silvicultural or environmental properties of the species. Thornless trees or shrubs with small-diameter stems are easy to cut with primitive implements and to transport. The wood should be easy to split and have a low moisture content or be relatively fast-drying, as considerable heat is lost in burning moist wood. For health reasons, smoke should be minimal and non-toxic (Poynton 1984) as ventilation is traditionally poor in most native houses. Sherpas in Nepal suffer respiratory problems resulting from home fires in confined spaces (S. Midgley, pers. comm.). In these same homes, however, the smoke has extended the life of beams and thatched roofs by inhibiting insect attack. For safety reasons wood should not spit nor spark while burning. Calorific values are not available for most species but there is usually a positive correlation between high wood density and heat produced per unit weight (calorific value). The best firewood burns slowly producing good heat from glowing coals. Some acacias have particularly good burning properties, and casuarinas are also highly regarded as firewood species. The fuelwood value of Australian species has been explored experimentally by Gardner (1989), Gough et al. (1989) and Groves and Chivuya (1989).

Desirable silvicultural and environmental properties of fuelwood species are given by Burley (1978) and NAS (1980). These include rapid growth, even on poor soils; ability to stabilise and improve the environment; minimal management requirements; disease and pest resistance; ability to coppice; hardiness to survive drought and other environmental stresses; and suitability for multiple use. Most of these qualities are not related solely to the use of trees for fuelwood.

### **Roundwood (poles, posts and stakes)**

Poles and posts are very important for home building and fences in many developing countries. Despite the importance, little has been written about the

**Table 3.2.** A guide to the processes involved in the selection of species/provenances/clones for simultaneous agroforestry technologies based on exploitation of natural variation in wild tree species.



**Table 3.3.** Some agroforestry technologies (after Young 1989) together with some products and services that can be produced within them.

<i>Agroforestry technologies</i>	<i>Products</i>	<i>Services</i>
Improved tree fallows	Fuelwood, poles	Improved soil physical and chemical properties Reduction in quantity of invasive weeds
Trees on cropland	Fruits, poles, fuelwood,	Improved soil fertility, leaf fodder for animals Soil erosion control
Multistoried tree gardens	Fruits, poles, sawlogs	Increased biodiversity of plants and animals, shade
Hedgerow intercropping	Fodder (cut and carry), mulch to improve soil fertility	Soil erosion control
Boundary planting	Poles, sawlogs	Confirm land title claims, windbreaks, live fences

management of trees for roundwood production or the use of roundwood timbers.

Commonly poles and posts are taken as saplings from native forests or are by-products of forest plantations grown for other purposes. Eucalypt plantations for sawlog production in Africa often have the first thinnings used for fence posts and later thinnings for telephone or electrical transmission poles, depending on size. At Ntabazinduna in Zimbabwe, a small plantation of *E. tereticornis*/*E. camaldulensis* is managed as a pole crop from coppice, with fuelwood as a by-product. Clump development of culms of *Dendrocalamus strictus* and other bamboos is encouraged in India and much of Asia to yield poles (Anon. 1980a) for scaffolding and house construction.

Poles are in great demand for rural house construction, especially as rafters that can bear heavy cross loads. In Africa, black wattle (*Acacia mearnsii*) or eucalypts are often used as house poles. In urban areas poles are required for scaffolding and it is not uncommon in India and other Asian countries to see tall buildings surrounded by a maze of bamboo, eucalypt or casuarina poles. There is a major market for eucalypt poles in the Ethiopian highlands for house construction. The shortage of poles is such that individual poles are split longitudinally to produce more. In Kenya both eucalypt and *Acacia mearnsii* stakes are used in the construction of woven wall frames for houses. These frames are then plastered with mud.

Poles and stakes are often required in mining areas. In Zimbabwe thin eucalypt poles are used to ram explosives into drilled holes, and there is an extensive use for poles for 'mat-packs' (solid piles of logs wired

together and stacked horizontally) in South African gold mines. In China an important use for eucalypt poles has been to provide props in mines.

Stakes are widely used for support for agricultural crops. In Rwanda *Sesbania sesban* stakes are used to support climbing beans. In West Africa supports are required to carry trailing yam vines and allow easy weed removal around the tubers.

In developing countries wooden posts are required for house walls and supports and are widely used for fencing. The wood of many Australian acacias is very durable and suitable for fencing. *Acacia acuminata*, for example, is extensively used as fence posts across the southwest of Western Australia. Underground piles is the principal use of *Casuarina junghubniana* in Thailand.

Both wood and silvicultural characteristics influence the suitability of species for poles. Poles should be durable, light, capable of taking high cross-loads (high strength to diameter ratios for a given length is vital), have minimal spirality, be resistant to termites and other wood borers, or be capable of taking preservatives easily. The tree should be straight, with strong apical dominance, few or thin branches and preferably self-pruning without leaving knots that cause weakness, little taper from bottom to top, and the bark should strip easily. For a discussion of the utilisation of eucalypt roundwood see Hillis and Brown (1978).

Similar properties are required of posts. Logs of larger diameter are usually required and they should be durable in the ground or in water, and be able to take high end-loads, e.g. if used as house bearing posts. For in ground use, the resistance to a wide range of termite species is essential.

## Fodder

In dryland areas, especially, trees may be required as an emergency fodder supply during drought periods. Ideally the foliage should be palatable, nutritious and digestible. Details of useful Australian fodder species for dry areas are provided by Chippendale and Jephcott (1963), Askew and Mitchell (1978) and Vercoe (1989). One should guard against introducing trees that are poisonous to livestock, especially species with palatable foliage.

For many species management requirements have not been examined. Fodder trees have to be carefully protected during their early years from all forms of livestock, especially goats. Trees should produce large crowns above the reach of livestock. The crowns must be capable of severe lopping during periods of high environmental stress. Alternatively in intensively managed agricultural areas, trees can be grown totally protected and the leaves then harvested and fed to livestock, e.g. *Leucaena leucocephala*.

By world standards Australia does not have many useful fodder tree species. Most Australian species are used only in emergencies, although *A. saligna* is widely cultivated as a fodder species in North Africa. Acacias, while having high protein content are very high in condensed tannins and other anti-nutritional properties, e.g. cyanogenic glucosides.

## Human food

Tree foods for human beings come in such forms as fruits, nuts, vegetables and honey. The domestication of Australian tree species to produce these products has not been remarkable to date. Australian Aboriginal people made use of nuts (*Macadamia*), fruits (*Eugenia*, etc.), vegetables (heart of palm, e.g. *Livistona*) and honey from wild bees. So far only *Macadamia* has been developed into a commercial crop, while the Australian honey industry is a significant rural industry largely based on nectar harvest from wild indigenous trees. The quandong, *Santalum acuminatum*, is emerging as a small plantation industry in South Australia. In nearby Papua New Guinea and the Pacific islands, tree nuts have been traditional important foods (Bourke 1994), being replaced in recent times with high-yielding root tubers such as sweet potato. Nevertheless nut trees are important food security in many Papua New Guinea villages and some have considerable potential for

commercial production, e.g. *Canarium*. Tree vegetables (leaves) such as *Gnetum* are locally important but probably not to the same level as those harvested from a related species, *Gnetum africanum*, in West Africa.

In the context of this book acacia seeds offer some exciting possibilities for human food. The most promising are desert species like *Acacia colei*, *A. cowleana* and *A. tumida* (Harwood 1994). These species have performed well in trials in Niger and are seen primarily as drought security food. Good quality honey is produced from eucalypts and many other species. In Ethiopia honey from *E. camaldulensis* is highly regarded, as nectar production is greatest when nectar production from indigenous species is quite poor. Australian acacias are an excellent source of pollen for bee protein.

## Live fences

Fences created with trees or shrubs are common in many developing countries because of their low establishment cost. Few are totally effective and gaps created by dying plants have to be plugged by either replanting or more commonly by using dead branches.

Species with prickles or spines, or having stiff branches, both with non-edible leaves, are preferred. In some instances trees capable of root-suckering can be usefully employed. Ideally species should be fast-growing, of medium height, long-lived and be capable of growing under adverse conditions and close together. Minimal maintenance is essential although some trimming can be undertaken.

In dryland Africa many temporary fences are erected by lopping thorny branches from bushes and trees and constructing barrier lines to restrict animal movement. These dry fences are often severely attacked by termites.

## Shade

Species selection will depend on the degree of shade required. Trees growing close to agricultural crops need to cast very light shade; for example, in India *Casuarina equisetifolia* is preferred on rice bunds because the thin narrow crowns cast minimal shade. Trees giving dense shade throughout the year are needed in many hot arid areas to relieve stress on grazing animals during the hottest part of the day.

A good shade tree should be evergreen, especially in the tropics, and have a wide spreading crown with a dense canopy. The amount of canopy closure is often determined by the branching pattern. Preferred species are fast-growing, long-lived, unpalatable and capable of tolerating soil compaction by animals camping beneath them.

## Windbreaks

Ideal windbreak trees should be bushy and capable of withstanding strong wind (hot or cold), or the effects of salt-laden wind in coastal areas or wind-borne sand in desert areas. Wind can desiccate crops and reduce body heat in animals, causing loss of productivity or even death.

There are several outstanding examples of successful windbreaks around the world. Since 1949 a windbreak of *Casuarina equisetifolia*, 3000 km long, has been established in China along the coast bordering the South China Sea. This has provided shelter for crops growing on the leeward side and has also stabilised drifting sand in the area (Turnbull 1983). In Egypt, casuarina shelterbelts have also been grown to protect agricultural land mainly from wind erosion (El-Lakany 1983). In New Zealand windbreaks of *Pinus radiata* effectively provide shelter for stock from cold winds. The windbreaks may be trimmed on their sides and tops to prevent too much shading of pastures and selected trees are sometimes pruned for sawlog production. By comparison the extensive windbreaks of *Eucalyptus cladocalyx* in southern Australia and of *E. diversicolor* in parts of South Africa have only a limited useful life because of the shedding of the lower limbs. These examples suggest that species selection is important and that the effectiveness and value of windbreaks can be improved by appropriate manipulation.

Some of the qualities required are tolerance of harsh environmental conditions, a crown which is bushy and deep but allows some wind penetration, delayed shedding of lower limbs, wind firmness of roots, rapid growth if early protection is required, long life, and pest and disease resistance. They also should not harbour pests of neighbouring crops, and the roots should not compete excessively for water and nutrients with adjacent crops.

## Soil protection — erosion control

Trees are often required to prevent soil loss through wind or water action and often very hardy trees are sought for poor sites. The basic idea is to prevent soil movement by root-binding the soil, preventing direct impact of rain-drops or by increasing the percolation of water through the soil. Leaf fall also provides ground cover to further protect the soil. The role of trees in preventing soil losses from agricultural lands in high-intensity tropical storms can be very significant (see Sanchez 1995) but species differ greatly in their effectiveness.

*Casuarina equisetifolia* has helped to stabilise coastal sand dunes in India by binding the sand with numerous fine roots and preventing sand movement by the heavy and continuous shedding of branchlets that form a thick and slowly decomposing interlocked mulch on the sand surface (Kondas 1983). In South Africa, North Africa and the Middle East *Acacia saligna* was introduced and used extensively and successfully to control sand drifts, but in South Africa it has now become a noxious weed (Anon. 1980b). In Argentina *Casuarina cunninghamiana* has been used successfully to control streambank erosion in the delta region of the Parana River (Mendonza 1983). In high-rainfall areas of Java, *Acacia auriculiformis* produces dense foliage thus providing ground cover while the extensive root system helps bind the soil (NAS 1980). *Melaleuca quinquenervia* was planted in swampy bog areas of Hawaii, resulting from clearing of the natural vegetation, to help stabilise the soil surface and to increase water penetration.

Common tree qualities sought for erosion control are: fast and healthy growth under adverse conditions; spreading crowns; vigorous root systems with soil binding properties; either vigorous vegetative reproduction, e.g. root suckers, or heavy natural seed fall and natural seedling development *in situ* without the tendency to become a weed; and trees having roots with high strength values — especially in areas prone to land slip; and fire tolerance.

## Soil improvement (including use of improved fallows)

This usually involves planting trees to increase the fertility (usually nitrogen content) of the soil. Nitrogen-fixing species form associations with nitrogen-

fixing organisms (rhizobia or *Frankia*) in their roots and have the ability to return atmospheric nitrogen to the soil through root decomposition or leaf fall. Such species may be rotated with other crops or grown as mixtures such that one may benefit from nitrogen and the other perhaps from shade.

In agroforestry in the tropics, rotational fallows (sequential agroforestry systems) are used in the highlands of Papua New Guinea. Here *Casuarina oligodon* is planted amongst cash crops such as coffee to provide shade and to improve soil fertility in the fallow period of bush gardens (Thiagalingam 1983). This technology has been widely adopted by local farmers and is spreading rapidly (Bourke 1985; M. Bourke, pers. comm. 1995). On Iwa Island, Papua New Guinea, a tree legume *Schleinitzia novo-guineensis* and another tree *Rhus taitensis* are said to be planted after the yam harvest to improve soil fertility (Hide et al. 1994). Green manure is popular in some countries and leaves of *Leucaena leucocephala* are said to rival animal manure in nitrogen content (NAS 1980) and can be collected and dug into fields to benefit subsequent agricultural crops.

*Sesbania sesban* has been tried in several research farming systems in Africa by ICRAF and local farmers (see Ndungu and Boland 1994). In western Kenya individual trees are left (or seed is broadcast) to provide scattered trees on farms. Farmers are very much aware that after trees die, or are harvested, the yield of the subsequent crop is much enhanced. In Zambia and Malawi research has been conducted on relay cropping (maize–sesbania relays) and use of *Sesbania* as an improved fallow (Kwesiga and Coe 1994). This technology is currently being taken up by resource-poor farmers in the region and *Sesbania sesban* has proved, so far, to be effective.

There is considerable international interest in growing mixtures of leguminous and non-leguminous species. Trials established in Hawaii showed increases in total biomass productivity with mixtures of *E. saligna* and various legume tree species, e.g. *Paraserianthes falcataria* (Binkley and Giardina 1997). Research is currently ongoing in Australia on eucalypt-acacia mixtures to assess the benefits each may derive from such mixtures (Khanna 1995). A critical factor in the long-term use of mixtures is the fate of the biomass of the N-fixing component. If this is removed from the site, the long-

term impact of the mixture may be adverse because of the hastened removal of nutrients other than N.

Soil improvement can also occur through the transfer of nutrients from the lower solum (that may move there through leaching or be released by decomposing parent materials) to the soil surface where they are available to crop and pasture plants. Certain plant mycorrhizal associations are also able to tap refractory phosphate, thus improving available phosphorus levels in phosphorus-fixing soils. In western Kenya recent research has shown that *S. sesban*, as well as being a legume and hence able to fix atmospheric nitrogen, can also tap pools of nitrogen trapped deep in the soil profile below the reach of annual crops (Sanchez 1995).

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