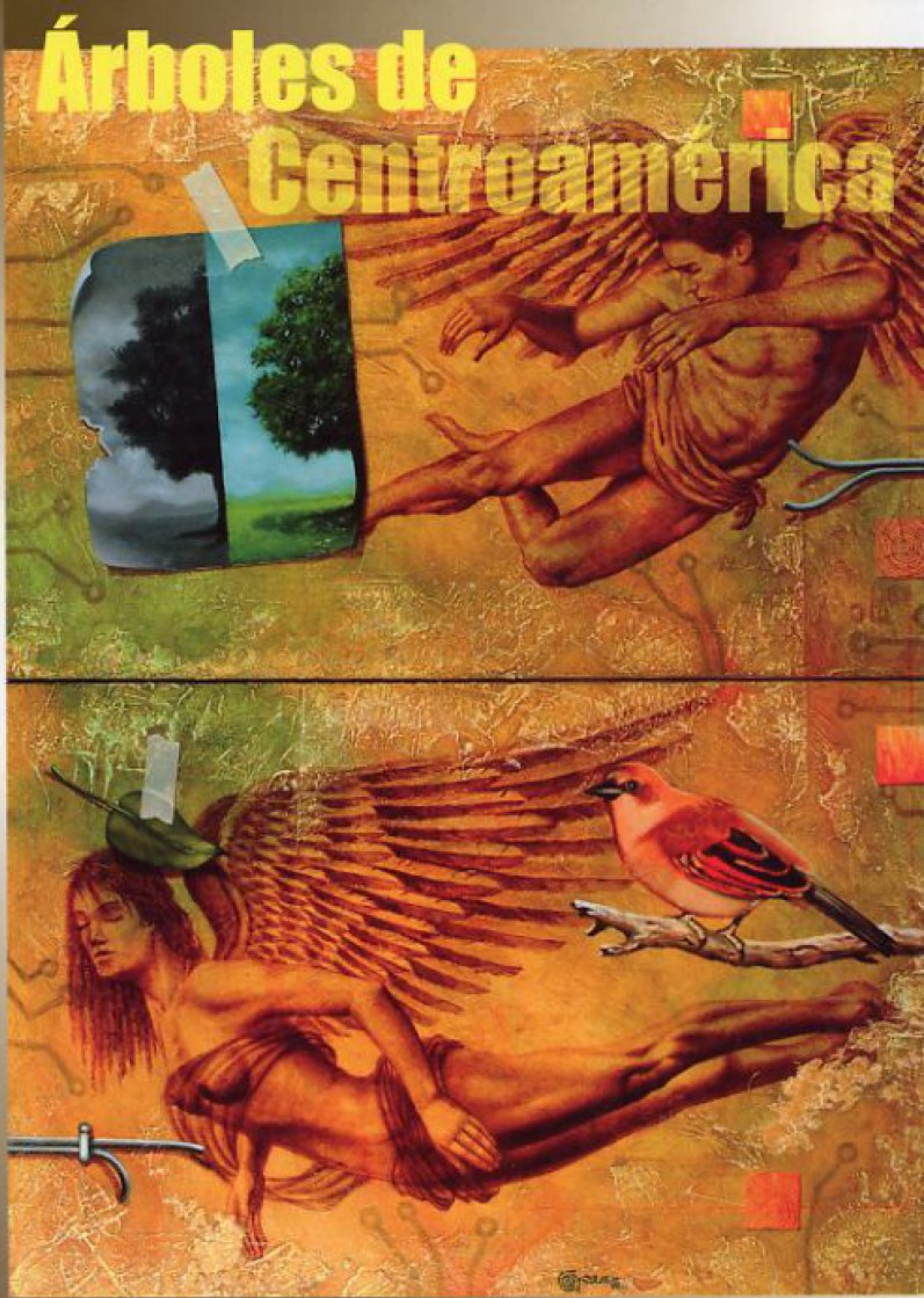
Árboles de Centroamérica



un Manual para Extensionistas

Editado por Jesús Cordero y David H. Boshier

6 Establishment and management of trees in agroforestry systems

In Central America almost all of the traditional agricultural systems, including livestock management, include isolated trees in the crop fields, or incorporate alternating zones of trees, crops and/or pasture. These are agroforestry systems. Even with the modernization of agriculture in the region, agricultural landscapes still contain a large number of trees.

These trees can provide a variety of products such as timber, firewood, animal fodder, fruit, and medicinal products; as well as providing services such as shade for crops and animals, and windbreaks. Trees increase the potential for biological diversity in agroecosystems by providing habitat in the branches, roots, and leaf litter; food in the form of leaves, sap, and nectar; and may provide essential protection during critical stages of organisms' life cycles. Trees improve soil fertility by adding leaves and fine roots to the organic material in the soil, and sometimes by fixing nitrogen. Trees contribute to ecosystem function, and are valuable in the formation of balanced ecosystems that have the capacity to sustain production and provide farmers with a reliable subsistence system.

J.Beer, M.Ibrahim, E.Somarriba, A.Barrance, R.Leakey

A bird's eye view

Management of trees on farms is a complex subject: Let's learn from past mistakes.

(p. 200)

How to choose and manage agroforestry systems

(see p. 201-205)

First we must come to understand the agroforestry systems that are used in Central America

(see p. 202-203)

There are many different trees, which ones will we use?

(see p. 204-205)

A comparison between systems: advantages and disadvantages

In order to incorporate trees in agricultural systems, we must choose the most convenient method of tree regeneration, and consider the possibility of mixing trees with crops or livestock.

(see p. 206-208)

Incorporating trees on farms

- **Natural regeneration**
  - **Agroforestry systems** → Continue in this chapter...
- **Plantations**
  - **Pure plantations** → Go to Chapter 7
  - **Agroforestry systems** → Continue in this chapter...

of the chapter

Agroforestry systems

If we're going to use agroforestry, how do we choose the components of the system?

(see p. 209-216)

Selection of timber trees

(see p. 209-211)

Selection of fruit trees

(see p. 212)

Selection of service trees

(see p. 213)

Selection of windbreak trees

(see p. 213)

Selection of trees for fodder banks

(see p. 214)

Selection of crops

(see p. 215)

Selection of the planting site

(see p. 216)

After the trees are planted, what do I need to do?

A short guide to the management of trees in agroforestry systems

(see p. 217-222)

Management of trees in agricultural systems

(see p. 217-220)

Management of fruit trees

(see p. 221-222)

Let's get to the point!!!

We offer detailed examples to help put five agroforestry systems into practice

(see p. 223-241)

Line planting: Windbreaks and Boundaries

(see p. 224-228)

Fodder banks

(see p. 229-234)

Isolated trees

(see p. 235-238)

Shade over perennial crops

(see p. 239-241)

The mistakes of the past

In order to decide which are the best options for tree planting or managing natural regeneration in a given area, it is essential to study existing agroforestry practices and the criteria local farmers use when deciding how to manage their farms. Among these criteria there are many that have social, cultural and/or economic elements, which are considered in Chapters 3 and 4. In this chapter we describe the factors for selection and management of agroforestry components that we must keep in mind when promoting the inclusion ands use of trees in agroforestry systems.

Sometimes we do not know enough to manage complex agroecosystems, so it is not surprising that mistakes have been made. One example is described in Box 1 and although this same process has occurred in places throughout the tropics, there have been particularly devastating consequences in Bahía, Brazil. Farmers enthusiastically cleared the forest, with the encouragement of the government, in order to increase their cocoa yields. The new full sun cocoa cultivation system required higher economic investments than the traditional subsistence agriculture systems, and also had unexpected problems which, ultimately, caused the failure of the system and significant economic losses. The lesson we need to take away from that experience is that it is necessary to be extremely careful in balancing the need to increase farmers' incomes and the need to protect their limited resources. Although it is possible to obtain substantial economic and environmental benefits from planting fruit, timber and other service trees along with staple food production, in general, these systems are safest when they require low investment and generate low but reliable returns.

1 Conflicting recommendations for the planting or removing of shade trees for cocoa

Traditionally, cocoa in Bahía, Brazil grew under the shade of a diversity of trees in the "Cabruca" system, until it was discovered that by removing the shade the production increased and at the same time decreased the incidence of the fungus that causes "Mazorca Negra". Therefore, government policy changed, stimulating farmers to reduce the shade in their plantations. The cocoa plantations in more sun require more agrochemicals, to combat the increased weed problems, pests and diseases and the reduced soil fertility. Ultimately the farmers were not able to combat the increased pest and disease problems with agrochemicals and there was a disease epidemic that devastated the cocoa crop and the local economy.

The species rich "Cabruca" system is a production system that requires little investment and generates low yields. It is sustainable and reasonably profitable. The conversion to a high investment, high yield system resulted in unsustainable production and financial loss.

How do we choose and manage agroforestry systems?

Whether it is advantageous to use an agroforestry system in place of pure reforestation depends on the objectives of the farmer, the characteristics of the site such as soil and climate, and the socio-economic conditions of the farmer (for example the availability of manual labour, land and cash), the characteristics of the tree and crop species involved, and the management of the components.

Generally we divide agroforestry systems into agrosilvocultural systems (trees with crops) and silvopastoral systems (trees with animals). Agrosilvopastoral systems are the most complex and include trees, crops and animals. These systems are common in Central America (see Box 2).

The integration of trees, crops and animals in these agroforestry systems can be spatial and/or temporal. In spatially integrated systems different species are cultivated at the same time in order to maximise the use of water, nutrients and light. Competition between the components of these systems must be managed. An example of a well known spatial combination in Central America is plantations of timber trees with perennial crops such as coffee or cocoa underneath. Even more common is the combination of perennial crops with service trees (Box 3) that do not provide commercial products, or if they do provide commercial products they are of low value. These trees are planted to provide shade to the principal crop, such as cocoa, fix nitrogen, or provide other services.

Temporal integration involves the temporal staggering of resource use by the different components, for example in the case of trees and crops planted in different months or different years. Examples of temporal combinations include the Taungya system (Box 2), and the grazing of forest plantations until the trees are well established and the canopy closes.

The classifications provided in Boxes 2 and 3 are useful in balancing the objectives of tree production with the needs of the associated crops. In practice there are an enormous diversity of systems that have been developed for the particular conditions of any site or field, including the soils, climate, and the farmer's economic situation. Because of this it is not advisable to develop strict guidelines about where and how to manage trees in agricultural systems. It is essential, rather, to first understand the particular conditions of each site, and then adapt the systems to the conditions. We can, however, use the lists of criteria to help us to make decisions in each case, based on the farmer's objectives and local information, such as:

- The selection of crop and tree species
- The spatial arrangement of the crops and trees
- The planting sequence, for example at the same time or staggered
- The management of the agricultural and forestry components.

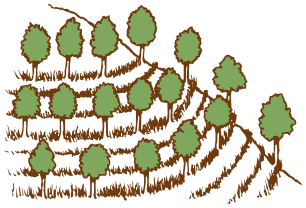
In order to advise people who want to plant or manage trees on farms, we must use these lists of criteria, and take into account the advantages and disadvantages of the different options. We can then reflect on which may be the principal factors in achieving success in planting trees with crops (see also Chapter 3).

Agroforestry systems used

2

Agrosilvicultural systems = Cultivos + Árboles

Shade-providing trees in plantations of perennial crops such as coffee or cocoa. Timber trees, multiple use trees and service trees. Service trees are managed only for the benefit of the crop, in order to fix nitrogen, modify the light environment and produce mulch (See Box 3).



Alley-cropping and live fences. These methods include the use of trees and shrubs, together with other components such as hay, to make lines between "alleyways" used, generally, for annual crops. This method is principally used to improve the soil, through nitrogen fixation and mulching, and/or to reduce erosion on slopes.

Taungya. This method involves the planting of annual crops during the establishment phase of forest plantations, fruit orchards or perennial crops such as coffee or cocoa.

Slash and burn agriculture or improved fallow. Traditional agricultural systems used to increase soil fertility and control disease in fallow fields or secondary forests.

Isolated trees in agricultural fields.

This category of tree includes natural regeneration and planted trees with any number of uses, including timber, fruit, soil improvement, fodder, firewood and medicine; at wide spacing (>10m), in areas used principally for annual crops.

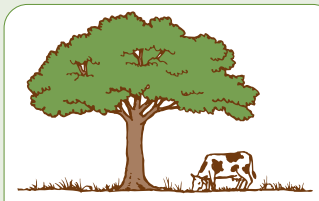
Line planting near agricultural fields. ITrees planted on the boundaries of agricultural fields, including live fences, boundaries and windbreaks.

in Central America

Silvopastoral systems = Árboles + Ganado

Grazing in secondary forests and forest plantations. This system is more common in young plantations (2-6 years).

Grazing in crop tree plantations such as coconut, African palm or citrus fruit



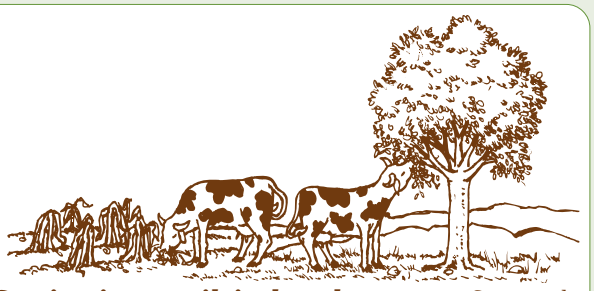
Isolated trees in pastures. Livestock managers may leave trees, for timber, shade, fodder or fruit, in pastures.

Fodder trees. This category includes fodder banks as well as any use of trees or shrubs, with or without grass, to provide fodder for domestic animals such as cattle or chickens.

Line planting. See agrosilvicultural systems

Silvopastoral systems = Cultivos + Árboles + Ganado

Homegardens. Generally a complex mix, with many layers of trees, shrubs, vines, annual and perennial crops, and animals, particularly pigs and chickens, which produce a variety of products for family use and with commercial value.



Grazing in agrosilvicultural systems. Commonly during the dry season following the harvest animals are grazed on crop remnants and trees, which are often the only green vegetation available at the time.

What types of trees

The majority, if not all, trees are 'multiple use trees', and are classified in more than one category. This functional classification was made on the basis of the primary use or product for the farmer. All trees have other

3

Timber trees

Timber trees are large components on the farm, often arising from natural regeneration. They generally require wide spacing (<100 trees per hectare when mature) and farmers often prefer to put them on the boundaries of the farm. Production is long term, generally more than ten years. It is important to consider the potential risk of damage to the crops, particularly perennial crops, by the trees, through competition for light and soil resources. On the other hand, the trees provide some financial security for the farmers, particularly because the trees can be harvested at any time of the year and the price of the timber is stable, with increases if inflation is taken into account.

Service trees

Trees that generally do not provide commercial products, but are used with annual and perennial crops to control soil erosion, for example in live fences, to provide shade, fix nitrogen, provide mulch, control disease and improve soil fertility are known as service trees. These trees are managed at densities from less than 20 trees per hectare for unpruned shade trees, up to more than 10,000 saplings per hectare in natural and improved fallow fields. Generally the trees are pruned or pollarded (pruned completely) every 3 to 24 months in order to reduce competition with crops and maximise the service value. Frequently these trees are leguminous nitrogen fixers, but the most important characteristics are the ease of propagation, by seed or vegetative propagation, and the capacity to resprout following intensive and frequent pruning. These characteristics allow the farmer to manage the crop-tree interaction to his or her liking.

to include and when?

functions, for example as habitat and food for animals with conservation needs.The categories of trees commonly included in agroforestry systems and their characteristics are presented in Box 3.

Fruit trees

Trees and shrubs whose principal products are fruit with potential commercial value and for family consumption are known as fruit trees. They are common in patios, semi-urban environments and homegardens and are managed at medium to low density (< 1000 trees per hectare). Optimal management for fruit production is not generally the same as optimal management for isolated trees in crop fields, in particular the timing and frequency of pruning must be a balance between the different demands. Local markets and prices for the fruit tend to be limited and unstable due to the cycle of the harvest and the difficulty of storing the products. In many traditional agroforestry systems there are only a few trees of any one fruit tree species, sometimes only one individual on the farm, but there tends to be a great diversity of species.

Fodder trees

Trees and shrubs that provide supplemental, high quality fodder for ruminants or other domestic animals, including chickens, especially during the dry season, are known as fodder trees. They are managed at densities varying from as low as 10 trees per hectare when the trees are relatively large, up to more than 10,000 trees per hectare in fodder banks or when grown for protein. The trees are intensively pruned every two to six months. The majority of the trees are leguminous and their easy seed or vegetative propagation, as well as tolerance of frequent, intense pruning are required attributes. It is common to encounter them concentrated in a limited area of an agricultural field or pasture, in small blocks or in live fences.

Trees for firewood and charcoal

Although all trees provide firewood, there are clear preferences for certain species due to the characteristics of the firewood such as calorific value, type of smoke and quality of the charcoal. These trees are found in scrub-land at densities greater than 1000 shrubs per hectare, as shade for coffee (<400 trees/ha), in pastures at varying densities, on boundaries or in live fences at spacing greater than one meter, and in small forest plantations at densities up to 500 trees per hectare. The trees are used to produce timber products such as posts and pitchforks as well as firewood for family use and for sale. The production cycle is 2-5 years and generally the trees are the result of natural regeneration rather than planting.

How to establish trees

Options for establishment: natural regeneration or planting?

The next question we will consider is how to establish the tree component in agricultural areas. Many traditional systems rely on natural regeneration, and this can be an option to help increase the tree component (see Chapter 5). In order to decide whether natural regeneration or planting is the best option, we will weigh the advantages and disadvantages of natural regeneration (Box 4).

4 Natural Regeneration: advantages and disadvantages

Advantages

- Local germplasm. Both the species and the providence are local (see Chapter 8), and therefore we assume that the tree is adapted to the site conditions, including rainfall and soil type.
- Low cost. Generally the only cost is weeding, sometimes transplanting, and clearing individuals that have grown in inconvenient locations.
- Sometimes it is necessary to intensively thin when there is abundant regeneration. This provides the opportunity to choose individuals that are particularly vigorous or have a good form.
- Easily accepted local technology
- There is no risk that the trees will have deformed roots due to mistakes in the nursery such as bags that were too small or late transplanting, or mistakes in planting such as holes that were too small or lack of care.
- If the species is already present in the area it is likely that there will be local knowledge of its characteristics, making management better and easier and also makes it more probable that the uses of the tree are appreciated and there may be markets for the products

Disadvantages

- Due to the species characteristics (Chapter 8) or lack of mother trees, it may be that there is not adequate natural regeneration of some species of interest
- The seed source is not chosen; therefore the seeds may come from very few trees or from one of low quality, which may, for example, produce poor truck form in a timber tree.
- There is no control over the date of planting with respect to the agricultural calendar of the farm. For example it would be preferable to avoid the need to look after recently established trees in the months when there is the maximum demand for manual labour for the crops.
- Natural regeneration produces an irregular distribution and variable density, there is therefore less of a possibility to choose the arrangement of the trees to achieve a homogenous distribution or concentrate the trees in certain areas, to form a windbreak for instance.
- It may be difficult to convince farmers to look after naturally regenerated seedlings because they are "free". This may not only result in mortality but also in poor form in the case of fruit and timber trees and lower commercial productivity.
- Initial growth may be slower, which increases the risk that the farmer may loose interest in the trees and look after them less.
- The farmers are limited to those species already present in the area.

Choose the most appropriate agroforestry system

in agroforestry systems?

Options for planting: pure plantation or agroforestry system?

Next, in Box 5, we describe the possible advantages and disadvantages of using agroforestry systems for reforestation with timber or fruit trees, versus pure forest plantations. This comparison refers to commercial tree plantations, but is not relevant for service trees (Box 3). It is important to note that not all advantages and disadvantages are relevant to every situation, and there are advantages and disadvantages that are apparently contradictory. All of the points in this list must be considered before making a decision, but some are not important in certain cases. It is preferable that the farmer makes the decision in consultation with the extensionist, based on his or her knowledge of the specific conditions of the farm and his or her objectives and priorities

Advantages and disadvantages of agroforestry 5

Disadvantages

- Where farmers are accustomed to using fire to clear agricultural areas, the practice can cause damage to the trees
- Due to competition for water, light and nutrients between the trees and crops, the trees may have a phase of slow growth and lower survival, particularly during establishment.
- It is probable that there are negative effects on the crops from competition with the trees. The intensity of the competition depends on the type of crop and its management, the type of soil and climate, the forest species and the state of development and management. For example, it is possible to use pruning and thinning of the trees to reduce competition, however this intensive management system is not necessary or appropriate for all types of tree production.
- The commercial value of timber products from agroforestry systems may be reduced by the conical and branching form that the tree trunks can develop when they are in open light conditions rather than in plantation blocks. It is therefore important to select species such as Cordia alliodora that self-prune in open light conditions.
- If the agricultural crop, particularly a perennial, was producing well and, in the judgement of the farmer, the yield is reduced too much by competition with the trees, the farmer may be tempted to prune the trees excessively and eliminate "future trees" (timber trees chosen for the final harvest based on their superior growth and form).
- Due to the fact that the resources necessary for the establishment and management of agroforestry systems are greater than those required for a pure tree plantation, the area that one is able to reforest is smaller.
- Poor management may lead to erosion, nutrient exhaustion, and overall site deterioration. This may occur if, for example, yucca is planted under trees and repeatedly harvested without fertilizers being applied to the field. Similarly, cultivation of annual crops under trees on steep slopes may lead to erosion problems.
- Crop management and harvest can damage trees. Trees roots may be disturbed during root vegetable harvest for instance.
- In medium or long-term associations silvicultural operations may cause harm to perennial crops, for example during thinning and harvesting operations in cocoa plantations.
- Crops or trees can have allelopathic interactions. Allelopathic effects occur when one species produces a chemical that affects the growth or survival of another species, usually negatively. To date only a very few alleopathic interactions have been reported for some trees with some crops.
- If the trees and crops are susceptible to the same pathogens or diseases, the association may be more detrimental or unstable.
- Timber trees in agroforestry systems are more exposed to adverse climatic conditions than are trees in forest plantations or natural forests. The trees must be able to adapt to conditions such as full sun.

PLANTING IN A PURE PLANTATION (See Chapter 7)

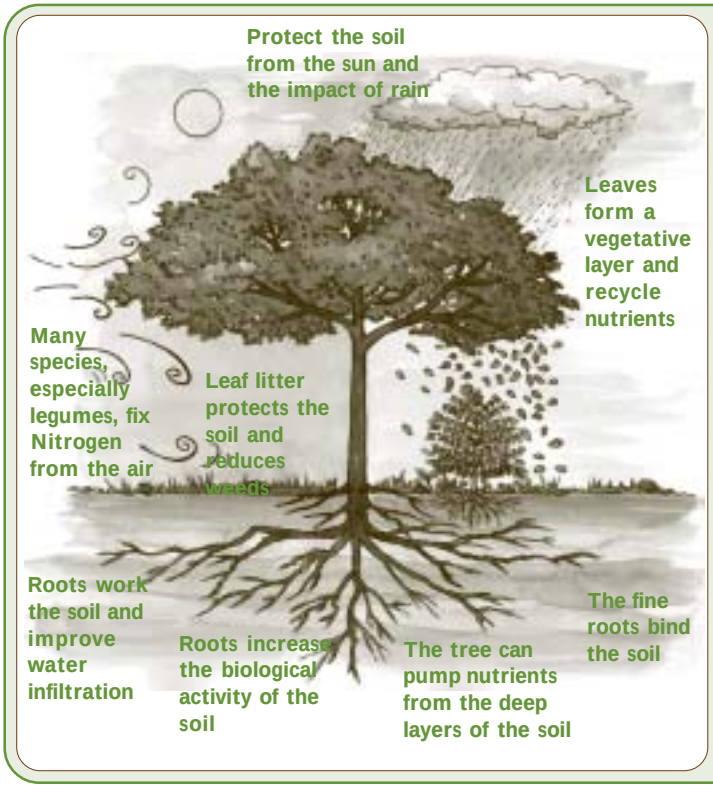
continues...

5

Advantages

- Income from agricultural crops may reduce or pay the costs of tree establishment. A Taungya (temporary association) would provide agricultural income during part of the tree rotation. A permanent association of the trees with a perennial crop may be able to generate agricultural yields during the entire tree rotation.
- Agricultural management such as clearing and fertilisation may improve the biophysical conditions of the site, resulting in better tree survival and growth rates.
- Due to the wider spacing, the growth rate of an individual tree in an agroforestry system may be better than trees in plantation blocks. Although pure reforestation may produce more timber per unit area planted, planting in agroforestry systems reduces the time until timber harvest.
- In dry areas, having crops rather than dry vegetation can reduce fire risk.
- Fences around crops reduce animal damage on both the crops and the trees.
- Agricultural fields are visited more frequently than are pure forest plantations. These visits provide the opportunity to detect and treat diseases and infestations during tree establishment.
- The association of trees with crops can reduce the dispersal of tree diseases such as Fusarium in the roots or insects such as shoot borer (Hypsipyla grandella) on Cedrela odorata and Swietenia macrophylla. Reductions in the problem may be due to increased vigour of the trees in the agricultural environment. Equally, crops may have lower incidence of disease when interspersed with trees.
- Leguminous crops can increase the soil nitrogen available for the trees.
- Agricultural crops planted after an area is cleared for reforestation may take advantage of soil nutrients that otherwise might be washed away during the rainy season.

Let's use agroforestry



The effect of trees on soil conservation and nutrient availability

How to select the system components for different objectives and sites

If it is decided that an agroforestry system is a better option than a pure plantation for establishing trees on a farm, the next step is to choose the components. It is important to emphasise that the characteristics of the trees and crops, and their interactions, can be modified with good management practice in order to take advantage of the positive characteristics and minimise the negative ones.

For example, we can manipulate:

- the dates and sequence of planting the forestry and agricultural components
- the spacing between the trees and between the trees and crops
- the duration of the association (the agricultural cycle)
- the management of the two components (pruning, fertilizing, weed control)

However, the conditions of each site must be evaluated and basically coincide with the requirements of the tree and crop species, for example it is best not to plant Cordia alliodora or beans on sites with poor drainage. When we want to establish a forest plantation using the Taungya system, the tree species must be able to compete with the agricultural component, and therefore must grow quickly, close canopy quickly and be tolerant of competition for light, water and nutrients during the first year.

Next we describe the characteristics that are desirable for timber, fruit and service trees. This list was developed to help the extensionist and the farmer choose the best tree species for the particular site conditions and the needs of the associated crops. The list is not in order of priority.

How to choose timber species

Local knowledge of the species: Previous successful experiences and existing preference for the species, in the area or in comparable areas, by other farmers or projects, provides a better assurance of success and adoption of the species. Local experience may include both native and exotic species, and the decision to choose one or the other should be undertaken by the farmer rather than the forestry officer.

Commercial value or local use of the species. It is important to emphasise this criteria because often the farmer will require that the trees produce, in the medium term, income that justifies the effort and investment the farmer has made. In the case of timber trees it is preferable that the trees produce timber of medium to high quality, such as *Enterolobium cyclocarpum*, *Carapa guianensis*, *Calophyllum brasiliense*, *Cordia megalantha*, or *Astronium graveolens*. The optimum would be to introduce timber trees with the highest quality and market prices, such as *Dalbergia retusa*, cedar or mahogany, when the environmental factors and growth rate are appropriate. The marketing options and the local and external demand for the products are the most influential factors in the species selection (see Chapters 4 and 9). Some of the species allow extraction of secondary products, such as posts and firewood, during pruning and thinning.

Rapid growth. In order to be satisfactory, the return on the investment in any business must be made in as little time possible. This is also an inherent reality of agricultural, livestock or forestry production. Rapidly growing tree species quickly generate a product and have a lower maintenance cost.

Self-pruning in open light conditions. Trees in agroforestry systems tend to have poor trunk form compared to trees growing in block plantations due to the wide tree spacing and lack of lateral competition. Trees in open conditions tend to have more branches and more persistent branches, higher harvesting costs, more waste at the sawmill and lower timber quality due to knots in the wood. However, in some timber species the lower branches "self-prune", which means they die and fall when in open conditions. These species are preferable for agroforestry systems because they have lower production costs and higher timber value. Both laurel (*Cordia alliodora*) and mundani (*Acrocarpus fraxinifolius*) self-prune, whereas melina (*Gmelina arborea*) and Mexican cypress (*Cupressus lusitanica*) do not.

Availability of certified germplasm. The probability of success is increased if certified seeds or seedlings are used. Where available, it is helpful to use high quality genetic material that produces strong and healthy plants, and avoid the use of genetic material of dubious quality or provenance (see Chapter 8). Choosing healthy and vigorous plants in the nursery or during thinning of natural regeneration is also important.

Lack of susceptibility to pests and diseases. Species susceptible to the pests and diseases of the area, or with other known problems, must be avoided. The family Meliaceae, for example, includes high value species such as cedar and mahogany that must not be planted in plantations due to shoot borer attack. However, the species are common components, at low densities, in traditional agroforestry systems such as coffee and cocoa plantations where shoot borer attack is much less.

Small and open crown. In order to minimise the competition for light with associated crops we recommend using species such as *Cordia*

6

Minimal negative effects for the associated crops. Even with crops that are generally grown under shade there are sometimes negative effects from competition for light, nutrients and water, for example Eucaliptus spp. sometimes have these problems in seasonally dry zones. These types of problems are almost inevitable in permanent agroforestry systems. In addition to managing the competition it is important to make sure that the trees do not have alleolopathic affects on the associated crops (see the Management section)..

- The trees can host pests and diseases that damage the crops
- They can produce excessive shade
- There can be excessive competition for water and nutrients
- The leaves of some trees can contain substances toxic to some crops

alliodora (open, narrow crown) or E*ucalyptus deglupta* (open crown). When harvesting the trees the work is less expensive and there is less risk of damage to the crops since the majority of damage is cause by the fall of the crown rather than the fall of the trunk. In addition, a small crown has lower wind resistance and lower risk of windthrow. It is preferable to have non-continuous foliage that provides patches of shade rather than a uniform canopy that creates a low quality light environment for the crops. In the case of deciduous trees associated with coffee or cocoa in the hot, dry regions, it is desirable that the tree rapidly develops new leaves in order to re-establish the original shade conditions. Finally, it is an advantage if the species has small leaves in order to avoid the effect of unifying the raindrops into strong steady streams of water that fall off the leaves, causing damage to both crops and soil.

Deep rather than surface root system. A root system on the soil surface creates strong competition with crops and is more susceptible to damage during crop management. Trees with surface root systems are also more susceptible to falling over (windthrow).

Una copa pequeña y abierta minimiza la competencia por luz con los cultivos asociados

Low maintenance management. Aggressive (*Eucalyptus* spp.) or robust (*Tabebuia rosea*) species are preferable due to their propensity to survive and grow quickly with little effort on the part of the farmer, which reduces the risks and costs of their establishment. These trees must be easy to propagate and, when newly established, tolerant of lateral shade and some vertical shade. Trees in the Meliaceae tend to have these qualities. It is important, however, that the trees do not reproduce like weeds.

Desirable characteristics in the selection of timber trees

7

- Local knowledge of the species
- Commercial value or local use
- Rapid growth
- Self-pruning in open conditions
- Availability of certified germplasm
- Resistance to pests and disease
- Minimal negative effects on the associated crops
- Small, open crown
- Deep rather than surface root system
- Low maintenance management

How to choose fruit trees in agroforestry systems

Studies of preferences for different tree species have revealed an interest among farmers in fruit trees, particularly in indigenous, non-domesticated species (see Chapter 9). Typically the local species have a long traditional history as forest species recognised for their domestic uses. Some of these species have been domesticated to some degree through a programme of improvement through selection, or, in some cases, as vegetatively propagated "cultivars". Generally the trees are selected based on size, flavour, season for fruit production, or colour.

Markets for many of these species have developed due to urbanisation. Other markets have developed at the regional or international level; such as "ethnic markets" catering to people from developing countries who now reside in Europe and the United States. Although the risk exists that certain fruits become popular at an international level and production of those fruits takes precedence over other traditional, or simply more diverse, activities; in general the markets for these fruit products are small and local and are of little interest to large scale, multinational producers.

8 Some criteria for the selection of fruit trees for agroforestry systems

- Commercial potential at the local, national or international level
- Local knowledge and traditional use
- Fruit characteristics that facilitate prolonged storage or post-harvest processing and transport
- Compatibility with other crops or trees, for example a crown that allows light to reach the associated crops
- Not acting as a host to pests and disease that are a threat to the associated crop
- Deep rather than surface roots
- Desirable characteristics for industrial uses, for example pectin content for jelly making
- High production of fruit or biomass
- Facility of rooting or germination
- High sustained productivity per tree and per hectare
- Ease of harvest, for example low, accessible crown or easily climbed trunk
- Good flavour and high quality
- Early or late production season to reduce competition with other crops
- Short period of establishment and precocious productivity
- Low incidence of pests and diseases
- Multiple use.

How to choose service trees to combine with perennial crop plantations

Service trees must meet the same criteria listed for timber trees except those attributes specific to timber production such as commercial value, self-pruning and certified germplasm. Additionally service trees should meet the following criteria:

- Robust rather than fragile branches and stems
- Capacity to use nutrients that are not available to the crops
- Nitrogen fixing
- Tolerance of frequent, intense pruning and capacity to resprout
- High biomass production in terms of litter fall and pruning products
- Resistance to pests and diseases that can cause sudden defoliation
- Absence of allelopathic activity
- Not acting as an alternative host to pests and diseases that affect the associated crops
- Branches and stems free of spines in order to make management easier

How to choose trees and shrubs for windbreaks

Windbreaks must be established using species that have the majority of their leaves all year, or at least during the windiest season. The species selection must vary with climate and soils and be based on the use, management regime and additional benefits expected (fruit, firewood, fodder). In selecting species one aspect to take into account is the density of foliage, which must be uniform from the very top to the bottom of the windbreak. However, the windbreak must allow approximately 20% of the wind to pass through. If the windbreak creates a complete wind barrier it will produce strong turbulence, which will eventually pass over the windbreak and cause significant damage to the crops that were to be protected. The overall area that will be protected depends upon the height of the trees, therefore, in order to protect the greatest area in the least time it is best to use trees that develop rapidly and to a suitable height (>20m) for the central line of the windbreak.

Some of the species used in the American tropics for the principal lines are Eucalyptus spp., Casuarina spp., Mangifera indica, Pinus caribaea and Pinus oocarpa. For the middle layers trees such as casia (Cassia siamea), guácimo (Guásuma ulmifolia), capulín (Muntingia calabura), neem (Azadirachta indica), pink apple (Eugenia malaccensis), uruca (Trichilia glabra), water apple (Eugenia jambos) or olive (Simarouba glauca) that reach 10 to 15 meters are suitable. For the bottom layer shrubs that reach 5 meters are best, such as amapola (Hibiscus sepium), mirto (Murraya paniculata), itabo (Yucca elephantipes), trueno (Ligustrum sepium) and some tall grasses such as elephant grass (Pennisetum purpureum), sugar cane (Sacharum sp.) and Indian cane (Dracaena fragans) may be used. In coffee plantations in El Salvador Croton reflexiofolius, Cupressus lusitanica and Cordia cana are traditionally used. In Chapter 3 we provide additional information on windbreaks from an example near León, Nicaragua.

How to choose trees or shrubs for fodder banks

High nutritional value. Species, varieties or provenances with high nutrition value (high protein and energy, low fibre) and low concentration of anti-nutritional compounds (tannins or alkaloids such as mimosina and cumarina) are ideal for fodder production. There is, for example, a significant difference in the concentration of cumarinas between provenances of Gliricidia sepium, and goats eat less when the concentration of cumarinas is higher. Leucaena leucocephala on the other hand is palatable but contains mimosina, which can seriously affect the animal's health and rate of consumption. Some trees and shrubs such as Morus alba, Brosimum alicastrum and Leucaena leucocephala provide better food than native, improved grass species. Mulberry (Morus) is 15 to 25% more digestible than the majority of improved grasses. The majority of traditional fodder species in Central America have sufficient quantities of minerals to satisfy the requirements of the animals.

Adaptation to the climate and soil conditions. When species are evaluated it is essential to consider their agronomic needs and their adaptability. Robust fodder species such as Brosimum alicastrum, Guazuma ulmifolia and Leucaena leucocephala grow better in alkaline soil and are drought tolerant (see Chapter 10). Other species that may be considered for the establishment of fodder banks include Gliricidia sepium, Trichantera gigantea and Cratylia argentea. Another robust species that grows well in calcareous soils is Parmentiera edulis, which produces a significant quantity of edible fruit for animals during the dry season.

Morus alba is a fodder shrub with a high potential for improving animal production. However, this species requires high soil nutrients and only grows well in fertile soils with large applications of nitrogen fertiliser (>300 kg N/ha/year). Planting nutrient demanding species in low fertility sites is not recommended.

Soil improvement. It is desirable to choose fodder species that also improve the soil. Fodder banks of leguminous trees such as Leucaena leucocephala and Gliricidia sepium can fix 75 to 200 kg N/ha/year. The requirement of Rhizobium, the root bacteria that fix nitrogen, must be considered for leguminous trees, particularly when planting the trees in low fertility soils. Some deep rooting species such as Brosimum alicastrum, Leucaena leucocephala, Guazuma ulmifolia and Gliricidia sepium have the capacity to accumulate and recycle minerals (phosphorus, potassium, magnesium, calcium and boron) from the deep layers of the soil.

Fire resistance. Livestock managers in dry zones usually burn the pastures at the end of the dry season to stimulate the growth of green, succulent vegetation during the rainy season. Fodder trees must therefore have some fire resistance. Both Gliricidia sepium and Guazuma ulmifolia have deep roots and are able to maintain food reserves in the base of the tree, which permits them to resprout from ground level following fires.

¿Cómo selecciono las especies?

Los árboles y arbustos:

- deben producir buena cantidad de rebrotes y hojas
- tienen que ser resistentes a podas fuertes y frecuentes
- resistentes al pastoreo y ramoneo
- nutritivas
- deben gustarles a los animales

Which crops can be associated with commercial trees?

The selection of compatible crops is as important as the choice of tree species. As ever, the criteria depend upon the objectives of the farmer. In Box 9 the selection criteria are considered for the situation where commercial tree production, such as fruit or timber, is the principal objective.

Selection criteria for crops associated with commercial trees

9

- The crop cannot produce dense shade before the trees are well established. For example, cocoa cannot be planted before a timber crop.
- Climbing species such as yam, vanilla, and pepper cannot be established while the trees are young or establishing.
- Crops such as hay that compete for nutrients and water should not be planted during the tree establishment stage.
- Crops such as banana and sugar cane that exhaust soil nutrients can negatively affect the later establishment of trees on the site if fertilizers are not applied to replace the nutrients.
- Root and tuber crops with extensive horizontal root systems (not including yucca) should be planted at a sufficient distance from the tree roots to avoid competition and damage during root crop harvest
- The crop should not cause physical damage to the trees. For example felling bananas in a new forest plantation can cause damage.
- It is an advantage if the crop fixes nitrogen.
- The crop should not have the capacity to behave like a weed. Although it has not been reported in Central America, in some African countries it is recommended that higuerilla (Ricinus communis) be excluded from young timber plantations.
- The crop cannot act as a host to pests and diseases that can affect the trees. The fungus Armillaria mellea, for example, can attack trees via yucca.
- In permanent agroforestry systems the crop must be shade tolerant, as ginger is, or shade demanding, such as cocoa.
- The crop cannot have allelopathic effects on the trees.
- The crop should have economic potential.
- There should be a tradition of, and experience with, the species in the region, or a newly established market.
- The crop should require little manual labour when it is intended to promote reforestation programmes. The manual labour required for the agricultural crop can limit the total area that can be reforested in agroforestry systems.

How to choose sites to plant commercially valuable trees

The discussion of the advantages and disadvantages of agroforestry, and the selection criteria for the components, brings us to the conclusion that different sites on the farm can vary in their appropriateness for establishment of commercial trees. We must take the site characteristics into consideration to assure the success of the investment.

The costs of establishment and protection. Protection and care of the young trees can be one of the most important costs. Establishing trees in an agricultural area is easier than establishing them in a pasture due to the physical damage the animals may do to the trees. If there are the resources to protect the trees until they reach 5m tall, the trees may be able to survive the livestock.

Competition with crops. Site should be selected that minimise the competition between the trees and crops, or where the presence of the trees (e.g. shade) favours the crops. The consequences of light competition are less when shade adapted crops, such as cocoa or coffee, are used, rather than when light demanding crops such as corn are used.

Soil fertility. Often governments and large businesses establish forest plantations on soils appropriate only for medium or long term crop production due to low soil fertility. The ecological benefits can be high, for example erosion mitigation or river protection, but the possibilities of success (see Chapter 3) are lower and the initial costs much higher. Farmers, however, due to their cash flow limitations, benefit from a shorter turnover from trees with commercial products. It is therefore recommended that reforestation programmes are started in an agroforestry system on good soil or in agroforestry systems with intensively managed crops such as coffee, where there is a greater probability of achieving satisfactory results in less time. Additionally, when there is rapid initial growth, the need for weeding and clearing, which is a critical factor in the success of many reforestation programmes, is reduced. Later, when the farmer has more experience, he or she may try to cultivate these commercial tree species on more challenging sites.

There are tree species such as Tabebuia rosea that can adapt to very wet sites or to the compacted soils of pastures. Cordia alliodora, on the other hand, is highly susceptible to compacted soils and poor drainage. These species provide an example for the essential rule that for each site on the farm appropriate species must be selected, and the same species can rarely be used everywhere. The mistake many reforestation programmes make is to offer too few species for planting (see Chapter 3). For example, along the length of a boundary, there may be different soil conditions such as compaction or poor drainage; therefore a combination of species must be planted in the different sectors. Look at the species descriptions chapter for examples of and recommendations for desirable site and soil characteristics.

Ease of harvest. The planting site must facilitate the harvest; this is a particularly important consideration for timber trees. Sites near rivers, in deep ravines or on precipices cannot be planted with commercial timber trees because they cannot be harvested or because the cost of harvesting is prohibitive. Trees on river margins and near brooks cannot be harvested for environmental reasons and, in many countries such as Costa Rica, cutting the trees is not permitted by law. In these areas it may be appropriate to plant fruit trees rather than timber trees, as the harvesting of the fruit does not require felling the tree.

How to manage the trees

Managing the trees in agroforestry systems

Before planting trees it is necessary to ensure that the resources such as time and money are available to maintain the trees. The majority of failures in reforestation occur because there is no weed control during the first two years, or it is done when it is convenient for the producer rather than when the tree needs it. We recommend that the number of trees planted is consistent with the resources available for adequate maintenance. Appropriate species selection (see How to choose the system components on page 209) can help reduce the amount of maintenance required, but there is always some effort necessary, for any crop, and to deal with unpredicted problems such as insect attacks. Regular monitoring on the part of the producer is essential for success.

The tree establishment is the most critical phase of the plantation. It is necessary to protect the trees from animals and people until they are 5 meters tall, for example by rotating pastures with bull calves, avoiding the use of aggressive grasses such as Brachiaria decumbens and taking care with the application of herbicides for clearing grasses or crops. In this section we cover various considerations on how to adapt pure plantation silviculture to agroforestry systems. The basic considerations for tree establishment, such as soil preparation, site marking and hole digging, planting dates, weeding, clearing, and pruning are not addressed here as abundant literature already exists in Spanish covering these topics (see examples of extension materials at the end of this chapter).

Vegetative propagation. Vegetative propagation of trees, using stakes less than 2.5 m long, is a common traditional practice farmers use to establish service trees such as shade trees over coffee and live fences. The method is also used to establish fodder trees, trees for firewood, hedges and alley-cropping systems. In Box 10 we describe the method for establishing a live fence.

Initial spacing. Pure timber plantations are established at high density with the intention of thinning the plantation later. In agroforestry systems, on the other hand, trees are generally planted at their final density. In agroforestry systems it is therefore necessary to have high survival rates, rapid initial growth, and, in the case of timber trees, good trunk form in all of the planted individuals. Another method used to achieve these aims is to plant three or four trees together, and when they reach approximately 5m tall, cut all but one. The initial spacing of the trees depends to a large extent on the objectives of the plantation (see Box 2), the growth habit of the species, site quality and management. If the farmer wants to produce firewood the initial spacing may be less than 2.5m in small plantations. For saw-wood plantations the spacing should be more than 3m, with later thinning. In boundary plantings initial spacing for timber trees should be 3-5m, whereas shade trees for coffee or cocoa should be at more than 8m spacing. Windbreaks should be planted in a line perpendicular to the predominant winds; the lines separated by 10-20 times the maximum height of the trees (see an example illustration on page 219).

Replanting. In some agroforestry systems, such as shade trees for perennial crops or windbreaks, replanting is much more important than in pure plantations because uniform cover is fundamental to the function of the planting. In windbreaks it is particularly important to have 100% of the positions planted during the first year since open places in the line create turbulence, windthrow

10 How to establish a live fence using large stakes

Materials:

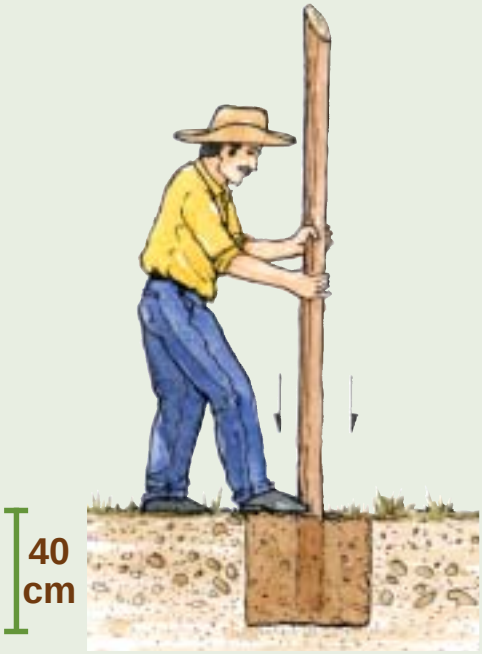
- Obtain stakes 5-15cm diameter and 2-2.5m long.
- Generally the stakes are cut at the end of the driest period of the year.
- Choose stakes (sprouts) from adult trees that were not pruned during the last 12-24 months.
- Respect the local traditions that provide guidance about when to cut and plant stakes in relation to the phases of the moon.
- Cut, prepare, and transport the stakes taking care not to damage the bark. A cushion of leaves can be useful for this.

Preparation

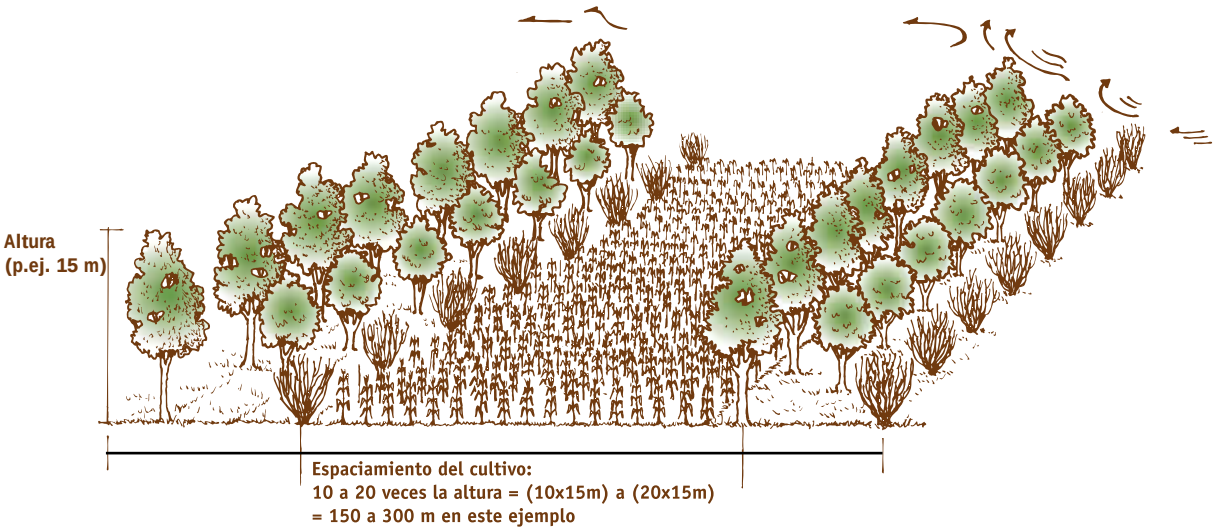
- To promote the accumulation of reserves in the base of the stake, place them in a vertical position, in shade, for 1-2 weeks.
- Before planting, bevel the apical point and cut straight across the area where the roots will emerge.

Planting

- Plant at the end of the driest part of the year
- Plant the stakes 1-2m apart
- In wet areas peel a ring in the bark just in the area that will be immediately below ground level in order to promote rooting
- Bury the stakes 20-40cm deep
- Fill the hole where the stake is buried with soil and pack it down, either using a soil compactor machine or by other means
- Secure the stake to the wire fence with string to keep it vertical until it has rooted
- Remove the wire fence 3-6 months after planting
- The live fence should be allowed to establish for at least a year before the first pruning.



Example figure: The spacing distance between the rows in a windbreak



and reduce the overall effectiveness of the windbreak. Replanting should take place one or two months after the initial planting; especially in areas with a significant dry season, as it is difficult for trees planted in the following years to succeed due to competition with the more advanced original seedlings.

Pruning. The principal objective of pruning in agroforestry systems is to reduce the shade on the crops. Timber trees in agroforestry systems tend to branch more than those in block plantations due to the wider spacing and reduced lateral competition, and therefore require more frequent and intensive pruning. However, no more than 30% of the crown should be pruned. The season for pruning depends on the seasons for tree growth and development and on the climatic conditions of the site. For example, it is best not to prune during the dry season when the crops need protection from the summer sun. Premature pruning can cause poor form in species such as Tabebuia rosea, therefore it is useful to have technical advice before undertaking intensive pruning.

Pruning timber trees, especially in agroforestry systems, can make a significant difference in the quality of the timber as well as provide additional products such as firewood, posts and fodder for the farmer. It is important that the pruning is done level with the bark of the trunk, without damaging the bark. Branch bases left projecting from the trunk produce dead knots in the wood, which reduced timber quality and may also provide entry points for disease, infection or termites. Fruit tree pruning is also important, but is done differently (see the next section "management of fruit trees").

The need for pruning, the intensity and frequency, varies from species to species and also depends on the nature of the associated crops. Some timber trees such as Cordia alliodora have thin canopies and self-prune (drop some of their branches in open light conditions) and therefore need less attention than do others such as pines. Often farmers cut the tree branches along nearly the entire length of the stem. Although this practice favours the crops, it may significantly retard the growth of the tree. Many farmers say the pruning serves to straighten the tree, however this is only

the case when the pruning eliminates one side of a bifurcation to favour the development of a single leader. Pruning lateral branches has no effect on the straightness of the trunk of a tree.

Thinning. Thinning allows the farmer to maintain the tree population within the limits acceptable from the point of view of the associated crops. It is also an opportunity to harvest some products from the trees, decide on the arrangement of the trees, control the shade they cast on the crops (e.g. leaving more trees on the limit than in the middle of the agricultural plots), and facilitate animal management (e.g. concentrating the trees around the gate of a pasture so that animals congregate there in the shade and are then easier to corral when necessary). In addition to the density and arrangement of the trees, thinning takes into account the form and health of the trees, eliminating the unhealthy, crooked or bifurcated trees.

It is best not to prune more than 30% of the crown, as it may damage the tree.

Management of fruit trees in agroforestry systems

On almost all tropical farms there are a number of fruit species (mango, banana, avocado, citrus, papaya, guava). Fruit trees can be used for almost any objective that trees might be used for in agroforestry systems (Box 2), depending on the needs of the farmer, the nature of the fruit species, and the other components of the system. Fruit trees such as Byrsonima crassifolia are often found as isolated trees among annual crops or in pastures, or situated along the farm boundary (see the section on "Trees in lines"). They may be used a hedges, individual trees or live fences (Spondias mombin). They may also be found in homegardens or as service trees among perennial crops (Pouteria sapota, Annona muricata, Anacardium excelsum). These fruit trees are important for domestic consumption and are also sold when a market can be found. Only in a few cases is there a commercial demand for fruit juices (Psidium friedrichstalianum, Psidium guajava, Annona muricata), or fruit (Byrsonima crassifolia). Unless commercial opportunities exist, and these are normally for the wealthy owners of large plantations, the market is usually supersaturated during the season and there is little incentive for farmers to manage these fruit crops intensively. As a consequence it is unusual to see fruit trees managed and even less to see managed fruit orchards. However, as the size of the property decreases it may become more attractive for the farmer to intensively manage a few fruit trees.

Fruit development is a competitive interaction between pollinated flowers. Optimising the use of light, water and nutrients during the formation and development of the fruit increases the quantity and quality of the fruit produced. Therefore, treatments to improve the capture of light and provide water and fertilizers will maximise the number of fruits that reach maturity. Abortion of fruits and flowers occurs when the inflorescence does not receive sufficient resources.

Pruning. The methods for pruning and form control in fruit trees are well known and are easily applied in the tropics. However, the techniques are rarely applied to promote fruiting in tropical trees, with the exception of coffee and cocoa. There are five reasons that it is important to prune and train fruit trees in agroforestry systems:

- Reduce competition for nutrients, water and light with the surrounding crops
- Reduce competition among branches for the tree's resources
- Promote regular flowering and fruiting
- Eliminate old, sick or damaged branches and sprouts
- Maintain a low crown that facilitates fruit harvest and the control of disease

Pruning is also done to stimulate new, vigorous growth, with pollarding and coppicing as extreme examples. Evergreen tropical fruit trees such as mango, avocado and citrus rarely require "renewal pruning" of this type.

Training. Horizontal sprouts trained along wires or flat against walls, have four principal goals:

- Promotion of flowering and secondary branching. Many sprouts become "short sprouts" or less vigorous sprouts with short internodes, and it is more probable that these will produce flowers
- Control the form of the tree crown
- Permit exposure of the shoots to the light in order to optimise photosynthesis
- Permit easy access to the branches with fruit

Training fruit trees along wires increases the density of fruit trees it is possible to establish in an agroforestry system without increasing the competition between trees and crops. The wires may be oriented in a direction relative to the sun such that during certain parts of the day the fruit trees receive the maximum light possible and at other times the crops receive the light.

Grafting. Fruit trees are grafted in order to

propagate desirable varieties, reduce disease problems by using resistant parents, and speed up fruiting. In addition, sprouts may be grafted onto mature rootstock in order to promote maturation and reduce the size of productive trees.

Flower stimulation. This method is used to encourage fruit production when the tree is young or when the environmental conditions or the season is not appropriate for natural flowering. The most reliable and practical method to stimulate flowering for a wide range of species, including mango and lychee, is ring-barking. This technique is extremely drastic and must be applied appropriately or it can result in the death of the tree. In addition it is a technique that cannot be used regularly every year without damaging the tree.

To induce flowering by ring-barking, a piece of bark 1-2cm wide is removed completely all around the branch before the flowering period. The site of the ring on the main stem or branch is critical and must be exactly above another living sprout. If it is not, the tissue below the cut bark will die, killing the sprout.

Do you think this producer need more trees or fewer cows in this pasture?

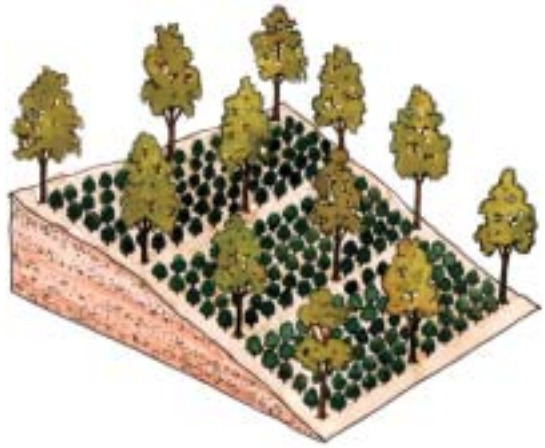
Design and management of different agroforestry systems

In the following sections we will describe the design and management of trees in four examples of agroforestry systems used in Central America. We also discuss modifications to standard agricultural and forestry practices. Hopefully the concepts we present can then be applied to other agroforestry systems that, for reasons of space, we cannot discuss here.

Boundaries and windbreaks

Fodder banks of perennial woody trees

Isolated trees in agricultural fields



Shade trees in plantations of perennial crops

Line planting: Windbreaks and boundary trees for timber or fruit

Windbreaks are lines of trees and/or shrubs of different heights planted perpendicular to the prevailing winds. They are used to reduce the speed of the wind and thereby avoid the loss of soil fertility due to wind erosion, reduce the mechanical action of the wind on the crops and animals, regulate microclimate conditions such as temperature, reduce evapotranspiration in cultivated areas, and control the transport of solid particles via the wind (reduce contamination).

Boundary trees are timber or fruit trees planted in a line on the boundaries of the farm or along internal farm divisions to diversify and/or increase productivity..

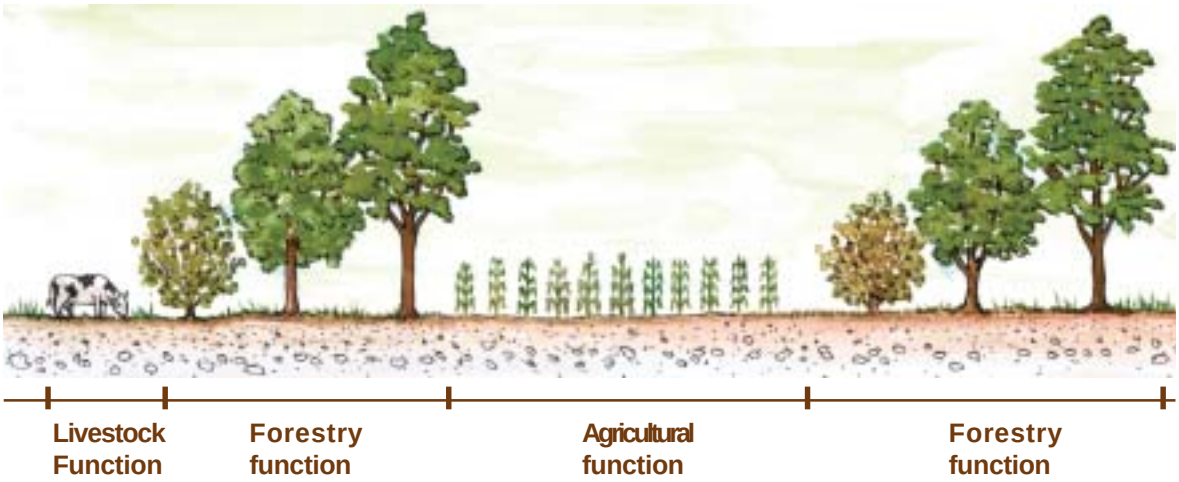
Where are they necessary?

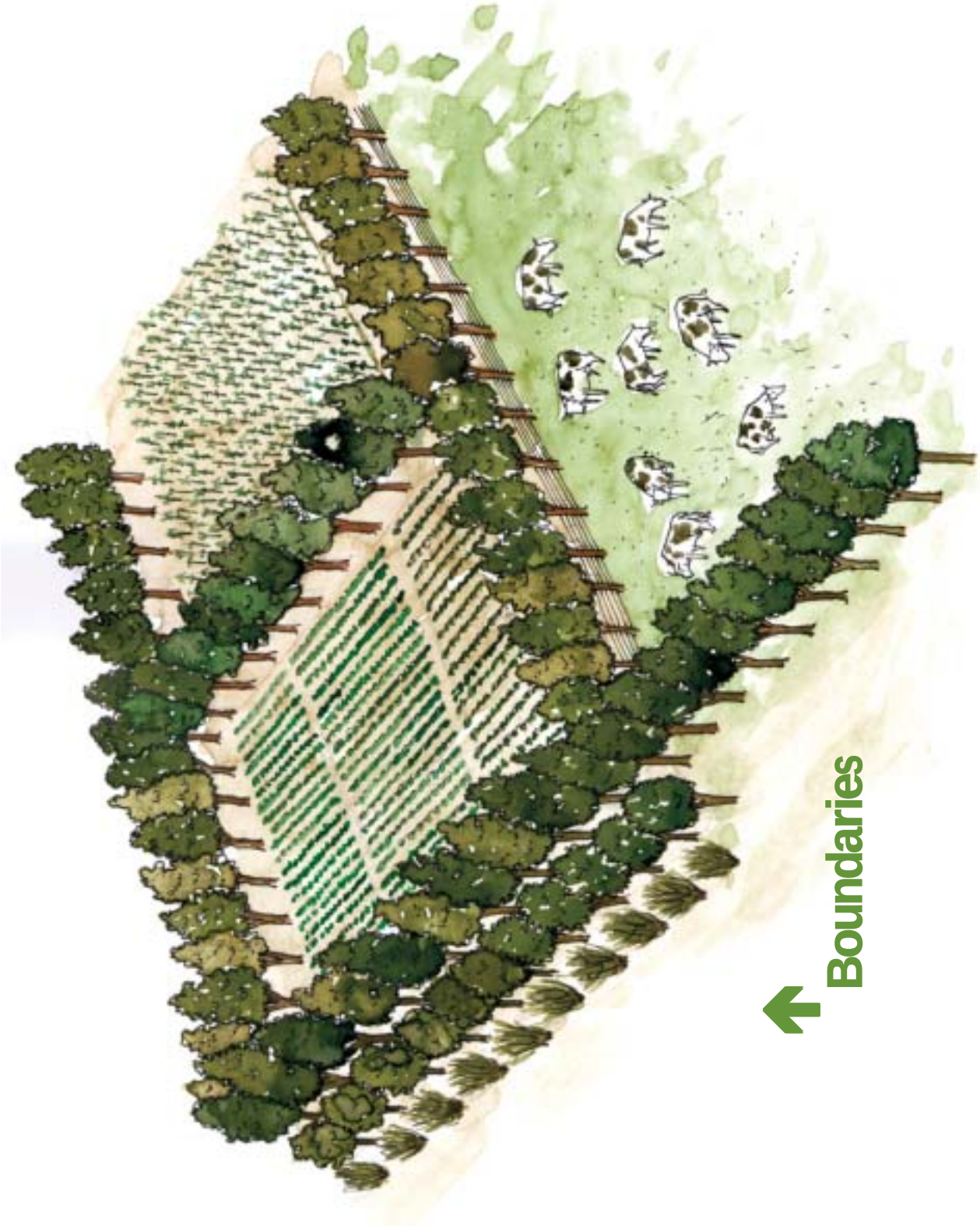
Generally windbreaks are used in semiarid areas to control the damaging effects of the wind, which causes erosion and damages crops, animals and humans. Windbreaks are also used in mountainous areas to alleviate the effects of the cold or drying wind.

Boundary trees may be established with crops or grasses. As the principal objective is production, whereas the objective of windbreaks is protection, it is necessary to ask whether it is better to plant the trees on the boundary or in a pure plantation (see Box 11).

How should windbreaks and boundary trees be arranged?

In agricultural areas we should sacrifice as little land as possible to the establishment of windbreaks or boundary trees. On very small farms we can use a narrow line of trees, sometimes only one row wide, which is called a tree boundary or a live fence. In this case it is best to use a species such as mango or Cupressus lusitanica with good leaf development beginning just above ground level.




Boundaries

11 Advantages and disadvantages of planting timber trees on boundaries versus using pure plantations

Advantages

- The establishment of boundary trees of this type allows the definitive demarcation of the farm or property boundaries, affirming the farmer's control, preventing legal conflicts with neighbours over land ownership, occupation of the land by other people, etc
- These trees produce commercially valuable timber or fruit in areas that are otherwise marginal or unused, with relatively little competition with the crops
- When the amount of land available is limited, the use of boundary trees allows small farmers to be included in reforestation projects
- Because in this system there is little lateral competition between the trees, it is possible to delay the thinning, which offers the owner more flexibility compared to block timber plantations where productivity may be permanently reduced if the thinning is not done at the most opportune moment.
- Boundary trees reduce the growth of other low vegetation on the boundaries, due to the increased shade, thereby increasing the benefit of the initial investment the farmer made in weeding and maintaining clear areas
- Increase the property value and increase the aesthetic value of the landscape
- Thinning and pruning can provide firewood, and posts to make a fence on the same boundary.

Disadvantages

- The costs of protecting the trees until they reach 5m tall may be higher than the costs per tree of establishing a pure plantation. This may be particularly true for boundary trees established in grazing areas, due to the possible damage from the animals. Animals can tread on the trees, scratch themselves on the trees and cause bark damage and damage the young foliage. Protecting the trees may also be critical in areas along public roads due to the damage people may inflict.
- The initial costs of maintaining the trees are higher than in plantations because along the boundaries the weeds grow more than in plantations where the canopy closes more quickly. As a consequence, the clearings around trees planted on boundaries must be kept clear for longer, at least until the trees can compete with the surrounding weeds.
- The influence of the boundary trees extends to both sides of the boundary, which may eventually cause conflicts of interest between neighbours, such as complaints about shade or conflicting claims on the commercial tree products. Therefore, before beginning to establish trees on the boundaries between different landowners, it is recommended that the landowners who may be affected reach a consensus about the management of the trees. A practical way to reduce these problems is to plant the trees at a certain distance from the boundary (1-2.5m). In this way at least the possibility that the neighbour will make a claim on the commercial products from the tree is reduced, however there is still the possibility of competition with the neighbour's crops.
- If the trees are on the boundary of a plot of land and serve to support a wire fence that divides two properties, it must be considered whether this practice may negatively affect the quality of the timber due to the use of nails or staples to fix the wire to the trees. It is possible that 1 to 1.5m of the base of the tree trunk, which is the most valuable part, may be lost. Again we recommend that the trees be planted at a prudent distance from the property limit so that the possibility of wire being nailed to the trees is avoided.
- If fruit species are planted on the boundary and the trees are used to support the wire of the fence, there is a natural tendency to use the wire to climb the tree to harvest the fruits. There is the possibility of damaging both the fence and the tree. The cost of repairing the fence in this case is increased by the damage that may be inflicted on the tree.

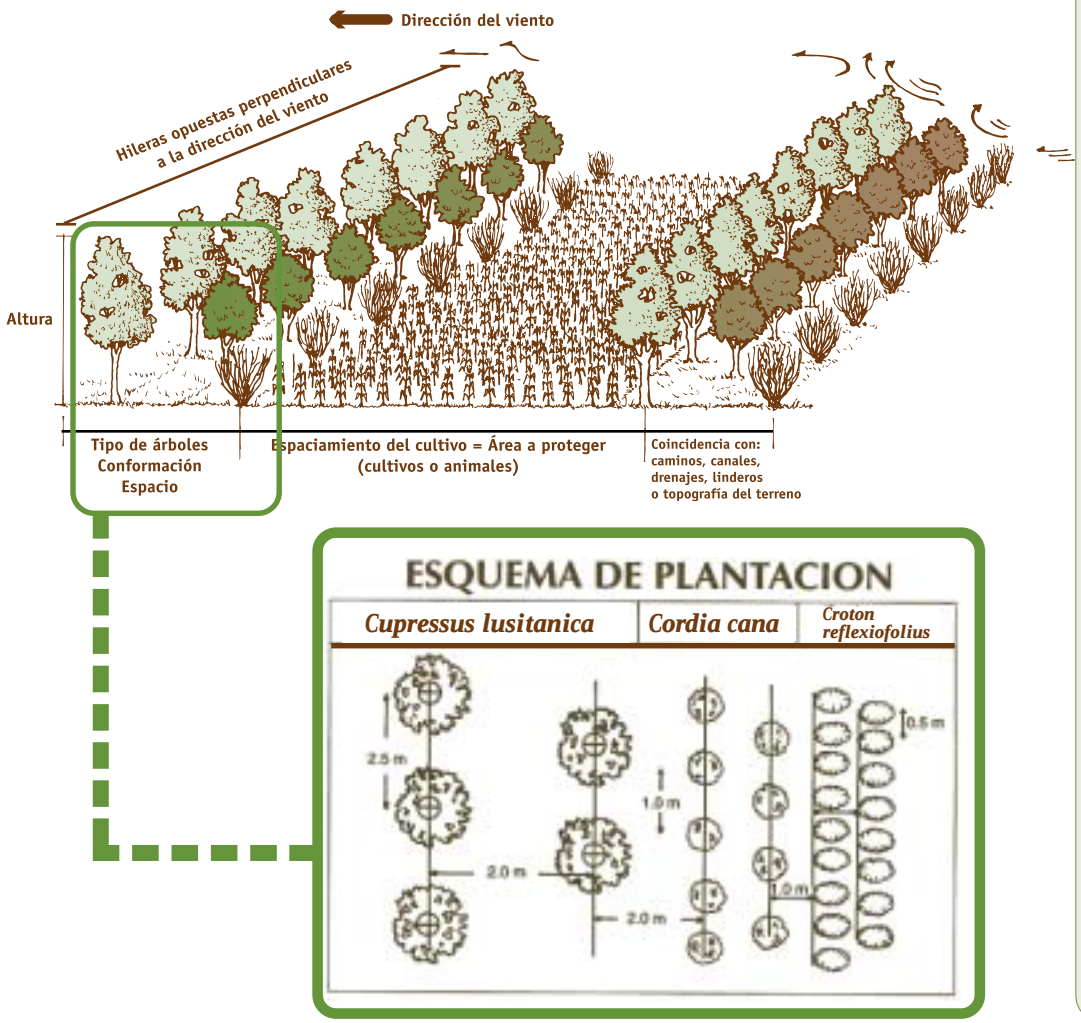
The benefits of windbreaks

Each situation must be analysed carefully so that it addresses the needs and desires of the farmers and also retains a minimum level of effectiveness. The ideal is to establish windbreaks perpendicular to the prevailing winds. In the case of a strong wind from only one direction, or in opposite directions, the windbreaks should be established in parallel strips. If the wind comes from various directions it will be necessary to establish a rectangular network, with the principal windbreaks perpendicular to the most intense winds and the secondary windbreaks perpendicular to the principal windbreaks (see picture below). The secondary windbreaks may be smaller and have wider spacing between the trees.

In some cases it may be necessary to accept the request of the farmer to establish windbreaks on a certain boundary, although it is not perpendicular to the prevailing winds. Windbreaks cannot be established next to irrigation works (covered canals) as the roots can destroy the canals.

Wind speed is greater at both ends of the windbreak, so we recommend that windbreaks are as continuous and long as possible to reduce this problem. A windbreak must be continuous. If it is not, the wind is focused into the open spaces and reaches higher speeds than it would have in the absence of the windbreak. If the windbreak is only

Las cortinas rompevientos: orientación, medidas y elementos



one line of trees, the risk that it will form holes or open places is greater than for a windbreak composed of various rows. We recommend that windbreaks be built of various layers, species and rows with a width of 4 to 15m, to form an adequate and long-lasting barrier. The spacing should take into account the desired structure and the requirements of each species in the windbreak. Indications of an effective design are that the windbreak reduces the speed of the wind by at least 20% and that the protected zone is up to seven times the maximum height of the windbreak on the windward side and up to 15 or 20 times the height on the leeward side. The height of the windbreak is based on the species selected as the tallest layer and the quality of the site.

Boundary trees for timber are made up of one line at an initial spacing of 2.5 to 5m. Generally the trees grow rapidly as there is little lateral competition, therefore an early thinning of up to 50% is recommended, leaving the remaining trees at their final spacing (5 m for Cordia alliodora up to 10 m for Terminalia ivorensis). In flood prone areas it is important to clear a 3m strip on both sides until the trees are taller than the weeds. Pruning is more important in pure plantations as it allows in some lateral light.

Fodder banks of perennial woody species

Fodder banks are small plantations in which perennial woody species and/or herbaceous fodder is cultivated in a compact block, at high density, with the aim of improving the diet of the animals, particularly in the dry season.

When to use a fodder bank

When there is a need to supplement the diet of the livestock, particularly ruminants, fodder banks are a good alternative or complement to less concentrated uses. Fodder banks are used principally to produce high quality fodder that is easy to digest and is high in protein. This supplement is especially important at the end of the dry season on the Pacific slope of Central America, when the dry grass and agricultural stubble are both scarce and of low quality, i.e. have a high fibre content and low digestibility.

Fodder banks are classified as silvopastoral systems because there are important interactions between the tree component of the fodder bank and the herbs in the adjacent pasture.

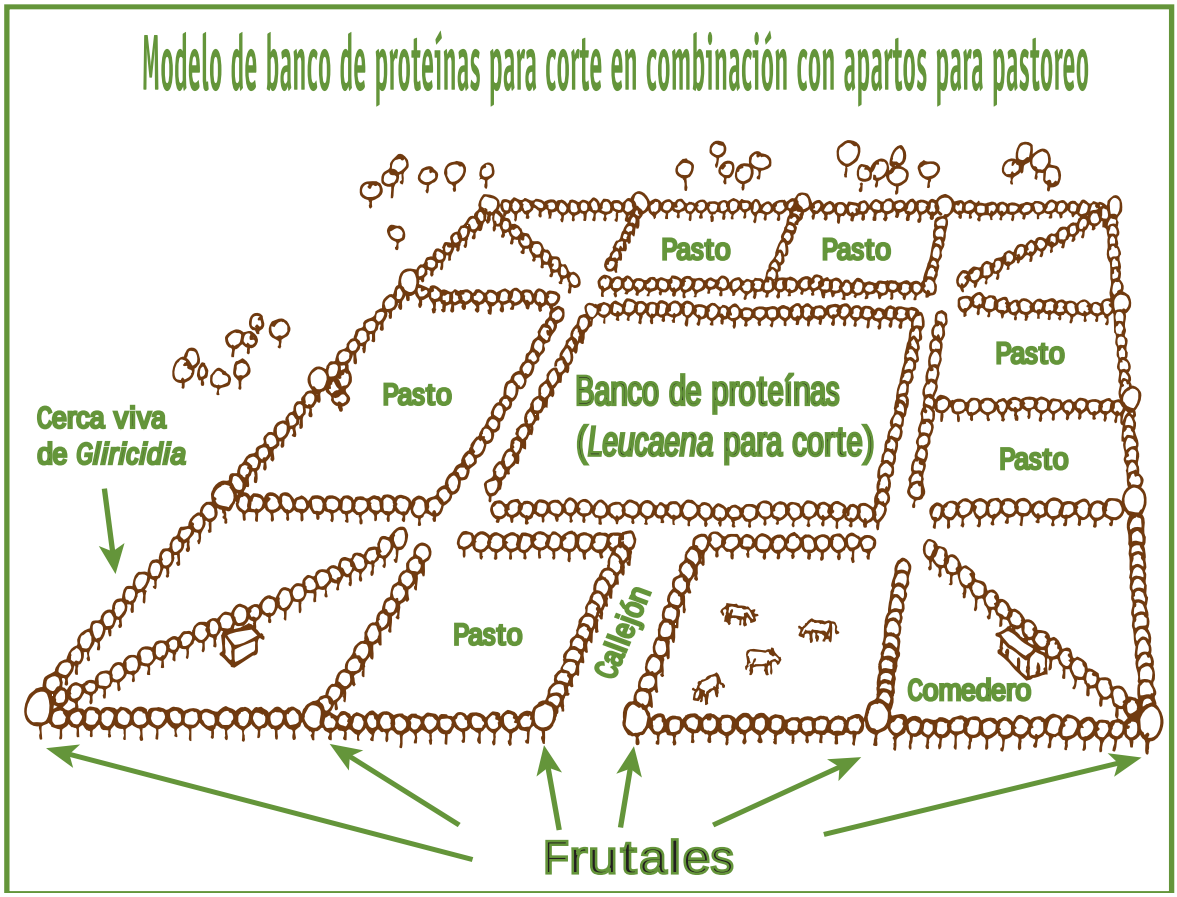
- A large quantity of the nutrients consumed by the animals in the fodder bank is mobilised towards the grasses
- The amount of fodder the animals consume in the bank depends in part on the production and quality of the associated grass
- When the animals are supplemented with material rich in protein they can eat and digest more low quality dry grass
- Much of the dung remains within the fodder bank

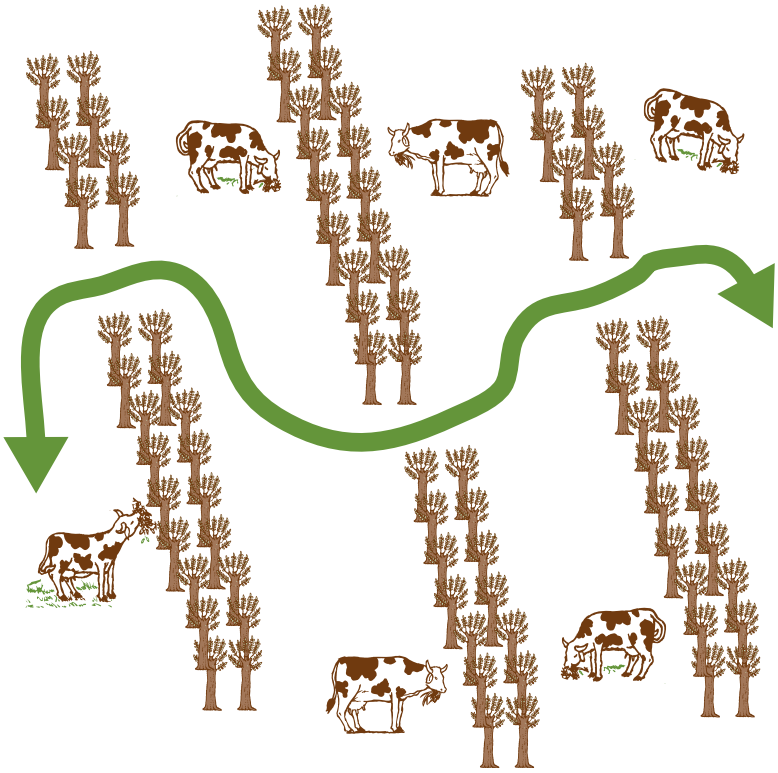
What should fodder banks be like?

Fodder banks may be made from woody perennials in alleys with herbaceous fodder in between. These lines of woody species may be fodder or live fences to control erosion, whose leaves are cut and used as supplemental food for the livestock stabled within. The length of planting depends upon the method for using the fodder and the species. In "cut and carry" systems the trees may be planted at densities of 20,000 to 25,000 plants per hectare (Leucaena leucocephala and Gliricidia sepium may be planted at 1 x 0.5 m or 1 x 0.4 m), or up to higher densities of 50,000 plants per hectare for species such as Morus alba, Malvaviscus arboreus and Trichantera gigantea. In pasture systems the trees are established at lower densities of 10,000 to 12,5000 plants per hectare (2 x 0.5m to 2 x 0.4m) to allow the animals access to the fodder. Higher planting densities limit the selection and the use of the fodder bank for the animals.

In pasture systems one method to increase the density, and therefore production, of fodder and at the same time reduce the damage to the trees from grazing and trampling, is planting the trees and shrubs in a double line every 2.25 meters (1m between the two lines of trees). This produces a spacing of 1.625 x 0.5m to 1.625 x 0.4m, with densities between 12,307 and 15,384 trees per hectare (see the Figure to the right).

In pasture systems continuous lines of trees are not recommended as the animals tend to move repetitively along the length of a single line, increasing soil compaction. It is preferable to leave occasional spaces in each line (1.75m apart) to allow the animals to move in the pasture with ease (see Figure to the right). This method also allows the animals to select the highest quality fodder.





In fodder banks one can plant:

only grasses...

shrubs or trees...

or a mixture of both

How to manage cut and carry fodder bank systems

In cut and carry systems, leaves and stems are harvested above a certain cutting height. Cutting frequency and height are the management factors that determine the quantity of digestible biomass the fodder bank produces. These factors must be adapted to the site conditions.

Establishment. In general trees and shrubs are slower to establish than grasses. However, with good management, fodder trees and shrubs generally maintain a long life cycle (>10 years), except for a few rapid growing species such as Sesbania sesban and Cajanus cajan that have short life cycles. The establishment of Leucaena leucocephala and Guazuma ulmifolia through direct sowing is much quicker than that for Brosimum alicastrum, which takes two to three years. However, the growth of Brosimum alicastrum depends on the provenance of the seed and the seed source (see Chapter 8). Under drought conditions seedlings developing from large seeds have a greater possibility of survival because they can more quickly develop a deep root system than can small seeded species.

Some fodder trees and shrubs such as Gliricidia sepium and Erythrina berteroana can be more quickly established using stakes than by direct planting (see Box 10). Other fodder species easily established using stakes are Trichantera gigantea, Morus alba and Malvaviscus arboreus. Trees established using stakes generally have a shallower rooting system and are less drought resistant than those established by direct sowing.

Fodder trees should bind the soil to control erosion and compete well with aggressive weeds, in particular grasses which have many roots in the top layer of the soil between 0 and 30 cm. Leucaena leucocephala is, for example, very susceptible to competition with weeds, which causes weak growth and high seedling mortality during establishment.

Starting the harvest. The first harvest should be held back to allow the plants to establish a strong root system and thick shoots. Fast growing species such as Gliricidia sepium, Erythrina berteroana, Leucaena leucocephala, and Calliandra calothyrsus may be cut 6-8 months after establishment when they are 1-2m tall. Slower growing species such as Brosimum alicastrum should not be cut during the first 12-15 months following establishment.

Cutting frequency. Production of digestible biomass increases with the length of the interval between harvests, however, if the interval is too long the proportion of inedible woody material may increase. Fodder banks are generally harvested when the edible biomass represents 50-60% of

When the fodder bank is used as a grazing or browsing system, it should be within the pasture

the total new foliar biomass production, this does not include trunk biomass. The ideal cutting frequency varies between species, planting density and seasonal conditions. In wet conditions fodder banks may be cut every 3 to 4 months. Leucaena leucocephala is known for its tolerance of harvesting every 2-3 months. In high-density plantations, harvesting must be done more frequently as light completion between shoots causes them to elongate, which can kill the leaves in the lower layers of the crown. The more dead shoots and leaves in the fodder, the lower the nutritional quality.

In seasonal dry zones fodder trees and shrubs such as Gliricidia sepium, Leucaena leucocephala and Guazuma ulmifolia in high density fodder banks can produce 8-12 tons/hectare/year of dry edible material. 35-40% of the production is during the dry period. These species may be strategically pruned 2-3 months before the dry season so that they do not flower, but rather increase the edible shoots and foliage available during the dry season. Where there is a dry season longer than 4 months, as in Pacific Central America where it lasts from January to May, we recommend three harvests in the wet season (with the last one in December) and one harvest during the dry season for fast growing species such as Leucaena leucocephala. Slow growing species such as Brosimum alicastrum should be harvested every six months.

Cutting height. The cutting height determines the productivity of fodder banks and depends upon the species and the cutting frequency. The higher the cut the more shoots there are and the higher the productivity. In general fodder trees and shrubs are cut at 65-90cm above ground level to allow resprouting. Low cutting (<60cm above ground level) should be avoided as it reduces the food reserves of the tree. Trees may be cut lower down if they are cut at longer intervals (>90 days).

Fodder banks are generally harvested when the edible biomass represents 50-60% of the total new leaf biomass production, not including the trunk.

Isolated trees in agricultural fields

Pastures and agricultural fields in Central America normally have isolated trees. Farmers maintain these trees for their products and services (see Box 12) and because their management is inexpensive and easy. However, some species can become invasive or cause severe economic damage to production, as occurred with marabú (Dichrostachys cinerea) in Cuba. Sometimes these trees are remnants of the original forest and have been conserved in order to provide, for example, shade in the pasture or because they may provide timber in the future. Sometimes these trees are really living fossils, incapable of reproducing in the agricultural environment, and because of this it is necessary to convince farmers to plant trees that, little by little will replace these relicts. In other cases farmers plant trees, particularly fruit trees such as aliso or jaúl (Alnus acuminata), in the mountain pastures of Costa Rica and Guatemala. There are also many native and introduced species that naturally regenerate and maintain important populations in agricultural fields and pastures. Some grow from seeds carried by the wind, birds, livestock and other herbivores, while others resprout from stumps. Producers need to manage and protect these populations in a manner compatible with the other crops and grasses that they produce on the farm.

Which species to use

There are abundant examples of tree species found isolated on farms. Laurel (Cordia alliodora), madreado (Gliricidia sepium) and sipia (Leucaena salvadorensis) are found in the fields in the dry zone of the south of Honduras. Laurel grows in the areas of shifting vegetable production in the Turrialba region of Costa Rica, bitter cedar (Cedrela odorata) and pochote (Bombacopsis quinata) in the banana plantations on the Island of Ometepe in Lake Nicaragua, sweet cedar (Cedrela tonduzii) in potato fields and other vegetable fields in Pacayas, Costa Rica, black coal (Acacia pennatula) in the pastures in the dry, cold zone of Estelí, Nicaragua; and in the whole dry zone of the Pacific slope guanacaste (Enterolobium cyclocarpum) and genízaro (Samanea saman) are grown in pastures.

At the time that farmers clear a field they may choose to leave seedlings or stumps of some species that have value for timber production (Cordia alliodora, Swietenia spp.), posts (Gliricidia sepium and Lysiloma spp.), and other products. On the other hand Gliricidia sepium has been known to cause corn growing underneath to fail or be unhealthy, possibly due to an allelopathic effect. Another consideration is that some species, such as chaparro (Curatella americana) have particularly large, thick leaves that, when they fall, can crush the crops established below.

Often livestock managers leave genízaro (Samanea saman) and guanacaste (Enterolobium cyclocarpum) in their pastures. Both species have ample canopies that provide fruit during the dry season when there is little grass, and good shade for the animals. In some cases communities protect olive trees (Simarouba glauca) in the middle of their fields due to the utility of the fruits in home soap production. Sometimes trees such as nance (Byrsonima crassifolia) and mango are found in the middle of fields and pastures, products of random dispersal by animals and people, or because they represent the remnants of homegardens that have disappeared. In fields dedicated to the production of corn, rice, vegetables and other crops that require full sun, farmers prefer trees with small, tall and open canopies that allow in lateral sunlight. Timber trees with these characteristics include Cordia alliodora, Cedrela odorata, Colubrina spp., Gliricidia sepium, huasicucho (Centrolobium ochroxylum) and motacú (Scheelea princeps).

When to use them: advantages and disadvantages

12

Farmers allow trees on their property for a number of reasons, which may be put into two principal groups:

1. To acquire useful or valuable products (posts, timber, firewood, fodder or fruit)

2. To provide some benefit or service to the agricultural or livestock production, such as shade for the animals or moisture conservation in the soil.

Sometimes trees do not provide benefits, or may even be a disadvantage, but the farmer may not have the manual labour available to eliminate the trees, or the trees may not be such a problem that it is worth the effort to remove them. The balance between the advantages and disadvantages of the trees that the farmers perceive, and the disposition of the farmers to maintain and protect the trees, depends to a large extent on the natural conditions as well as the farmer's situation.

The proximity of markets for timber and firewood may motivate the producers to protect the isolated trees on their farms. In deforested areas the scarcity of firewood, posts and other wood products and non-timber forest products, encourages the farmers to maintain more isolated trees on their agricultural fields.

Soil moisture conservation is a key aspect of the Quezungual system practiced in the west of Honduras (see Chapter 2), in which trees are trimmed and the foliage used to cover the soil. However, this service is only important in areas with significant seasonal dry periods.

Advantages

- Useful or valuable products for subsistence or sale such as:
  - o Bole timber or saw wood
  - o Fencing posts
  - o Pillars, beams and other rural construction materials
  - o Firewood
  - o Fodder and other animal food products
  - o Green fertilizer or mulch
  - o Fruit or other food for human consumption
  - o Non-timber forest products (medicine, herbs, etc)
- Provision of service
- Shade and protection for animals
- Moisture conservation for crops and grass
- Soil enrichment
- Windbreaks
- Aesthetics
- Protection of water sources

Disadvantages

- Shade that may slow or impede the development of crops or grass
- Concentration of rainwater into streams on the leaves that fall and damage the crops below the tree
- Damage to the crops from large leaves falling on them
- Trees may attract lightning
- The usual problems with mixing trees and crops, as shown in Box 6.

Management of isolated trees in agricultural fields

Management has the following objectives: i) to assure the number of trees necessary to obtain the products and services desired without negatively affecting the production of the neighbouring plants and ii) to obtain more and better tree products and services. The principal management activities are:

- Selective protection of species with the desired characteristics at the time of converting a fallow area to agricultural production
- Restriction of agricultural activities that may damage the trees, such as the use of fire
- Progressive thinning of the remaining trees to achieve the ideal density and arrangement, and selection of the best individuals
- Pruning in order to reduce the shade over the crops and improve the timber quality
- Trimming to stimulate regrowth and the desired products such as foliage, shoots, mulch, posts, or firewood

Next we present a brief description and some examples of these management practices used in the management of isolated trees.

Establishment. The system of dispersed trees is not well disposed towards regeneration through planting. Planted seedlings represent a significant investment of time and resources. Because they are randomly distributed in the middle of pastures and cultivated land, the seedlings are vulnerable to damage by animals and agricultural activities, particularly weeding, and there is therefore a high risk of loosing the investment. Some farmers plant trees at random, such as the seed of Gliricidia sepium y Cordia alliodora. This system is inexpensive but requires abundant available seed and works best with large seeded species with easy germination and rapid initial growth. Many producers manage the resprouts from stumps such as Cordia alliodora and Eucalyptus spp., but in this case the use of fire to prepare agricultural areas or rejuvenate grasses may be a problem. Generally many resprouts come from a single stump and at the beginning it is preferable to leave all of them to see which grows most strongly. However, once it is evident which will be dominant, the straightest, best attached to the stump and closest to the soil, it is best to cut the others so that all of the resources are concentrated in the one shoot.

Many farmers avoid the use of fire or herbicides so that they do not damage the natural regeneration of the trees that may be useful. Others burn, but they do it by piling up the agricultural residues to burn them or by leaving unburned areas around the trees that they want to protect. The point to which that farmers modify their practices to favour the trees depends on whether the farmer has sufficient manual labour available to clear manually, or whether the benefits obtained from the trees are economically important.

If isolated trees were left in the field during the last cultivation cycle, the resulting population of trees may be a diverse mix of small and large trees.

Natural regeneration is the principal method of establishment for numerous species of isolated trees in agricultural fields. Some species such as saray (Eugenia guatemalensis) or muñeco (Cordia coloccoca) in coffee plantations near lake Apanás, Jinotega, Nicaragua or lengua de vaca (Conostegia xalapensis) in the pastures of Santa Cruz, Turrialba y Monteverde, Costa Rica, are bird dispersed. In this case it may be that the trees are only found growing in the shade of other trees, such as within windbreaks, where the birds perch under cover, avoiding open areas where they risk encountering predatory birds.

Other species such as Cordia alliodora, Cedrela odorata, macuelizo (Tabebuia rosea) or Bombacopsis quinata are wind dispersed. The seeds of these species are small, light, and have appendages that help to keep them airborne. They are produced in large quantities that allow them to explore nearly every available niche surrounding the parent tree. These species establish adequately in bare soil and are therefore common in vegetable and staple grain production areas. Populations of these species are maintained in agricultural fields because the season for seed dispersal coincides with the season for soil preparation for sowing annual crops in bare soil. Many seedlings germinate in the field s and the farmers select those individuals with the best form, growth and location in the field in appropriate densities to allow crop growth and production. Numerous species such as Samanea saman y Enterolobium cyclocarpum use cattle as seed dispersers and take advantage of the amenable conditions in the cattle manure to become firmly established in agricultural fields. Notorious examples, including extreme examples of trees becoming weeds, include black coal (Acacia pennatula) and guava (Psidium guajava).

Pollarding. Pollarding is the practice of cutting the tree crown, including the principal leader, resulting in the production of new growth. This practice is used to reduce shade, as is pruning, or to stimulate resprouts when they are useful, for example for edible foliage. Pollarding of some species, such as Gliricidia sepium and chayote (Sechium edule), produces numerous uniform and straight sprouts, characteristics particularly sought after for posts for live fences, and firewood for family consumption or sale. In the traditional agroforestry system "Quezungual" used in the west of Honduras (see Chapter 2), pollard products are used as a mulch (layer of vegetative material) that is spread to conserve water. The height of pollarding depends on the objective and the system within which it is being used. If the objective is only shade reduction, the most important thing is that the resprouts do not occur close to the level of the crops (at least 1 m high), so that lateral sunlight may reach the crops. If the resprouts are to be used for firewood, for examples, and animals are grazed in the area, it is necessary that the pollarding be done at such a height that the branches are not browsed. On the other hand, if the animals are to eat the shoots for summer fodder, the shoots must be at a height that the animals can reach.

Shade trees in plantations of perennial crops

The most common perennial crops in Central America, coffee and cocoa, are cultivated in the shade, with the exception of some coffee plantations managed on optimal sites or with intensive management and the application of agrochemicals. The productive potential of the canopy/shade layer is generally under-utilised, although this layer offers an excellent opportunity for diversification with commercial tree species.

Management of shade trees in plantations of perennial crops

Each shade species requires unique management because of:

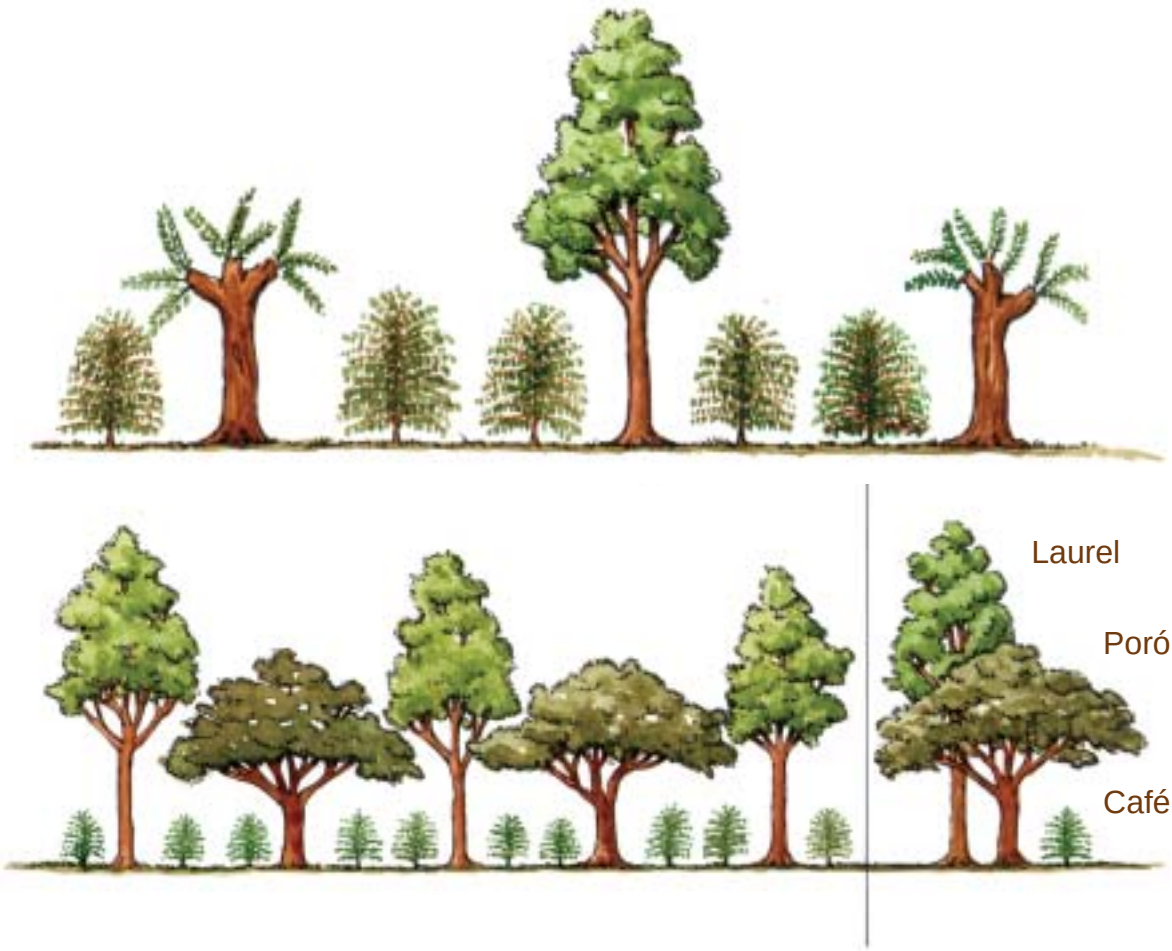
- the physiology of the crops and their microclimatic needs
- the phenology of the shade species
- the local soil and climate
- the growth characteristics of the shade species and their pruning tolerance
- the perception of the farmers of the different shade species and associated crops

As an example we consider the case of a plantation of cocoa with 1100 plants per ha, moderately fertile soil and good agronomic management that functions optimally with

- an average level of shade below 50% and
- 20% shade during the main flowering period of cocoa and during the months with the most cloud cover and relative humidity. Humidity favours the development of a fungal disease that attacks cocoa.

These optimal shade conditions can be obtained with shade canopies of different designs. For example, with a monospecific canopy of Inga edulis or with a stratified canopy of planted Erythrina poeppigiana and naturally regenerated Cordia alliodora. If the design of the canopy is different, the management of the species should be as well in order to obtain the desired shade pattern. We can prune Erythrina poeppigiana 2-3 times and Inga edulis only once per year. We can manipulate the density and patterns of planting of each species, or select timber species that drop their leaves during the months when cocoa needs the most light. We must avoid always imposing the same rhythm of pruning, as it may favour some species and affect others unfavourably. For timber trees, species selection (crown shape, foliage density, phenology, etc) and management (initial spacing, plantation arrangement, thinning) are vital in order to maintain acceptable levels of shade for the perennial crops.

Coffee plantations with different shape and phenology of trees: a) narrow or open crowns; b) mixed crowns.



Thinning

The thinning design for shade tree in plantations of perennial crops is one of the critical aspects of the system and must take into consideration the natural mortality of the species and respond to the following questions:

How many trees to thin? For timber trees the number to maintain can only be manipulated between strict margins, and the typical initial density (generally <300 trees per hectare) is near to the recommended final density for pure plantations of timber species. Cordia alliodora is planted at 150 to 200 trees/ha, Terminalia ivorensis at 80 to 100 trees/ha, and Tabebuia rosea is planted at 100 to 150 trees/ha. The light requirements of the crop depend on the site climate and fertility and the density and intensity of management of the crop. The number of trees will nearly always need to be reduced. We cannot recommend an optimal density for each timber species associated with perennial crops, but we can provide examples for Cordia alliodora, Tabebuia rosea and Terminalia ivorensis.

A study of different densities of Cordia alliodora as a shade tree for coffee found that the final density should not be above 100 trees per hectare. As a guideline we suggest the following final densities for timber trees above cocoa:

- 50-60 trees/ha for Terminalia ivorensis
- 100-120 trees/ha for Tabebuia rosea
- 120-140 trees/ha for Cordia alliodora

These densities are based on the following criteria:

- Due to the crown width of Terminalia ivorensis, and the dense foliage of both Tabebuia

rosea and Terminalia ivorensis, they produce more shade than Cordia alliodora, with its narrow crown. It is therefore necessary to thin Terminalia ivorensis y Tabebuia rosea more intensely.

- The notorious problems of dieback with Terminalia ivorensis and the virtually non-existent mortality problems of Tabebuia rosea, mean that Terminalia ivorensis should be more conservatively thinned than Tabebuia rosea.

- Mature cocoa plants require less than 50% shade

When to thin? Farmers are afraid to damage the cocoa or coffee during the harvest of the shade trees, and do not like to thin smaller trees as they are not commercially valuable. For these reasons it is best to thin early and quickly to reach the ideal density of timber trees.

Which trees to eliminate. Among timber trees the first to eliminate are those with poor form, disease, and poor growth. This is known as selective thinning. Good trees are only thinned to improve spacing and shading for the crops. Service trees such as Erythrina poeppigiana and Inga spp, on the other hand, may be thinned systematically, i.e. the middle tree or middle line of trees may be removed irrespective of tree form because the only objective is to maintain uniform shade. Service trees may be thinned by ring-barking or poisoning them. However, it is recommended that the thinning is done with a chainsaw and the continued elimination of resprouts from the trunk, to avoid damage to the cocoa and risks for people when the dead branches fall from standing dead trees, and the toxicity of many herbicides that may be used on trees. The thinning and harvesting of timber trees can damage the associated perennial crops, however, with good planning the majority of this damage can be avoided (Box 13).

13 How to reduce damage to perennial crops during thinning and harvesting of timber trees used for shade

- Cut the trees during years when the perennial crop is earning low prices so that the economic consequences of any damage are reduced. During these years the extra income from the timber is also more useful!

- Choose the sites, such as boundaries, where the timber trees will be established, with an eye towards the possibilities for places to fell the trees where they will not damage crops, such as roads or unplanted areas. Extraction costs are also reduced in these areas.

- Cut the trees immediately after the principal harvest of coffee or cocoa, and before the annual pruning of the perennial crop, so that the pruning of the perennial crop may be used to repair any damage caused during the timber felling and extraction.

- Choose timber species with small canopies and little branching. The crown, not the trunk of the tree, causes the majority of damage to crops. Fell deciduous species after leaf-fall when the crown is lighter.

- Remove the branches from the tree with a machete before felling the tree.

- To reduce the damage to crops during tree felling, the tree to be cut, especially with timber species, may be tied or attached to the immediate neighbours.

- On sloped land, common in coffee plantations, fell the trees upslope so that they fall with less force onto the crop.

- Plant or leave naturally regenerated trees between the lines of the crops. The trees may then be felled between (and along) the lines of crops, rather than across them

We recommend for consultation

Below we present a list of resources that we recommend to provide a deeper understanding of the topics covered in this chapter.

We would also like to mention in the sources used, the work of other authors from whom we have taken some of the ideas expressed here.

We recommend

- Kapp, G. B., Kremkau, K. & Dixon, F. 1991 Manejo sostenido de bosquetes en fincas privadas de los tropicos húmedos El Chasqui 26:5-25
- Beer, JW. 1987. Advantages, disadvantages and desirable characteristics of shade trees for coffee, cocoa and tea. Agroforestry systems 5: 3-13.
- Budowski, G. 1986. Características críticas de árboles en sistemas agroforestales. Turrialba, Costa Rica. CATIE. 7 pp.
- Geilfus, F. 1994. El árbol al servicio del agricultor. Manual de agroforestería para el desarrollo rural. V 1. Principios y técnicas. ENDA CARIBE - CATIE. Turrialba, Costa Rica. 337 pp.
- Jiménez, F; Vargas, A.. 1998. Apuntes de clase del curso coto: sistemas agroforestales. Turrialba, Costa Rica. CATIE/GTZ. 360 pp. (Serie Técnica. Manual Técnico/CATIE; No. 32).
- Lok, R. 1998. Introducción a los huertos caseros tradicionales tropoicales. Módulos de enseñanza agroforestal N° 3. CATIE/GTZ. Turrialba, Costa Rica. 157 pp.
- Méndez, E; Beer, J; Faustino, J; Otárola, A. Plantación de árboles en línea. Módulos de enseñanza agroforestal N° 1. CATIE/GTZ. Turrialba, Costa Rica. 134 pp.
- Muschler, RG. 2000. Árboles en cafetales. Módulos de enseñanza agroforestal N° 5. CATIE/GTZ. Turrialba, Costa Rica. 139 pp.
- Pezo, D; Ibrahim, M. 1999. Sistemas silvopastoriles. Módulos de enseñanza agroforestal N° 2. CATIE/GTZ. Turrialba, Costa Rica. 275 pp.
- Schlönvoigt, A. 1998. Sistemas taungya. Módulos de enseñanza agroforestal N° 4. CATIE/GTZ. Turrialba, Costa Rica. 117 pp.