8

FROM PRINCIPLES TO PRACTICE: KEY SYSTEMS

8

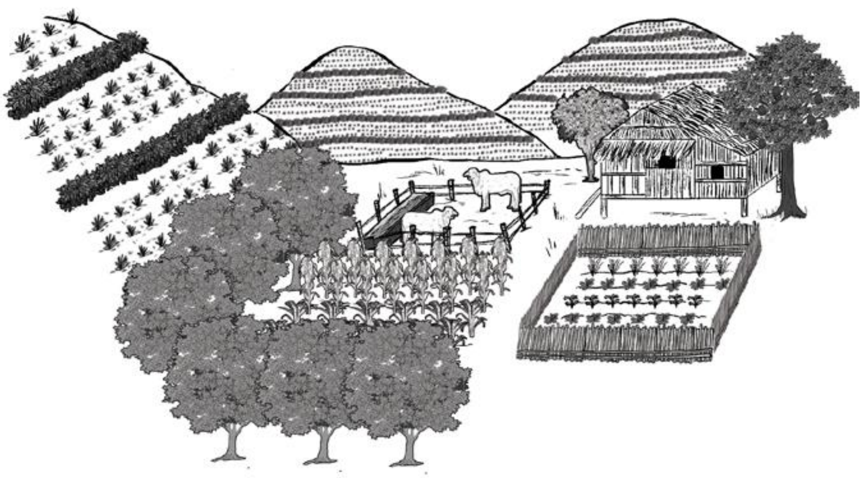
When applying the three principles of agroforestry design (farmer-centredness; aptness to place, people and purpose; and synergy), it is important to recognize that each landscape is unique and should therefore have its own unique agroforestry systems. Trees in these systems can have very different functions, ranging from being flotilla species in systems that focus on food production, to being the flagship species in systems that are designed to restore degraded forested landscapes.

This chapter describes a small selection of featured systems to illustrate the different functions of trees and the resulting design and management implications. The featured systems should not be read as blueprints for direct application, but as examples of common and robust systems that might be used in specific locations after appropriate modifications.

Annual crops with trees (ACT)

In these systems, a tree component provides ecosystem services that increase the productivity of the flagship component, an annual crop. The selected tree species often also provide useful products. Because annual crops are usually sun-loving, the design and management of these systems seek to increase the numbers of trees on the farm without creating competition for light.

ACT systems follow two main approaches. In intercropping, trees are planted among the crops. In niche planting, the trees are planted in 'niche' locations, such as farm boundaries, places with low soil fertility, riparian sections and home compounds. Niche planting is often preferred when cropping areas are very small, or when the work needed to manage competition would be out of proportion to the benefits gained from the trees.



ACT systems are most appropriate for farms that have low productivity, particularly when caused by the following factors:

- low soil fertility
- vulnerable soils – whether due to low organic matter or high risk of erosion
- climates in which prolonged drought or irregular rainy seasons are common.

Trees help to counteract these causes of low productivity by increasing soil fertility, keeping moisture in the soil for longer periods, and preventing soil erosion (see Chapter 3, **Agroforestry systems as circular systems**). These pros need to be weighed against the following cons:

- loss of physical space for the flagship species (because trees will occupy space where crops could be)
- reduction of crop yield due to shading
- in semi-arid regions, potential water competition between trees and crops.

Design guidelines

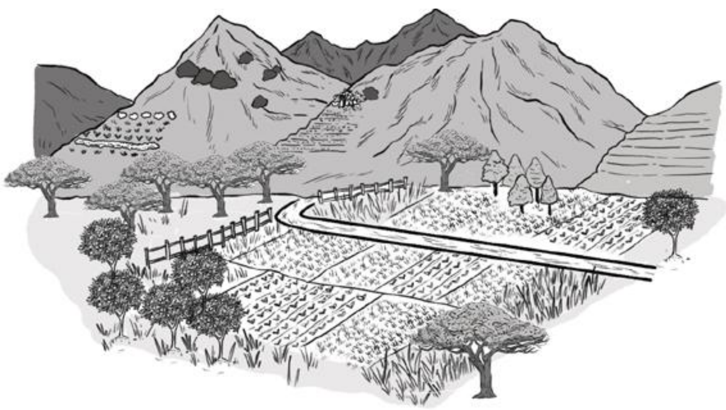
ACT systems are often introduced to farmers as part of agroforestry programmes that aim to restore or improve soil fertility, increase farm productivity, and boost household income and well-being. ACT systems are very variable and context specific. Institutions and individuals supporting farmers should work with them, following guidelines such as those outlined in Chapter 5, **Co-design and establishment of agroforestry systems**. This will ensure that the system is aligned with the farmer's goals and their household's needs.

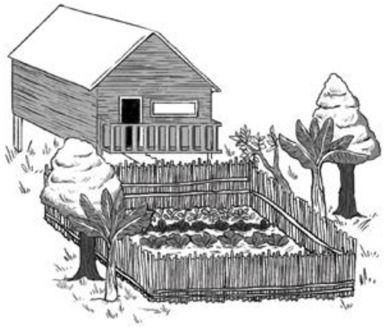
The benefits of tree flotilla species to the farm, crop and farmer will be highest if the following rules are followed:

- select the right tree for the farmer
- select the right place for the tree
- select the right type of tree for the system, considering growth rate, crown type and root systems.

On sloping land, trees should be planted along contour lines to stabilize the slopes and prevent the soil from eroding. Tall trees and shrubs mixed with grasses can be a good combination, because these each bind a different layer of soil. Having species of different heights also reduces shade. Where erosion is already a problem, trees should be planted at close spacing so that as much as possible of the area benefits from the soil-binding effect of their roots. Later, the trees can be thinned to manage the canopy size and shade.

On flat areas, especially small fields, trees are usually scattered in with crops. This allows the crops to directly benefit from the trees – particularly nitrogen-fixing species – without receiving too much shade.





Planting niches should be identified with the farmer and other household members, making sure that the practical aspects of management are considered. For example, fodder trees should be close to livestock pens. Fruit trees should be planted close to the house, both for ease of harvest and for security reasons – the same applies to other high-value species.

Livestock are an essential part of some ACT systems because their manure serves as organic fertilizer. On steep slopes, zero-grazing strategies are more appropriate, as they prevent livestock from damaging both the soil and the system.

The components (crops, trees, livestock) and how they are best arranged differ from farm to farm, but we list some general guidelines below:

- Trees are usually less demanding of nutrients than are crops. It is generally desirable that trees growing with crops should have deep roots, with fewer roots near the soil surface where most crop roots are found.
- Competition effects can be reduced by watering, fertilizing and mulching at competition zones.
- Farmers can correct excessive shade by pruning or thinning the trees responsible.
- To minimize shading effects, tree rows should be planted parallel to the path of the sun.
- Some tree species naturally produce less shade. Such trees may have small leaves, have leaves that tend to go upwards rather than outwards, or be bare or partly bare (the latter trait is particularly useful if it coincides with the cropping season).

- The chosen species should have deep roots, grow quickly, preferably fix nitrogen, and have a light crown that allows sunlight to pass through easily.
- Highly productive, fast-growing types of trees such as eucalypts and acacias use a lot of water, and they can reduce water availability for other components in a system. These kinds of trees can best be used on farm as a block or woodlot.
- High-yielding perennials that need a lot of light, such as oil palm, are not suitable to be grown under trees, but they make excellent shade trees for smaller plants such as cacao and coffee (see **Multistrata cacao agroforestry systems in Central America and the Philippines** in this chapter).
- In semi-arid areas, termites can cause serious damage to seedlings and mature trees, so mitigation measures like selecting termite-resistant species and employing protection strategies are very important. Strategies include removing dead and damaged wood from trees quickly after damage, mulching to provide alternative food sources, and careful management of the tree (especially when it is young) to keep it healthy and able to resist termites. Pesticides can be used, but they tend to kill natural enemies, and are most effective when used to kill termite colonies rather than to protect individual trees, which is undesirable. Several botanical extracts can be used to control termites.[8]

[8] For more information on controlling termites in agroforestry, see Nkunika P, Sileshi G, Nyejeo P, Ahmed BM 2013. *Termite management in tropical agroforestry*. Lusaka: University of Zambia Press. http://dspace.unza.zm/handle/123456789/6496.

Management guidelines

Many farmers deliberately maintain mature trees in their fields and/or protect naturally occurring seedlings so that they grow into mature trees (a technique known as 'farmer-managed natural regeneration'). However, farmers usually have little experience of managing trees that have been reintroduced into landscapes dominated by annual crops. Unlike farmers who specialize in tree crops such as fruit species, coffee or cacao, or that have timber plantations, they may be unfamiliar with tree growth in height, girth and roots over time, and may not have been trained in how to maximize growth or productivity.

The following points are often key elements of successful management:

- The most important activity in managing ACT systems is the management of the trees' crowns to minimize shading of sun-loving annual crops.

- Several factors affect the amount of time it takes before trees begin to interfere with crop growth, including soil fertility, climate, crown shape, root types and the shade tolerance of the crops in question. Farmers need to be trained to understand how the various elements of an agroforestry system respond to tree pruning and thinning (see Chapter 7, **Management of trees in agroforestry systems**).

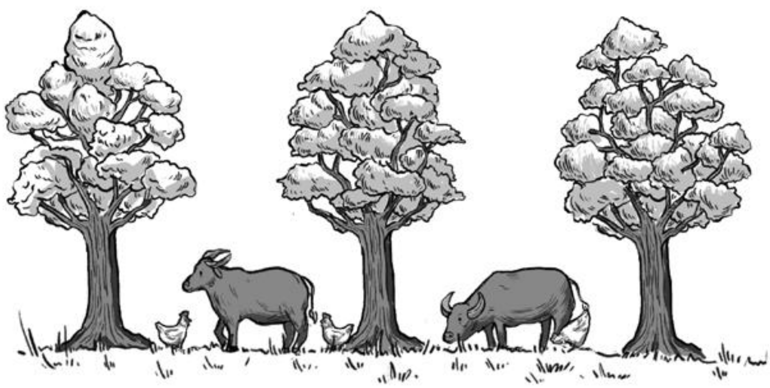
- Warning signs of light competition include yellowing of the crop leaves – which suggests low photosynthesis and chlorophyll levels – and, in cereal crops, stunting and thinness. Trees that are grown too close together usually respond by putting all their energy into height growth, rather than growth in diameter.

- Pruning, coppicing and pollarding are important in reducing competition. They also provide useful products such as firewood, mulch, green manure, fodder and stakes for climbing plants.

Livestock with trees

Description of the system

We are focusing here specifically on livestock in mixed farming systems. For the integration of trees in intensive cattle ranging systems, see Box 7. As an integrated part of the agroforestry system, livestock offer opportunities for increased profitability, risk reduction through diversification, better human nutrition, improved land use and higher agroecological efficiency. Trees are planted to provide ecosystem services to the livestock; however, they also introduce some environmental and health risks that must be mitigated by informed and careful management.



Box 7. The untapped potential of living fences

An important use of linear planting of trees is as live fences to control livestock. Fencing is very expensive, but live fences are cheaper to establish than their dead post counterparts. Live fencing is widely practiced on ranches around the world, including in Honduras and Nicaragua, where the system has recently been studied in depth.[9]

Fencing prevents animals from straying and allows land to be divided into grazing blocks for rotational grazing. Large-scale cattle producers generally have low tolerance of trees in open pasture, and in Honduras they usually remove them when canopy cover reaches 20%. However, they actively plant trees around field boundaries.

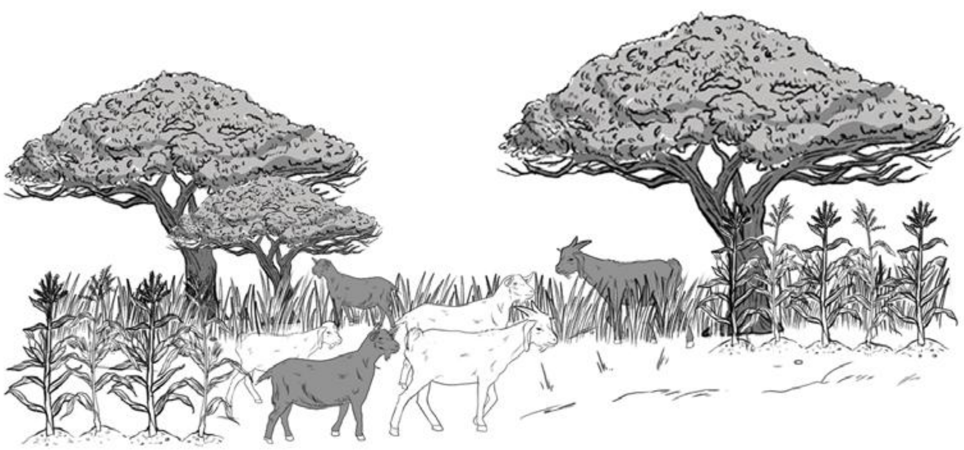
Live fences are very productive. An inventory of cattle ranches across 25,000 hectares in Catacamas municipality, Honduras, identified more than 10,000 fence segments spanning 1,730 kilometres, with a linear density of almost 70 metres per hectare, covering 6.4% of the land. The potential for timber production from live fences in the 2.9 million hectares of pasture in Honduras was estimated to be equivalent to 200,709 hectares of conventional timber plantations, given that one kilometre of live fence is equivalent to the yield of one hectare of plantation.

[9] Somarriba E and Quesada F. 2009. *Agroforestry farm planning: manual for farming families*. 1st Edition. Costa Rica: CATIE.
Somarriba E, Orozco-Aguilar L, Cerda R, López-Sampson A. 2018. Analysis and design of the shade canopy of cocoa-based agroforestry systems. *In* Umaharan P. ed. *Achieving sustainable cultivation of cocoa*. London: Burleigh Dodds Science Publishing, 1–31. https://doi.org/10.1201/9781351114547.

Livestock, especially browsers like goats, can cause serious damage to crops and trees if not controlled. In sloping landscapes, free-grazing livestock can seriously affect soil stability, and thereby undermine the sustainability of the entire farm.

Zero-grazing systems, as opposed to free grazing, are those in which livestock are not free to roam the farm to access grazing, browsing or other feed resources. Usually, this means that animals are housed in buildings or pens, to which their feed is carried. The system is particularly appropriate for smallholder farmers that own livestock but have limited lands and income. Livestock are often kept on small farms to provide food for the farming household and income from milk, eggs or meat. The animals that are kept are usually cows, sheep, goats, pigs, rabbits, and, in some places, guinea pigs.

Although small-scale farmers often tether animals where feed can be found, such as along farm boundaries, on roadsides or in other accessible land, the limited space available on farm usually leads to animals being kept under a 'zero grazing' regime. Trees and shrubs in the system are selected to provide high protein alternatives to add to the basic crop-residue animal feed. This improves the condition of the livestock and avoids using all the available crop residues – some of which should be left on the field as mulch and for soil erosion control – or buying costly commercial feed supplements.



Zero grazing offers farmers several advantages. It can improve livestock management or make it easier, in the following ways:

- It can allow livestock to be kept on farms that would otherwise be too small.
- Because zero-grazed animals are usually kept close to the homestead, household members can more easily manage them as part of their general activities.
- Farmers are more likely to notice pests and diseases.
- More accurate management of the nutrition of individual animals is possible, by feeding them controlled amounts of different foods. This can improve feed use and is an important first step towards market orientation (for example, engagement in the small-scale dairy sector).

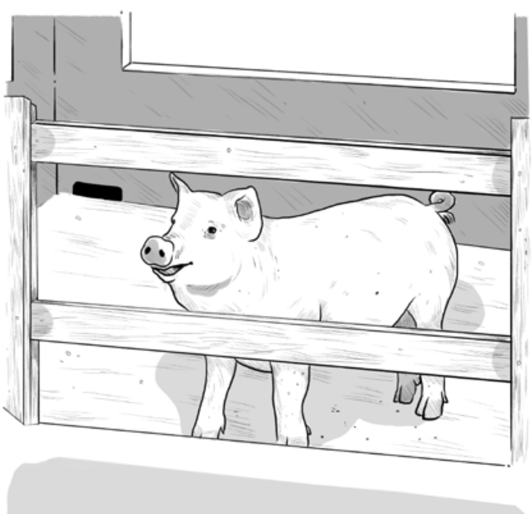
It also offers advantages in overall farm management and other important aspects:

- Manure is easily collected and recycled to crop fields, increasing resource-use efficiency across the whole system. Animal manure is rich in nitrogen and is a particularly important source of phosphorus.

- Confinement of the livestock prevents adverse effects on soil and natural vegetation, and damage to the crops of farmers and their neighbours is also minimized.
- Housed animals are less vulnerable to theft and predation.

Zero-grazing systems also have some potential disadvantages. They are labour intensive, and availability of labour may limit the number of animals that can be kept. Furthermore, buildings and equipment cost money. The investments needed may be recouped by greater future profits, but nevertheless may be unacceptable to more risk-averse farmers. Although the monetary costs may be reduced by using local materials and building methods, they will rarely be zero.

Zero grazing can also have adverse effects on the health of animals and their keepers. For the farming family, close contact with livestock brings an increased risk of zoonotic disease. The livestock, too, are at greater risk of disease and transfer of parasites. For the animals, however, the effects on health and welfare can be more far reaching. Unfortunately, zero-grazed animals are often kept in inhumane conditions, with inadequate space, lack of bedding and insufficient shelter from the weather. Confinement is not healthy for any animal, and a lack of exercise can lead to long-term discomfort and psychological impacts. Where possible, steps should be taken to minimize these animal welfare problems. Those supporting and advising farmers can contribute to this by pointing out the advantages of avoiding adverse effects like foot damage, joint damage, skin damage, increased aggression, other behavioural changes and poor reproductive performance. All of these are distressing to the animal and result in reduced longevity and lower productivity.

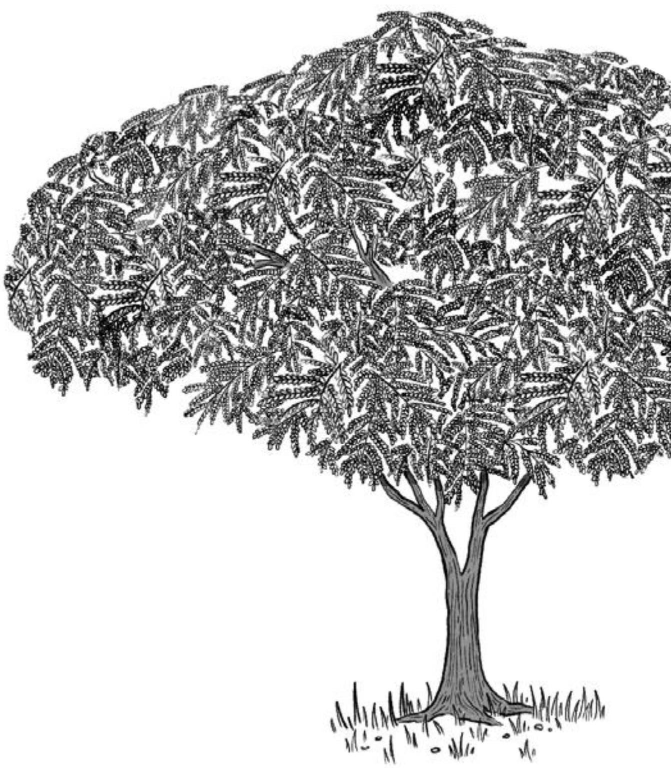


Design guidelines

Fodder tree production

Fodder for zero-grazed animals is often provided in the form of grasses, fodder legumes, and branches cut from shrubs and trees. There are many ways to include fodder trees for zero-grazed livestock in agroforestry systems, such as in ACT systems or as living fences. Good candidate species produce large amounts of high-quality, palatable fodder; grow relatively fast; remain productive during the dry season when fodder grass is scarcer; and tolerate frequent coppicing or pollarding. Species that are going to be planted with the main food crops should have small, sparse crowns (to reduce shade) and roots deeper than those of the crop (to reduce competition for nutrients and water). Some leguminous species offer the additional benefit of improving soil fertility by fixing nitrogen.

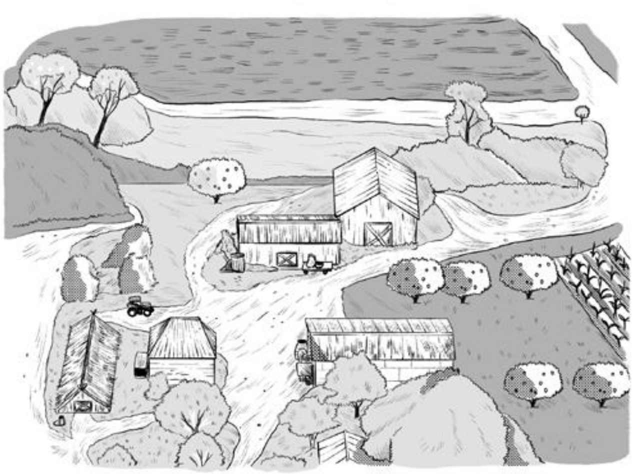
On sloping fields, as in the aforementioned ACT systems, trees and shrubs should be planted along contour lines to prevent soil erosion. In locations such as field boundaries, riparian stretches and small vacant plots, trees and shrubs can be grown more densely in fodder banks, which are permanent plots that maximize foliage production. Associated grass species should be fast growing; highly productive; well adapted to frequent cutting or defoliation; able to provide good soil cover; palatable to livestock; high in nutritional value; and either easy to conserve as hay or silage, or able to stay green in the dry season.



Livestock type

Any type of livestock species or breed may be kept under a zero-grazing system. However, zero grazing requires relatively high capital investment and ongoing managerial and material inputs. Therefore, farmers are more likely to use the system for animals that generate substantial returns, such as dairy cows or sheep reared for meat that will be marketed. Eggs, which can be produced in large numbers from improved hen breeds, often have ready demand and can command a high price. On the other hand, the ease and efficiency of feeding small livestock, such as rabbits, can make them an attractive simple option, both for the family diet and for sale.

Investment in improved breeds (such as crossbred dairy animals or specialized sheep breeds) allows farmers to make the most of the opportunities for higher incomes that zero grazing offers. However, these animals do not automatically produce more: they require much improved feed management (see below) to reach their potential, as well as careful attention to their health and well-being.



Location

The siting of a zero-grazing unit will be influenced by several factors, which need to be balanced. Closeness to the homestead makes monitoring of animals simple, but if many animals are kept, and feed and water sources are not close, the labour needed may be beyond the capacity of the farming family. Other considerations include road access, electric power and availability of local building materials. Each farmer needs to consider their own situation with respect to location and try to identify the most appropriate compromise.

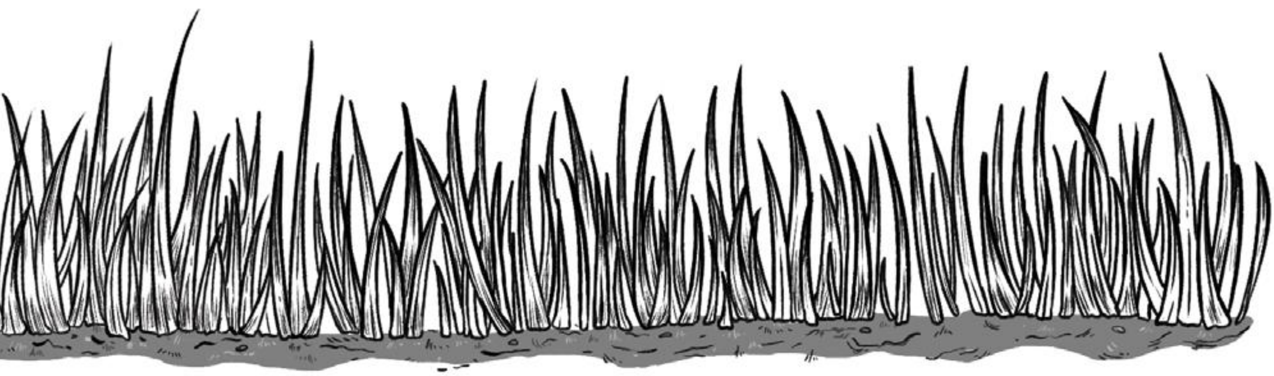
Housing and associated infrastructure

A variety of housing designs can be used for zero-grazing livestock, depending on the farmer's wider objectives. For example, slatted floors can greatly improve manure recycling efficiency, if this is an important consideration. However, slatted housing for large ruminants must be extremely robust, and is therefore relatively expensive to construct. The importance of well-designed equipment, such as feed troughs, should not be underestimated. Inadequate feeders can cause wastage of up to 30 percent of offered feed, and this wastage will reduce profitability.

Management guidelines

Tree and shrub management

Effective management for animal feed of trees, shrubs and other fodder plants can be quite complex: it requires experience and access to good, reliable information – for example from extension services. Indonesia's three-strata forage zero-grazing system, developed for dry areas, is a good example. It combines fodder plants, grasses, ground legumes, fodder shrubs and fodder trees. Its components have differing life cycles or growth patterns, so high-quality fodder is available all year round. Grass and ground legumes are harvested during the wet season, shrub legumes during the dry season, and fodder trees during the late dry season when little else grows.[10] In Rwanda, fodder banks are less complex, as farmers prefer to plant leguminous shrubs such as calliandra with the crops to support soil fertility. Fodder banks are usually designed and planted around a main fodder grass, such as Napier grass, but in rotation with other grass species that are used for other purposes. They are also grown in permanent positions on land not used for cropping, for example along rivers.



[10] For an example of planting for year-round fodder see Nitin IM, Lana K, Sukanten W, Suarna M, Putra S. 1989. The concept and development of three-strata forage systems. *In* Proceedings of the IDRC workshop Shrubs and Tree Fodders for Farm Animals, Denpasar, Indonesia, 24–29 July 1989. 92–102 https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/18656/IDL-18656.pdf.

Feed management

Decisions regarding the appropriate feeding of livestock always involve a compromise between production objectives (which can be multiple and conflicting) and the range and quantities of feeds that can be made available. Some cut-and-carry systems operate efficiently on feed resources that are collected locally from common land (such as roadside grasses), while others may be wholly dependent on planted forages and other feed or food-feed[11] crops. Trees and shrubs, particularly legumes, provide high-quality, nitrogen-rich feed to complement crop residues.

Manure collection and handling

Zero grazing offers an important opportunity for farmers to make more effective use of the manure produced by their animals. In some cases, it may be used as fuel, but recycling nutrients by applying it to croplands is also a very widespread practice. In addition to improving resource use efficiency through the system, manure recycling can deliver direct financial benefits by reducing expenditure on purchased fertilizer. Direct application to crops should be avoided. Farmers need knowledge on good composting practice to maximize the value of manure.

Watering

Watering is often overlooked, but is of critical importance for housed livestock, which are unable to find water for themselves. Water requirements have been discussed in the livestock section under the High needs for care and maintenance subsection. Common sense is also helpful: if a farmer expects a dairy cow to produce 20 litres of milk each day, but only offers her 10 litres of water, disappointment is going to be the only outcome!

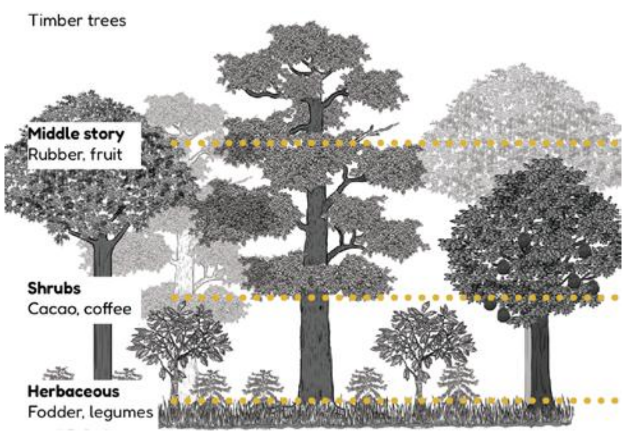
[11] Food-feed crops are those consumed by both people (food) and animals (feed).

Multistrata perennial agroforestry

Description of the system

Multistrata perennial agroforestry systems are the most complex of all kinds of agroforestry. They include both simultaneous and successional systems. In a simultaneous system, the same species, with their horizontal and vertical arrangements, are maintained for the system's entire productive lifetime. In a successional system, species composition and structure change over time.

Both systems take advantage of species' differing needs for water, light and nutrients. Simultaneous systems deliberately combine species that reach different heights, dividing into different layers the vertical space between soil and sun. Plants and trees are selected in such a way that, at any given moment, each species or group of species ideally occupies a specific layer based on its relative height and its need for sunlight (see Chapter 7, **Management of trees in agroforestry systems**). However, as tree height



changes over time, management is needed to maintain the different layers. In successional systems, this resource-sharing strategy is taken further by planting species with different life cycles. Over time, the species succeed each other; plants with shorter lives develop alongside longer-lived ones. When they are pruned or complete their life cycle, they leave a beneficial legacy: organic matter in the soil, and the results of their interactions with other plant, animal and microbial species. These improve the soil's structure, fertility and moisture content.

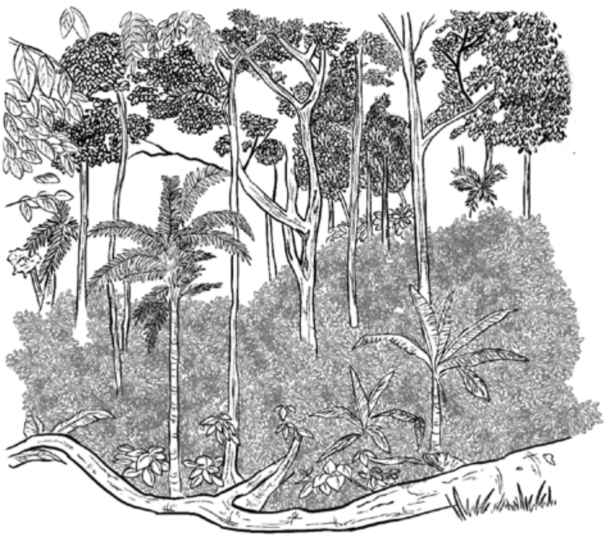
Multistrata systems vary greatly in their design and species composition, depending on the region and the type of farming community. However, they are usually designed around one flagship crop that represents the main production objective for the farmer or the farming community. Often, the production objectives change over time as different products become available, as different components of the system mature, and as market conditions and product values change. Because of the high investment required in labour and planning, it is essential that the farmer is closely involved in design and planning. Only farming communities that fully understand the time and commitment needed to manage these systems will be successful in reaping their benefits.

Design of multistrata systems entails optimization of the use of space by arranging plants in space and time, thereby ensuring maximum productivity of the flagship crop through careful management of the density of the different layers. Well-designed multistrata systems take advantage of existing seed stocks by supporting the natural regeneration of native tree species, while deliberately adding new components with important livelihood potential, such as fruit trees or commodities like oil palm and rubber.

Design guidelines

A carefully designed canopy structure is required to optimize the use of horizontal and vertical space. This is done based on the productive life cycles and heights of different species.

In hilly terrain, trees should be planted following contour lines, to minimize soil erosion.



The system is initially designed around optimization of the productivity of the flagship species (which varies from place to place), with flotilla species chosen to maximize synergies. This requires detailed knowledge of the flagship's physiological needs and productive stages.

Trees that produce a lot of foliage, and nitrogen-fixing species, enhance nutrient circulation in the system. In successional systems, these functional groups of species should be represented in each stage of the succession to reduce dependency on commercial fertilizers. The life cycles and productivity ranges of the different species should be mapped out to time the planting of the successional stages. This avoids productivity gaps and cash flow shortages. It is important to avoid production gaps between the end of one succession's lifespan and the productive period of the next.

Components need to be managed continuously throughout the productive cycle of the system to regulate their population density, minimize competition, and enhance complementarity. Farmers need to be aware that managing such a system is a full-time job. It is very demanding in terms of labour requirements at all stages (planning, planting and management). These demands need to be compatible with labour availability and the farmer's knowledge, experience, learning capacity and aspirations.

Livestock can be included in the system, but plant species then need to be protected from damage and overgrazing. In uplands with steep slopes, zero-grazing strategies are more appropriate, as they prevent livestock damage to both the land and the system.

Management guidelines

The basic principle for managing multistrata systems is to manipulate the species composition and the spatial and temporal structure to provide the right amount of shade at the right time for the plants in the system. This requires detailed knowledge of the phenology of each species – that is, about the timing of leaf loss, production of new leaves and shoots, flowering and fruiting.

Light triggers plant growth and, therefore, extraction of nutrients from the soil. In low-fertility sites, and if fertilizer has not been added, excess light will stress the plant, leading to poor growth and low yield. Signs of stress include discoloration or death of leaves, and general weakness; highly stressed plants can die. Farmers can achieve maximum production for a given level of soil fertility by managing light penetration.

To assess whether the shading of the system is optimal, extension workers can follow an easy, three-step procedure:

1. Assess the exposure to sunlight of the system at different times of the day. Even on the same farm, different areas can receive very different amounts of sunlight, depending on their position in the landscape.

2. Walk through the system at different times of the day and observe the light penetration on the ground. This will tell you whether the system is too dense and if it requires thinning or pruning.

3. Discuss with the farmer the level of productivity that they can manage. How fertile is the soil? Can they afford to buy and apply additional fertilizer? Based on the available sunshine hours, decide on an optimal shade regime to achieve that productivity level.

Using the assessments made in the above three steps, work with the farmer to develop an optimal monthly routine for managing the canopy and stock density.

Multistrata cacao agroforestry systems in Central America and the Philippines

Description of the system

Cacao was first cultivated as a shade crop under the canopies of native trees. In many countries, however, the availability of full-sun varieties, coupled with pressure to increase production, eventually led to replacement of these systems. Yield in unshaded systems can be five times greater than in shaded systems, but they also demand a lot of nutrients, leading to soil exhaustion. As a result, cacao farmers tend to open new fields when establishing plantations, often leading to deforestation.

Because of its shade tolerance, cacao is one of the crops most suited to agroforestry systems, especially for farming families who prefer diversified income streams to reliance on one crop. There is also renewed interest among large chocolate producers in agroforestry, because climate change is beginning to affect plantations in traditional cacao growing areas. Cacao plants are highly sensitive to variation in climate, particularly temperature, but also changes in rainfall and in the number of hours of sunlight. Concern is also growing over deforestation caused by cacao expansion.

The diversity, botanical composition and structural complexity of cacao agroforestry systems varies widely between geographical regions, between farms within a region, and even between sections within a plantation. Across regions, design and management are often deficient, leading to suboptimal shade (excessive, deficient or uneven).

Design guidelines

In this multistrata system, cacao is grown as an understorey of the canopy and emergent layers (Figure 6). In a well-managed system, ground-cover crops such as forage legumes and grasses can also be grown beneath the cacao.

The layers optimize the use of light, water, nutrients and space. The emergent and canopy layers maximize light utilization and provide shade to the cacao trees, which absorb both direct and diffused light.

Below ground, the range in root depth allows the system to exploit more water and nutrients, and protects the soil against erosion and landslides. Deep rooted trees bring up nutrients such as nitrate, phosphate and organic acids from deep in the soil, and make these available to shallow-rooted trees, including cacao, through their litter.

Management guidelines

To ensure maximum health and productivity of the plants, shade levels must be carefully planned, monitored and managed over the lifetime of a shade cacao system.

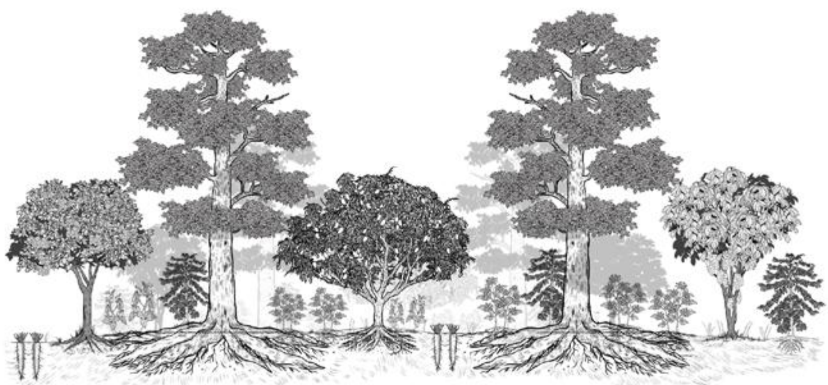
Inappropriate shade levels have dramatic effects. Under-shaded trees will show stunting, signs of water stress, scalded leaves and stems, flower cushions damaged by scalding, fewer leaves and low yield. Over-shaded trees will also show stunted growth, together with elongated stems and leaves, low flowering rates, fewer pods, higher incidence of disease (including *Phytopthora*, cherelle rot, pod rot and swollen-shoot virus), and higher incidence of pests such as pod borers.

The amount of shade required in a particular plantation depends on the degree of self shading, phenological stage, site conditions and canopy characteristics, as explained below.

Self shading
In the crown of a cacao tree, upper leaves and branches cast shade on lower leaves, while neighbouring cacao trees cast shade on each other. Both are examples of self shading. If self shading is high, then less overstorey shade is needed. If this happens, fewer shade trees will be required and the farmer loses the option of producing additional goods (timber, fruit, etc.) and services (cultural, environmental) in the cacao plot.

Self shading is determined by factors related to the form and size of the cacao tree, and to planting configurations and spacings, alone and in combination. Important ones include:

- age of cacao plants (young plants have small crowns, hence low self shading – overstorey shade is needed)
- pruning frequency and intensity (infrequent and light pruning results in tall cacao trees, crown overlap between neighbouring cacao trees and high self shading)
- whether the trees are grafted or grown from seed (grafted cacao trees tend to be shorter and more open crowned than trees grown from seed, resulting in less self shading if the plantation is well managed)
- tree spacing (triangular planting arrangements allow more cacao trees per hectare than square or rectangular configurations. Self shading is higher in such 'packed' planting configurations).



Temporal dynamics

In addition to the changes in self shading that occur as cacao plants grow older and bigger, the light requirements of a cacao tree vary according to its annual cycle: light is particularly needed at the flowering and pod-filling stages. For optimal cacao performance, shade must be adjusted to the monthly rhythms of the cacao plant by timely pruning or pollarding of the shade trees.

Site conditions

Several site factors influence the amount of light reaching the cacao plot and the optimal level of shade required:

- the latitude, exposure and slope of the land determine the amount of sunlight reaching it
- high prevalence of cloud reduces sunlight
- the topography of the surrounding land and the height of the surrounding vegetation affect the degree of lateral shade cast on a plot
- soil fertility: in infertile soils, farmers can only grow low-shade cacao if they apply fertilizers. If they are unable to buy fertilizers, then more shade is needed, because it reduces sunlight and demand for soil nutrients
- rainfall: for each location, it is important to establish the annual rainfall below which the introduction of trees to unshaded cacao would result in poor crop performance due to competition for water
- altitude: cacao can be planted from 50–1,200 metres above sea level. The optimum elevation is around 400–800 metres. Above 500 metres, cacao requires less shade than at lower elevations
- temperature: the higher the temperature, the more shade is required, so cacao trees generally require more shade during the dry season. This has implications for pruning practice: shade trees should be pruned at the onset of the rainy season and allowed to regrow during the dry season to provide the required shade during this period.

Canopy characteristics
The shade cover should be similar in the different parts of a cacao plantation. In practice, however, many cacao plantations have patches with either too much shade or no shade at all. In part, this results from variation in the vertical and horizontal distribution of the canopy cover and its botanical composition. Tall trees cast less intense shade than short ones, and tree species differ both in the time of the year when they become leafless and in the duration of leafless periods.

Case studies

Cacao agroforestry in Central America
Several Indigenous Peoples of the Mesoamerican Biological Corridor, including the Chibchas and Mayas, cultivate shade cacao. These cacao plantations usually harbour between 125 and 145 tree species at densities of 85–166 trees per hectare. Most trees are planted (except in rustic cacao systems, which make use of thinned natural forest), although some are derived from natural regeneration. Shade trees are used for timber (*Cordia alliodora*, *Cedrela odorata*), fruit (*Musa* spp., citrus, avocado, coconut, peach palm, mango), and shade (*Inga* spp., gliricidia, leucaena). Tree canopies have three vertical strata (low <10 metres, medium 10–20 metres and high >20 metres), containing about 50%, 30% and 20% of total tree density, respectively.

In these systems, cacao is cultivated at 100–800 metres of elevation in small plots (1.2 hectares per farm). Cacao trees are typically spaced at 4 × 4 metres (625 plants per hectare) in most countries. They are usually produced using hybrid seed from either controlled pollination or from pods selected on local farms. Grafted cacao has been used only since around 2010 and is still scarce. Most farmers have two or more cacao plots per farm.

Five basic types of shade canopy are used in the region:

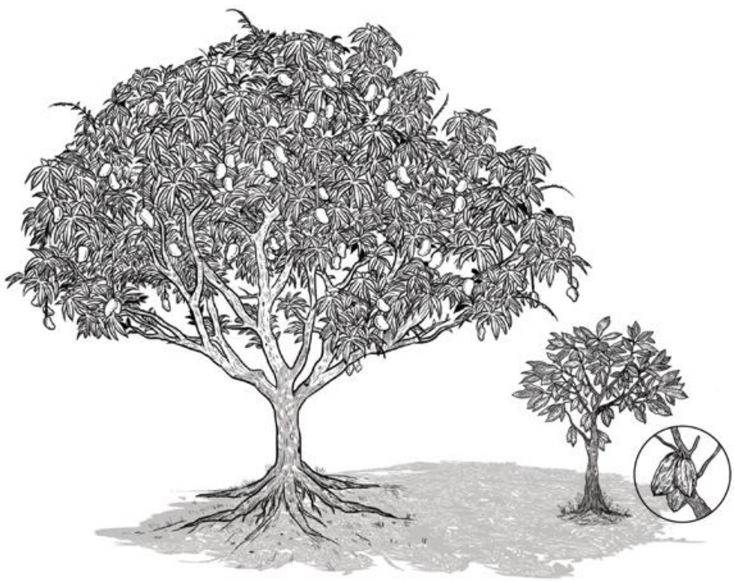
1 cacao under shade of one species, either a timber species (for example, *Cordia alliodora*) or a nitrogen-fixing legume (for example, *Inga* species)

2 cacao under two shade strata composed of a mixture of fruit (for example, citrus, *Nephelium lappaceum*, peach palm), legume, and timber species (*C. alliodora*)

3 cacao intercropped with banana and fruit species under one shade species (timber or legume)

4 diversified home gardens with cacao, fruit, timber and legume species

5 rustic cacao ('cabruca'): cacao planted under thinned natural forest.

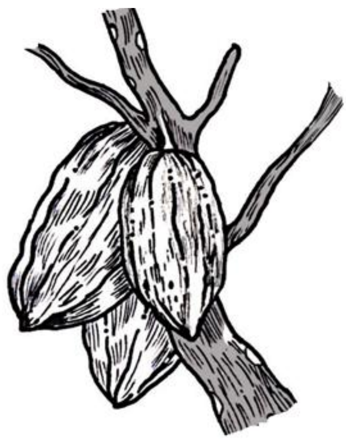


Cacao agroforestry in Claveria, the Philippines
Claveria is an upper-watershed town in eastern Misamis Oriental Province on the island of Mindanao. Land-use practices in the region affect lives and livelihoods of people living in the 13 downstream coastal municipalities: soil erosion from poor land management contributes to the siltation and pollution of downstream water bodies, and affects the quality and availability of marine resources.

In this context, cacao agroforestry is particularly important, because it provides permanent soil cover and reduces erosion, landslides and runoff. Due to its multiple components, the system acts as a climate adaptation and mitigation measure, ensuring climate-resilient, sustainable streams of products and services. It also helps to buffer farmers against fluctuations in commodity prices.

Cacao combined with rubber, fruits and forage legumes is common in sloping lands in the region. In this system, contour lines with 0.5-metre natural vegetative filter strips are laid out every 10 metres. Rubber trees are planted at a spacing of two metres apart, approximately 25 centimetres above the grass strips; about 500 such trees can be accommodated on one hectare. Two rows of cacao trees at three-metre spacing are planted in the alleys (between the grass strips), 3.5 metres from the rubber rows, resulting in around 660 cacao trees per hectare. Bananas are then planted between the rubber trees at a density of 500 per hectare. Fruit trees such as durian or langsat are then planted in the middle of each cacao row, spaced at 10 metres apart (100 per hectare). Pinto peanut, a forage legume, can also be planted as a ground-cover crop.

Cacao with coconut and fruit trees is also used on sloping lands, while cacao with rubber, vanilla and banana is used on flatter areas. Cacao is also used in parkland systems, both on sloping and flat areas.



Oil palm agroforestry

Description of the system

Agroforestry systems for commercial oil palm are multistrata systems that offer an alternative to farmers and companies that want to produce palm oil, but do not want to specialize in just one crop – or who would like their oil to have a smaller environmental footprint.

The system was developed with farmers in Brazil. Individuals had a strong influence on the spatial design of the systems and the selection of the species, so no two systems are the same. They require agricultural technology packages different from conventional oil palm models. Instead of maximizing palm oil yields per hectare, they aim to diversify livelihood options by combining oil palm with other crops of commercial value, allowing simultaneous production of food crops. They also aim to improve nutrient and water flows by taking advantage of the synergies between the different components. To provide space for the other components, palm density varies from 60 to 100 trees per hectare, whereas the density in conventional systems is 144 per hectare.

Management of oil palm agroforestry systems requires considerable knowledge, so training and technical assistance for farmers are important elements of creating, implementing and maintaining systems that will be successful and profitable.

Design guidelines

Oil palm agroforestry is suitable for all soil types and land types that are suitable for oil palm – that is, well-drained soil in flat areas.

The components and spacing are designed around the flagship crop, oil palm. Flotilla species are selected based on how each farmer prioritizes objectives such as incomes, food provision, and contributions to soil health and biodiversity. In Brazil, farmers selected cash crops such as cacao and fertilizer species, including inga, gliricidia and Mexican sunflower.

To simplify the harvesting and transport of fresh fruit bunches from the oil palm, it is advisable to plant oil palm rows in sections, with light-loving crops and trees interspersed between the sections. In Brazil, farmers have opted for double, triple or quadruple rows of oil palm, keeping the conventional 7–9 metre spacing between the palms.

Oil palm is the most productive oil producing plant and has very high light and nutrient requirements. It is therefore important to avoid creating competition for these resources. As in all multistrata systems, competition for light is managed by selecting species that reach different heights, effectively dividing the horizontal space between soil and sun into different layers (see **Multistrata perennial agroforestry** in this chapter), and by actively managing the system once the components grow. Oil palm trees should not receive more than 10–15% shade, so high-strata trees should be placed at maximum distance from the oil palm rows and be carefully chosen for a crown shape that is as porous to light as possible.

Shade-loving crops like cacao, ginger, turmeric, some woody ornamentals and – possibly – coffee can be grown underneath oil palm trees. As oil palm seedlings have very fast-growing, aggressive, shallow roots, perennial components such as cacao must be planted simultaneously to make sure that they establish good root systems and are able to thrive.

The components need to be arranged both to avoid shading the oil palm, and to ensure appropriate light levels for other components in the system. Sun-loving plants should not be planted directly under oil palm. However, it is generally advisable to err on the side of planting too many at the start: it is easier to get rid of surplus plants than to establish them later.

When integrating food crops, it is important to take advantage of the oil palm's life cycle. The palms take five years to reach maximum height and crown cover. During this period, they do not cast much shade, and sun-loving crops like maize and cassava can be easily grown between the oil palm and the other perennials in the system. Beyond this time frame, and depending on the system design and spacing, many understorey crops – particularly the annuals and biennials – will only have adequate light to grow for a few more years. Once the system matures, perennial and semi-perennial food crops like bananas can be planted and can stay in the system for about 8–10 years.

Oil palm agroforestry is relatively labour intensive, and, as in all agroforestry systems, the more integrated the components, the more labour is generally required – especially in the first few years. This adds to the labour demand for the oil palm itself, which tends to increase over time, in contrast to many other crops. As such, it is important to design and implement the system at a scale that is manageable, given the amount of labour that is available to the household or landowner.

Management guidelines

Some of the shade-loving crops that can be grown in an oil palm agroforestry system, such as cacao and cut flowers, may be financially almost as important as the oil palm itself, so their needs and light requirements must be carefully managed. At times when oil palm prices are low and those for other cash crops are higher, farmers can prune their palms more intensively than usual to provide more light and increase the yield of the understorey crops.

Pruning is an important element in any kind of oil palm cultivation, and farmers need to be well trained in the basic principles of managing productive adult oil palms.

Because oil palm is a 'hungry' crop, it will require fertilizer, especially during the first five years, to ensure good yields and prevent stunting – particularly when farmers are working on degraded soils. Organic fertilizer can be created on-site by composting available biomass, though the system will not be able to supply adequate on-site fertilizer for the first few years.

A biodiverse, successional oil palm agroforest can reduce or eliminate the need for pesticides, though particular organic inputs and agroecological techniques will be required to address these issues, particularly in the shorter-term.

'Slash-and-mulch' of fertilizer species (which produce biomass very efficiently) is an important element of soil health management. This feeds the system on a continuing basis.

Rainforestation farming

System description

Rainforestion farming is a successional, multistrata agroforestry system developed to restore native forest cover and forest diversity, while providing diverse income streams to farmers from multiple crop and tree products, including timber. Such systems are designed to shift the livelihood component gradually from crops to trees, ensuring that farmers have an incentive to contribute to forest restoration.

Rainforestion farming was developed in the Philippines in the 1990s as a solution for community forest areas. Exploitation of the natural mixed dipterocarp forests had turned these areas into highly degraded biological and agronomical 'deserts'. Upland areas without trees were dominated by highly invasive grasses such as *Imperata cylindrica*, a land cover type that does not adequately support the needs of local communities.

Initially, fast-growing exotic species were used to reforest government land, but these proved ill-suited to withstand the typhoons that regularly hit the archipelago. So, researchers – together with communities – began exploring the use of more resilient pioneer and hardwood native tree species, particularly those from the dipterocarp family. The rainforestion farming systems they developed proved to be relatively resilient to environmental shocks such as extreme weather events, as well as livelihood challenges such as market fluctuations and food insecurity.

Rainforest farming is often used on government land, so specific attention needs to be given to tenure rights. On land where the community does not have the right to harvest the timber, farmers must be compensated for their labour in planting and managing native timber trees. In this way, the community becomes a partner in a private–public restoration effort.

Seedling sales have also provided a major source of income for many rainforestion farming communities, especially if governments actively promote procurement from community managed nurseries in national reforestation programmes.

Design guidelines

- Rainforestation farming systems build on traditional community knowledge. Soil types, whether of ultramafic, sedimentary or volcanic origin, affect what species can be grown in the system. A good knowledge of the site, the forest species, and their interaction is essential.

- It can also be extremely valuable to involve all family members – including children – in the development of a rainforestion farming system, because the management needs and benefits from a successful system will span generations.

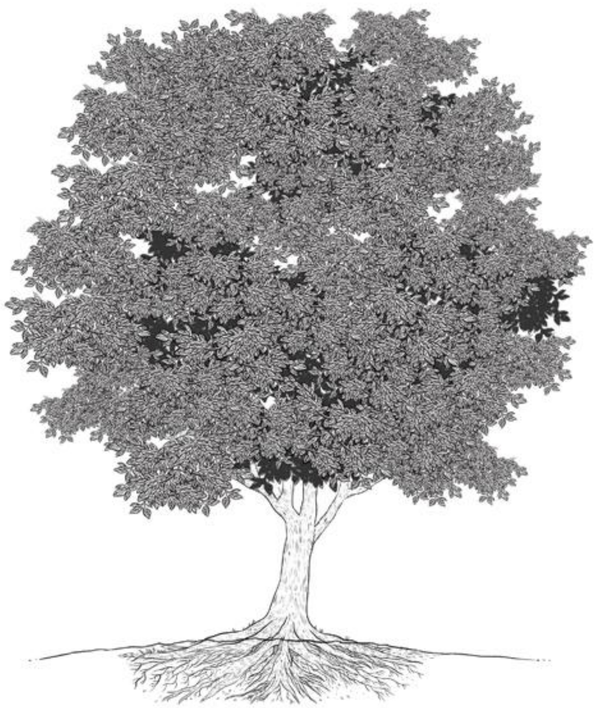
- For areas with little tree cover, a successional model in which agricultural crops give way to fruit trees, which in turn give way to timber trees is common. The spatial layout must be adjusted to the individual growth of the trees to ensure that fruit trees aren't too quickly overtopped by the timber trees, which could lead to an unacceptable decline in production. In open areas, native tree spacing of 2,500 trees per hectare is currently recommended, as this allows quick canopy closure and site capture.

- Many dipterocarp seedlings are sensitive to light and temperature. For this reason, they are grown under a canopy of nurse trees. This canopy is made up of fast-growing, native, pioneer species planted together with the fruit trees. The shade of any pre-existing exotic tree species, such as mahogany or mangium, can be taken advantage of, but these should be slowly replaced by native trees. Existing trees can be used as supports for other crops such as yams and black pepper.

- Sun-loving root and ground crops, such as cassava, sweet potato, taro, yam and pineapple are planted at the early stages, but once trees grow taller and denser, and light infiltration is less than 70%, they need to be replaced with shade-tolerant crops such as coffee, cacao and ginger.

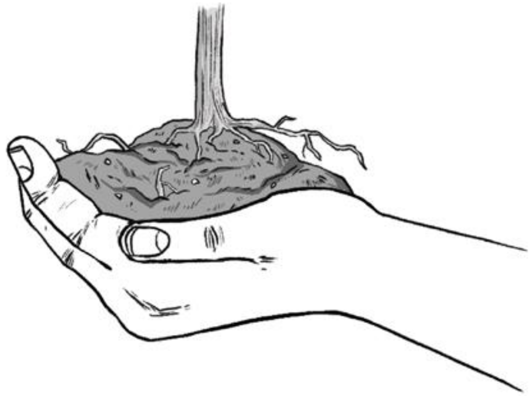
- On Leyte Island in the Philippines, abaca has been a particularly successful cash crop for rainforestion farming. This endemic relative of bananas is harvested for its high-quality fibre, which is widely used and valued internationally in products such as teabags. Traditionally, it is grown under nitrogen-fixing trees such as *Erythrina fusca* and narra. It is fast growing and quick to recover after extreme weather events such as typhoons, and is most productive in an environment with around 50% shade. The fibre extracted from the abaca's pseudostems amounts to only around 2% of the plant's biomass; the rest is left on the farm as mulch, so abaca can be cultivated in one spot for around 40 years. One option for integrating abaca into a rainforestion farming system is to plant it a couple of years before planting canopy trees, so that it then provides useful shade for the tree seedlings when they are small.

- Integration of animals such as chickens and small ruminants is encouraged to enable nutrient cycling from their manure.



Management guidelines

- The guiding principle for managing rainforestion systems is the same as for all other multistrata systems: that is, to manipulate the canopy structure through spacing, thinning and pruning to provide the right amount of shade at the right time for all the plants in the system.
- The strong emphasis on timber trees is a distinguishing characteristic of rainforestation systems. Consequently, silvicultural treatments such as thinning and pruning to remove overhead shade, and cutting of vines and climbing bamboo, need to be done continuously.
- Naturally occurring tree seedlings need to be actively managed and protected by controlling competing grasses, shrubs and climbers (assisted natural regeneration).
- On degraded sites, the natural dipterocarp seedling stock is usually very scarce or absent. Dipterocarps therefore must be planted, a process called 'enrichment planting', using seeds and seedlings collected from or near mother trees in natural forest.
- Dipterocarps do not produce seeds every year. Rather, seed is produced every 2–10 years. In such 'mast years', all trees of a species produce their seeds at the same time. Dipterocarp seeds are recalcitrant, so seed storage is not possible.



- In years when there is no seed production, wildlings (small seedlings from natural regeneration) can be extracted from the natural forest. This practice is not harmful in places where natural regeneration is abundant (for example, under mature trees). Wildlings are often damaged during extraction and transport, but if they are placed in a shaded recovery chamber – a small, closed structure of bamboo and acetate plastic sheets, with relatively constant temperature and high humidity – their survival rate will be close to 100%.