2

COMPONENTS OF AGROFORESTRY SYSTEMS

Agroforestry systems are composed of trees and crops, trees and livestock, or trees with both crops and livestock. In this section, we explore the attributes of these components in more detail.

A given agroforestry system is often centred on one species, which we call the 'flagship species'. This is the species that the farmer considers to be the most important one – often because it contributes most strongly to their livelihood. Other components, which we call **'flotilla species'**, are added to provide **agroecological services**, such as shade, that support the flagship species. The needs of the flagship species (for example, for light or water) determine the types of flotilla species needed, even when these also produce useful goods. For example, when growing shade-intolerant crops like cereals, farmers need to select and plant trees that do not compete with the cereals for light. In many agroforestry systems, the flagship species is an annual crop, a perennial (long-lived) crop (including tree crops), or a livestock species; it can also be a timber species. Some agroforestry systems may have more than one flagship species. Flotilla species can be trees or crops.

Attributes of crops

Rice

Maize

Potato

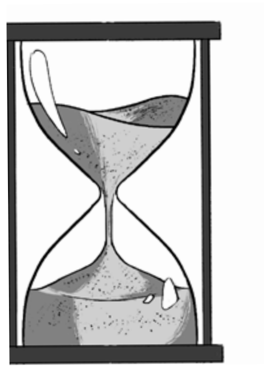
Cabbage

Soybean

Crops grown in agroforestry systems include well-known staples such as maize and rice, as well as longer-lived crops like cassava; cash crops like cacao, coffee and soybean; and crops used to feed livestock.

Lifespan

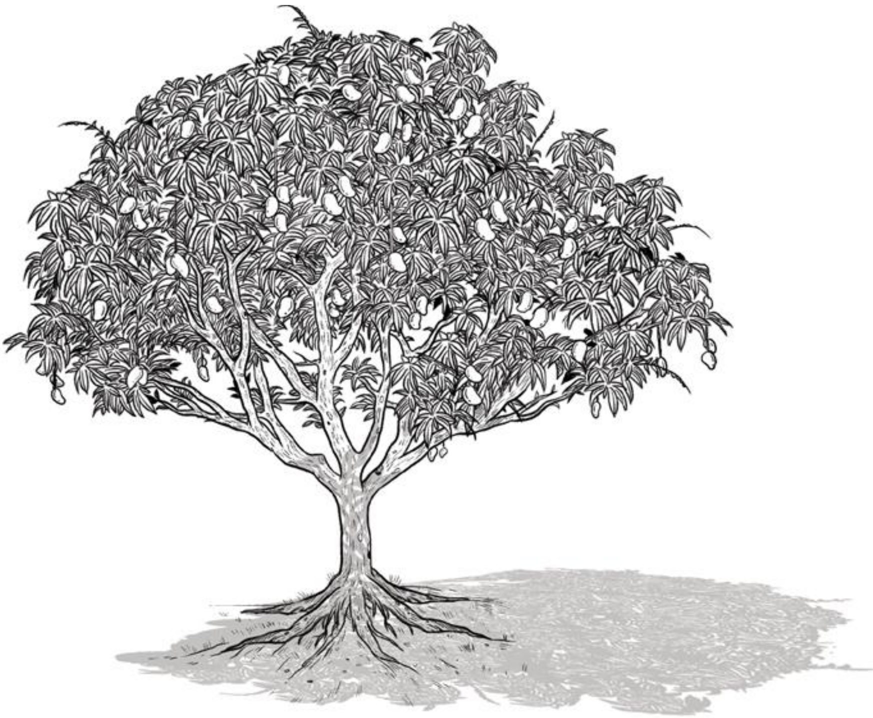
The lifespans of crops vary greatly. Many staple food crops, such as beans, maize, rice and wheat, are annuals: they germinate, grow, flower and die within a single season or year. All other plants are perennials, with lifespans that range from a few years to decades, or even centuries. Farmers shorten the lifespan of some perennial crops, such as sugarcane and cassava, when they harvest them. Lifespans are also shortened when farmers replace older, unproductive plants with new ones, such as in the replanting of coffee and cacao plantations.



Domestication

Almost all crop species have been **domesticated** to some extent: that is, farmers and plant breeders have altered their genetic characteristics by selection and breeding. In many cases, domestication has altered them so much that they no longer look like their closest wild relatives. Many **modern varieties** of staple crops need more nutrients and water than traditional varieties. Similarly, many improved varieties of coffee and cacao, which are still often grown under shade in agroforestry systems, have been selected in unshaded conditions. For both staple and cash crops, thriftier and more resilient **traditional varieties** may be more suitable to agroforestry systems than alternative, highly improved varieties.

Light demand and shade tolerance

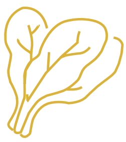


Light is one of the most important resources for plants, and limitations in its supply reduce survival and growth. Different kinds of plants have different levels of tolerance to shade, and some plants do better in shady conditions than under full sun.

Almost all major cereal crops are light demanding, so shade may reduce crop yields.

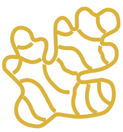
Fruit vegetables – those whose edible part is a fruit, such as cucumber, bell and chilli peppers, pumpkin and tomato – are some of the least shade-tolerant crops. When shaded, they will often fail to flower, which means they won't produce fruit.

Root vegetables – such as taro, arrowroot, yam, beet (beetroot), carrot and potato – will grow in partially shaded areas that have less direct sunlight, but usually benefit from at least a half-day of full sun.



Leafy vegetables – such as chard, spinach and salad greens – are the most shade tolerant of all vegetables.

Cacao and coffee can be grown successfully under shade in most climatic conditions, and their quality is often improved by doing so (see **Multistrata cacao agroforestry systems in Central America and the Philippines** in Chapter 8).

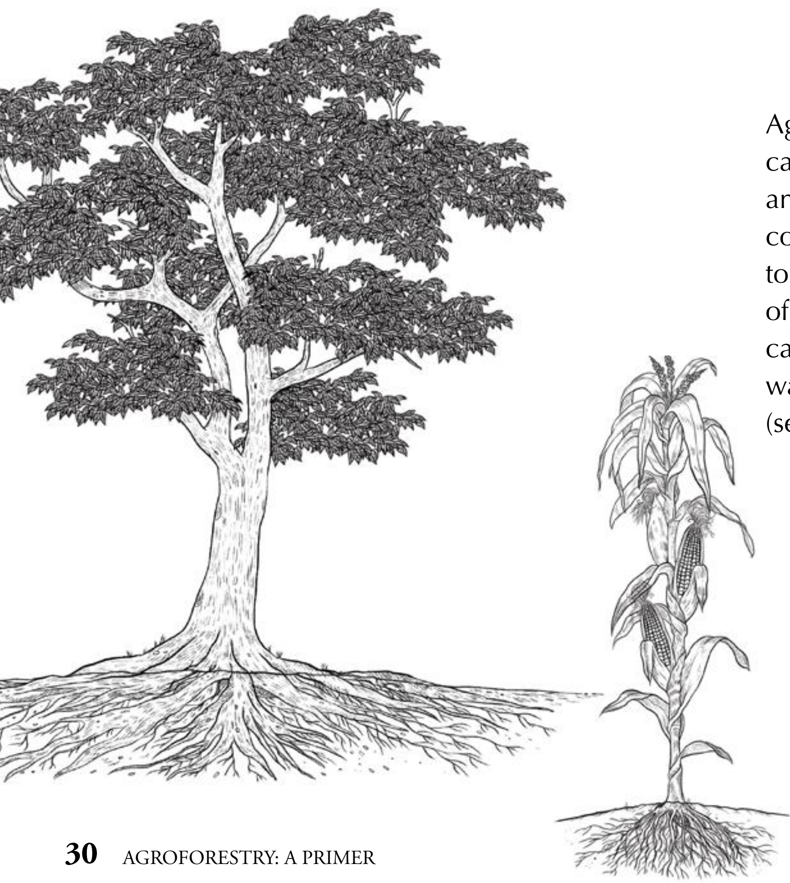


Many other crops – such as ginger, mint, parsley and turmeric – are also shade tolerant. Grass species vary in their shade tolerance, and several tropical forage legumes do well in shade.

Agroforestry systems carefully combine trees and crops to maximize their use of light. Care is taken not to grow light-demanding species in shade, while shade-tolerant species can exploit areas with lower light. Some crops, such as coffee and cacao, are often deliberately grown in the shade of trees, and thrive under those conditions.

Water needs

Crops differ greatly in their water requirements. When combined with other crops or trees, the various components may compete for water. Highly productive species that consume large amounts of water and nutrients, such as maize and other members of the grass family, can severely reduce the growth of tree seedlings. On the other hand, tree roots close to the soil surface can easily outcompete the roots of leafy vegetables.



Agroforestry systems carefully combine trees and crops to avoid harmful competition for water, and to maximize the benefits of available water and the capacity of trees to access water from deep in the soil (see Chapter 3).

Root types

Crops demand a lot of nutrients, and their root systems are adapted to absorb readily available nutrients from the topsoil and from water. Roots can form immense structures of millions of branch roots reaching tens of metres in length. They are both the feet and the hands of the plants; anchoring plants in the soil, but also extracting the nutrients the plant needs from the soil (Figure 1).

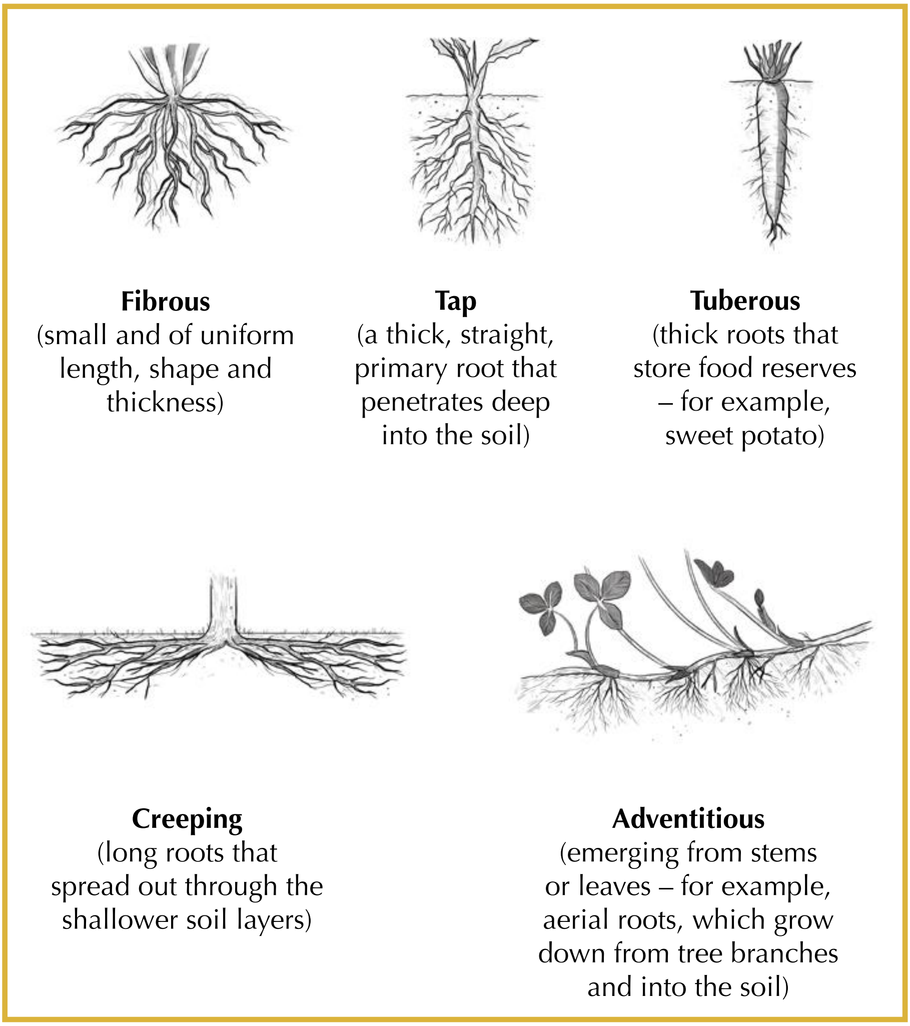
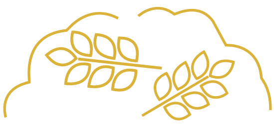


Figure 1. Some root types

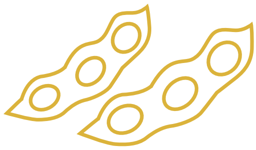
Agroecological role

In agriculture, large quantities of **biomass** and nutrients are taken out of the landscape when the crop is harvested. This depletes the soil, and yields will fall unless these are replaced. Agroforestry can return important biomass and nutrients to the system (see Chapter 3, **Agroforestry systems as circular systems**).

Crops also make positive contributions to system functioning. The following are particularly important:



Crop residues are an important source of **organic matter**.



Leguminous crops increase availability of nitrogen to other system components. Other fertilizer species, such as bananas and Mexican sunflowers, can also play important roles in nutrient capture and flows.

Cover crops help to control weed competition.

Fodder crops provide nutrients and water to livestock.

The **high value** of crops often justifies weeding and cultivation activities that also benefit other system components.

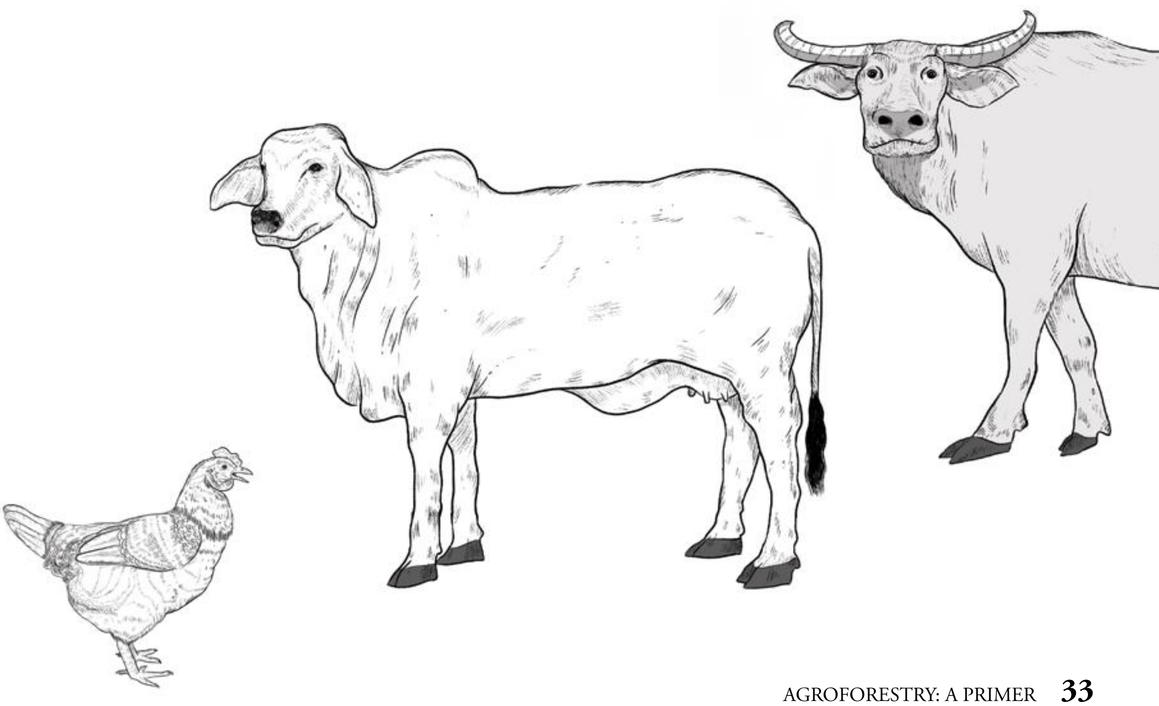
Tree crops play similar agroecological roles to those of other trees (see **Attributes of trees** in Chapter 2).

Attributes of livestock

The term 'livestock' means all domesticated animals that are kept for food and other agricultural products.

Associations between livestock and trees occur in a wide range of agroecosystems. The public often views these associations negatively – for example, when demand for cheap beefburgers leads to expansion of pastureland and to deforestation. However, livestock also interact synergistically with crops, trees and soils, and it is difficult to see how some mixed farming systems could be sustained without the contribution of livestock to household income and maintenance of soil health.

Livestock differ from other system components in several important ways. These affect both the commitment needed to manage them and the potential benefits they can bring. The most relevant characteristics are outlined below.

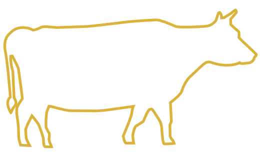


High value

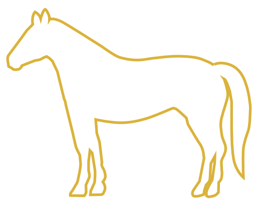
Almost all farming families in the tropics and subtropics keep livestock, ranging from a few chickens to herds of cattle. They do so because livestock offer a range of important benefits. Some of these are listed below:

Nutritional benefits:
dairy products, eggs and meat are important sources of proteins, fats and commonly deficient micronutrients such as iron.

Regular income:
from sale of eggs and dairy products is very important for covering recurring expenses, such as food, transport, ongoing medical costs or school fees.



'Banks on legs':
livestock, particularly cattle, can readily be sold to cover major expenses, such as university fees, weddings or unexpected medical costs.



Draught power:
Oxen, horses and other large ruminants can be used on farm or rented out to pull ploughs, to power low-tech machinery such as sugarcane presses, or for transport.

High needs for care and maintenance

Each animal is valuable, and a large proportion of farmers' wealth may be invested in them. Their loss or devaluation through disease, accident and death – none of which are rare – can have catastrophic consequences: livestock farming is not risk free. This risk, coupled with the animals' need for access to feed and water, means that they require regular or even constant attention. If kept in pens, or confined in other ways, their keepers must feed and water them at least once a day, while free-ranging livestock must either be guarded (for example, by shepherds) or kept within regularly checked fencing. All these activities cost time and labour. On the positive side, the regular contact allows for close monitoring of health and reproduction.

Livestock need large amounts of food and water. For example, cattle need the dry feed equivalent of 3% of their bodyweight, plus 18 litres of water for each 100 kilograms of bodyweight, every day, so a cow weighing 400 kilograms has a daily requirement of 12 kilograms of dry feed and 72 litres of water.

When – as is common – resources are limited, either seasonally or for longer periods, consumption of feed and water is likely to be determined not by such guidelines, but by what is available. This limits productivity. In such 'lean periods', livestock keepers will often concentrate on keeping animals alive and as healthy as possible until the scarcity has passed. Long periods during which feed and water availability falls significantly below these levels will pose a risk to the health and well-being of the animal.

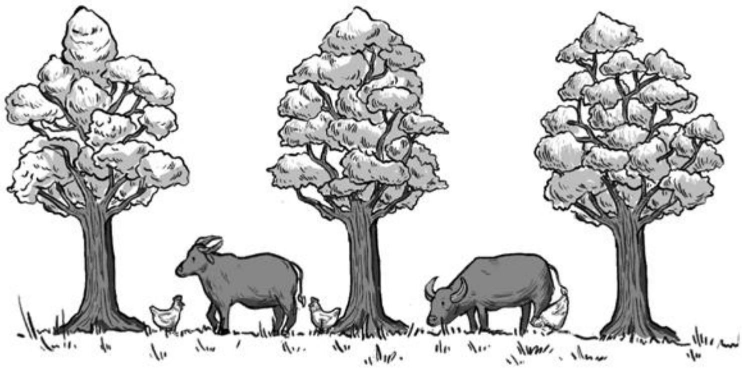
If more feed is available than what is needed for maintenance or survival, then livestock production will be proportional to the intake of balanced nutrients. Dairy livestock are a special case: they require sufficient water to support their milk output volume, irrespective of how much feed is supplied.

Mobility

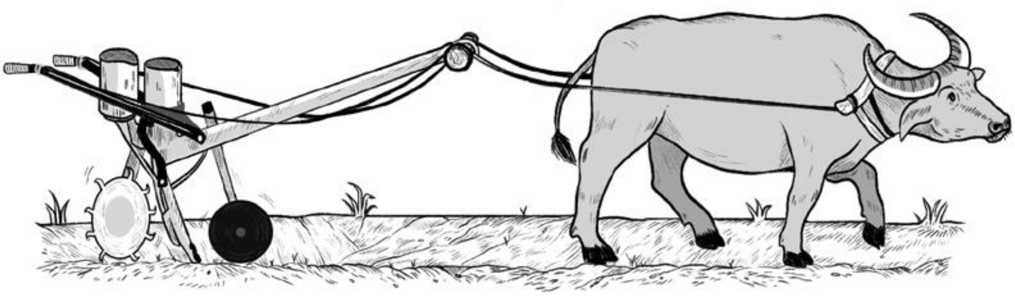
Unlike trees and crops, livestock have brains and often choose to pursue their own objectives, including going where they're not supposed to! This is one reason why they need careful oversight. But mobility also has its advantages. Unlike crops and trees, livestock are able to move to where food and water are available. This ability is useful even within a farm.

Agroecological and environmental benefits

Livestock offer both agroecological and wider environmental benefits. As part of balanced, well-managed agroecosystems, they can be highly beneficial to long-term sustainability. Some of these benefits are listed below.

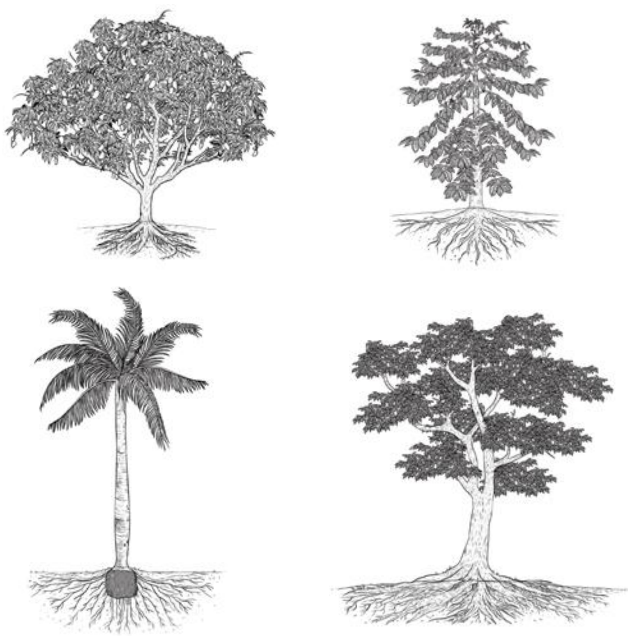


- **Livestock can make farming more efficient** by feeding on weeds or other plants that are planted as forage. Much of the nutrient content from these resources can then be recycled as manure to support other parts of the agroecosystem. Livestock waste (urine as well as manure) is a valuable resource for soil amendment, fuel and other uses.



- **Livestock can contribute to land restoration.** For example, they can provide draught power for operations that would otherwise require heavy and debilitating manual work or the use of expensive machinery. Their livelihood benefits can also act as drivers of adoption of environmental protection measures. For example, fodder plants – including trees – can be grown on contour banks, water diversion banks and other soil and water conservation structures to provide livestock with feed.

Attributes of trees



The role of trees

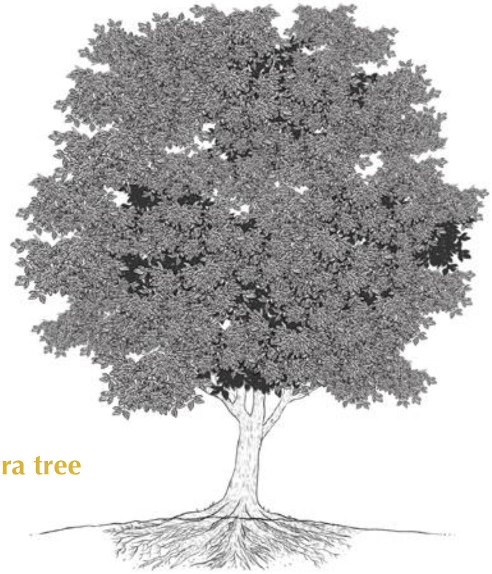
All agroforestry systems include trees. Flotilla tree species have two main functions:

1. They provide agroecological services to the flagship species or to the system as a whole.

2. Their products diversify the main income stream generated by the flagship species.

In selecting flotilla species, we need to consider not simply their own characteristics, including the goods and services they produce, but how well they will combine with the flagship species and other components of the agroforestry system.

In some traditional agroforestry systems, such as the damar and rubber agroforestry systems, the trees themselves are the flagship species. Some large-scale, mechanized agroforestry systems are also designed around timber trees.



Narra tree

Falcata tree

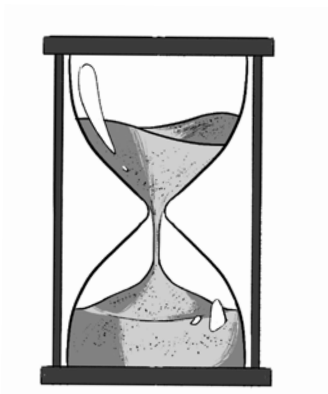
Musizi tree

Domestication

Unlike almost all crops, most trees in agroforestry systems are undomesticated. That is, they are very similar to their wild relatives.[2] Tree species are among the most genetically variable organisms on the planet. Because of this, seed sources for agroforestry trees must be chosen with care; the option of simply buying certified seed does not usually exist (see Chapter 6, **Planting material in agroforestry**).

By contrast, many fruit tree species have been domesticated and, as a result, have less genetic diversity. Clonal varieties of fruit species such as avocado and mango are an extreme, but common, case. They have no genetic variation, unless more than one variety is used.

Lifespan



The lifespans of trees vary from less than two decades to hundreds of years, but most timber or fuelwood species will be harvested long before the end of their natural lifespan. Lifespan and **rotation length** are important for two main reasons:

1. Farmers' choice of tree species is often strongly dependent on when they can expect a return.

2. Timber trees are difficult to harvest without damaging understorey crops. It is therefore better to synchronize felling with replacement (replanting) of flagship understorey species.

[2] Tree breeders have developed improved seed for some tree species. Trees of these genetically improved populations look very similar to those from unimproved or wild populations, although they may grow faster or have better form.

Crown characteristics

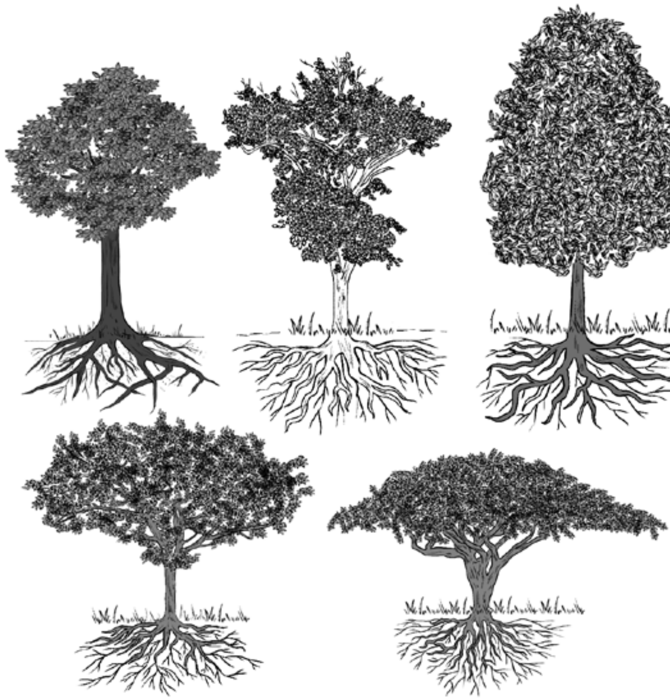


Figure 2. Variation in crown shape in tree species

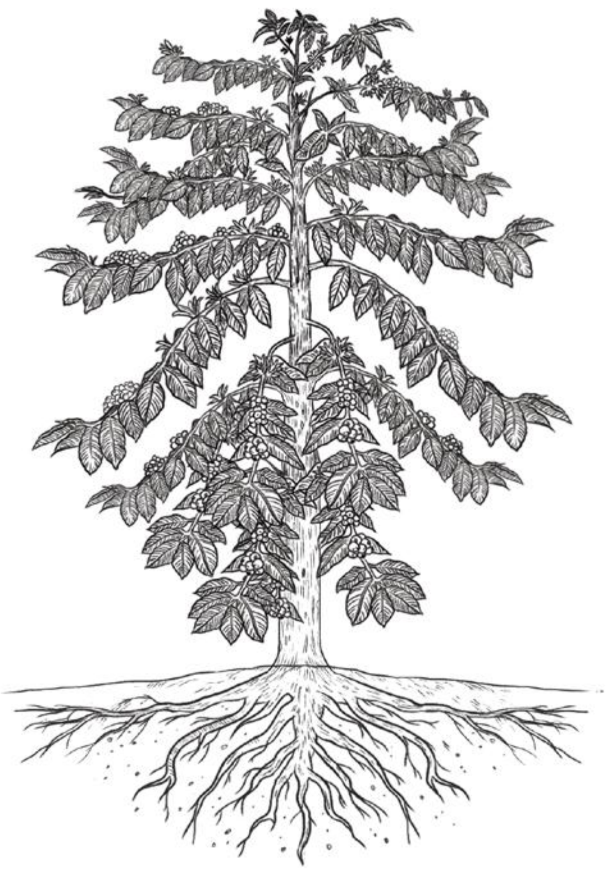
The crown of a tree consists of the live branches and leaves. The shape and density of the crown affect the amount of light reaching flagship species in agroforestry systems, and the choice of crown type and positioning of trees is critical in managing light. Tree crowns take many forms (Figure 2) but can be described simply using measures such as crown shape, size (diameter and height) and density.

Knowledge of crown characteristics of different species is needed to decide on 'the right tree'. If it is not possible to choose tree species with crown types that best suit the rest of the agroforestry system, then crown shape, size and density must be actively managed (see Chapter 7, **Management of trees in agroforestry systems).**

Deciduousness and leaf size

Whether and when a tree loses its leaves is also important: in particular, the timing and duration of leaflessness in relation to crop growth and to seasonal variations in rainfall and temperature. Some tropical tree species are leafless for extended periods at the hottest time of the year.

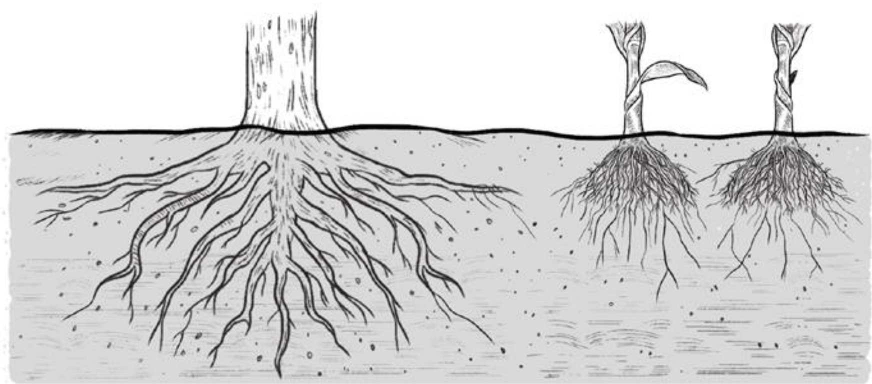
Some tree species naturally produce less shade than others. Such trees may have small leaves, or leaves that tend more to a vertical, rather than horizontal orientation.



Root characteristics

In general, trees have much larger root systems than annuals and other non-woody plants. They can extend for tens of metres – both in depth and horizontally.

However, although they often have deep roots, trees – like other plants – get most of their nutrients from soil layers near the surface, where their roots will compete with crop roots. Woody roots near the surface can also interfere with ploughing.



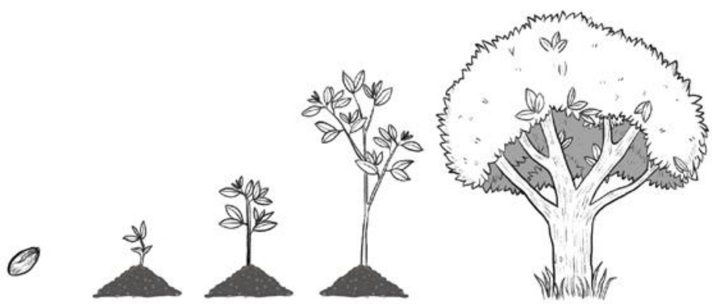
Some types of root systems combine very well with flagship species and other system components, particularly those that are deep enough to bring water and nutrients from layers that crops can't reach, and that have limited horizontal reach – and therefore compete little with crops. Although there is little scientific information about characteristics of root systems, farmers are often well aware of differences between species. This knowledge should be tapped in species selection (see Chapter 5**, Co-design and establishment of agroforestry systems**). However, local soil characteristics, such as density, structure, texture, moisture content and nutrient availability, also affect what the root system of an individual tree looks like.

Growth rate and invasiveness

In general, rapid growth of trees in agroforestry systems is an advantage. It speeds establishment of the system and reduces the time that farmers must wait for financial returns.

However, fast-growing trees use a lot of nutrients, and some species are so vigorous that they may be a poor choice for certain agroforestry systems. For example, all the commonly planted eucalypts are very fast growing, and when moisture or nutrients are not in abundant supply, they will often reduce the growth of flagship and other species. Many other species grow very quickly, but most eucalypts are adapted to survive and grow in nutrient- and water-scarce places, so they require special caution.

Fast-growing exotic species may also produce large quantities of easily spread seeds. The combination of fast growth and abundant seed enables them to invade natural vegetation and farmland, causing ecological and economic damage. Some invasive species, such as mahogany, do not grow particularly quickly. Farmers or their advisers should check candidate tree species against the **global invasive species database** before making final decisions.



Agroecological contribution

The central role of agroforestry in responding to global challenges is very much based on the agroecological contributions of trees. Some of these are outlined in Chapter 3, **Agroforestry systems as circular systems**. It is important to note that the environmental benefits of trees in agroforestry systems go beyond the scale of individual agroforestry systems, providing benefits at the scales of **landscape** (water regulation, **habitat connectivity**), region (climate regulation) and planet (climate-change mitigation).

Soil life

The soil is more than simply the earth in which plants are anchored. In a healthy agroforestry system, it should contain millions of living organisms that play vital roles in the agroecosystem. Without these, the nutrients that plants need to be healthy and productive are not available, and there is almost no biomass circulation in fields. Table 1 lists five important functional groups of soil life; organisms in the same functional group contribute to the same ecosystem function.

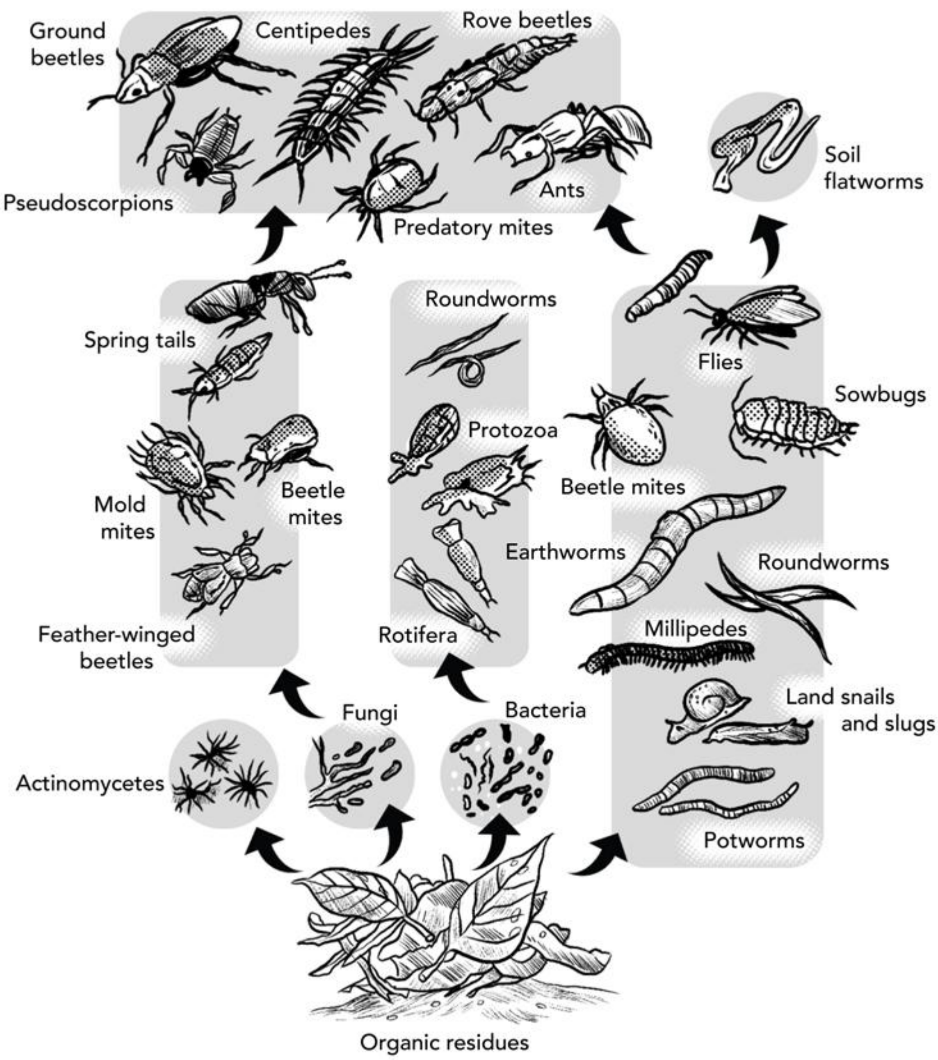
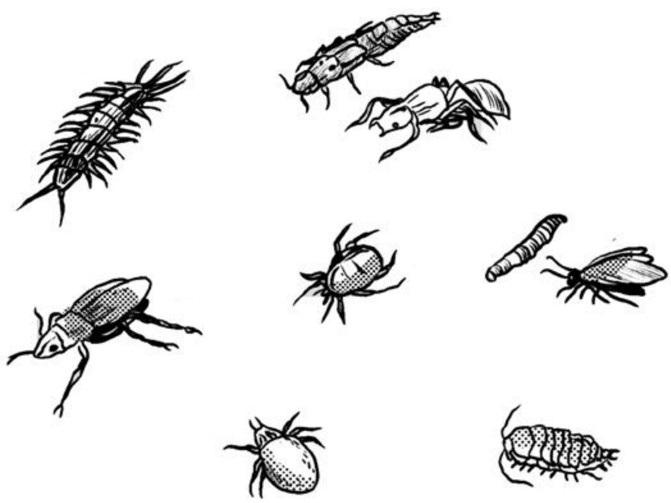


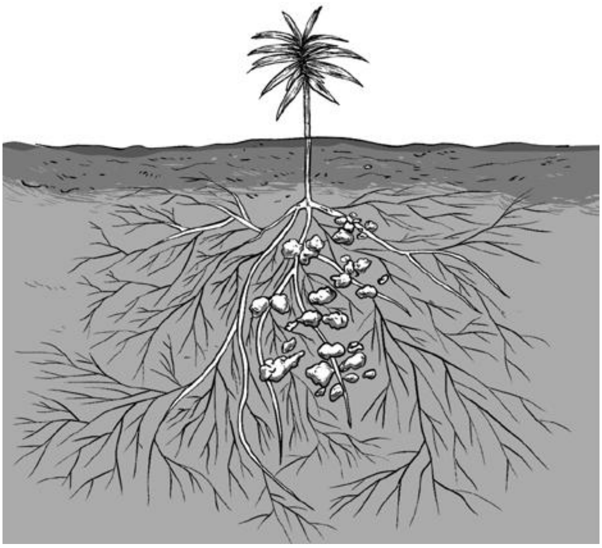
Table 1. Functional groups of soil organisms and the agroecological services they provide[a]

Functional group	Agroecological services provided
Microsymbionts	Plant nutrition and water supply Resistance to pests and diseases
Soil engineers	Soil structure (regulation and maintenance)
Decomposers	Decomposition Formation of soil organic matter
Elemental transformers	Nutrient supply
Soil engineers	Soil structure (regulation and maintenance)

[a] Based on Swift et al. 2004. Table 1: Relationship between key functional groups of organisms, the ecosystem level functions they perform and the ecosystem goods and services they provide. *In* Biodiversity and ecosystem services in agricultural landscapes – Are we asking the right questions? *Agriculture Ecosystems & Environment*. 104(1):132.



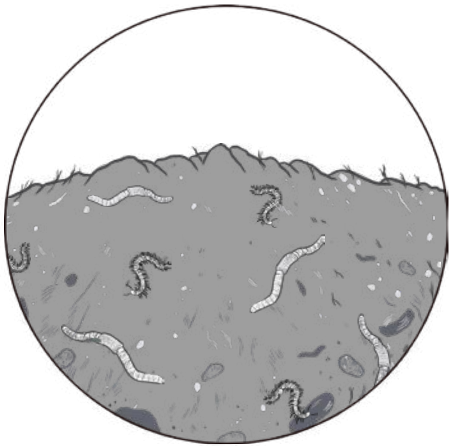
Microsymbionts



Microsymbionts include mycorrhizal fungi and nitrogen-fixing bacteria. Their importance is difficult to exaggerate. Roots are not 'just roots'; in most species they form close, mutually beneficial relationships called 'mycorrhizae' with certain types of fungi. These mycorrhizal fungi greatly increase the volume of soil that plant roots reach, help to make phosphorus available to plants, improve drought tolerance, and help prevent root infections. In addition, increasing evidence suggests that nutrients can move directly between trees through mycorrhizal connections – even between trees of different species.

Nitrogen-fixing bacteria form relationships with so-called nitrogen-fixing trees (see Chapter 3, **Agroforestry systems as circular systems**). In reality, the bacteria, not the trees, are responsible for the fixation process. This is the process by which the nitrogen in the air – where most of the planet's nitrogen is found – is 'fixed' in compounds that, unlike atmospheric nitrogen, can be absorbed by plant roots. These bacteria are responsible for about two-thirds of nitrogen fixation on Earth. Before the invention of efficient methods to manufacture nitrogen fertilizer they fixed almost 100%.

Soil engineers



Soil engineers include earthworms, termites and other invertebrates. They form and maintain the structure of the soil by burrowing, transporting soil particles and transforming these particles into soil lumps of different sizes.

Decomposers and elemental transformers

Decomposition is the gradual breakdown of dead animal and plant matter. Invertebrates start the process; the end point is the release of energy, water, carbon dioxide and nutrients as a result of the activities of bacteria. Elemental transformers are bacteria that obtain energy from simple substances; they convert the complex molecules in organic matter into forms that plants can use as nutrient sources. They are important in cycling important nutrients like carbon, nitrogen and sulphur.