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AGROFORESTRY SYSTEMS AS CIRCULAR SYSTEMS

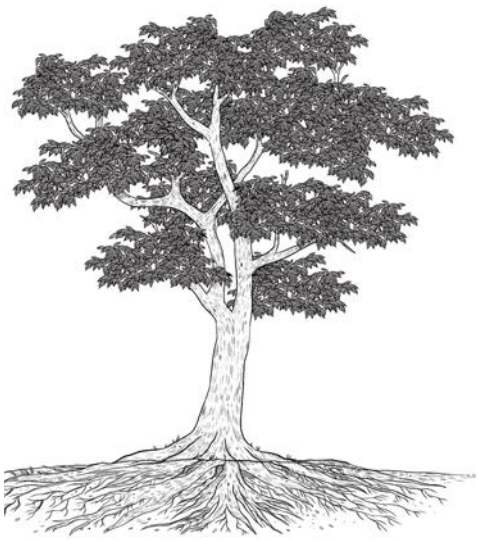
In agriculture, sustainability is often synonymous with increased efficiency of production. This implies increasing yield while reducing, or not increasing, the area of land used and consumption of water and fertilizer. Modern agriculture, which depends on the regular use of fertilizers, is a linear production process, whereby nutrients and water (agricultural inputs) are added to the system and converted into biomass, which is then exported in the form of animal or crop produce. Integrated farming systems, on the other hand, are circular systems that combine a diversity of crops, animals and trees with varying spatial and seasonal arrangements. They mimic natural water and nutrient-flow processes, with less need for artificial inputs like fertilizers, herbicides, and pesticides. In addition, agroforestry systems – one form of integrated farming system – are unmatched by other land uses in their ability to provide multiple goods and services at the same time.

To understand what these advantages are based on, it is useful to explore how agroforestry systems work. The following sections describe how agroforestry contributes to nutrient and water management, soil conservation and erosion control.

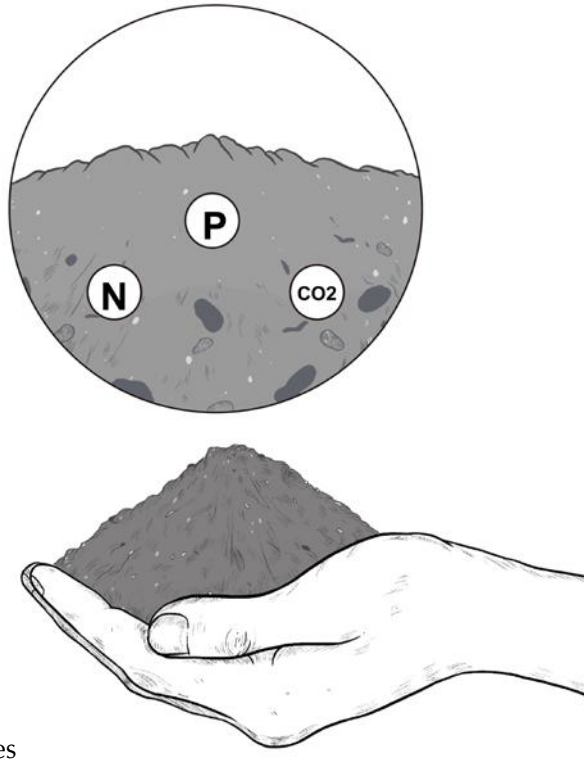
Nutrients and water

Plant nutrients are the chemical elements that make up the food that plants need to grow and thrive. These nutrients are found in the soil, and come principally from the rotting of leaves, twigs, stems and animal material; the very slow breakdown of minerals in the soil; and fertilizers applied by farmers. Soils that have low levels of nutrients are referred to as having low fertility and are not very productive.

Most soil nutrient sources are found in the upper soil layers. If the soil is in good health – with sufficient air, water and organic matter – it retains the nutrients, which can then be gradually absorbed by growing plants. If the soil is exposed, its upper layers – and the nutrients in them – can be washed away in water runoff. In poor quality soils, particularly those that are sandy textured and free draining, nutrients can also be washed rapidly into deeper soil layers, below the level of crop roots. This is called 'leaching'.



Trees can play an important role in keeping nutrients available by preventing runoff of water and improving its retention in the soil. Their deep roots can also pull up water and nutrients from far down in the ground. Nutrients make up the 'building blocks' of stems and leaves, or are used by the trees in other ways. After the old leaves, stems, twigs and branches fall as litter, they rot and provide more nutrients needed by plants. Trees are therefore important nutrient-recycling 'pumps' that maintain good soil conditions for plant growth (Figure 3).



Nitrogen and phosphorus are two of the most important minerals for plant growth. Lack of both is one of the main reasons for resorting to artificial fertilizers, which is why effective nutrient recycling is so important. Nitrogen-fixing trees, which come mostly from the very large legume (pea) family, can substantially improve the fertility of soils, and can be used in several ways in agroforestry systems. One approach is to grow them in rows, with crops planted in between, so that the falling leaf litter directly fertilizes the soil. Young tree branches can also be cut and mixed into the soil. Sometimes 'tired' soils are left in fallow – that is, without crops – to allow trees and bushes to grow back naturally. Fallowing allows soils to recover from overuse, and nitrogen-fixing shrubs and trees, such as some leguminous species as well as alder and casuarina, can be grown on the fallows to speed up that process.

Efficient fixation of nitrogen requires a minimum level of phosphorus in the soil; fixation can be insignificant in soils that are low in phosphorus, and this is often the limiting growth factor. Animal manure is a good source of phosphorus, which is one reason why livestock are an important part of numerous agroforestry systems. Many trees provide shoots and leaves that can be fed to animals; the resulting nutrient-rich manure can then be applied to crops in the system, including by carrying manure to fields from animal pens (see **Livestock with trees** in Chapter 8).

Soil health depends not only on the presence of nutrients and water, but also on its physical quality. Farmers can maintain that quality by ensuring their soil always contains sufficient organic matter. Soils that are low in organic matter are easily washed or blown away, lose water and nutrients, and can become compacted and difficult to cultivate.

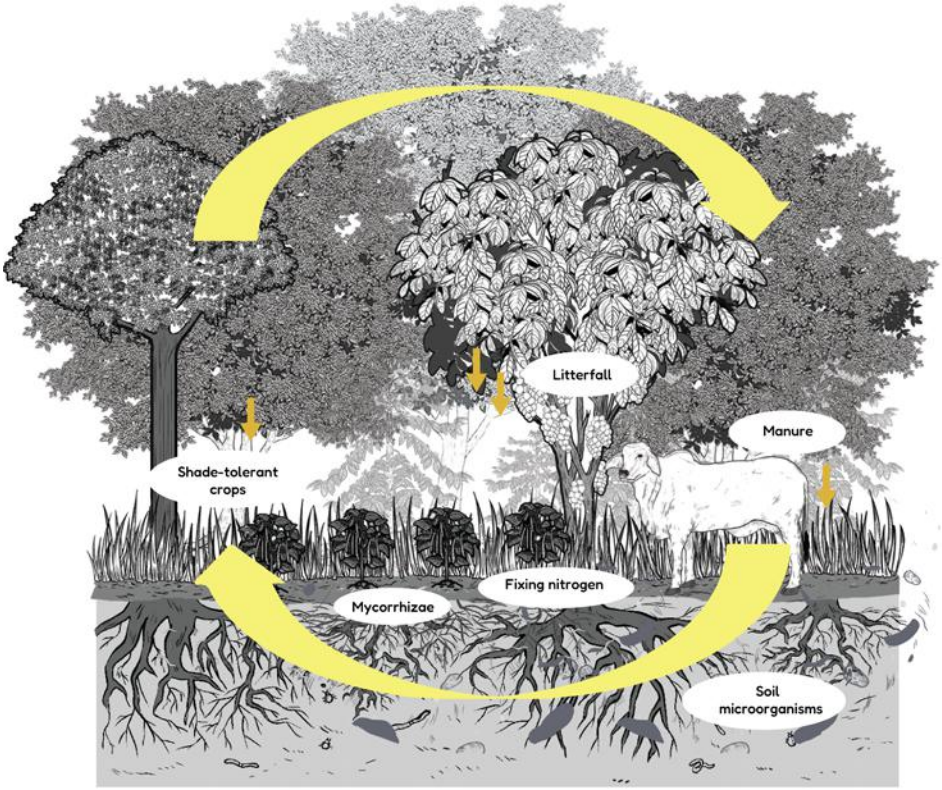


Figure 3. The nutrient cycle

Trees pull up water from the soil through their roots. Some of this water is then released into the air by a process called 'transpiration'. Water that falls as rainfall either evaporates (due to the sun's heat), infiltrates the soil, or flows as surface runoff into watercourses, ponds and lakes. The combined process of transpiration and evaporation is known as 'evapotranspiration'. It is the total amount of water that is released to the atmosphere (Figure 4). Water infiltration into the soil depends on the structure of the soil's surface and lower layers, which is strongly influenced by its organic matter content.

Trees also help to regulate temperature. Their shade reduces daytime temperatures, which can protect crops from extreme heat. At night, the tree canopy increases temperatures by trapping heat, which can prevent frost damage, but may also reduce yield. In **multistrata systems**, the

shade cast by upper-storey trees cools the lower storeys, which reduces evapotranspiration and helps to keep water in the soil.[3]

Trees usually consume more water than crops; they may therefore compete with crops for water. Fortunately, crops mostly take up water from the upper soil, while trees usually have deeper-reaching roots and can access water from deeper soil layers, which can reduce competition between the two components. However, the level of potential competition varies depending on the tree species, and expert advice from farmers or professionals is needed when deciding which trees to plant with which crops.

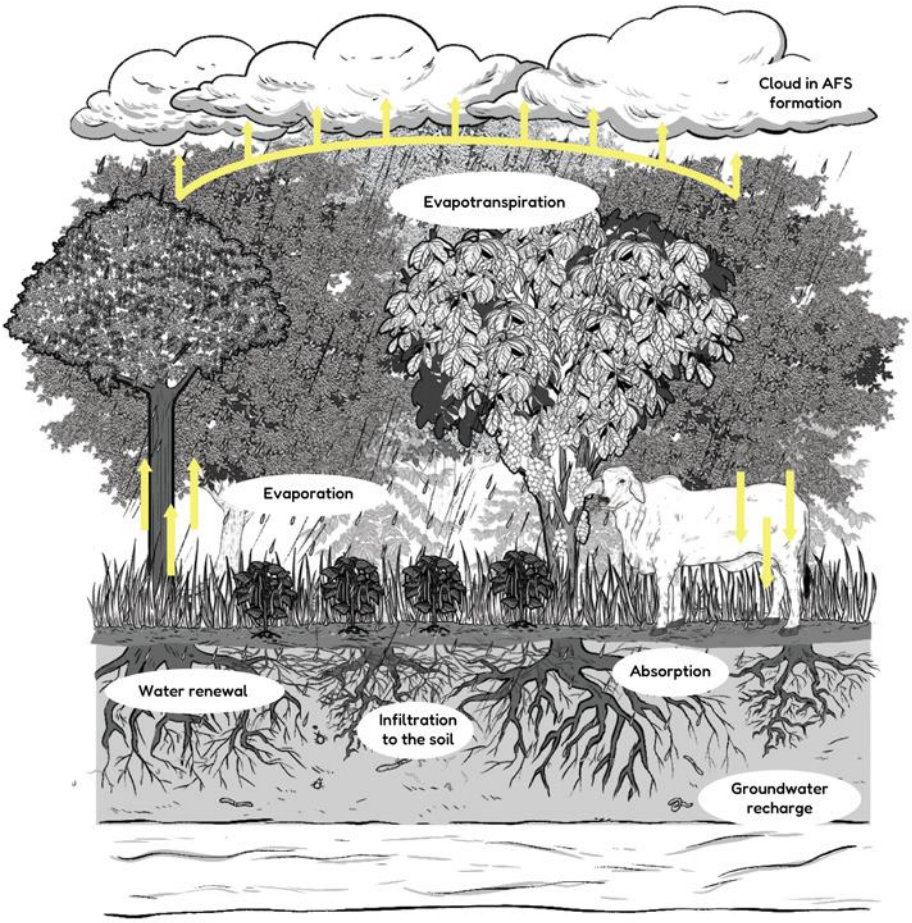
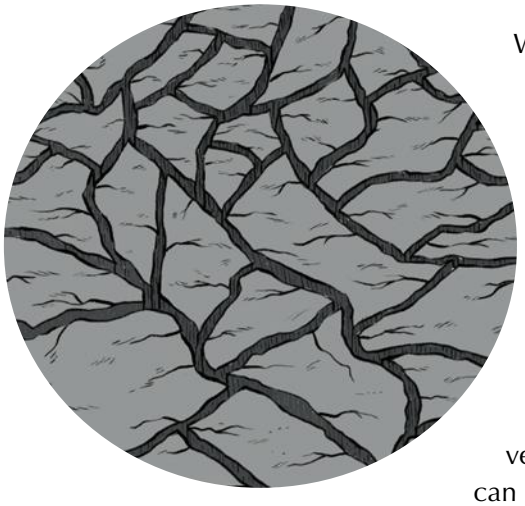


Figure 4. Water cycling in an agroforestry system

[3] For more information on this complex topic see Gosme M, Dufour L, Inurreta-Aguirre H, Dupraz C. 2016. Microclimatic effect of agroforestry on diurnal temperature cycle. Paper presented at the 3rd European Agroforestry Conference, Montpellier, 23–25 May 2016. http://www.repository.utl.pt/bitstream/10400.5/11690/1/EURAF2016%20-%20Book%20of%20Abstracts%20final.pdf.

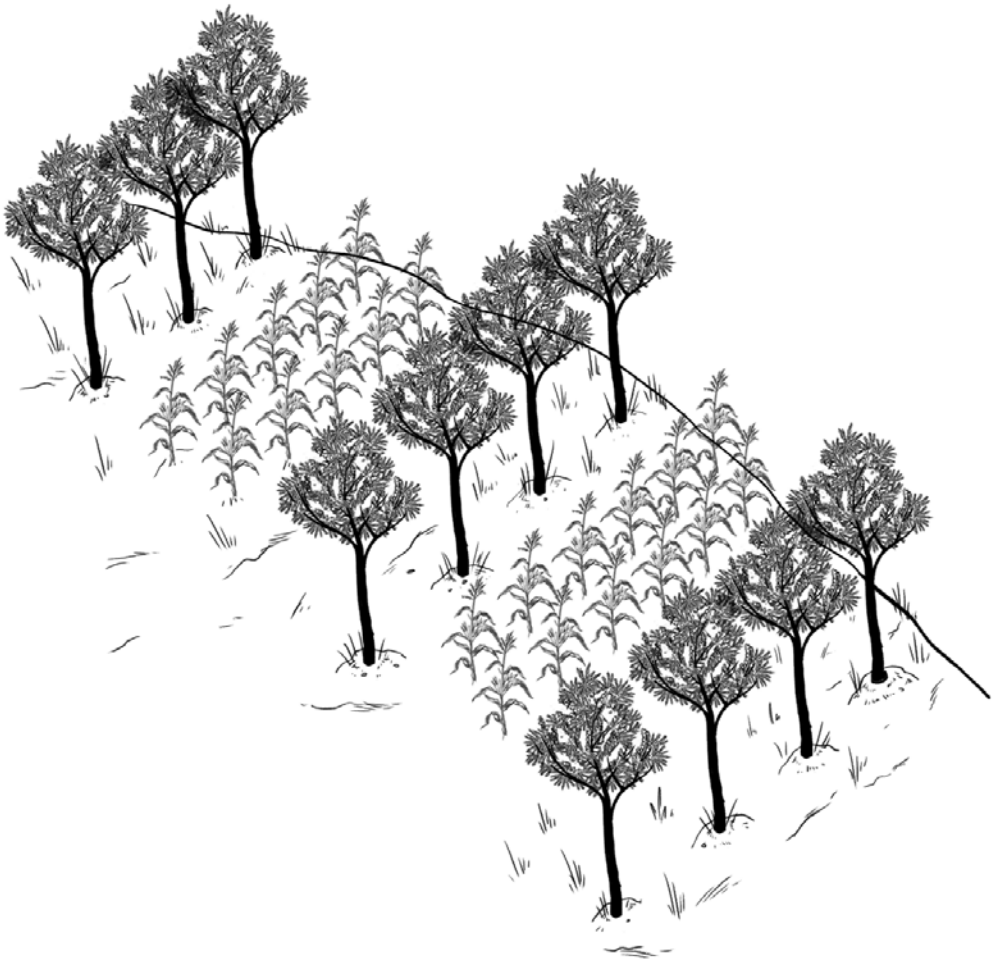
Soil conservation and erosion control



When soil is exposed by the preparation of land for crop planting, it is vulnerable to being blown away by the wind (wind erosion) or washed away by the rain (water erosion). Such soil loss can seriously reduce a farm's capacity to grow crops. The risk of erosion is particularly high in windy locations; in places where the bare soil has been exposed by removal of all vegetation; and on slopes, where rain can quickly wash the soil downhill.

The first way of preventing erosion is to ensure that the land is managed in a way that retains as much plant cover as possible (the cover approach). Then, erosion can be controlled by preventing water flow from carrying away the soil (the barrier approach). Barriers can hold water long enough for it to penetrate the soil, but if local conditions lead to an excessive build-up of water, the barriers should allow controlled runoff to minimize erosion damage and allow the water to reach natural streams and lakes.

In agroforestry systems, trees provide continuous vegetation cover, and their roots play an important role in binding the soil and protecting it from erosion. If planted on slopes, they create barriers that prevent rapid water flow.[4] Grasses like Napier and vetiver can be planted between tree rows to make the barrier more effective, while providing food for livestock.



[4] Zomer, Robert J, Bossio DA., Trabucco A, Yuanjie Li, Gupta DC, Singh VP. 2007. *Trees and water: Smallholder agroforestry on irrigated lands in Northern India*. IWMI Research Report 122. Colombo, Sri Lanka: International Water Management Institute. 41p. https://doi.org/10.3910/2009.122.