Agroforestry in Europe

A practical handbook

By Mauricio Sagastuy & Anna Ternell

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Introduction

Agroforestry is the intentional integration of trees in agriculture. It involves cultivating trees alongside crops and animals to increase the productivity and profitability of farms, while also providing several environmental benefits. Agroforestry has gained increased recognition throughout the world due to its potential to address many contemporary challenges, such as climate change mitigation, loss of topsoil, loss of biodiversity, and increase farmers' resilience towards climatic changes and market variability.

While scientists have consistently demonstrated the enormous potential that agroforestry has for regenerating farmer lands and increasing their productivity (Schievano et al., 2022), there are still many challenges for farmers interested in working with agroforestry. The challenges range all the way from the "know-how", to getting the right support, to market opportunities, or to legislation.

In Europe, studies have shown that agroforestry has the potential to store up to a third of all European carbon dioxide emissions (Aertsens et al., 2012) and produce 20–30 % more than monocultures (Dupraz et al., 2005). To turn these impressive benefits into real-world impact, they must be translated into clear and actionable information for both farmers and city planners. How can European farmers and urban decision-makers implement agroforestry with minimum risks and in a viable way?

This handbook aims to answer these questions by providing practical information and simplifying the principles of agroforestry. To provide a deeper understanding, we examine both the benefits and challenges of working with agroforestry. Additionally, we provide many examples of how farmers are working with agroforestry around Europe to make the information more relevant and context specific.

After reading this handbook, you will have a better understanding of what agroforestry is and how to create agroforestry systems adapted to your own goals, needs and conditions in a European context.

As part of this handbook, Mauricio Sagastuy – the lead author – visited over 40 farms practicing agroforestry across Europe. During these visits, he interviewed farmers to understand how agroforestry is being practiced in different European contexts. The insights and experiences shared by these farmers form the basis of this handbook. We are deeply grateful for their contributions and their generosity in welcoming us onto their farms.

Below you can see a map showing the countries we visited as part of this handbook:

CHAPTER 1

What is agroforestry and why is it important?

What is agroforestry?

Agroforestry is a land use system where trees and shrubs are deliberately integrated with crops and/or livestock on the same area of land. This integration is not incidental – it is intentional, interactive, and designed to harness synergies between woody perennials and agricultural components. Agroforestry includes both the integration of trees on farmland and the use of agricultural crops and livestock in woodlands. According to the European Union (Regulation 1305/2013, Article 23), agroforestry is defined as:

"Land use systems in which trees are grown in combination with agriculture on the same land."

This includes both planting new trees and managing existing ones in ways that bring benefits to the farm and the wider landscape. The practice encompasses a wide variety of systems and designs, adapted to different landscapes, farm types, and cultural contexts. Agroforestry is distinct from both forestry and conventional agriculture. It also differs from mixed farming (which combines livestock and crops) by explicitly integrating woody perennials into the production system (Figure 1). It represents a hybrid approach that draws from both ecological principles and agricultural innovation.

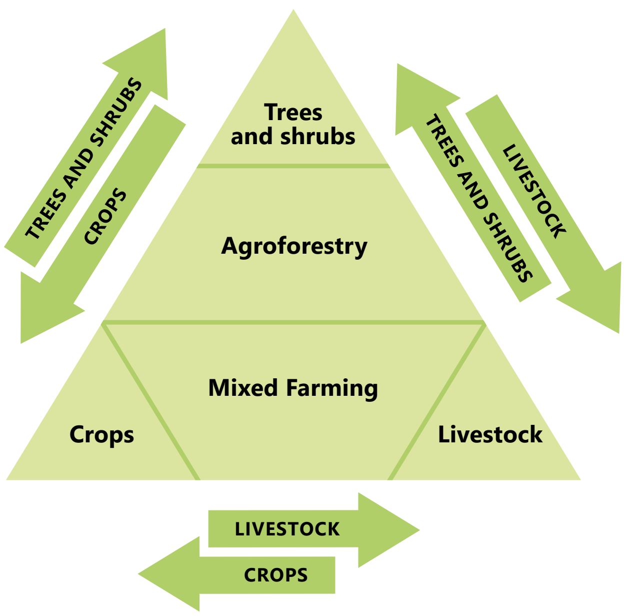

Figure 1 *Comparing agroforestry to other farming systems. Adapted from Herder et al. (2015)*

What are the different types of agroforestry?

While agroforestry typically focuses on integrating trees into agricultural systems, its principles can also be adapted to gardening, public parks, and forestry. In urban environments like gardening and public parks, the goal is to create a forest-like ecosystem designed to produce food. This type of system is commonly referred to as forest garden or homegarden. In forestry, the aim is to introduce crops that thrive in shaded and moisture-rich environments. This practice is called forest farming.

There are countless different spatial configurations and species compositions for European agroforestry. However, to understand agroforestry, it is useful to divide agroforestry systems into certain categories. Rosa Mosquera et al. (2016) identified five distinct types of agroforestry in Europe as part of one of the largest European agroforestry research projects, called AGFORWARD:

- Silvopastoral agroforestry: the combination of trees and livestock
- Silvoarable agroforestry: the combination of trees and crops
- Hedgerows, shelterbelts and riparian buffer strips
- Homegardens/Forest gardens: combinations of trees and food production close to homes
- Forest farming: crop cultivation within a forest environment

A similar categorization has been described by Worms & Lawson (2024), giving more detail on whether agroforestry exists on agricultural or forest land, and whether it is located within or between fields (Table 1).

<table>
<tr><th colspan="4">A typology for types of agroforestry in Europe developed from Worms, P., & Lawson, G. (2024)</th></tr>
<tr><th rowspan="2">Tree location</th><th rowspan="2">Agroforestry system</th><th colspan="2">Agroforestry practice</th></tr>
<tr><th>Agricultural land</th><th>Forest land</th></tr>
<tr><td rowspan="4">Trees inside parcels</td><td>Silvopastoral agroforestry</td><td>Wood pasture</td><td>Forest grazing</td></tr>
<tr><td>Silvoarable agroforestry</td><td>Alley cropping
Alley coppice</td><td>Forest garden</td></tr>
<tr><td>Permanent crop agrofo-restry</td><td>Orchard cropping
Orchard grazing</td><td>Forest farming</td></tr>
<tr><td>Agro-silvo-pasture</td><td colspan="2">Mixture of the above</td></tr>
<tr><td rowspan="2">Trees between parcels</td><td>Windbreaks</td><td>Hedges
Shelterbelts</td><td>Forest strips</td></tr>
<tr><td>Riparian Forest Buffers</td><td colspan="2">Riparian Forest Buffers</td></tr>
<tr><td>Trees in settlements</td><td>Urban agroforestry</td><td colspan="2">Settlement agroforestry</td></tr>
</table>

Table 1 *A typology for types of agroforestry in Europe. Adapted from Worms and Lawson (2024)*

In this handbook we will focus on the first four categories described above by Rosa Mosquera et al. (2016). We are choosing to focus on these categories as these are the systems that are most relevant for agricultural land (the first three systems) and urban environments (the fourth system). Additionally, we are dividing the third system into two categories; windbreaks and riparian forest buffers, because these systems are very different from each other.

In the following five chapters, we describe each agroforestry system in more depth. We outline their most common characteristics, highlight their benefits and limitations, and provide practical information for those interested in establishing these systems on their land. We arranged the five following chapters starting from systems with less tree densities (windbreaks) to systems with more tree densities (forest gardens). Moreover, we added one more Chapter titled "Other agroforestry systems." This chapter explores the many ways farmers are practicing agroforestry across Europe. The way farmers are implementing agroforestry is often a blend of the different classifications, and in some cases, their systems don't fit neatly into any single category. Therefore, it is important to highlight this diversity and emphasize that agroforestry should be adapted to the unique context of each farm, rather than fitting the farm into a predefined system.

The 6 following chapters are:

1. Windbreaks
2. Riparian forest buffers
3. Alley-cropping*
4. Silvopasture
5. Forest gardens
6. Other agroforestry systems

** Alley-cropping is a word commonly used to describe silvoarable agroforestry systems. We are choosing to use the word alley-cropping instead of silvoarable for this chapter.*

Why is agroforestry important?

Agroforestry improves the health of the agroecosystems (agricultural ecosystems) by incorporating more trees into the land and mimicking natural ecosystems. A healthier agro-ecosystem leads to a wide range of benefits for the farmer, the environment and society.

These benefits can be divided into:

- Increased farm resiliency and productivity
- More diverse and profitable farm-enterprises
- Societal benefits: for the farmers and society
- Environmental benefits

Increased farm resiliency and productivity

There is enough evidence showing that **agroforestry systems can produce more per hectare compared to if the crops, animals or trees are cultivated separately (monoculture systems)** (Dupraz et al., 2005). This increased productivity is quantified using the **land-equivalent ratio (LER)**, a metric that compares the yield of intercropping systems to that of sole-cropping systems.

For example, an agroforestry system with a LER of 1,4 indicates that 100 hectares of land managed under agroforestry produces the same amount of combined crops and tree products as 140 hectares of farmland where trees and crops are cultivated separately (see Figure 2 below).

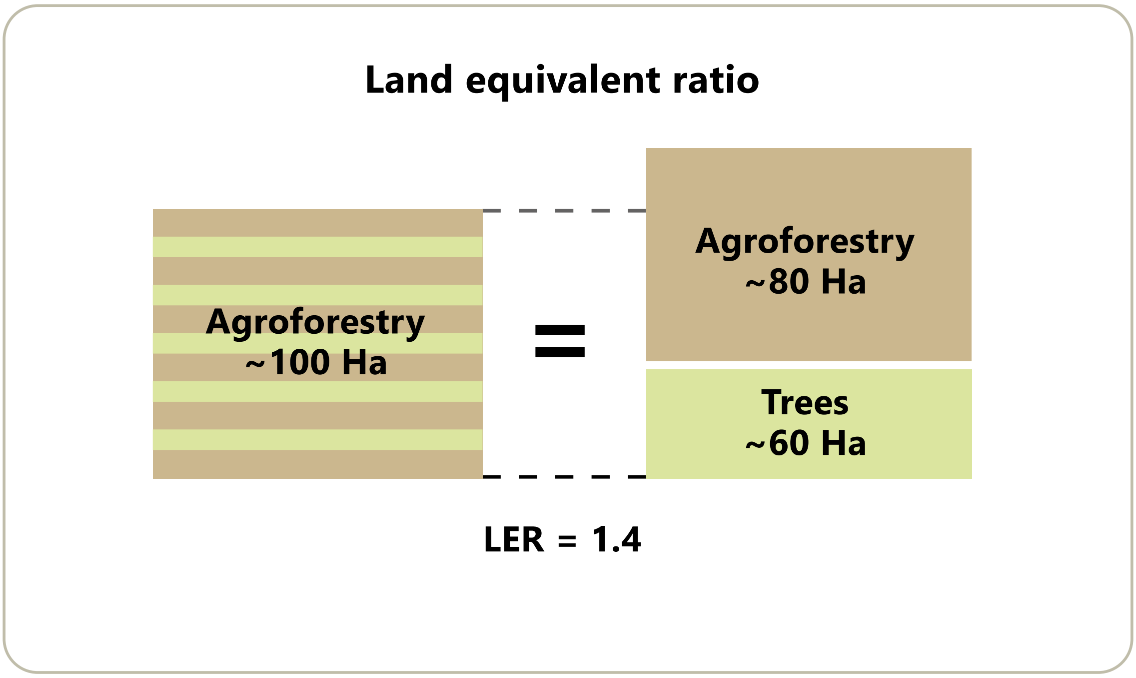

Figure 2 *Land Equivalent Ratio. Adapted from Mead and Willey (1980)*

A pan-European project modeled 42 combinations of trees and crops in silvoarable agroforestry, which resulted in LERs of at worst 1,0 (equal to monoculture) and at best 1,4 (40 % more productive) (Dupraz et al., 2005). Most LERs were in the range of 1,2–1,3, meaning that **European agroforestry systems were on average 20–30 % more productive than monoculture farming systems**.

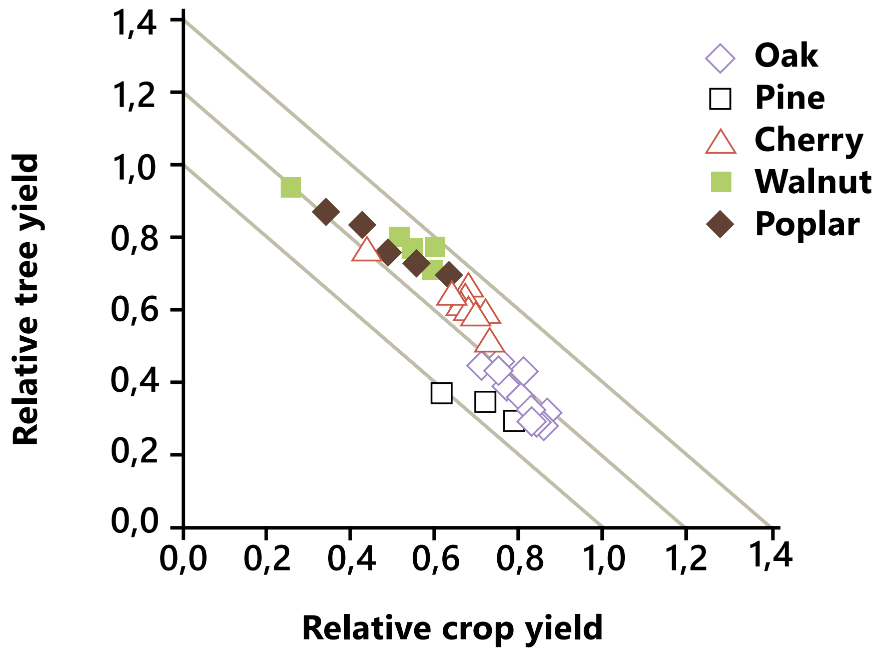

Figure 3 *Figure 3 Land Equivalent Ratio for different tree species. Adapted from Graves et al. (2007)*

Well-designed agroforestry systems integrate trees in ways that maximize the synergistic relationships between trees, crops, and animals. Trees provide **shelter and wind protection**, while at the same time **reducing soil erosion and nutrient loss.** Additionally, trees grow better in agroforestry systems compared to orchards or forestry, because they have more space between each other leading to **less root and canopy competition.** This spatial arrangement also fosters better air circulation, **reducing the prevalence of pests and diseases** commonly found in dense monoculture plantations. These synergistic relationships lead to a more resilient and productive system that can better cope with the ever-increasing environmental changes.

More diverse and profitable farm enterprises

Working with agroforestry is like investing in a farm's infrastructure and investing in a new farm-enterprise at the same time.

The farm's "infrastructure" refers to **all the agroecological benefits that trees provide**, such as reduced soil erosion, minimized nutrient loss, enhanced water retention, increased biodiversity, and protection from the wind. These agroecological benefits create a more stable and supportive environment for crops and animals, which leads to higher productivity and resiliency.

At the same time, agroforestry represents an investment in new business opportunities. By incorporating trees into farms, farmers can **diversify their income by selling additional products from the trees** such as fruits, nuts, timber, firewood, and even medicinal plants. Moreover, farmers can minimize the costs in their farms by being less dependent on external inputs and utilizing the tree-products on their farms, for example firewood or fencing posts.

The most common tree-products that farmers produce in agroforestry are the following:

- Food for humans (fruits, nuts, berries, etc.)
- Fodder for animals
- Materials: fiber, timber, energy

Figure 4 *Landowner Jósef Rogalski (right) and a co-worker in an intercropped orchard, southern Poland. Photo by Mauricio Sagastuy*

Social benefits: for farmers and society

At the core of everything we do lies the emotions we seek to experience. For many, **joy and meaning** are found in contributing to a healthier environment and a more sustainable society. This sense of purpose resonates strongly with many farmers who view their work as more than managing a farm – it becomes a mission to nurture a thriving agroecosystem. Agroforestry aligns with this vision, offering not just practical benefits but also an emotionally rewarding experience. The integration of trees into agriculture enhances the natural beauty of the landscape, creating **more aesthetically pleasing and enjoyable workplaces** that inspire pride and connection.

Beyond the individual level, agroforestry fosters **stronger social bonds within farming communities**. Farms practicing agroforestry often become **hubs for visitors and tourists**, drawn by the beauty and sustainability of these systems. This increased engagement can lead to more frequent interactions with friends and family, who might participate in tree planting or management activities, and even **provide opportunities to employ new staff**, strengthening the local economy. These connections enhance the sense of community and belonging in rural areas.

Additionally, rural landscapes that are more ecologically stable, interconnected, and visually appealing significantly improve the **quality of life for residents**. Beautiful, biodiverse environments attract visitors, benefiting local tourism industries and stimulating economic growth. Moreover, the presence of healthy ecological systems brings a host of intangible benefits – improved mental health, reduced stress, and a deeper sense of connection to nature. These systems also deliver long-term societal gains, including enhanced biodiversity, better air and water quality, and increased resilience to environmental changes, many of which are challenging to quantify in monetary terms but are invaluable for human well-being.

Agroforestry, therefore, is not just an agricultural practice; it is a holistic approach that enriches the lives of farmers, communities, and societies, creating landscapes that are as emotionally rewarding as they are ecologically and economically resilient.

Environmental benefits

The scientific evidence is clear: agroforestry stands out as one of the agricultural practices with the highest potential to generate multiple environmental benefits. A landmark investigation conducted by the Joint Research Centre (JRC) of the European Commission provides compelling evidence to support this claim. Tasked with identifying agricultural practices that could enable Europe to achieve its environmental targets under the new Common Agricultural Policy (CAP) for 2022–2027, the European Commission sought to synthesize existing scientific knowledge.

To accomplish this, the European Commission wanted to gather all possible scientific evidence to determine which agricultural practices could help Europe meet their environmental goals in the new CAP 2022–2027. The Joint Research Center of the European Commission analyzed 32 meta-analyses, 29 of which directly compared agroforestry systems with conventional agricultural practices. Each meta-analysis synthesized findings from 3 to 140 individual studies, providing a robust evidence base. The results consistently demonstrated that agroforestry outperforms conventional agriculture across multiple dimensions, particularly in areas such as carbon sequestration, biodiversity, soil fertility, water retention, and erosion control. These findings highlight agroforestry's ability to integrate productivity with ecological sustainability, making it a cornerstone for transitioning toward more resilient and environmentally friendly farming systems. The meta-analyses consistently showed that, compared to conventional agriculture, agroforestry performs better in the following areas:

- Reducing erosion
- Improving biodiversity and increasing the number of pollinators
- Reducing diseases and pests in agriculture
- Increasing carbon sequestration in the soil
- Reducing greenhouse gas emissions
- Increasing soil water retention capacity

The most important findings of the cited study are summarized below:

Soil health

The health of the soil reflects the overall health of the agroecosystem. Healthy soil supports long-term agricultural productivity, enabling farmers to achieve better yields sustainably. Unfortunately, the health of agricultural soil is declining globally, primarily due to soil erosion and nutrient loss. Globally, conventional cropland erodes at a rate of 30 tons per hectare per year (Pimentel et al. 1995), while forests experience erosion rates of just 0,004 to 0,05 tons per hectare per year. This stark contrast highlights a critical issue: soil is being lost from agricultural lands 10 to 40 times faster than it is formed, threatening global food security and resulting in trillions of dollars in lost yields and livelihoods (Pimentel et al., 2013).

Agroforestry offers a solution by significantly reducing soil erosion and enhancing soil fertility. This improvement is achieved through better nutrient cycling, increased soil organic matter, greater soil carbon sequestration, and higher water retention. Four meta-analyses demonstrated that, compared to conventional agriculture, agroforestry increased nutrients stocks in soils by 20–70 % (Schievano et al., 2022). Moreover, 3 meta-analyses showed that agroforestry decreases soil erosion and nutrient runoff by 50–80 % (Schievano et al., 2022). These results underscore agroforestry's potential to restore and maintain healthy soils.

Biodiversity and pollination

Tree-based ecosystems are the richest land-based ecosystems on the planet. Globally, forests cover almost one third of the land area, and they hold around 80% of all land-based biodiversity (United Nations International Year of Forests, 2011). Integrating trees into farms creates new habitats for insects, birds and other animals. This **increase in biodiversity** creates more stable and resilient systems that can better cope with environmental changes, pests and diseases. Trees and shrubs also **feed the pollinators**, which improves farmers' yields by pollinating the plants that feed us. Three different meta-analyses demonstrated that, compared to conventional agriculture, agroforestry increases biodiversity indices by 20–50% (covering several taxa like plants, birds, invertebrates, reptiles, fungi, mammals, and amphibians or functions (e.g. pollination)) (Schievano et al., 2022).

Carbon sequestration

Agroforestry can be a great tool to **reduce the emissions of greenhouse gases** in agriculture. A shift from conventional agriculture to agroforestry can mitigate 14–27 tons of CO2 per hectare per year, at least for the first 14 years after establishment (Kim et al., 2016)

A study analyzing the carbon sequestration potential of various agricultural practices revealed that if all European farmers were to adopt agroforestry practices, Europe could sequester one-third of its CO2 equivalent emissions (CO2-e emissions in the EU in 2007). This study also concluded that, among various agricultural practices including (1) agroforestry, (2) introducing hedges, (3) low and no tillage, and (4) cover crops, **agroforestry is the agricultural practice with the highest potential to store carbon**, accounting for 90% of the total potential of all the measures studied (Aertsens et al., 2012).

Measure	Potential area EU-27 (mio ha)	Potential per ha per year (tonne C)	Potential EU-27 mio tonnes C/year	Potential EU-27 mio tonnes CO2-eq./year
Agroforestry on arable land	90	2,750	248	906
Agroforestry on pastures	50	2,750	138	503
Hedge rows	178	0,100	18	65
Cover crops	119	0,160	19	70
Low/no tillage	60	0,100	6	22
All			**428**	**1566**

Table 2 *The carbon sequestration potential of different agricultural measures in Europe. Adapted from Aertsens et al. (2012)*

Water

Global warming, environmental pollution and the increased pressure on our natural resources are affecting the stability of water resources around the world. Given that freshwater is becoming a scarce and valuable resource, it will become increasingly important that we produce more food with less water and that we find ways to reduce water contamination.

Integrating more trees into agricultural land **reduces evapotranspiration, improves the soil's structure** via the roots and **increases the soil organic matter** via the leaves. This leads to an **increased water-holding capacity** and **improved water-infiltration**.

According to 5 meta-analyses, the water retention in soil increased to 50–100 % when introducing agroforestry practices to conventional agriculture (Schievano et al., 2022). This is becoming increasingly important for farmers, due to the constant rise in temperatures and droughts.

Additionally, agroforestry mitigates the environmental impact of common agricultural practices by **reducing the number of eroded particles that end up in streams**, rivers and lakes (50–80 % less soil erosion and nutrient runoff according to 3 meta-analyses) (Schievano et al., 2022). Less eroded particles in waterways means less sedimentation and **less contamination from leached nutrients, fertilizers and pesticides.**

CHAPTER 2
Windbreaks

What are windbreaks?

Windbreaks, also known as hedges or shelterbelts, are rows of trees or shrubs planted to protect crops and animals from the wind and snow. They help decrease soil erosion, reduce evapotranspiration, increase farmers' yields, and provide many more benefits to the farm. Moreover, an additional benefit is that windbreaks can be established with relatively low establishment and management costs, and without trees taking too much space in a farm.

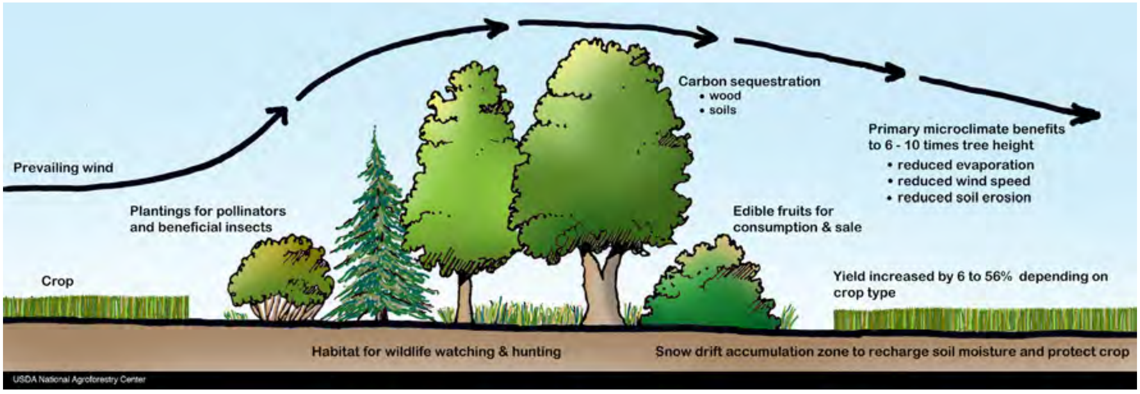

Figure 5 *Illustration of a multifunctional windbreak. Source: USDA National Agroforestry Center, Illustrator: Gary Bentrup,* CC BY 2.0

Figure 6 *Windbreaks protecting the crops in a farm in the region of Västra Götaland. Sweden. Photo by Mauricio Sagastuy*

Windbreaks have several different positive effects on the land, and they can be planted for several different purposes. Therefore, **windbreaks can be thought of as the green infrastructure of a farm.** By strategically placing them, farmers can create a web of trees that improves the health of the entire agroecosystem without them disturbing the farm's management or taking too much productive land from the farm.

As shown in the image below, windbreaks can be planted for many different purposes. The four functions they usually have are**: (1) wind protection (2) snow management (3) habitat for beneficial organisms**, and **(4) new products from trees and shrubs.** Additionally, **windbreaks can fulfill other roles as well**, such as blocking unpleasant smells, blocking chemical spray particles, reducing nutrient leaching, and assisting with water management. The specific functions you are trying to get from your windbreaks will determine where you should place them in your farm.

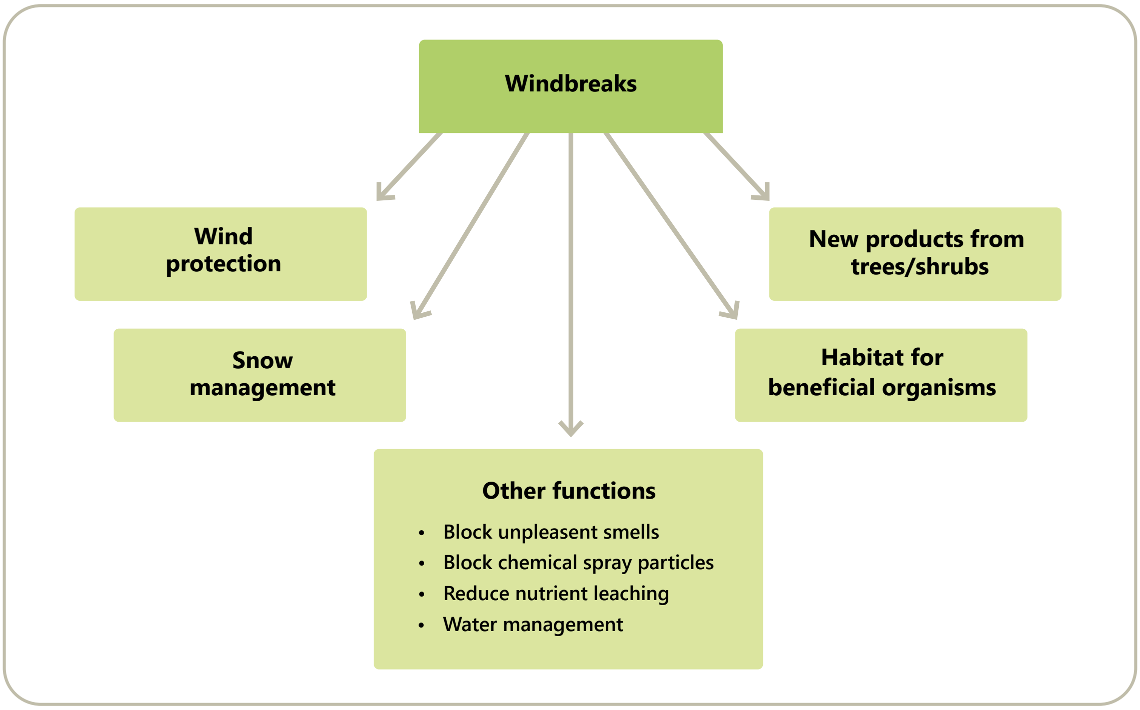

Figure 7 *The most common functions of a windbreak.*

Wind protection is the most obvious function of a windbreak. Protecting your crops and livestock from the wind will allow them to grow better and produce better yields. The health of the soils on your farm will also improve by reducing evapotranspiration and soil erosion. Additionally, windbreaks help protect farm buildings from the wind, leading to reduced heating costs.

Windbreaks can also help **control the movement of snow on the farm**. By protecting your crops and livestock from snow, you reduce the stress they are exposed to. Additionally, windbreaks can prevent snow from accumulating in areas like feedlots and help protect barns from heat loss.

Another function of windbreaks is to **provide habitat for wildlife**, which increases a farm's biodiversity. They can attract beneficial organisms, such as pollinators or natural predators of insects that damage farmers' crops. This may lead to increased yields and improved farm resiliency.

The fourth main function of windbreaks is to **produce new products from the trees and shrubs**. These products can range from products with well-established markets, such as fruits, berries, nuts, or timber, to more niche products like flowers or Christmas products (e.g. Christmas trees, holly, mistletoe).

As shown in the image above, windbreaks can have several other purposes. They can be planted to **block unpleasant smells** from livestock and its manure, or to **block chemical sprays**, such as pesticides or herbicides, that are blowing to or from a field. Strategically placed windbreaks can also **reduce nutrient leaching**. Moreover, windbreaks can help **manage the presence of water in a field and redirect its movement**, for example by absorbing water through their roots, preventing soil erosion, or by increasing the moisture in the soil.

The benefits and limitations of windbreaks

Windbreaks are in general beneficial for crop and livestock production. However, there may be some situations where windbreaks can harm crops or livestock production. Below, we present the main benefits and potential limitations of incorporating windbreaks into a farm (Marshall, 1967; Osorio, 2018; Smith et al., 2021). In this list, we also explain what you can do to minimize the risks of certain limitations:

Benefits:

- Significant reductions in wind speed
- Higher concentrations of soil moisture
- Higher daytime air-temperatures and lower evening air-temperatures
- Higher soil temperatures
- Higher relative humidity during the day
- Significant reductions in evapotranspiration
- Habitat for beneficial organisms & increased biodiversity

Limitations:

- Higher competition for water and nutrients with trees in areas just next to the windbreaks.
- Shading from trees in areas adjacent to the windbreaks.
- Windbreaks will remove some land from production.
- Windbreaks will require intensive management in the early years and a slow return on investment.
- Fungi thrive in humid environments. Too little airflow can create a more humid environment that increases the risk for fungal diseases. Make sure to let enough air flow through the windbreaks to minimize this risk.
- Windbreaks may create a beneficial environment for damaging organisms, such as certain insect species, certain bird species, or damaging fungi. Thus, you should select tree species that won't attract damaging organisms to your farm.
- Windbreaks should not block cold air flowing downhill, thereby increasing the risk of frost.

The effect that windbreaks have on the land

Most types of agroforestry systems provide some kind of wind protection; therefore, it is important to understand the effects that windbreaks can have, regardless of the type of agroforestry system you want to establish.

The image below shows the impact of windbreaks on the lee side, the side of your field that is protected from the wind (Marshall, 1967). As you can see, **by reducing windspeed you reduce evaporation and increase air and soil temperatures. This leads to higher soil moisture and increased crop yields.** The taller the windbreak, the broader its protective effect will be on the lee side of your field. A simple guideline is that **for every meter of windbreak height, it provides protection over an area 10 times as wide. For example, a 10-meter-high windbreak can protect an area up to 100 meters wide.**

As shown in the image below, the influence of windbreaks diminishes with increasing distance from the windbreak. The closer the field is to the windbreak, the more pronounced the effect will be.

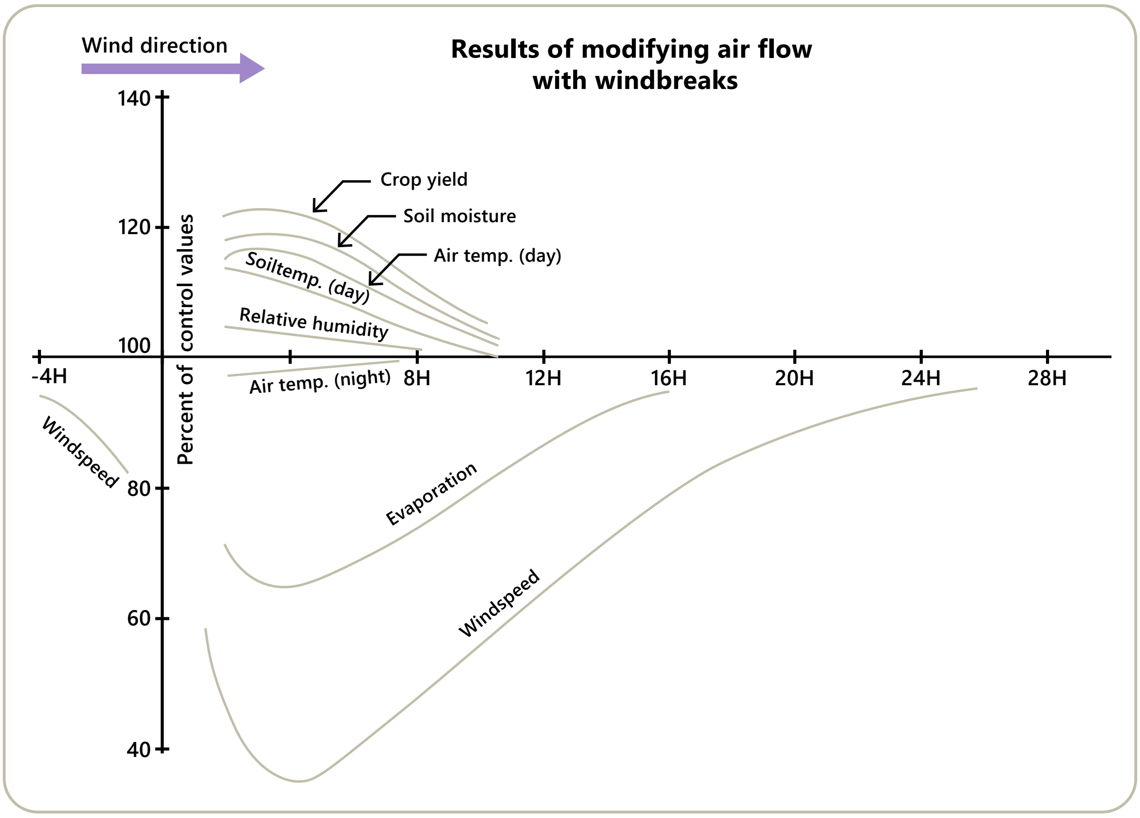

Figure 8 *Patterns of microclimate and crop production. "H" stands for multiples of windbreak height. Adapted from Marshall, J.K. (1967)*

How windbreaks affect crop production

Looking at the graph above, you may wonder how these effects influence your crop production. To begin with, it is important to note that shading, interception of rainfall, and competition for water and nutrients are going to negatively impact crop yields in areas closest to the windbreaks – approximately within -1 H to 1 H on either side of the windbreak (see Figure 9). The rest of the field that gets wind protection and isn't too close to the windbreaks will experience the positive effects listed above. The area that will experience most of the positive effects is the leeward area that is approximately 1-10 H from the windbreak. Additionally, you can expect your yields to increase in the windward side of -1 to -4 H and in the leeward side area of 10–15 H, even though these increases in yields won't be as significant as for the leeward area between 1–10 H. To sum up, **you should expect the total yield of your crops to be higher with windbreaks in most cases, even when taking its negative side-effects into consideration.**

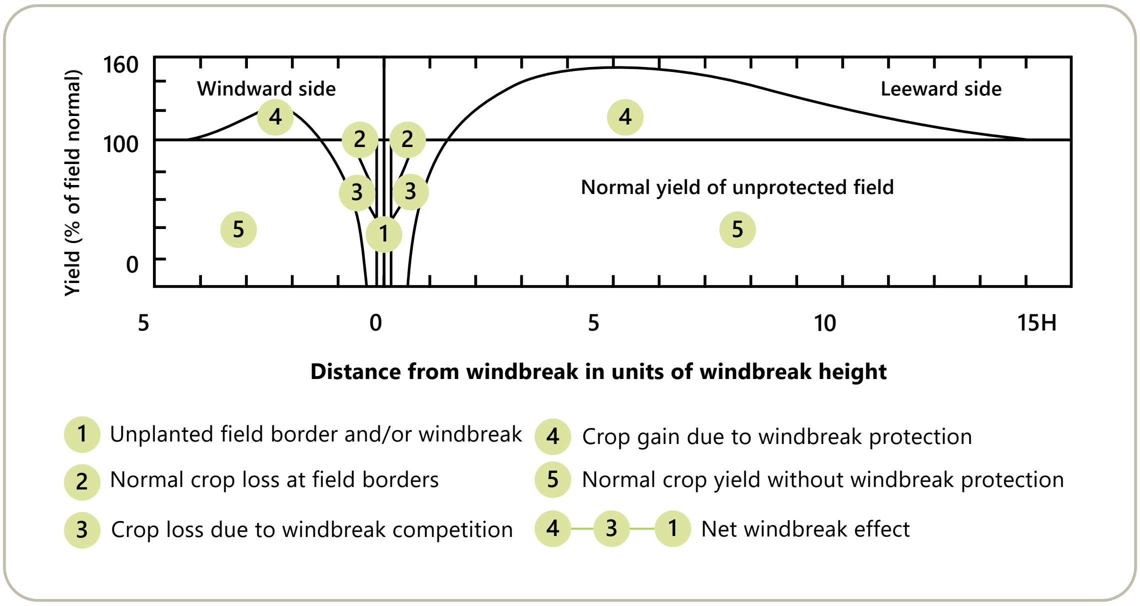

Figure 9 *Crop field response for a field windbreak. Adapted from Osorio, R. J. (2018)*

Another aspect to consider is understanding how much specific crops will benefit from wind protection. Not all crops benefit equally as much from wind protection. To estimate the potential yield increases for your specific crop, you should look for scientific studies that analyze the impact of wind protection on your specific crop. Below, you can see a table showing the yield increases of different crops when wind protection was provided.

Crop	Number of field years	Mean yield increase (in %)
Oats	48	6
Spring wheat	190	8
Maize	209	12
Soybeans	42	16
Rye	39	19
Grass hay	14	20
Winter wheat	146	22
Barley	30	25
Raspberry	2	27
Tomatoes	3	29
Plum	2	34
Snap beans	2	40
Millet	18	44
Strawberry	3	56

Table 3 *Yield increase of different crop species with wind protection. Data from Bagley (1964), Baldwin (1988), Brandle et al. (2009), Norton (1988), Kort (1988), and Osorio et al. (2018). Number of field years means all the added years that scientific studies were conducted for each crop.*

Some crops are more sensitive to wind than others. **In general, fruit, nuts, and berries are the agricultural crops that benefit most from wind protection.** A more stable microclimate is especially beneficial during flowering and fruit development. Additionally, reduced wind speeds can improve pollination, minimize damage to delicate fruit, and reduce fruit drop.

Vegetables are the second group of agricultural crops that benefit most from windbreaks, particularly those with large and vulnerable fruits. **Cereals, root vegetables, and legumes are the third group, as they are generally less vulnerable to wind damage and exposure**. However, this classification is a broad generalization. For example, as seen in Table 3, millet is more sensitive to wind than plums or raspberries.

You can calculate how much your yield will increase or decrease by following these steps:

1. Write down the percentage (%) of productive land that will be lost due to the establishment of windbreaks.
2. Multiply the remaining productive land by the current yield plus the added increase in yield shown in Table 3.
3. Subtract your current yields from the result you got from step 2 to determine how much your yields will change by establishing windbreaks.

For example, a common scenario is planting a 10 m thick and 20 m high windbreak every 200 m. This would reduce the crop production area by 5 %. To maintain previous productivity, you would need at least a 5 % yield increase. In other words, even with a 5 % reduction in productive land, overall yields should still be higher with any crop listed in Table 3 – even for those that experience the least benefit from wind protection.

Figure 10 *Windbreaks at the Cean-Doldut production farm, Cluj County, Romania. The windbreaks were planted in 1952 as part of a research site established during the time of the Soviet Union. Photo by Adrian Gliga*

The increases in yield shown above are very significant for most crops. This means that establishing windbreaks is a smart economic decision in most cases. You should outweigh yourself if the expected benefits make up for the land that will be lost from production, the money you will have to invest, and the time you will put into its management. As mentioned in the beginning of this chapter, windbreaks are the type of agroforestry systems that require less investment and management. Therefore, windbreaks are the type of agroforestry system that should work best for you if you don't want to invest too much money into your system or you don't want to make major changes to your farm's management.

What's truly remarkable is that the benefits listed above don't even account for the additional ecosystem services provided by windbreaks, such as reduced wind erosion, improved insect biodiversity, and decreased nutrient runoff.

How windbreaks affect livestock's yields and wellbeing

Windbreaks can also provide many benefits for livestock. **By protecting livestock from the wind, their cold stress gets reduced, which has several positive effects on their health and well-being. This improves both animal welfare and productivity.**

Studies have shown that sheltered areas can increase dairy milk production by 17 % (Blore, 1994) and boost sheep live weight by 10–21 % (Raskin & Osborn, 2019). Windbreaks can also significantly reduce livestock mortality rates at birth or during extreme weather conditions. Trials in southeastern Australia demonstrated a 50 % reduction in newborn lamb losses where effective shelter was in place (Broster et al., 2012). Another study in New Zealand found that wind protection reduced twin mortality by 14–37 % and overall mortality by 10 % (Raskin & Osborn 2019). Shelter also lowers the risk of ewe mastitis (Raskin & Osborn 2019).

Additionally, livestock require significantly more energy to maintain their health in exposed conditions. **Sheltered animals use less energy to regulate their core body temperature, leading to lower feed costs.**

As you can imagine, calculating the increase in yields for livestock is not as easy as with crops. Animals can move around the field to find the most sheltered areas and can also seek shelter within their herd, which complicates wind exposure calculations. Additionally, to estimate improved profitability, one needs to calculate reductions in feed costs and livestock mortality. However, it is still possible to make good estimations of how much your livestock is affected by wind and how much you can save on feeding costs with windbreaks. Below, we explain this in more detail.

To begin with, it is important to understand what “wind chill” is and how it affects livestock. **Wind chill refers to the effective air temperature animals experience, which is influenced by both the actual air temperature and wind speed (see Table 4 below).** As wind speed increases, more heat is lost from the animal to the environment.

Estimated Wind Speed (km/h)	Actual Thermometer Reading (°C)									
	4	-1	-7	-12	-18	-23	-29	-34	-40	-43
	Equivalent Temperature (°C)									
Calm	4	-1	-7	-12	-18	-23	-29	-34	-40	-43
8	2	-4	-11	-17	-24	-30	-37	-43	-49	-53
16	1	-6	-13	-20	-27	-33	-41	-47	-54	-58
24	0	-7	-14	-22	-28	-36	-43	-50	-57	-61
32	-1	-8	-16	-23	-30	-37	-44	-52	-59	-63
40	-2	-9	-16	-24	-31	-38	-46	-53	-61	-64
48	-2	-9	-17	-24	-32	-39	-47	-55	-62	-66
56	-2	-10	-18	-26	-33	-41	-48	-56	-63	-67
64	-3	-11	-18	-26	-34	-42	-49	-57	-64	-68
80	-3	-11	-19	-27	-35	-43	-51	-59	-67	-71
97	-4	-12	-20	-28	-36	-44	-52	-60	-68	-72

Frostbite times		
30 minutes	10 minutes	5 minutes

Table 4 *Wind chill temperatures based on air temperature and wind speed. Adapted from the United States National Weather Center*

Different animal species and breeds have different tolerance levels to cold stress (see Table 5 below). **Animals with thicker or more insulating fur/coats, as well as those with higher metabolic rates, are more resistant to cold stress.** For example, sheep and goats tolerate wind exposure better than pigs or chickens. Similarly, cattle with winter coats are more resilient to cold than those with summer coats.

As illustrated in Table 5, the more tolerant an animal is to cold stress, the lower its "lower critical temperature" (LCT) will be. The LCT refers to the effective temperature below which an animal must increase its metabolic rate to maintain a constant body temperature. In other words, when the effective air temperature falls below the LCT, animals experience cold stress and require extra energy – either from feed or energy reserves (body fat) – to maintain their core body temperature.

Coat Description	Critical Temperature (in °C)
Summer Coat or Wet	16
Dry Fall Coat	7
Dry Winter Coat	0
Dry Heavy Winter Coat	-7

Table 5 *The lower critical temperature of different cattle breeds. Adapted from Ames (1978)*

Table 6 below shows the percentage increase in maintenance energy requirements for cattle per °C below the LCT. By using tables 4–6, you will be able to determine how much your livestock is affected by wind chill and estimate potential feed savings by providing wind protection. Below, we explain how to calculate your livestock's feed needs (maintenance energy requirements) both with and without shelter:

Coat Description	**Cow Weight, kg**			
	455	500	545	590
	Percentage Increase per (°C) Degree of Coldness			
Summer Coat or Wet	3,6	3,6	3,4	3,4
Fall Coat	2,5	2,0	2,2	2,3
Winter Coat	2,0	2,2	2,0	1,8
Heavy Winter Coat	0,7	0,9	1,1	1,3

Table 6 *Percentage increase in maintenance energy requirements for cattle per °C degree below Lower Critical Temperature. Adapted from Simms (2009)*

Maintenance energy requirements = (Effective air temperature (windchill) - **Lower Critical Temperature) x Percentage increase in maintenance energy per degree of coldness** (for your livestock's breed and weight).

For example, a 450kg cow, with its winter coat, has a lower critical temperature of 0 °C (Table 5) and requires 2 percent more feed per °C degree of cold (Table 6). If the temperature is -12°C and the wind speed is 16 km/h, the windchill temperature would be -20°C (Table 4). By following the formula above, you will realize that in this case your livestock would need 40 % more feed.

If your livestock were protected by a windbreak that provides a 70 percent reduction in wind speed, the wind chill factor would change from -20 °C to around -14 °C. This would result in a 6 °C difference between the "effective air temperature" and the "lower critical temperature." As a result, the feed requirement would increase by only 28 %, saving you 12 % in feed costs. Colder temperatures or higher wind speeds would lead to even greater savings due to windbreak protection.

Case study: Windbreaks transforming the agricultural landscape in Turew, Poland

In the vast agricultural landscapes of Wielkopolska, Poland, wind and low rainfall has always been a problem for farmers. To make matters worse, climate change has intensified these challenges by increasing the rate of steppification - the transformation of farmland into dry grasslands due to increased aridity.

It is in this region, around the town of Turew, that a general named Dezydery Chłapowski established an extensive 17 500-hectare network of windbreaks in the early 19th century to make agriculture more resilient and productive. The windbreaks were planted to decrease soil erosion, increase soil humidity, and increase yields.

The windbreaks around Turew are typically 200–300 meters apart and 12–15 meters wide. This setting allows for efficient fieldwork while maximizing wind protection. The first windbreaks were established using mainly black locust (*Robinia pseudo acacia*). Over time they have become more diverse, including species such as birch (*Betula spp.*), oak (*Quercus spp.*), elm (*Ulmus spp.*), linden (*Tilia spp.*), and pine (*Pinus spp.*).

***Figure 11** Windbreaks at Turew, Poland. Photo by Mauricio Sagastuy*

Nowadays, intensive farming is being practiced inside the windbreaks. Both large agribusinesses and smaller family-run farms cultivate the land. The windbreaks of Turew have stood the test of time and they are a clear reflection of what agroforestry represents. Planting them was an uncommon approach at the time, and despite the initial higher investment costs, farmers nowadays enjoy their benefits. Both large-scale agribusiness and smaller family-run farms want to preserve the windbreaks, as they make their farms more productive and resilient, especially when facing future climatic changes.

Figure 12 *Windbreaks at Turew, Poland. Photo by Mauricio Sagastuy*

CHAPTER 3
Riparian forest buffers

What are riparian forest buffers?

Riparian forest buffers are strips of grass, shrubs, and trees planted along waterways to protect water quality. Their main function is to filter agricultural runoff, prevent soil erosion, and provide habitat for aquatic and terrestrial species. They are particularly effective in reducing nutrient loading into rivers and streams, thereby mitigating problems like algal blooms.

Riparian forest buffers are typically divided into 3 different vegetation zones. Each vegetation zone has a specific purpose for filtering agricultural pollutants and protecting the adjacent aquatic system. This three-zone system allows for effective management while maximizing the environmental benefits of the buffer.

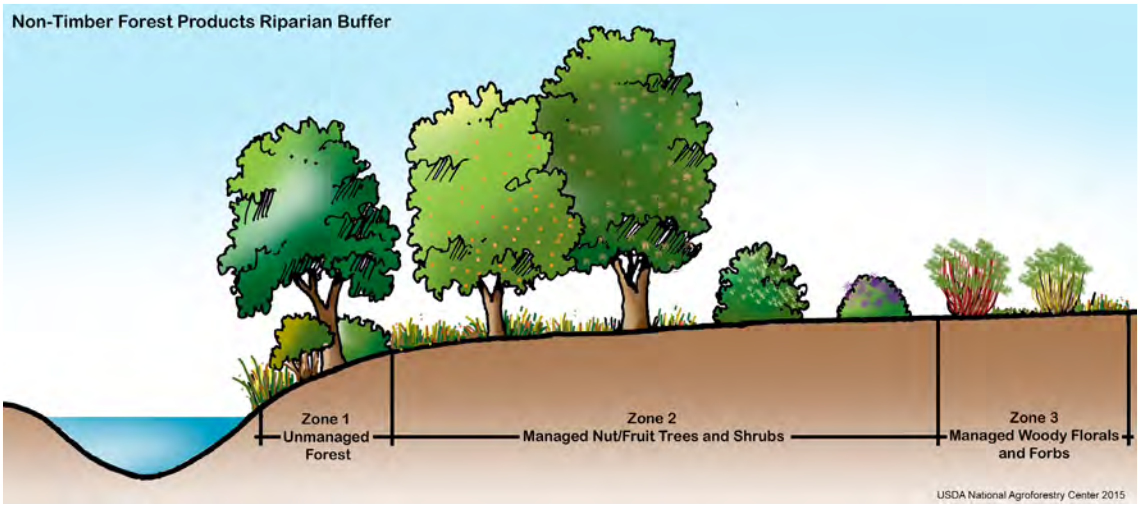

Figure 13 *The three-zone-system of riparian forest buffers. Source: USDA National Agroforestry Center, Illustrator: Gary Bentrup,* <u>CC BY 2.0</u>

Zone 1 is the zone directly bordering the water body. Its main purpose is to stabilize stream banks, shade the water source, and provide habitat for aquatic organisms. Additionally, the vegetation in this zone produces leaf litter, which serves as a food source for macroinvertebrates, which are then consumed by fish.

This zone is mainly composed of native tree species adapted to floodplain hydrology. This area should not be disturbed by practices like grazing, logging, or heavy machinery, as they can impact the ecological balance, and the environmental benefits provided by this zone.

Zone 2 is the transition zone between grassland and forest. Its primary purpose is to filter pollutants, reduce sedimentation, and provide habitat for wildlife. This zone consists of native trees and shrubs that can tolerate periodic flooding. This area can also be managed to generate additional income from timber, nuts, fruits, berries, or woody floral products.

Zone 3 is the area adjacent to crop fields or grazing lands. It acts as the first line of defense by absorbing nutrients, providing high infiltration, filtering sediments, and slowing water runoff. This zone consists of native grasses, wildflowers, or other herbaceous plants that must be continuously removed to provide effective nutrient sequestration. Removal may be in the form of grazing or mowing but it is essential for maintaining the vigor of the plant community.

Figure 14 *Riparian forest buffer in Iowa, United States. Source: USDA National Agroforestry Center,* CC BY 2.0

The benefits and limitations of riparian forest buffers

Benefits:

Water quality: Riparian forest buffers act as natural filters, absorbing and filtering animal waste, nutrients, sediments, and pesticides from crop and rangelands.

Wildlife habitat: Riparian forest buffers provide habitat and travel corridors for diverse plant and animal species. They offer food, shelter and breeding grounds for fish and aquatic organisms, as well as terrestrial wildlife. The shade that the trees and shrubs provide regulates the water temperature, which is especially important for aquatic cold-water species.

Erosion control: The vegetation in riparian buffers stabilizes streambanks and shores, preventing erosion caused by water flow and minimizing soil loss.

Flood mitigation: Riparian forest buffers slow down surface runoff and absorb excess water, which reduces peak flows during flood events and lessens downstream flooding.

Additional income: Riparian forest buffers can increase the land value and provide extra sources of income. Trees can produce profitable timber or non-timber products while at the same time maintaining buffering capacity. Additionally, increased wildlife habitat may attract game animals, allowing landowners to lease hunting rights.

Figure 15 *Tree rows with natural understory vegetation protecting a stream from nutrient runoff at Domin's farm, Brandenburg, Germany. Photo by Mauricio Sagastuy*

Limitations:

Loss of productive land: Establishing riparian forest buffers reduces the amount of land available for crops or livestock. However, riparian areas are prone to periodic flooding and have a shallow depth to the water table, which results in lower agronomic yields. Riparian forest buffers can offset the loss in yields, and even increase them, by having vegetation that favors pollinators and crop pest predators (Pywell et al., 2015).

Increased management: Riparian forest buffers require ongoing management, particularly in the early years. How much management is needed depends on the chosen plant species and its design. Typical management tasks include weed control, pruning, replanting, protection from wildlife, and irrigation (during the establishment phase).

Financial costs: Establishing and maintaining riparian forest buffers may require significant investments, such as planting, protection from wildlife, and increased management time.

Possibly, lower yields in the riparian forest buffer: Riparian areas often experience periodic flooding and shallow water tables, which pose risks to harvestable products. Selecting plant species adapted to floodplain hydrology can mitigate these risks.

Design considerations

The same principle that applies to any type of agroforestry system applies to riparian forest buffers as well: how you design your system depends on the outcomes you want to achieve. Riparian forest buffers can be planted for many different purposes, and the function(s) you want them to have will influence their design. Below you can see a figure showing the recommended buffer widths based on the benefits you want to achieve. For most of these benefits, research is limited, so the indicated widths represent best estimates (Schultz et al., 2022).

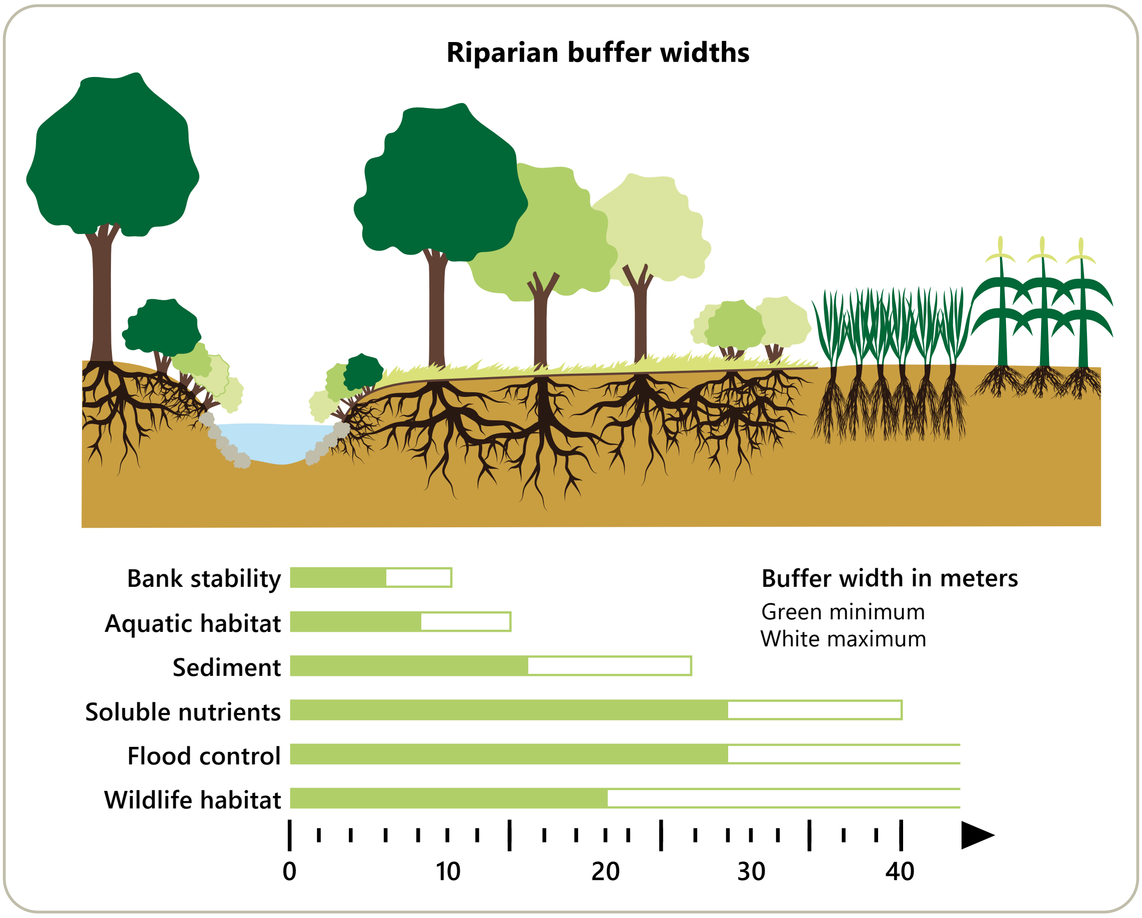

Figure 16 *Estimated buffer width required for providing each specific benefit. Adapted from Schultz et al. (2022)*

As shown above, the width of a riparian forest buffer will influence its function and the benefits it provides. The wider your riparian buffer, the more functions it fulfills. Therefore, a good rule of thumb for riparian forest buffers is: "the wider, the better".

Besides the width of the riparian buffer, the plant species you choose will also determine its function. Different plant species impact the function of a riparian forest buffer in different ways via their roots, organic matter, the nutrients they absorb, and the way they grow. Thus, you should choose plant species that will help you achieve your desired outcomes and plant them strategically in each buffer zone. The table below illustrates how effective grasses, shrubs and trees are at contributing to specific benefits.

Benefit	Vegetation type		
	Grass	Shrub	Tree
Stabilize bank erosion	low	high	high
Filter sediment	high	medium	medium
Aquatic habitat	low	medium	high
Range, pasture, and prairie wildlife	high	medium	low
Forest wildlife	low	medium	high
Economic products	medium	low	medium
Flood protection	low	medium	high
Filter nutrients, pesticides, microbes			
Sediment bound	high	medium	medium
Soluble in surface runoff	medium	low	low
Soluble in subsurface flow	high	medium	high

Table 7 *Specific benefits that different types of vegetation provide. Adapted from Dosskey, Shultz, and Isenhart (1997)*

The third aspect that will influence your design is how you divide the different zones of your riparian forest buffer. Using the three-zone system allows for efficient management while maximizing its environmental benefits. While strictly following this system is not required to achieve your desired results, aligning your design with it as much as possible will help retain the buffer's critical environmental functions.

Below, we outline key design considerations for each zone. These recommendations serve as general guidelines (Schultz et al., 2022; University of Missouri, 2018), and can be adjusted to fit your specific context and objectives.

Zone 1:

- This zone should be **at least 5 meters wide.**
- **Select tree species that can withstand the frequency, magnitude and duration of the flooding regime at your site.**
- Choose tree species adapted to the depth of the water table during the growing season.
- **Native species** are recommended for this zone, due to their importance for aquatic and terrestrial wildlife.

- **Fast growing tree species adapted to floodplains** are preferred, especially if the channel is incised or if rapid streambank stabilization is needed. Examples of such tree species are willow (*Salix* spp.), cottonwood (*Populus* spp.), green ash (*Fraxinus pennsylvanica*), and silver maple (*Acer saccharinum*).
- Shrubs, deep-rooted grasses and herbaceous plants can also be planted in zone 1, however they do not provide the same stability to steep banks because of their more rapid turnover.

Zone 2:

- This zone is usually **at least 18 meters wide.**
- It is recommended to have **4 to 5 rows of trees in this zone.**
- **Trees in rows 1 and 2 (nearest the stream zone), and possibly row 3, should be selected for their ability to develop roots quickly and be adapted to floodplain hydrology, which increases bank stability.** The recommended species for these rows are like those for zone 1, such as willow (*Salix* spp.), cottonwood (*Populus* spp.), green ash (*Fraxinus pennsylvanica*), and silver maple (*Acer saccharinum*).
- **The outer area of the tree zone (rows 3 to 5) can be managed for additional income.** Tree species that produce bioenergy, firewood, high-value timber, nuts or fruits are good choices for these rows.
- If the water table is at least 1 meter below ground for most of the growing season, plant tree species that require good drainage. For sites with poor drainage, select species more tolerant to wet conditions.
- Shrubs also develop a perennial root system, and they can fulfill similar functions as trees, though trees typically provide greater benefits. **Extra rows of shrubs can be planted outside the tree zone to add diversity, enhance wildlife habitat, and produce additional products.** Multi-stemmed shrubs also slow floodwater and trap floating debris, keeping it out of adjacent crop fields or pastures.
- If desired, herbaceous plants and wildflowers can also be established in this zone to further increase the biodiversity of the system.
- Planting a diverse mix of species is recommended, as it increases the resiliency of the system, enhances wildlife habitat, and prevents the loss of benefits if one species fails.

Zone 3:

- This zone is usually **at least 6 meters wide**.
- **The primary function of this zone is to filter sediment and pollutants.** The best way to achieve this is by planting **grasses** with the following characteristics:

- **Dense and stiff stems,** which slow overland water flow, increase infiltration rates and block sediments carried by water.
- **Large and deep root systems**, which improve infiltration rates and increase soil organic matter.
- **High rates of biomass production**, which further improves soil quality by adding organic matter.
- Native forbs and wildflowers can also be included, especially if seeded in clumps alongside native grasses.

Finally, it is important to note that riparian forest buffers alone may not always be sufficient to prevent pollutants from entering water streams (Schultz et al., 2022). **In such cases, it may be necessary to implement upland buffers and filters, especially in complex landscapes with long and steep slopes.** These buffers can consist of grasses alone, a mix of grasses and forbs, or a combination of grasses, shrubs and trees. In most cases, these upland buffer systems will be narrower than the riparian forest buffers.

Case study: Riparian forest buffers in the plains of Västra Götaland, Sweden

The plain of Västra Götaland is one of the most important agricultural regions in Sweden. It is characterized by intensive farming, vast flat plains, and fertile soils. As a result of intensive farming practices and climate change, this region is facing growing challenges related to drought, biodiversity loss, and degradation of water bodies (SMHI & Naturvårdsverket, 2000). It is in this agricultural landscape that Rune and Irene Karlsson have been working to transform their farm for over 40 years. They are combining intensive farming methods with agroecological conservation techniques to increase the biological diversity and resiliency of their farm.

Figure 17 *A dam surrounded by a riparian forest buffer at Stora Holmen-Mörkagården, Sweden. Photo by Mauricio Sagastuy*

Rune and Irene Karlsson´s farm is called Stora Holmen-Mörkagården. The farm has 200 hectares of forest and 450 hectares of arable land. In it, they have around 1 000 meters of windbreaks combined with riparian buffers around dams and ponds. Additionally, they implement countless methods and techniques to promote even more biodiversity and resilience on their farm. These methods include keeping dead wood on the land, flowering meadows, piles of sand next to flowering meadows, insect hotels, poles for birds of prey, and many more.

To manage water sustainably, Rune and Irene created a network of ponds and small wetlands by building nearly one small dam each year. This network of dams helps them store water during the drier months of the year.

Many of the dams created at their farm are riparian forest buffers, as they are surrounded by trees, shrubs, and a thick herbaceous layer. This dense vegetation attracts beneficial insects to their farm, prevents nutrients from entering the water bodies, and attracts game animals. The attraction of game animals is especially relevant for Rune and Irene Karlsson, as one of their main hobbies is hunting. Additionally, the hunted animals supplement part of their diet.

Today, Stora Holmen-Mörkagården is a thriving example of how integrating dams, windbreaks, and riparian forest buffers can create a more sustainable and resilient agricultural system. Their farm now stands as a beacon for other farmers looking to combine intensive farming practices with modern ecological techniques to support both their livelihoods and the environment.

CHAPTER 4
Alley cropping

What is alley cropping?

Alley cropping involves planting rows of trees and/or shrubs to create alleys where agricultural or horticultural crops are grown. In alley cropping, farmers aim at maximizing the overall productivity of the farm. Both the products of the trees and the agricultural crops are important sources of revenue. This is slightly different compared to other types of agroforestry systems, such as windbreaks or riparian buffers, where generating revenues from trees is not as important. The simple yet efficient design of straight rows of trees allow for an effective management of the trees and crops. Additionally, just like other types of agroforestry systems, the trees and shrubs provide several environmental benefits to the farm such as enhancing biodiversity, sequestering carbon, and reducing soil erosion and nutrient loss.

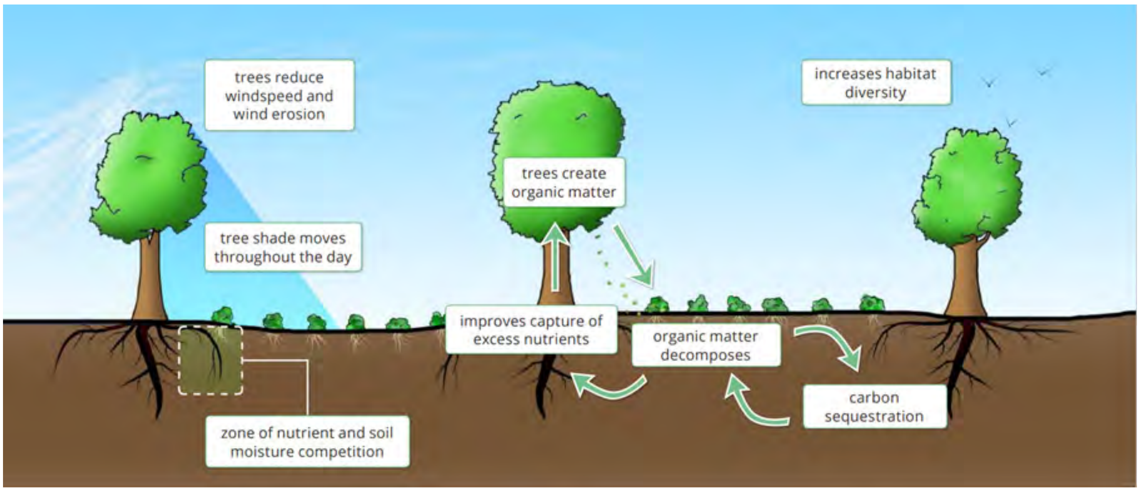

Figure 18 *Illustration of an alley cropping system. Illustration from the USDA National Agroforestry Center,*

A common pattern in most alley cropping systems is that the annual crops generate the most revenue during the first few years. However, once the trees start producing, they often become the primary source of income, as their products can usually be sold at significantly higher prices compared to cereals or vegetables. This is especially true when the trees produce high-value products such as fruits or nuts.

When alley cropping systems are designed and managed properly, they generate yields that are significantly higher than if the trees or agricultural crops were cultivated separately. This effect can be measured via the "Land Equivalent Ratio" (LER) (see Chapter 1, under *Increased farm resiliency and productivity*). The reason for higher yields in alley cropping compared to monoculture, is that you maximize the positive effects, such as microclimate improvement and wind protection, while mitigating negative side-effects, such as reducing root competition through root pruning or decreasing light competition by pruning lower branches.

The benefits and limitations of alley cropping

Benefits:

- **Increased productivity per hectare:** Well-designed alley cropping systems create synergistic relationships between trees and crops, increasing the farm's overall productivity.
- **Increased economic diversity:** Trees produce valuable products, generating new sources of income and enhancing the farms resilience to market fluctuations.
- **Improved microclimate:** The rows of trees create a microclimate that benefits most crops and helps buffer against extreme climatic conditions.
- **Improved nutrient cycling:** Trees "pump" nutrients from deeper soil layers through their roots and generate more organic matter, improving soil quality.
- **Improved wildlife and pollinator habitat:** Trees and shrubs can attract beneficial organisms, such as pest predators and pollinators, which increases crop yields.
- **Improvement of various ecosystem services:** These include carbon sequestration, enhanced biodiversity, erosion control, and reduced nutrient leaching into streams and groundwater.

Figure 19 *Rye in a no-till alley cropping system between poplar rows at Wilmars Gärten, Brandenburg, Germany. Photo by Mauricio Sagastuy*

Limitations:

Competition for resources: Trees and crops compete for water, nutrients, and sunlight, which could reduce crop yields. Measures such as pruning, and root prunning can help minimize this negative side-effect.

Increased management complexity: Introducing trees into arable land will require certain adjustments in the management practices.

Higher initial investment: Establishing rows of trees requires a significant investment, particularly for high-value trees like fruit or nut trees.

Reduced farm flexibility: Trees act as semi-permanent structures, limiting crop and pesticide options due to the level of shade in the alleys and the risk of harming tree crops with pesticides for the crops (and vice versa).

Less efficient tree management: Widely spaced trees are more time-consuming to manage than orchards or forests.

Costly tree protection: Fencing a large area cost more than fencing a smaller area. Trees take more space in alley cropping systems compared to orchards, because of the larger distance between the tree rows. Thus, fencing an alley cropping system becomes more expensive than fencing an orchard.

Suitable tree species for alley cropping

Alley cropping systems can be composed of many different tree species. Which tree species you choose will depend on the outcomes you want to achieve.

Most farmers plant trees that generate additional income, such as those grown for timber, bioenergy, fruit, nuts, or berries. Increasingly, they favor high-value crops like fruits and nuts over less valuable ones such as timber or berries. Another trend is planting rows of fast-growing trees, which get established quickly and are easily managed.

In alley cropping systems, it is not advisable to “sacrifice” productive arable land to plant several rows of trees that won’t generate additional income. Trees that don’t produce additional products are better suited for other types of agroforestry systems, such as windbreaks or riparian buffers.

Figure 20 *Alley cropping system with several rows of poplar in Forst, Germany. Source AGFORWARD project,* CC BY 2.0

Your choice of tree species should take the following aspects into consideration:

1. The soil and climatic conditions of your field
2. The management requirements of the trees
3. What products do you want to produce (if any)?
4. Do you want to prioritize your agricultural crops, your trees or both? Will this prioritization change over time?
5. How will shade and root competition affect your yields?
6. What beneficial organisms or pests could your trees or shrubs attract?
7. Are your tree species compatible with your crops in terms of light absorption (see more below), chemical compounds in the soil, and the timing of the different management tasks, such as harvesting or pruning?

Examples of potential tree and shrub species for alley cropping							
Tree or shrub species	**Shade produced***			**Root competition***			**Special Remarks**
	Low	**Medium**	**High**	**Low**	**Medium**	**High**	
Black Walnut	X				X		High value. Contains growth inhibitor that affects some companion crops.
Elderberry	X			X			Several suitable species. Good in combination with trees.
Willow	X				X		Provides early season pollen and nectar.
Apple		X			X		Some varieties require frequent pesticide application for diseases.
Pecan		X			X		High value both nuts and wood.
Poplar		X				X	Lower value but fast growing.
Chestnut			X		X		Some varieties susceptible to chest-nut blight.
Oak			X		X		Slow growing.
Pine			X		X	X	Several suitable species.
**Shade can be reduced by high pruning the stem.*							
***Root competition can be reduced through deep plowing or ripping at the outer edge of the tree line (drip line).*							

Table 8 *Examples of tree and shrub species and how they influence the system. Adapted from Kate MacFarland (2017)*

Design considerations

As usual, there is no single design pattern or ideal spacing that works best for all farms. Your design will depend on both the current conditions of your farm and the specific goals you want to achieve. Below, we explain the most important design considerations for alley cropping systems.

1. The direction of your tree rows

In most temperate or colder climates, it is advisable to plant trees in a north-south direction, to allow the most sunlight into the alleys, as the strongest sunlight comes from the south in the Northern Hemisphere. However, in addition to sunlight, there are other factors to consider when deciding the orientation of your tree rows. These factors include:

- **Wind:** Positioning tree rows perpendicular to the most damaging winds reduces wind damage.
- **Water:** Planting your tree rows parallel to contour lines can increase water intake by the trees, increase soil moisture, and reduce soil erosion. This is particularly important in dry climates, soils prone to water erosion, or in hilly terrains.
- **Drainage system:** If there are drainage pipes or ditches in the field, you need to plant your tree rows parallel to them to avoid damage.

Figure 21 *Alley cropping systems with apple trees and pears in Uppland, Sweden. Source: Furenhed, Pasquier, Sagastuy (2024). Photo by Sara Furenhed*

2. The width of your alleys

How wide your alleys should be will depend mostly on the 3 following factors:

- **The height of your trees:** The taller your trees are, the more they will negatively impact the crops in the alleys through root competition and shade. However, greater tree height also provides more extensive wind protection for your crops. **As a rule of thumb, for every meter of tree height, you can expect approximately 10 meters of shelter on the lee-side** (see Chapter 2 - Windbreaks for more details). To maximize the microclimatic benefits of your trees, the maximum width of your alleys should be about 10 times the height of your trees. For example, if your fruit trees are 3 meters tall, the alleys should be 30 meters wide or less.
- **The machinery you own:** In alley cropping, you want to drive efficiently in the alleys and avoid having to turn back to cover areas that your tractors missed. To do this, **your alleys should be wide enough to accommodate for the widths of your different machines.** For example, if your plough is 4 meters wide, your harrow is 6 meters wide, and your harvester is 8 meters wide, you should have alleys that are a multiple of these widths, such as 24, 48, or 72 meters.
- **The climate of your farm:** In colder climates, crops require more warmth and sunlight to grow well. In these regions, wider alleys are recommended to prevent the trees from shading too much of the alleys. In warmer climates, crops may benefit from more shade and cooler conditions. In such regions, narrower alleys or larger trees that give more shade can be used to provide a cooler microclimate.

3. The distance between the trees in the rows

The distance between your trees in the rows depends primarily on the tree species you choose. Some species grow naturally large, while others are smaller in nature. Larger trees require more space between them than smaller trees. Another factor to consider is how you prune the trees. Pruning can influence the size and width of the trees, which may affect the optimal spacing between them.

4. The width of your tree rows (the non-cultivated strip)

It is advisable to leave a non-cultivated strip on both sides of your tree lines to avoid damage from machinery and to provide space for the roots of the trees to develop. **Leaving a 2–4-meter-wide non-cultivated strip, with the tree line positioned in the center of this strip, is generally recommended for most alley cropping systems** (Raskin & Osborn, 2019). If you plant several rows of trees in your “tree row”, for example when planting fast-growing tree species, you should adjust the width of your non-cultivated strips accordingly.

Figure 22 *Aerial view of the non-cultivated strips in Wakelyns alley cropping system, UK. Source: AGFORWARD project,* CC BY 2.0

How to manage the competition between trees and crops

1. Pruning

You can influence how much sunlight reaches the alleys by how you prune your trees. The more you prune them, the more sunlight will enter the alleys. However, you should be mindful of not pruning too much to damage your trees or decrease their production.

In general, it is advisable to prune the lowest branches to increase the sunlight that reaches the alleys and to decrease the risk of machinery damaging the trees - especially during plowing, harrowing, or harvesting.

2. Root pruning

Root pruning can reduce competition between tree roots and crops. The most effective method is using a subsoiler, running it 1–2 meters away from the tree lines. Additionally, routine plowing naturally prunes the roots, however it does not reach as deep as a subsoiler.

3. Use complementary tree and crop species

Trees and crops can complement each other in several ways. One of the most evident is when they photosynthesize at different times of the year. For example, autumn-sown crops like winter wheat can absorb sunlight while leafy trees remain dormant from December to May. Once the crop is harvested, the trees can then utilize the available sunlight (see Figure 23 below).

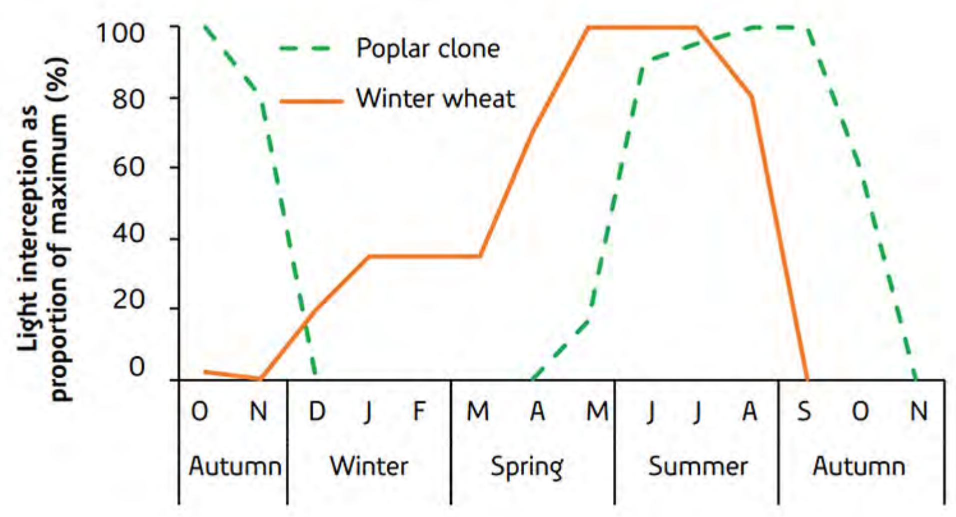

Figure 23 *Complementary light interception of poplar hybrid Gibecq and winter wheat. Adapted from Incoll & Newman (2000), and Pasturel (2004)*

Case study: Alley cropping for decreased soil erosion and increased profitability, Germany

In Brandenburg, Germany, farmers have long struggled with low rainfall (less than 600 mm/year) and low-quality sandy soils. These challenges have only intensified with climate change, which has further increased the vulnerability of farms (Gutzler et al., 2015). However, Thomas Domin, a forward-thinking farmer, found an innovative solution through agroforestry.

Since 2015, Thomas has been integrating different types of agroforestry systems into his farm to reduce wind speeds, decrease soil erosion, increase soil humidity, reduce nutrient leakage, and produce higher yields. Initially, he established alley cropping systems using only fast-growing species. Over time he expanded and planted a silvopastoral system (in 2016), an alley cropping system with high-value trees and fast-growing species (in 2020), and orchards with a diversity of species (in 2022). Below we focus on describing his alley cropping system.

Thomas manages a 370-hectare farm, on which he planted around 10 hectares of alley cropping. In 2015 he planted 7 tree rows composed of fast-growing species: hybrid poplar (*Populus spp.),* Robinia (*Robinia pseudoacacia),* and Black alder (*Alnus glutinosa*). In 2020 he expanded by planting 3 more tree rows where he combined fast growing species with: Sweet chestnut (*Castanea sativa*), Field maple (*Acer campestre*), Turkish hazel (*Corylus colurna*), Amelanchier (*Amelanchier lamarckii*), and Elderberry (*Sambucus nigra*). The combination of fast-growing tree species with high-value trees in the same rows has been very successful. The fast-growing species are planted in the outer rows to shelter the high-value trees in the middle. This creates a favorable microclimate for the high-value trees in an otherwise harsh, wind-exposed landscape. Additionally, Thomas selectively removes fast-growing species to give the high-value trees an advantage once they start competing for resources.

Nowadays, Thomas harvests the fast-growing trees for heating purposes on the farm and sells some for biomass production. In the future, he plans to generate additional income by selling fruits, nuts and high-quality roundwood. Additionally, he is experimenting with converting the biomass to biochar and applying it on his land, which further enhances the soil quality, stores more carbon, and improves the land’s resiliency. Thomas has helped advance agroforestry in Germany with his innovative practices, and due to his efforts, he got awarded in 2024 with the Highest Honor from the German Ministry of Agriculture, the Professor Niklas Medal.

Figure 24 *Tree row with chestnuts between poplars. Photo by Thomas Domin*

Figure 25 *Aerial view of Thomas Domin's farm. Photo by Thomas Domin*

CHAPTER 5

Silvopasture

What is silvopasture?

Silvopasture integrates trees, pasture, and livestock in a combined system, where trees are intentionally planted or retained with pasture for grazing. Silvopastoral systems create environments that promote livestock's health and welfare. This leads to higher livestock yields and more resilience against weather extremes. Additionally, the integration of trees can increase forage production and generate additional income from the products of the trees.

The benefits and limitations of silvopasture

Silvopasture offers the same ecological and economic benefits as other types of agroforestry systems, such as better soil health, more biodiversity, more carbon sequestration, higher productivity per hectare, and income diversification. Besides these benefits, silvopasture has several positive effects for livestock. Below, we list these livestock benefits:

Benefits:

Reduce heat stress: Trees provide valuable shade that protects livestock from heat stress. Heat stress can lead to disease, such as mastitis. Heat stress can also reduce a cow's fertility and, during pregnancy, may lead to smaller newborn calves. In the U.S. alone it is estimated that $2,4 billion are lost annually in livestock production due to heat stress, including losses of around $900 million for the dairy industry and losses of $370 million for the beef industry (St-Pierre, Cobanov, & Schnitkey, 2003).

Reduce cold stress: Windbreaks, hedgerows and other linear features reduce wind speed which leads to less cold stress. Additionally, the microclimate under a tree canopy is warmer compared to open pastures, even when the trees have lost their leaves.

Better microclimate for fodder production: Trees create a microclimate that allows forage to green up earlier in the year and to withstand drought conditions more easily.

Better social cohesion: Trees provide natural spaces where livestock can seek shelter and shade. In environments with sufficient tree cover, animals don't have to compete for these valuable resources. With less pressure over essential resources, livestock experience a calmer environment, leading to healthier social interactions within the herd (Améndola et al., 2013). Additionally, in well-designed silvopastoral systems, livestock tend to graze more evenly compared to open pastures.

Scratching posts: The trunks of mature trees and their low branches provide ideal scratching posts for livestock, offering them a natural way to groom. Daily grooming is essential for animals to maintain a healthy coat. Rubbing against trees helps remove dead skin and loose hair. Poultry, in particular, benefit from preening under tree canopies, which enhances feather condition.

Less pests and diseases: Silvopasture creates new habitats that attract different types of wildlife. Well-designed systems can attract natural predators of pests that harm livestock, such as those that prey on flies.

Supplementing livestock's diet: Most tree species have higher levels of micronutrients than grasses. Tree fodder can potentially address micronutrient deficiencies and be anti-parasitic for livestock. Tree fodder can also be used during drought events. Fodder can be harvested and stored for up to 24 months prior to use.

Figure 26 *Cows grazing in a silvopastoral system in southern Poland. Photo by Mauricio Sagastuy*

Limitations:

Initial investment and increased management: Establishing a silvopastoral system often requires a significant initial investment in tree planting, fencing, and infrastructure to protect young trees from livestock. Maintenance, such as pruning or weeding, is essential for ensuring that the system remains productive. Thus, silvopastoral systems often require more management time, especially during the establishment phase, compared to conventional pastures.

Risk of overgrazing and tree damage: Livestock can damage trees by overgrazing foliage, chewing bark, or trampling young saplings. To mitigate these risks, careful management, such as rotational grazing and the use of tree guards, is required.

Competition between trees and grass: While trees improve the microclimate, they can also compete with grasses for sunlight, water, and nutrients. A good design and proper tree management are essential for maximizing synergies and decreasing competition.

Pests and diseases: Introducing trees into pastures can sometimes create new pest or disease problems. Certain tree species and tree densities may create an environment that is favourable for pests harmful to livestock. Thus, choosing the right tree species is key for minimizing this risk and potentially attracting beneficial organisms instead.

Management complexity: Silvopasture requires more knowledge and skills compared to conventional systems. Farmers working with silvopasture need to know how to balance tree growth, livestock rotation, and forage production while monitoring the system's health. Not all farmers have the time or are sufficiently interested in learning these new skills.

Figure 27 *Marcin Przytocki shows how his horses damaged the bark of his trees, north-western Poland. Photo by Mauricio Sagastuy*

Common design patterns

There are 3 broad categories into how trees can be arranged in a silvopastoral system: **(1) linear tree systems, (2) regularly spaced tree systems, and (3) woodland grazing**.

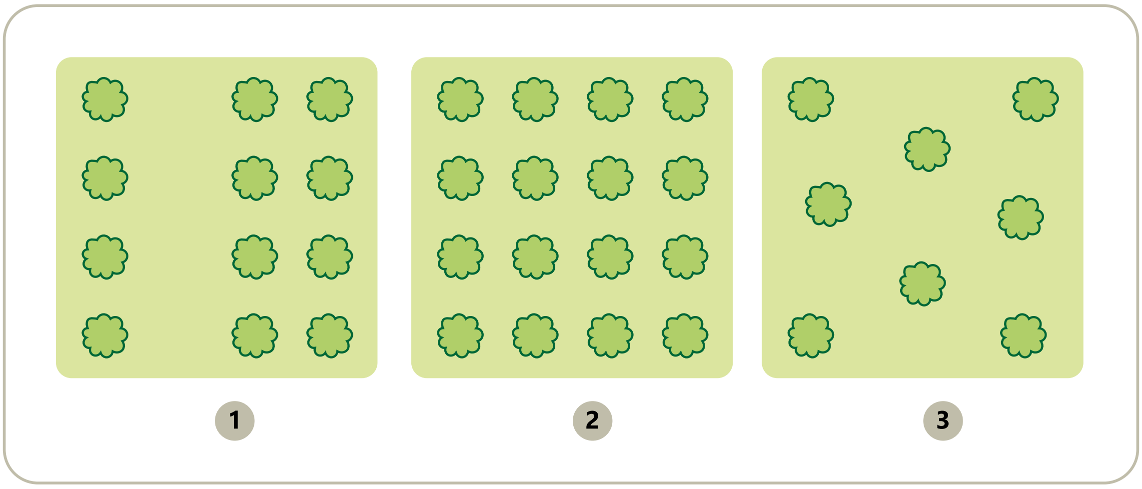

Figure 28 *Spatial configurations of the three most common design patterns in silvopasture*

Linear tree systems are rows of trees that serve as some form of buffer - like wind protection, soil, or water quality. Some examples of these systems are windbreaks, hedgerows and riparian forest buffers.

In these systems, trees are planted closely together in one or more rows. In each row, one or more species can be planted. This setup can provide "nursing" benefits, where one species supports the growth of another. The rows should be spaced wide enough to allow access for machinery or livestock movement.

As in regularly spaced systems, shading of the grass becomes an issue as the canopy grows. This can be minimized by planting rows in a north–south orientation to optimize light availability.

Row systems offer opportunities to produce multiple products, such as fruits, nuts, and browse for livestock. For fodder or biomass production, easily coppiced species such as alder (Alnus spp.) or willow (Salix spp.) can be planted in shorter rotations to limit shading effects.

Figure 29 *Linear silvopastoral system with poplar and pigs in Denmark. Photo by Marianne Fløe Hestbjerg*

Regularly spaced tree systems are systems where trees are integrated into pastures in regular patterns or in rows, usually with the intention of producing or maintaining high-value tree products, such as fruits, nuts, or timber. Some examples of these systems are grazed orchards, row systems, and clump systems (which are groups of trees growing closely together).

In regularly spaced tree systems, the tree density ranges from 100 to 400 trees per hectare (Raskin & Osborn, 2019). At these densities, the tree canopy is unlikely to overshade the pasture during the first 12 years of establishment for most species. However, fast-growing species like ash (*Fraxinus spp.*) and alder (*Alnus spp.*) may begin to cast significant shade earlier. To manage this, consider using shade-tolerant grass varieties or raising the tree crowns to reduce shading effects.

Once the canopy begins to close, selectively thinning the trees can help maintain the pasture and create space for the remaining trees to grow. The thinned trees can then be used for firewood or fencing timber.

Compared to individual tree planting, clump systems offer several advantages in terms of reduced costs and biodiversity. Clumps can reduce costs associated with tree protection while potentially enhancing biodiversity by creating microhabitats.

Woodland grazing is the controlled grazing of livestock within woodlands and forests. This system combines silviculture (forest management) with pastoralism (livestock management). The aim is to use the land for both grazing and timber production. Examples of these systems are: pannage systems, silvopoultry, and parklands.

Design for livestock benefits

Reducing cold stress

To reduce cold stress, it is important to decrease wind speed and provide shelter for livestock. A very effective method is planting rows of trees in perpendicular direction to the predominant winds. The most effective tree species at reducing cold stress and wind are evergreen trees with thick branches, such as spruce and fir. These trees are especially important during winter when other trees are dormant.

Additionally, shrubs or lower trees will reduce wind speeds in the lower tree layer. Deciduous trees also offer wind protection, and they can increase the temperature under the canopy. During the winter, their wind reduction capacity will decrease, but it won't totally disappear. For deciduous trees, studies have shown around a 50–60 % reduction in wind speeds and a 50–60 % reduction in protected distances during the winter (Heisler & DeWalle, 1988). How much wind protection deciduous trees can give during the winter will depend on how high the tree density is and how thick the windbreaks are.

Reducing heat stress

Broad-canopied trees provide shade, reducing heat stress for livestock. These trees are often relegated to field boundaries or hedgerows to minimize competition with pasture, however this can lead to overcrowding and hygiene issues. Instead, regularly spaced tree systems distribute shade more evenly, promoting natural livestock behaviour and preventing excessive poaching. For effective shade, focus on high-use areas, such as post-milking zones or crossing points, especially in fields with southern exposure.

Figure 30 *Silvopastoral system with hens and poplar in northern Germany. Photo by Mauricio Sagastuy*

Silvopasture for ruminants

Shade and shelter are the primary benefits that ruminants get from silvopasture. Shelter is particularly important for upland farming systems or extensive grazing systems where animals are more exposed to harsh weather conditions. Windbreaks and woodlands may be the best option for these conditions, because they offer the best protection against extreme weather due to their dense woody vegetation.

Regularly spaced trees provide more even shade, but they offer less shelter compared to windbreaks or woodlands. Regularly spaced tree systems may work best in lowland pastoral systems, where livestock is less exposed to harsh weather conditions.

Silvopasture for poultry

Silvopasture is particularly appealing for farmers interested in organic and free-range poultry, where chickens have access to an outdoor run. The presence of trees not only provides essential shelter to chickens, but it also encourages ranging behaviour, which has positive effects on their welfare (Raskin & Osborn, 2019). This leads to improvements in their health and productivity.

Silvopasture for pigs

Woodland grazing is often the most suitable silvopastoral system for pigs. Pigs benefit particularly from having shade during the summer. Moreover, pigs are omnivorous and have access to a broad range of food types within forests (including roots, berries, nuts and plants). Additionally, their rooting behaviour can be beneficial for removing weeds and encouraging seedling germination, however they must be carefully managed to prevent soil and tree damage (Raskin & Osborn, 2019). To minimize their impact, maintaining a low stocking density is often necessary.

Establish and manage silvopastoral systems

Choosing the right tree species

Planting trees and managing them can be expensive and time consuming. Therefore, choosing the right tree species is very important. **Three key factors to consider when selecting your tree species are: (1) the suitability of the tree species for your site (2) that you have the adequate resources to manage them, including time, and (3) that the tree species are aligned with the goals you want to achieve.**

For example, on farms with harsh weather conditions, trees must withstand strong winds, a varied climate, and seasonal waterlogging. In these conditions, hardier tree species will do best, such as aspen (*Populus tremula*), birch (*Betula spp.*), rowan (*Sorbus aucuparia*), blackthorn (*Prunus spinosa*), hawthorn (*Crataegus monogyna*), and poplar (*Populus spp.*). In such farming systems, the primary motivation for planting trees tends to be the agroecological benefits, such as providing shelter or mitigating foot rot, rather than the production of fruits, nuts or high-value timber.

Conversely, farms with milder climates may prioritize tree planting for production purposes, with agroecological benefits as a secondary goal. A milder climate and good soils lead to better production, compared to if the site has harsh weather conditions or bad soils.

Tree protection

Livestock and wild animals can harm tree stems, roots, and ground vegetation. Grazing animals trample (in the case of cattle) or browse and rub which means that establishment is impossible in most cases without protection and constant monitoring.

Figure 31 *Tree protected by a tree guard at Rieckens Landmilch silvopastoral farm, northern Germany. Photo by Felix Riecken*

Tree protection involves significant costs. Sheep are the easiest to protect against, but safeguards are still expensive. Cattle require taller and sturdier barriers, while horses and wild ruminants, like deer, demand even better fences. Protecting individual trees is more expensive than guarding rows or clumps or trees. Some tree species may also need protection from poultry. Additionally, rabbits and voles can harm the lower trunks, which must also be taken into consideration.

If rows of trees are spaced widely enough to allow vehicular access, forage can be harvested for hay or silage during the first few years. However, this only postpones the need for protection, as livestock will inevitably damage the trees once they access the pasture.

In existing woodland systems, managing livestock access through permanent or temporary fencing allows for natural regeneration. This often involves reducing livestock density or excluding them from specific sections of the woodlands. The optimal grazing regime will depend on the woodland type and the livestock system you use.

To protect seedlings from cattle with an electric wire, you should place the wire at 1–1.25 m from the seedlings and at hip height.

Light competition and grass growth

During the initial stages of tree growth, the impact that shade has on forage production is minimal. However, as trees mature, proper management (such as pruning and thinning) is required to reduce excessive shading from the tree canopy and maintain forage quality. As trees mature, they limit the light available to forage, but they bring other benefits as well. The shelter provided by trees creates a more stable microclimate that protects forage from extreme weather conditions. In spring, this microclimate helps forage to green up earlier, while during hot periods, it reduces heat stress on the grass.

Trees can also help improve the nutrient profile in the soils. They can do this by accessing nutrients from deeper soil layers and returning them as leaf litter. When leaf litter decomposes it adds more organic matter and nutrients to the soils, which improves the forage quality and yields. When nitrogen-fixing trees are included in the system, they can significantly reduce or even eliminate the need for chemical fertilizers to.

Ongoing tree management

Tree management is an essential part of any silvopastoral system. If you want your trees to thrive, you must constantly manage them.

After you plant new trees, it is very important that you weed around the base of each tree (for the first two to five years). You can do this via chemical, mechanical or biological means. Tree protection should be another integral part of your tree management. Any protective measures you have established, such as guards or fencing, must be inspected, maintained, and replaced if damaged to keep trees safe.

As trees mature, they may require pruning for production and tree maintenance, as well as for allowing more sunlight to reach the grass. Trees with poor form should be selectively thinned. Moreover, tree management can produce a set of secondary products that can be used on farm including firewood, woodchip for livestock bedding, or Christmas trees.

Finally, farmers need to practice rotational grazing in most types of silvopastoral systems to minimize damage to the trees.

Case study: Sheep silvopastoral system in Transylvania, Romania

Silvopasture is the most common agroforestry system in Europe, accounting for around 90 % of all agroforestry practices (Mosquera-Losada et al., 2018). A reason for this is because large areas in Europe are still being managed by traditional silvopastoral practices. Examples include open oak woodlands with livestock in Spain and Portugal (called dehesas and montados respectively), reindeer husbandry in Nordic countries, and woodland grazing, which has been practiced all around Europe. In Romania, sheep herding has been a vital tradition since ancient times, especially in the Carpathian Mountains (European Review, 2023).

In Covasna County, in eastern Transylvania, Tudor Popa´s farm serves as an excellent example of how modern farming is being combined with traditional practices to manage a large-scale silvopastoral system. Tudor manages a silvopastoral farm that sells sheep products (milk, cheese, meat, wool) and timber.

Due to its large size, Tudor's farm is managed more like a landscape than a farm. This means that the shepherds working on his farm work closely with the natural succession of the ecosystem and use low-input techniques to influence tree growth. This way of managing silvopastoral systems is very common, especially in large farms and in traditional silvopastoral systems.

An example of this is the way that shepherds "plant" new trees in the grassland. Instead of planting new trees, they simply select and protect young trees that have already started growing naturally in the landscape. They protect these young trees from wild animals and grazing sheep by creating a "nest" of branches all around the trees (see image below). Through this method, they influence which trees they keep on the land. Another method to achieve the same outcome, commonly practiced in silvopasture, is planting trees surrounded by thorny bushes.

Tudor Popa sees many benefits in having more trees on his farm. Some of the key benefits that he gets are more shade during the summer, more wind protection, additional fodder in autumn (especially acorns), and early grass growth in the spring. Tudor believes that trees play a crucial role for his sheep and that many livestock farmers can reap similar rewards once they start integrating more trees into their farms.

Figure 32 *Aerial view of Tudor Popa's farm in Transylvania, Romania. Photo by Adrian Gliga*

Figure 33 *A flock of sheep grazing on Tudor Popa's farm in Transylvania, Romania. Photo by Adrian Gliga*

Figure 34 *Tudor Popa creating a "nest" of branches to protect a young tree from wildlife and grazing sheep. Photo by Mauricio Sagastuy*

CHAPTER 6

Forest gardens

What are forest gardens?

Forest gardens, also called food forests, are cultivation systems that mimic the structure and design of a forest ecosystem. Like forests, forest gardens are composed of several vegetation layers with trees, shrubs, herbs, and vines growing in the same place. The difference between natural forests and forest gardens is that the latter are specifically designed to produce food, medicines, wood, or other products for human consumption.

In Europe, forest gardens are typically smaller, rarely exceeding 2 hectares. As their name suggests, these systems are usually managed as gardens rather than farms. Therefore, forest gardens are usually not created for commercial food production. Instead, forest gardens are normally used for self-sufficiency, to provide ecosystem services or simply as a hobby. Rather than being a large-scale farming practice, forest gardens have higher potential to be used in gardens or in public parks.

Figure 35 *Juan Anton picking a banana in his forest garden near Valencia, Spain. Photo by Mauricio Sagastuy*

The benefits and limitations of forest gardens

Benefits:

Nutrient self-sufficiency: In forest gardens, trees and shrubs "pump" nutrients from deeper soil layers to the top of the soil via their leaves. Additionally, the dense vegetation adds more organic matter to the soil. This high plant diversity together with an undisturbed soil promote the growth of mycorrhizal fungi and other soil microorganisms. These organisms make nutrients more available to the plants, thus accelerating the nutrient-cycling process.

High biodiversity: Forest gardens tend to have a high diversity of plant species, ranging all the way from trees to shrubs to a herbaceous layer. This diversity attracts a wide range of insects and other animal species.

Product diversification: Forest gardens produce a wide variety of products. The most common products coming from forest gardens are food, medicine, and wood. This diversity makes them less vulnerable to market changes.

Self-regulated system: Forest gardens require less management over time. This is achieved by planting perennial crops, choosing the right plant species for the right location, and by mimicking the structure of a forest ecosystem.

Limitations:

Lack of efficiency: The high complexity and diversity of forest gardens can make their management less efficient.

Hard to mechanize: It is hard to mechanize a system that works with several plant species and many vegetation layers.

Knowledge intensive system: Cultivating different plant species in combination with one another requires specialized knowledge and expertise.

Five key principles for creating a forest garden

1. Seven vegetation layers

Forest gardens aim at maximizing sunlight absorption and increasing the resiliency of the system by having a high plant diversity. In theory, forest gardens should have 7 different vegetation layers, like a forest ecosystem. Each vegetation layer fulfills a unique set of ecological functions, and they increase the leaf area for maximal sunlight absorption, which increases the overall productivity of the system. The 7 vegetation layers are the following:

- Tall trees
- Low trees
- Shrub layer
- Herb layer
- Ground cover layer (ground cover plants)
- Vine layer (climbing plants layer)
- Root layer (root plants)

In practice, you don't have to establish all seven vegetation layers to have a thriving forest garden. The key is to maintain a high plant diversity and a dense vegetation to maximize sunlight absorption.

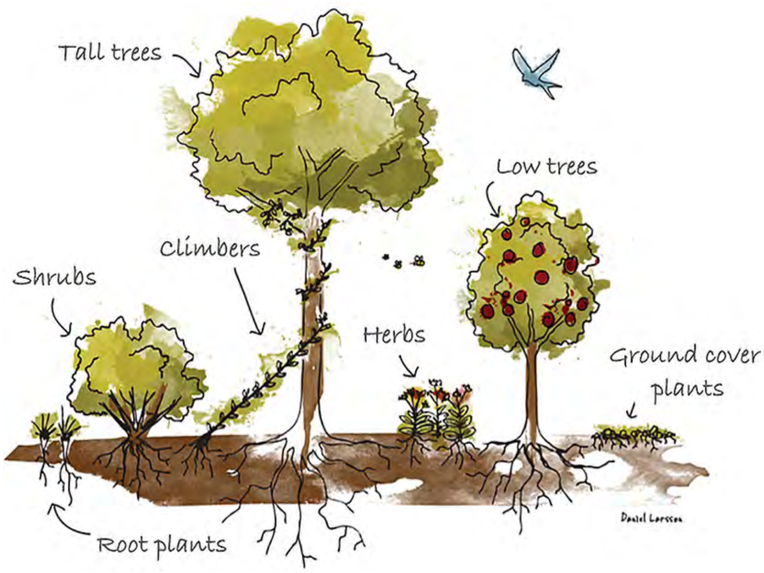

Figure 36 *The different vegetation layers in a forest garden. Source: Stolz and Schaffer (2018), Illustrator: Daniel Larsson, CC BY 4.0*

2. Using plant species that are best adapted to the different areas of the land

Forest gardens are characterized by structural variability, plant diversity, and varying levels of shade. These factors create different microclimates that change over time. Thus, "forest gardeners" must thoughtfully consider where to place each plant species. Placing the right plant in the right location leads to a more efficient use of natural resources.

3. Focus on perennial crops

"Forest gardeners" use more perennial crops such as fruit and nut trees, berry shrubs, and perennial vegetables, than annual crops. Unlike annual crops, which must be planted every year, perennial crops provide a reliable source of food each year with minimal input. Their deeper root systems can also access nutrients and water from deeper soil layers, reducing the need for irrigation and fertilizers.

4. Improved soil fertility by adding organic matter

"Forest gardeners" create a thick vegetation and add its organic matter to the soil to improve soil fertility over time. They use plants that produce a lot of biomass and plants that can draw nutrients from deeper soil layers. Additionally, they use a technique called "chop and drop", where leaves and branches are cut and spread throughout the system to enrich the soil with organic matter. This technique, along with thick vegetation and a high plant diversity, improves soil fertility over time.

Figure 37 *Plant and structural diversity in a Swedish forest garden. Forest garden at the school Naturbruksförvaltningen Angereds Gård, Gothenburg, Sweden. Photo by Mauricio Sagastuy*

5. Mimic the natural succession of a forest ecosystem

"Forest gardeners" reduce their workload over time by mimicking the natural succession of a forest ecosystem. The forest garden gradually moves from an early level of natural succession to a later level of succession until it reaches a stage where little management is needed. At this point, when the forest garden has matured, it will produce its own fertility by recycling the nutrients in the system.

Figure 38 *Gamelgaard Forest Garden in southern Sweden. Photo by Mauricio Sagastuy*

Case study: Highly productive commercial forest garden in Aarhus county, Denmark

In Denmark, where conventional agriculture has dominated for decades, a growing number of farmers are exploring more resilient and sustainable farming methods. Among them is Myrrhis Permakulturhaven, a pioneering agroforestry farm that is both ecologically diverse and economically successful. Founded in 2012 by Tycho and Karoline, Myrrhis has been at the forefront of small-scale agroforestry in Denmark for over a decade.

In 2017, Tycho and Karoline established a small-scale, 4-hectare agroforestry system. It was designed to produce perennial vegetables, berries, fruits, seeds, and plants for their nursery. This agroforestry system is highly productive, and it serves as a model for how commercial forest gardens can look in practice. Two-thirds of their income comes from selling their products, while the remaining third comes from offering courses and farm tours. This is something special, as there are few farmers that live from what they produce from small-scale agroforestry systems in Europe.

The 4-hectare system could be described as an organized forest garden with aspects of alley-cropping and silvopasture in it. The areas that need management most are closest to where they move the most, which is the entrance. Here, they planted rows of trees that support their perennial vegetables. The further away from this center, the more they plant trees that need less management, such as hazelnuts (*Corylus avellana*), walnuts (*Juglans spp.*), and sweet chestnuts (*Castanea sativa*), and combine them with pasture grazing.

Tycho and Karoline have developed a successful business by cultivating trees, shrubs and perennial crops in the same land. Their farm, Myrrhis Permakulturhaven, serves as an outstanding example, demonstrating that small-scale agroforestry systems can be economically viable in Europe as well.

Figure 39 *Aerial view of Myhrris Permakulturhaven farm, Aarhus County, Denmark. Photo by Karoline Nolsø*

CHAPTER 7

Other agroforestry systems

Introduction

Agroforestry is a land use system that includes a wide range of different practices. In the previous chapters, we explored several types of agroforestry systems, such as windbreaks, riparian forest buffers, alley cropping, silvopasture and forest gardens. These represent some of the most used agroforestry practices, however there are still many more different ways one can work with agroforestry. For instance, agroforestry can also be implemented in forests, orchards, or urban environments.

In this chapter, we want to showcase the diversity of agroforestry by providing three examples of how farmers are working with agroforestry across Europe. The following short case studies feature systems that do not always fit neatly into the categories discussed in the earlier chapters.

As seen in the case studies of the previous chapters, many farmers adapt agroforestry to suit their farms, rather than modifying their farms to fit a specific agroforestry system. This adaptive approach is a common thread among practitioners. The following examples are intended to broaden your perspective on how agroforestry can be applied across various landscapes, farming systems, and climatic conditions.

Case study:
La Florentina, near Valencia, Spain

Vicente Borrás is the landowner and manager of the farm La Florentina, an agroecological fruit orchard covering 17 hectares. On the farm, he cultivates 11 fruit species and more than 20 cultivars. The orchard is surrounded by windbreaks composed of over 165 tree and shrub species, all are native to the Mediterranean region.

In addition to the high diversity of trees and shrubs, Vicente Borrás has implemented several measures to further enhance the system's resilience and ecological diversity. Among these are the creation of multiple ponds across the farm, the installation of insect hotels, and the placement of perches for birds of prey. He also uses biological methods to manage pests and diseases, avoiding chemical inputs.

A particularly interesting aspect of Vicente's farm is its ability to produce its own nutrients. Organic materials from the windbreaks – such as fallen leaves – are collected and composted, then transformed into nutrients that are fed back to the fruit trees via the irrigation system.

Figure 40 *Farmer pruning the windbreaks at La Florentina. Photo by Mauricio Sagastuy*

Figure 41 *The understory vegetation in the orchard helps improve water infiltration, retain soil moisture, and enhance soil fertility. Photo by Mauricio Sagastuy*

Figure 42 *Water pond at La Florentina. Photo by Mauricio Sagastuy*

Figure 43 *Insect hotel at La Florentina. Photo by Mauricio Sagastuy*

Case study: Ellenäs Fruktodling, Sweden

Per-Anders Almén is the landowner and manager of Ellenäs Fruktodling, a meadow orchard spanning 6 hectares. The orchard primarily cultivates apples but also includes plums and pears. Apples grown in the meadow have a distinct flavor compared to commercially available varieties. This is due to the nutrient-poor soil – an essential condition for creating these types of meadows in Sweden – which influences the taste of the fruit. This unique flavor helps the orchard attract more customers and market its produce as a specialty.

Ellenäs Fruktodling is a remnant of a once widespread cultural landscape in southern Åsnen, a region in southern Sweden. Historically, farmers in this area combined meadows, grazing cows, and apple production on the same land. Apple trees were grafted and pruned in a way that lifted the crowns high enough to prevent cows from reaching the fruit. In this way, farmers produced hay, dairy products, meat, and apples from the same orchard. Today, this cultural practice has largely disappeared from the landscape.

Figure 44 *Apple trees in a meadow in Ellenäs Fruktodling. Photo by Mauricio Sagastuy*

Figure 45 *Per-Anders Almén, owner of Ellenäs Fruktodling. Photo by Mauricio Sagastuy*

Case study: Semi-subsistence farms, Romania

Romania hosts over 2,8 million small farms – the highest number in the European Union – accounting for approximately one-third of all EU farms. An estimated 93 % of Romanian farms are small scale (under 5 hectares), collectively managing 30 % of the country's agricultural land (European Commission, 2025).

These farms are typically semi-subsistence in nature, producing primarily for household consumption, with a limited surplus sold in local markets. Despite their modest commercial output – contributing only 10–15 % to national agricultural production – semi-subsistence farms play a vital role in sustaining rural communities. They are an essential part of Romania's social fabric, supporting rural livelihoods and enhancing food security.

Although modernization and agricultural intensification have led to the widespread removal of trees in many parts of Europe, Romania's semi-subsistence farms have largely retained them. Trees are preserved on farms for various purposes, such as providing shelter, regulating the microclimate, enhancing ecological resilience, offering aesthetic value, and producing goods for self-consumption or sale.

Figure 46 *Semi-subsistence farm in the county of Bistrița-Năsăud, Romania. Photo by Adrian Gliga*

Figure 47 *Trees shaping the landscape of semi-subsistence farms in the county of Bistrița-Năsăud, Romania. Photo by Adrian Gliga*

Figure 48 *Small tractor in the shade of a tree on a semi-subsistence farm in the county of Bistrița-Năsăud, Romania. Photo by Mauricio Sagastuy*

CHAPTER 8

Context specific agroforestry design

The design framework

In this chapter, you will learn how to design your own agroforestry system step by step, and most importantly how to do it for your specific context.

To begin with, it is important to be aware of the principle of **risk-management** when designing an agroforestry system. Integrating trees into farms carries certain risks, such as losing money, increased management time, competition for sunlight and nutrients, or the possibility of trees getting damaged or diseased. However, not having trees on a farm is risky as well. Those risks include exposure to negative weather conditions, soil erosion, loss of biodiversity and natural predators, or vulnerability to market changes. By focusing on risk-management you will be able to minimize both the existing risks on a farm and those related to implementing agroforestry practices.

Another principle to be aware of during the design process is **balancing complexity and efficiency**. Adding more complexity to a farm can bring several benefits, such as increased biodiversity, better protection against pests, more diversified production, and greater resilience towards climatic changes. However, the more complexity you add to a farm the less efficient its management becomes. A less efficient management may lead to increased working hours, which lead to higher costs. Additionally, the more species you work with, the more knowledge you need to have of how to manage, harvest, and sell them.

It is worth pointing out that **a good design can help you increase the diversity in the system without adding too much complexity to its management.**

As illustrated in the figure below, **risk-management** and **complexity vs efficiency** are two overarching principles you should be aware of during the design process. Besides these overarching principles, there are 6 steps you need to take to design your agroforestry system:

1. Define your goals
2. Analyze your starting point
3. Brainstorm your desired plant species
4. Get advice/have a mentor
5. Do a market analysis
6. Agroforestry design

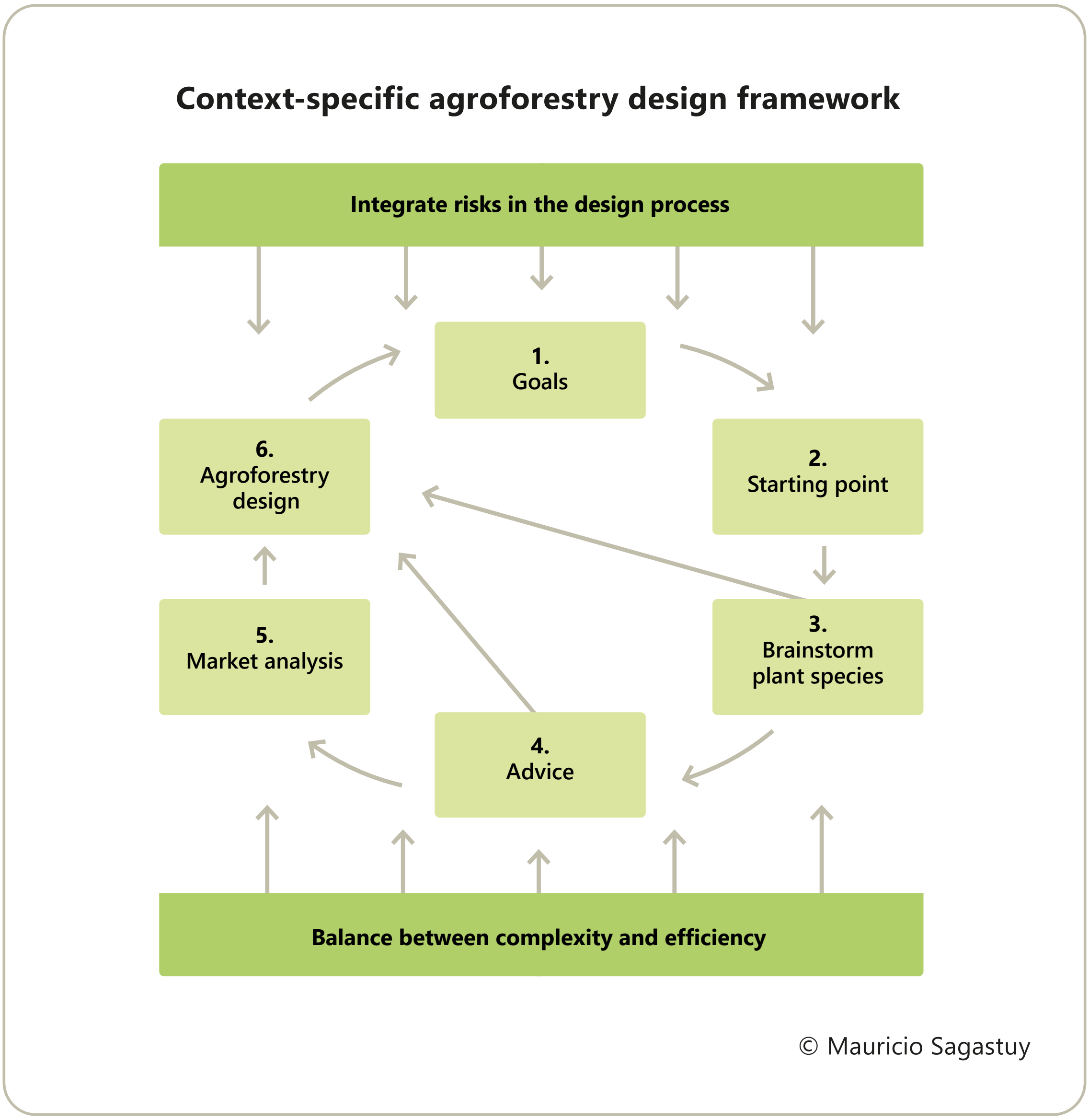

Figure 49 *This figure shows how to design an agroforestry system. The purpose of this design process is to serve as a flexible tool that can be adapted to real-life scenarios. This framework was created by Mauricio Sagastuy.*

The design process is shown as a circle, because designing and creating an agroforestry system can be a never-ending process for two reasons. First, you will probably have to re-do your original drawing several times until you have a design you feel satisfied with. Secondly, even after you have established the agroforestry system, you may want to keep re-designing and developing it in the long run. Over time, you will notice which plant species grow better in your land, which ones do not grow well, and what effect trees have on your farm. Thus, in the future, you may want to develop your agroforestry system by removing, replacing or introducing new plant species.

The strength of this design process is that it is flexible, and it lets you skip certain steps when they are not needed. For example, if you have knowledge about how to grow and sell the products of your chosen tree species (step 3), then you probably don't want to hire a consultant (step 4) or do a market analysis (step 5). Or if you hire a consultant (step 4) that has knowledge about the market opportunities, then you can skip doing a market analysis (step 5) for your chosen tree species.

You should see the above-mentioned steps as a flexible framework that can be modified to your specific circumstances and knowledge. You can decide for yourself which steps of the design process you want to do, and which steps you want to skip. In the following pages, we will describe each step in more detail.

Creating a vision for your agroforestry system is one of the most exciting parts of starting an agroforestry system. Good luck and have fun with the process!

Integrate risk management in the design process

Before you start designing an agroforestry system, you should learn how you can minimize risks. A good way to start is by listing the different risks that you think are involved with your future agroforestry system. Once you have done this list, you can brainstorm different ideas of how you could mitigate these risks. This will give you a good overview of the potential risks and measures you can take to reduce or eliminate some of these risks.

Additionally, the following aspects can further help you minimize risks during the design phase:

1. **Plant trees to minimize other risks in your farm:** Plant trees with the specific purpose of reducing risks that are already present in your farm. Adding more trees to certain areas of your farm can help:

- Reduce heat and cold stress
- Reduce erosion
- Provide wind protection
- Protect against floods
- Protect against pests by attracting natural predators
- Create a green wall to protect against salty winds, chemical compounds, or other damaging compounds or organisms

2. **Plant trees with multiple purposes:** Plant trees that serve multiple purposes. By expecting a variety of benefits from your trees, you also reduce risks - if one benefit doesn't materialize, you will still gain from the others.

For example, you may choose to plant rows of poplar (Populus spp.) to (1) generate a direct income by selling them as wood chips, (2) improve your farm's microclimate, (3) reduce soil erosion, and (4) get an indirect income by selling "carbon credits" or other ecosystem services.

In this scenario, it could be that selling the wood chips will only cover the management costs without generating any extra profits. However, if you achieve outcomes (2), (3) and (4), your farm will still benefit from incorporating the tree rows. Your tree rows will increase your farm´s productivity (outcome 2 and 3) and they will even generate an extra income (outcome 4), even if you didn't generate extra profits from your wood chips.

3. **Establish the system step-by-step:** When you establish an agroforestry system step by step you will make steady progress, and you will learn from small mistakes. Big experiments can lead to big failures and thus demotivate you in the process. Another way to de-risk your learning process is to start planting trees in parts of your land that are less productive or fertile. Once you feel more confident, then you can start planting them in larger numbers or in more fertile parts of your land.

4. **Increase your tree management skills:** Increasing your tree management skills leads to higher tree survival rates and better production in the long-term. There are different ways you can improve your tree management skills, such as:

- Having a mentor/consultant
- Taking a course or having someone teach you the skills you are lacking
- Learning more about the new markets you would be getting into
- Being part of a community/network that is working with agroforestry

Risk management is a good starting point for your design process. Remember to keep this concept in the back of your mind as you continue with the next steps.

Step 1: Define your goals

Different farmers have different goals and reasons for why they want to work with agroforestry. The first step in your design process should be to define your goals and the reasons why you want to achieve them.

Below you can see some examples of the most common goals farmers have when working with agroforestry. The bullet points below each goal define the outcome in more detail. The clearer and more specific the goals are defined; the higher the likelihood of achieving them.

Increase profits

- in 1–5 years
- in 5–10 years
- in 10–20 years
- in over 20 years: pension or next generation

Ecosystem services

- Carbon sequestration
- Biological diversity
- Wind protection
- Minimize erosion
- Improve the microclimate
- Protect against floods

Diversification and creation of new farm enterprises

- Being less vulnerable to market changes
- Get higher profits on the farm

Bring more people to the farm

- Get family members or friends more involved in the farm
- Hire new workers on the farm

Self-sufficiency

Agritourism

Aesthetics

→ Remember that having several purposes/goals with your tree planting is a good way to mitigate risks (see risk-management above).

After defining the goals, it is equally important to know the reasons why you want to achieve them. Knowing why you want to introduce trees on your land will give you the clarity, motivation, and strength you will need when challenges arise.

Moreover, after reflecting on why you want to establish an agroforestry system, your goals may change as you become more aware of your deeper motives for action.

Figure 50 *Juan Anton in his forest garden, primarily used for self-subsistence, near Valencia, Spain. Photo by Mauricio Sagastuy*

Step 2: Define your starting point

Agroforestry systems can look in many ways. Which spatial and species configuration works best for your farm will depend on the goals you want to achieve and the specific context of your farm. In this step, you want to get a clear picture of your farm's context. In this way, you will have a clear map that can guide you through the whole design process.

To define your specific context, you will need to get a clear picture of:

1. Your current agricultural system
2. Your farms landscape
3. Your resources

2.1 Define your current agricultural system

This step is very simple. You should simply define what kind of agricultural system you are working with. Some of the most common examples are written below:

- Grazing
- Large-scale production of annual crops
- Small-scale vegetable production
- Fruit orchard
- Nut orchard
- Garden
- Forest

2.2 Analyze your farms landscape

In this step, you want to understand the ecology of your farm and the different factors that affect plant growth or your animals' wellbeing. By doing this analysis you will be able to plant the correct tree species where they grow best and where they are needed the most.

The best way to do this landscape analysis is to have a map of your farm or a satellite picture (for example via *Google Maps*). You can then draw on the map while you also write the answers to the questions on a piece of paper or on your computer. The aspects you want to analyze are the following:

Soil

What kind of soil do you have on your farm (clay, silt, sand)? Is your soil too wet or too dry? Are they rich in organic matter? Do you have different soils in different parts of your farm? Is the soil more fertile in some areas of your farm than in other areas?

Different tree species will thrive best in different kinds of soil. Having the right kind of soil for the right tree species will allow your trees to grow well and be healthy.

The slopes and valleys of your farm

Do parts of your land incline more to the north, east, south, or west? How much inclination do you have in the different parts of your farm? The inclination of your land will affect how sunlight reaches different parts of your land and how water moves in your farm.

Having a map with contour lines is the easiest way to capture this step.

Water and moisture

How does water move into and out of your land? Do you have areas of your land that are drier or wetter than others? Do you have dams, rivers, or lakes in or around your property? Which parts of your land have access to water for irrigation?

How water moves in your land is very closely related to the inclination of your land and the types of soils you have. It is also important to know where you have access to water if you need it for your new plantations.

Sunlight and shadow

How does sunlight reach your land during the different times of the day? Do you have areas that are more exposed to sunlight than others? How will tree planting affect the sunlight reaching the soil?

For this step, it is useful to know how much sunlight your crops and trees need. Some plants are more shade-tolerant than others. Besides that, it is also important to remember that most berry bushes, fruits, and nut trees need sunlight to produce.

Figure 51 *Ancient oak trees in a meadow at Rogalin Landscape Park in west-central Poland. Photo by Mauricio Sagastuy*

Wind and shelter

From which direction do you get the most wind in your land? Are there areas of your land that are more exposed to strong winds than others? Do you need more protection from the wind in certain parts of your farm?

Wind protection may be one of the most beneficial effects of having trees on your land. When you design your system, you should remember that there are some trees that are more resistant to wind than others. Moreover, different tree species have different growth rates. Fast growing and wind resistant tree species are great choices as windbreaks, since you get quick wind protection from them.

Flora and fauna

What kind of wild animals and insects live in and around your farm? Could they damage your crops, trees or livestock? What type of weeds grow on your farm and how will you manage them?

Tree protection is crucial if there are wild animals that could damage your trees. Some of the most common wild animals that could damage your trees are deer, wild boars, hares, and voles.

Ecosystem

Reflect upon what kind of ecosystem you have around your farm. Are there any lands with rich biological diversity where your agroforestry systems could serve as a buffer zone or as a green corridor?

Aesthetics

Can trees and shrubs create a more beautiful environment on your land? If you receive visitors, can trees create a more welcoming and aesthetically appealing environment?

2.3 Resources

Time

Planting trees is like having a baby. The work doesn't end when you plant them.
The trees will continue to need care for years to come, especially during the first 2–3 years. How much care they need depends on several factors, like soil characteristics, local weather, how much it rains, the chosen tree species, weed pressure, etc.
In general, the faster the trees grow the quicker they will be established.

Mental and physical energy

Starting a new project will bring lots of challenges with it. Therefore, you should be clear on why you are starting the project and which outcomes you want to achieve.

Having this mental clarity and purpose will keep your motivation going when challenges arise.

Additionally, you should be aware of how much physical energy will be required from you. Do you have any physical limitations? Are you planning on carrying out the project by yourself or do you want to get help from friends, family members or a new employee?

Figure 52 *Jose Luis Moreno in his forest garden, primarily used for self-subsistence, near Valencia, Spain. Photo by Mauricio Sagastuy*

Knowledge

Do you have the necessary knowledge to start this project? How can you get the knowledge you need? Having a mentor, advisor, or a community can support you throughout this process.

Money

Starting an agroforestry system often requires a significant investment. Some of the items that cost the most are:

1. **Trees and bushes** – you can reduce costs by propagating them yourself
2. **Protection against wild animals** - such as fencing and tree guards

3. **Irrigation systems**
4. **Weeding measures** - such as plastic or organic mulches, mechanical or manual weeding, herbicides
5. **Management time**

Machinery

What kind of machinery will you need for your system? Do you already own the necessary machinery? Will you need to buy new equipment for establishing and managing the agroforestry system? Do you know people that could lend you the necessary machines for key moments?

Different trees and bushes may require machinery for different aspects of the production system. Some of the most common moments where you need a machine are planting trees, mechanical weeding, harvesting (especially for berry bushes), and processing the harvest, if you decide to do that on the farm.

Remember that you don't need to own a machine if you only require it for key moments in managing or harvesting your products. In this case, verify that the company or person you borrow from has the machine available when you plan to use it. It can be hard, for example, to borrow a harvester if many other farmers in your region are harvesting the same product at the same time of the year.

Your sources of nutrients and organic matter

Do you have access to nutrients and organic matter on your farm? If not, can your neighbors provide these materials, or will you need to purchase them from the market?

To save costs and time it is better to use the nutrients and organic matter from your own farm or neighbors, such as hay, manure or compost from local organic matter. However, you may need to buy fertilizers or organic matter from outside sources as well, especially when you start establishing your system.

Step 3: Brainstorm plant species

In this step, you should brainstorm different plant species that you would like to have in your agroforestry system. Start your brainstorm by reflecting on the 7 following aspects:

1. Goals

On step number 1, you wrote your goals and why you want to achieve these goals. Now you should write which plant species you think could help you achieve these goals.

2. Site characteristics

On step number 2 you described the specific site characteristics of your farm. From the list written in the previous step, select the plant species that should grow well on your site. **Establishing the right plant species for the right site is one of the key factors for success in any agroforestry system**.

A good question to ask here is "What grows well in your region?". If you establish tree species that are already being cultivated in your region, you will have higher chances of success.

However, it is worth mentioning that sometimes it is better to plant tree species that are not common for your region, if these species are expected to be better adapted to the coming climatic changes. To adapt to future climatic changes, it is a good idea to plant trees that 1) grow well in a warmer climate, and 2) grow well in a broader spectrum of weather conditions. This is because we don't know exactly how the weather will change in the different regions of the world during different times of the year. Climate change is not only about the world getting hotter, but it is also about more unpredictable seasonal patterns.

3. Resources for managing the desired plant species

It is important to reflect upon how you are going to manage your trees and bushes. Different plant species require different resources for managing them efficiently. Resources are things such as time, knowledge, specific tools/machinery, infrastructure (fencing, support, protection against wildlife), nutrients and water.

For example, fruit trees will generally require more pruning, management time, expertise, and infrastructure compared to timber trees. Moreover, the machinery needed for harvesting fruits is completely different than the one needed for harvesting timber.

Figure 53 *Shrubs planted around a tree to protect it from wild animals and grazing livestock at OIKOS farm, southern Poland. Photo by Mauricio Sagastuy*

The 3 aspects mentioned above are important for any person wanting to integrate trees into their farm, regardless of their goals. The following 4 aspects are still relevant for most farmers; however, they are especially relevant for farmers that want to sell products from their agroforestry system.

4. Harvesting

Reflect upon the harvesting methods used for your desired species. How can you harvest these products efficiently? Do you require certain machinery, or can you harvest the products by hand? Can the products be harvested via U-pick methods or by contracting a third party?

5. Storage

If you are planning on producing more than your household can consume, then you should think about how you are going to store the harvest.

What kind of storage does your specific product need? Do you need to buy a refrigerator or equipment to be able to dry your products? Do your harvested products require any treatment before storage? Check the storage requirements for the products you want to produce. Some products are easier to store than others and different cultivars may have different storage requirements as well.

6. Transport

How will you transport the harvested products to your customer(s)? Are there any special requirements needed for being able to transport your goods? Do you own the machinery yourself or do you need to contact people to be able to transport your goods?

7. Costs, risks and profits

If you want to generate profits, you should pay extra attention to this aspect. Before you choose a tree species, you should know the costs, risks and potential profits related to it. It is important to talk to an advisor or an experienced practitioner if you are planning on investing a significant amount of money. An advisor or an experienced practitioner can guide you with the right knowledge and expertise.

Step 4: Advice

Having a mentor will increase your chances of success with your agroforestry system. Having a mentor is especially important if you're planning on selling what you produce. Your mentor could be an agricultural advisor or another farmer that has experience working with the system you want to work with.

Finding an agroforestry advisor can be hard, depending on the country you live in. If you can't find an agroforestry advisor, you can look for advisors that have knowledge about the tree species you want to work with. These advisors can probably help you, even if they do not have strict knowledge about agroforestry. The best approach is to reach out to them, share your plans, and ask if they can assist you or recommend someone better suited for the task.

Relevant topics that you can discuss with your advisor are:

- The suitability of your chosen plant species for your specific soil and weather conditions
- The economic and market opportunities of your chosen species
- Management recommendations and efficient harvesting methods
- Storage and eventual processing of the end products

Figure 54 *Marcin Wójcik explaining the design of his silvopastoral system at OIKOS farm, southern Poland. Photo by Mauricio Sagastuy*

Step 5: Market analysis

When you analyze the market opportunities for your desired tree crops you continue to minimize risks and increase your chances of success. A market analysis will shed insight into how economically viable it is to establish an agroforestry system. This process can help you in deleting or adding certain plant species to your list. It could also help you in defining which cultivars you should grow, and what costs and revenues you should expect.

Below, you can see the 6 steps for making a thorough market analysis. Remember that it is up to you to decide how big or how small your market analysis will be. We would recommend you adapt the size of your market analysis to your own circumstances and goals.

6 Steps to do a market analysis

1. Define your objectives with your market analysis

Before you do a market analysis, you should have a clear objective in your mind. **What is it specifically that you want to know or investigate?** There are many different things you may want to investigate. You can have one or several objectives with your market analysis. Below, you can see some examples of what you may want to investigate.

- What products would future customers like to buy, which cultivars, and how much are they willing to pay?
- Who should be your target audience and how can you market your products to them?
- What are the future national and international trends of your desired tree crops? Is the demand expected to increase or decrease? Is the market you will be getting into already saturated or are there many opportunities for new growers?

2. Understand your future industry

In this step, you want to gather information about the industry you plan to enter. In this case, the "industry" refers to the crops you want to cultivate and the products you intend to sell. To determine whether entering this industry is a wise choice, you should understand its status and future trends. To gain a comprehensive overview of the industry you should gather the following data:

1. the industry's size
2. its trends
3. the projected growth
4. market saturation

You may be able to find this information online or, for faster results, you can contact a cooperative or association that works with the products you want to sell. They can provide valuable insights or direct you to the right person.

For example, if you want to sell apples, you want to know if the demand for apples is growing or shrinking. You may also want to know if people in your region are expected to buy more in local stores or if they want to get the products delivered to their homes. On the other hand, if you want to open a restaurant where you will sell your own products, then you will want to understand the larger trends of eating lunch or dining out. Are people eating at restaurants more and more overtime? Or is the market potentially shrinking as consumers prefer to buy grocery delivery services?

3. Define your target market

Not everyone in your region will be your customer, and it would be a waste of time to try to get everyone interested in your products. Instead, you want to know who is most likely to want to buy your products. Your goal is to understand their needs and interests, as well as the factors that might influence their buying decisions. To do that, you should start by gathering the following information about your potential buyers:

- Age
- Income
- Gender
- Location
- Education
- Marital or family status
- Buying behaviors and trends
- Their likes and dislikes
- Their personality

To give more structure to this information and make it more applicable, you might want to create a customer profile or a persona that reflects your **ideal customer**. By understanding your ideal customer, you will be able to focus your efforts on a smaller number of people.

4. Analyze the competition

The competitors are other farmers, companies or organizations that sell the same or similar products to yours. Analyzing the competition will allow you to carefully plan what you want to sell, how you will sell it, and the marketing strategy behind it.

To start your analysis, you should make a list of your future competitors. Once you have listed your competitors, you need to investigate how you can differentiate yourself from them and where you can leverage a competitive advantage. Put yourself in your customers' shoes and ask yourself: *What would lead a customer to choose your product over another business product?*

One useful tool for understanding your competitive advantage is conducting a SWOT analysis. A SWOT analysis stands for Strengths, Weaknesses, Opportunities, and Threats. Start by doing a SWOT analysis of your business and your competitors. Ask yourself the following questions:

- What are your/their **strengths** and **weaknesses**?
- What do these companies don't have that you could offer? Do you have a competitive advantage already now in some way (**opportunities**)?
- Do they pose a **threat** to the business you want to get in? Are there other risks you need to be aware of?

Once you have performed a SWOT analysis, you can analyze the results. In your analysis, see if there are things that stick out to you. Are there common threats or opportunities in your results? Can you see clearly a competitive advantage, a strength or a weakness of your business? Going through your results will give you a clearer picture of which way to go.

For example, if you are planning on incorporating chicken into your farm. You may find out that none of your competitors sells regionally grown chicken. Moreover, in your market analysis you discovered that your ideal clients are environmentally conscious local customers. Thus, you might decide to invest in fencing and similar equipment to have pasture raised chicken in your farm. This allows you to sell your chicken for a higher price. In this scenario, you will probably have a high demand for this product, since it fits perfectly with your ideal client who is interested in locally grown products and in animal welfare.

One last reflection about "competition" is that your competitors can be your collaborators as well. Most farmers like to cooperate with each other and support each other. Therefore, even if in the market you might compete, you shouldn't underestimate the value of being able to collaborate with like-minded individuals in your endeavors.

5. Pricing strategy

Once you have analyzed your competition, you want to set the right price for your product or service. The price you set will significantly affect your farm's revenue. What price you decide to set will depend on several factors. Some of the most relevant factors are:

- Your **goals**
- The **costs** involved in producing and delivering your goods or services
- The **time** spent producing and delivering your goods or services
- The **quality** of your goods or services
- The **prices of competing products** on the market
- Your **sales and marketing strategy**

Figure 55 *Ploughing in between 14-year-old walnut trees, Domaine de Restinclières, Montpellier, France. Source: AGFORWARD project, CC BY 2.0*

Step 6: Agroforestry design

6.1 Agroforestry design – support species

The first step in agroforestry design is to decide if you want to include commercial tree crops. Commercial tree crops are tree species that produce valuable products you can sell. Commercial tree crops are usually more expensive than other tree species, and if you decide to have them, they will become the most valuable element of your system.

After selecting your commercial tree crops, you should define the support species of your system. Support species are those that provide a specific benefit to your system. Most tree species can be a support species as long as they are placed correctly. The benefits that support species provide are:

- shelter
- nitrogen fixation
- attracting beneficial organisms, such as pollinators or predators of pests
- producing organic matter
- fencing - protection against wild animals

- producing fodder
- reducing erosion
- increasing soil water retention

Once you have selected your commercial tree crops and your support species, you can start designing your system. Try to place your commercial tree crops in sheltered areas with fertile soil. Afterwards, place your support species strategically to maximize their benefits for your system.

6.2 Agroforestry design – synergies

The second step in agroforestry design is to maximize synergies while minimizing the negative side-effects of competition. There are basically 3 broad categories where you can enhance synergies and decrease competition between plant species:

Physical components, such as wind, shadow, humidity, shelter, root-system competition.

Chemical environment, such as nitrogen-fixation, nutrient-cycling, allopathy (chemicals released by certain plant species to inhibit the growth, germination, or survival of other plants nearby).

Biological environment, such as attracting pests, beneficial organisms, or pollinators, fostering mycorrhizal fungi, increasing biological diversity, and creating a humid environment that favors damaging fungi.

6.3 Agroforestry design – management

The final step is to plan how you will manage your system. This is one of the most important steps of your whole design process, because it is crucial that the system can be managed efficiently and that it fits your current farming system. To ensure that you have effective management, consider the following aspects:

A balance between efficiency and complexity: Early in this chapter, we introduced the concept of balancing efficiency and complexity as a key principle in the design process. Balancing complexity and efficiency give you the benefits of diversity without losing efficiency in its management.

Adding complexity to a farm can offer several benefits, such as increased biodiversity, better protection against pests, a more diversified production, and greater resilience to climate change. However, if you make your system too complex, farm management can become inefficient. Inefficiency leads to longer working hours and higher costs. Additionally, managing a greater variety of species requires more knowledge.

A good design can help you increase diversity in the system without adding too much complexity to its management. For example, it is possible to create a system where you have windbreaks with a high diversity of tree species and one commercial tree crop species in the sheltered area. All the tree species in the windbreaks could be managed with the same methods. Additionally, having just one commercial tree crop would reduce the complexity of its management and sales.

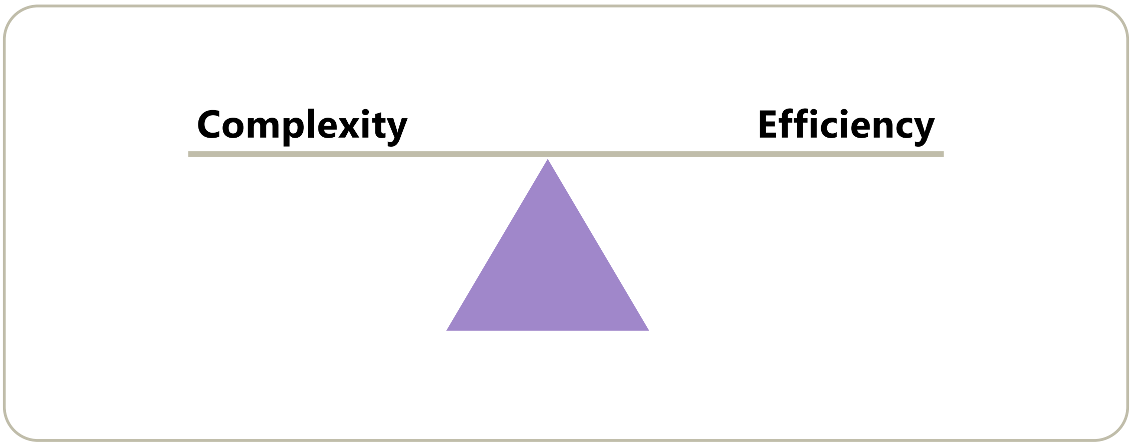

Figure 56 *Managing complexity and efficiency is an important aspect of any agroforestry system.*

The machinery: You should design your system so that your farm machinery has enough space to move efficiently throughout the system. For example, if you want to establish an alley cropping system, and you have a plough that is 4 meters wide and a harvester that is 6 meters wide, then you would want to create alleys that are a multiple of those numbers: 12 meters, 24 meters, 36 meters, etc. In this way, you would be able to drive your tractor efficiently without overlapping working areas.

Pesticide treatments for different plant species: Different plant species may require different pesticide treatments. When designing your system, arrange the trees in a way that allows for easy pesticide use. Some pesticides are restricted to specific plant species and cannot be applied to others. In such cases, it is best to avoid grouping incompatible species within the same management units.

Agroforestry regulations: Agroforestry regulations vary across European countries, including rules on spacing, density, and permitted tree species. Investigate your country's specific requirements, as they may affect your design.

Harvesting: Different tree crops have different harvesting periods and methods. For example, nut trees require different harvesting techniques compared to fruit trees. To optimize the harvesting process, avoid planting tree crops with different harvesting methods or periods in the same rows.

CHAPTER 9

Establishment and management

Establishing an agroforestry system

This section describes the most important steps that need to be taken to establish agroforestry systems.

Step 1 – Protect against wildlife

Before planting trees, it is advisable to assess the risk of wildlife damage in your area. Browsing and bark stripping by animals such as deer, wild boars, rabbits, hares, and rodents can significantly impact young trees, slowing their growth or even killing them. Damage prevention strategies must be implemented before planting, or as you plant, to avoid tree damage.

The most effective method of protection depends on the species causing damage. For larger animals like deer, you need to protect your trees by installing perimeter fencing, tree shelters, or wire mesh. Perimeter fencing is the most effective method for areas with high wildlife pressure and agroforestry systems with high tree density. If wild boars enter the field under the fence, you may need to install an electric wire 30 cm above the ground in front of the fence.

Figure 57 *Perimeter fence at the land management school Naturbruksförvaltningen Angereds gård, Sweden. Photo by Mauricio Sagastuy*

The downside of perimeter fencing is that it is expensive, especially when covering large areas. A more affordable alternative that still provides good results is electric fencing. This setup consists of two electric wires placed one meter apart, both positioned 30 cm above the ground. Additionally, a third wire is placed 1,5 meters above the ground, closest to the plantation (see Figure 58). This structure tricks deer into not jumping over, while also offering protection against wild boars - but not hares. Electric fencing becomes a less effective solution if it snows heavily in your region. Snow could cover the electric wires placed 30cm above ground, making it easier for deer or wild boars to enter the field.

Another effective method for areas with low wildlife pressure is the use of repellents made from sheep fat. These repellents must be applied several times during the season. Repellents made from sheep fat are particularly effective at repelling deer, but they can also help repel other animals such as hares, rabbits and moose. If you are going to plant several hundred expensive trees, such as fruit trees or nut trees, then it is recommended to use perimeter fencing, which gives you more effective protection.

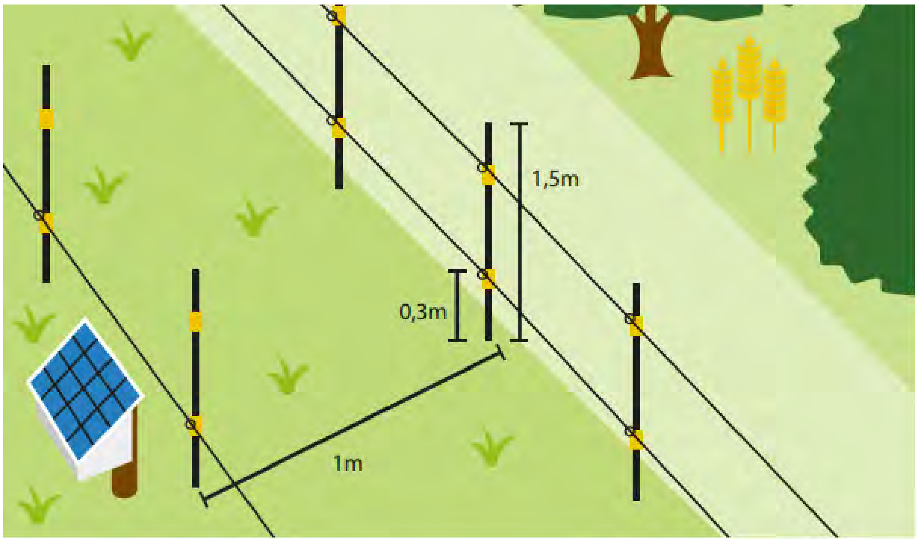

Figure 58 *Electric fence. Source: Fuhrenhed et al. (2024)*

For smaller animals like rabbits and rodents, placing individual plastic tree guards is needed. Otherwise, they will gnaw at the bark of the trees. Heavy snowfall can allow hares to reach higher up on the fences and tree guards, which may require additional protection. Maintaining a bare-soil area around the base of the trees can discourage rodents from nesting.

To control vole populations, you should first aim at disturbing their habitat. Voles like to be in areas with ground cover, tall grass, vegetables, and root crops. They also like to feed on the roots of trees, especially those of the rose family (*Rosacea*) and sea buckthorn. It is important to disturb these habitats and ensure extra protection when establishing palatable tree species. You can disturb the voles' habitat by cutting the grass, and by disrupting their burrows by harrowing or tilling the soil alongside tree rows.

Mesh root baskets can be used as a preventive method to avoid voles from reaching the roots of trees. Installing high perches to attract birds of prey or setting up nesting boxes is another strategy against voles. Additionally, traps can be used to reduce vole populations.

Damage from wildlife is often the most severe during winter and early spring when natural food sources are scarce. Regular monitoring and adopting protection strategies as needed will help ensure a successful establishment of the trees.

Figure 59 *Chestnut tree protected with a tree guard and mulched with woodchips at Gamelgaard Forest Garden, Sweden. Photo by Mauricio Sagastuy*

Step 2 – Prepare the soil

To give your trees the best environment to grow well, you need to plant them in weed-free soil. This will significantly reduce the competition with weeds, which is one of the main reasons why agroforestry systems fail. To have weed-free soil, you can have a six-month fallow period with repeated harrowing, do a deep plowing followed by harrowing, or by covering the soil with plastic two years before planting.

Figure 60 *Weed-free soil prepared with a rotary tiller for tree planting at Naturbruksförvatlningen Angereds gård, Sweden. Photo by Mauricio Sagastuy.*

Another aspect to consider is the **soil structure**. A good soil structure has a well-balanced pore size distribution and a high content of organic matter, which improves aeration, water retention, and root penetration. You can improve the soil's structure by adding organic matter, reducing compaction and decreasing excessive tillage. Organic matter can be added in the form of compost, mulch, manure or by having cover crops, also called green manure. A subsoiler can help in loosening the soil and improving aeration before planting.

To enrich the soil before planting, **consider using cover crops**. These plants, such as legumes or mustard, can be grown and then incorporated into the soil to increase organic matter and nitrogen levels. Green manure improves soil fertility, enhances microbial activity, and suppresses weeds. A two-year green manure cycle with deep-rooted plants can help loosen the soil and positively affect tree establishment and growth. Two examples of deep-rooted plants include sweet yellow clover (*Melilotus officinalis*) and alfalfa (*Medicago sativa*). Green manure may require manure fertilization to kick-start growth and effectively cover the soil.

Step 3 – Fertilization

Before you start planting trees, it is advisable to take soil samples to assess the nutrient profile and determine the need for fertilization. One key parameter in soil tests is **the pH level**. If the pH level is too low, it can harm tree growth by limiting nutrient availability and increasing the risk of root damage. To address low pH levels, you can apply dolomite lime, crushed or ground limestone, or industrial lime derived from sugar or vacuum salt production (Annex II of EU Regulation 2018/848, Part I, and Article 2 of EU Regulation 2021/1165, Annex II).

If the pH is too high, it can reduce the availability of essential nutrients, particularly iron, manganese, and zinc. To lower the pH level, you can incorporate elemental sulfur, acidifying fertilizers such as ammonium sulfate, or organic materials like peat or well-decomposed compost. In some cases, applying chelated micronutrients can help improve nutrient uptake in high-pH soils. Regular soil testing and targeted amendments help maintain an optimal pH level for tree growth.

Soil testing also provides valuable information about the **macronutrient and micronutrient profile** of the soil. For young trees, nitrogen availability is crucial for early growth, while phosphorus promotes root growth (Tahir, 2014). Potassium and calcium are needed for proper establishment and winter hardiness. The need for both nutrients, potassium and calcium, increase as trees mature and begin fruit production. Micronutrients like magnesium, boron, and sulfur also play essential roles in tree health and should not be overlooked.

Efficient nutrient management is key for maintaining soil fertility and ensuring long-term productivity. The use of manure increases organic matter content, supports beneficial soil microorganisms, and improves soil structure while providing a long-term release of nutrients. Applying manure in rows before planting is recommended, especially if it is well-composted manure. If necessary, synthetic fertilizers can also be applied to improve the soil's nutrient profile. Organic alternatives, such as rock phosphate for phosphorus and wood ash for potassium, are also effective options where synthetic fertilizers are not preferred.

While fertilization is essential, it is equally important to avoid excessive applications, as nutrient imbalances can negatively impact tree health. Overuse of phosphorus can reduce the availability of zinc and iron, while excess potassium may interfere with magnesium uptake. Excess nitrogen increases the risk of apple scabs, canker, and aphid infestations. Applying nutrients at the right time – typically before planting and during parts of the growing season – ensure trees receive the right nutrients at the right time, which promotes a healthier tree growth. When each nutrient should be applied depends on the specific nutrient you are applying.

Step 4 – Tree species selection and spacing

Chapter 8 described in detail how to choose the right tree species for your specific context. Once you have chosen the right tree species for the right site, you should buy your trees from well-established nurseries that have high-quality planting material. Healthy plants with well-developed root systems increase the likelihood of successful establishment.

Before you buy fruit trees, nut trees, and berry bushes, you must ensure that your cultivars can pollinate each other. Proper pollination is essential for achieving good yields and optimal fruit size. To maximize pollination, consult pollination charts to confirm that your chosen varieties are compatible. If necessary, include pollen donor plants that can provide pollen to multiple varieties.

Proper spacing between trees allows for adequate light, air circulation, and root development. The spacing depends on the chosen tree species, your farm machinery, and the specific outcomes of your system.

Step 5 – Planting

Once you have gone through steps 1–4, your site will be ready for planting. The last step in the establishment phase is planting your trees. Proper planning and careful execution are essential for the successful establishment of trees.

The best time to plant trees is typically in late autumn, alternatively in early spring. During these periods there is high soil moisture and temperatures are moderate for planting. When planting, it is important to ensure that the root system is properly spread out and not compressed. For bare-root trees, roots should be kept moist before planting, and the planting hole should be large enough to accommodate the entire root system. Container-grown trees should be removed from their pots, and any circling roots should be gently loosened to prevent root girdling. The planting hole should be approximately twice as wide and one and a half times as deep as the container. After placing the tree in the hole, fill it with soil and press the soil gently to eliminate air pockets.

Figure 61 *Planting an apple tree at the test field for agroforestry at Naturbruksförvaltningen Angereds gård, Sweden. Photo by Mauricio Sagastuy*

Newly planted trees require sufficient water during the growing season, especially during the first 2–3 years after planting. Mulching around the base of the tree with wood chips, straw, or compost can help retain soil moisture, suppress weeds, and improve soil structure. However, mulch should be kept a few centimeters away from the trunk to prevent rot and pest issues.

Regular monitoring and early maintenance, such as watering, weed control, and replacing failed trees, will ensure good tree growth.

Water management

Drainage

It is often said that "drainage is your first irrigation." Roots will not grow deeper than the water table. If drainage is inadequate, root depth becomes restricted, making crops more susceptible to drought. Well-functioning drainage allows crops to spread their roots and access water deeper in the soil. This increases the availability of plant-accessible water, thereby reducing the need for irrigation.

To ensure that subsurface drainage functions properly, it is important to prevent surrounding ditches from becoming overgrown and to avoid tree roots invading the drainage system or damaging the outlets. The required distance between trees and drainage infrastructure depends on factors such as soil type, tree species, and drainage system.

For water utility pipes in urban areas, a minimum distance of 7 meters is recommended, for most tree species (Östberg et al., 2010). In agricultural fields, the required distance may be greater, as drainage pipes are perforated and soil conditions differ. Fast-growing, water-seeking species like willow and poplar should be planted at least 10–15 meters away. However, there are reports of poplar roots spreading as far as 15–17 meters (Persson, 2018). Shrubs with smaller root systems, such as gooseberries, currants, or American blueberries, can be planted 3–5 meters from drainage systems.

The larger the tree, the stronger and more extensive its root system will be. Tree root growth can be controlled by pruning, as it prevents trees from growing too large. Alternatively, you can cut down trees once they reach the desired height. You can also trim the roots mechanically by using a subsoiler. Additionally, plowing the field will prune the roots, even though it won't be as deep as if you use a subsoiler.

Figure 62 *Installation of a drainage system at the test field for agroforestry at Naturbruksförvaltningen Angereds gård, Sweden. Photo by Mauricio Sagastuy.*

Main Drainage

For subsurface drainage to function properly, the main drainage system that channels water away must also be working. This main drainage system can consist of both open ditches and piped drains.

It is important to determine the specific regulations and responsibilities for your ditch. The ditch may be part of your property and must be maintained by you, or it could be part of a larger drainage association, such as a drainage company.

Maintenance

When it comes to trees and shrubs near ditches, two important aspects must be considered: whether they obstruct maintenance of the ditch, and whether they could negatively affect slope stability and cause erosion.

Ditch maintenance requires that there are no trees or shrubs blocking access for equipment, such as excavators. Roots from trees near the ditch can compromise slope stability if they penetrate it, which may lead to erosion. Trees and shrubs should not be planted directly in the ditch, as it would hinder water flow and raise the groundwater level, which would cause erosion and harmful water accumulation in the drainage system. In some cases, it is possible to have trees and shrubs on one side of the ditch as long as the other side is accessible for maintenance.

The shadow of trees and shrubs can be beneficial for the fauna in and around the ditches. However, they may also overshadow the under-vegetation, which can lead to exposed soil and erosion. Trees shade the most when they are located south-west of the ditches (in the Northern Hemisphere).

Water does not respect property boundaries and can affect neighboring areas even if you only plant trees on your own land. Therefore, trees planted on your land must not cause damage to others.

Irrigation

Water is one of the most important factors for the survival of trees. If you want your trees to grow well and produce abundantly and quickly, they must have good access to water.

How much irrigation is needed will depend on your chosen tree species, and the specific conditions of your site. In Europe, most tree species require irrigation during the establishment phase (first 2–3 years). However, there are some tree species that are more resistant and require less irrigation than others, for example black locust (*Robinia pseudoacacia*) or poplar (*Populus spp.*), provided they are planted in suitable sites. Fruit trees, nut trees and berry bushes that are continuously irrigated after establishment will normally produce higher yields.

Figure 63 *Drip irrigation. Source: Fuhrenhed et al. (2024)*

The most efficient method to water is through drip irrigation. Additionally, it is important that your drainage system functions well, as it allows roots to grow deeper and be more resistant to drought and flooding.

If you can't install a proper irrigation system, you can plant fewer trees and irrigate them with water tanks. However, this method is less efficient, and it requires more management time in the long run.

Before establishing an irrigation system, make sure to check what regulations apply to your land and whether a permit is required.

Management

Weed control

Having a plan to manage weeds is crucial, and it is especially important during the first 2–3 years after planting trees. There are different methods you can use, depending on the cultivation system and the scale of the operation.

A **rotary harrow** is suitable for systems with tree rows containing several hundred trees. Rotary harrows are used in fruit orchards to control weeds. The rotary harrow is used 5–10 times a year, depending on the weed pressure and the season. One advantage of the rotary harrow is that, in addition to weed control, it also destroys vole tunnels. The downside is that it is relatively expensive.

Figure 64 *Rotary harrow weeding the tree rows at the test field for agroforestry at Naturbruksförvaltningen Angered gård, Sweden. Photo by Mauricio Sagastuy*

Green manure can also be used to control weeds. Green manure can be in the form of perennial ground-covering plants, or annual or biennial cover crops. The downside of perennial ground-covering plants is that this method becomes very expensive when you need to buy several hundred plants to cover the soil. Annual or biennial cover crops, such as clover or other forage seeds, are cheaper to establish. However, in the long run, there is a risk that weeds will take over areas with cover crops if these areas aren't properly maintained and resown when needed.

Managing weeds with **herbicides** can be an effective and affordable option, particularly during the early years of establishment. However, it is important to verify whether herbicide use is permitted in your region. To minimize environmental impact, herbicides should be used sparingly and only during the initial years, in the lowest effective doses.

Mulching

Trees and shrubs get established better if they receive some form of mulch after planting (Rodker, 2021). Mulch can be organic (e.g., straw, wood chips, or compost) or inorganic (e.g., plastic, gravel, or rubber). Mulching helps with weed control, increases soil moisture, and raises soil temperature.

Covering the ground with landscape fabric is a reasonable method for weed control when planting fewer trees. There is landscape fabric made from plastic and landscape fabric made from biodegradable materials. Landscape fabric made from plastic often tears into small pieces of plastic with the passing of time, which then spread to the rest of the field. If you are using plastic landscape fabric, you need to have a plan of how to take it away once it has fulfilled its function. The challenge with landscape fabric made from biodegradable products is that it is more expensive than the one made from plastic.

Covering the soil with organic mulching material is a good method to suppress weeds and increase soil organic matter over time. Chipped material from fresh branches with a diameter of no more than 10 centimeters (ramial woodchips) is particularly beneficial during tree establishment phase, as it promotes the formation of mycorrhiza (Westaway, 2020). Mycorrhiza refers to a symbiotic relationship between plant roots and fungi, in which both partners benefit: the fungus aids in nutrient and water uptake, while the plant provides carbohydrates.

The challenge with mulching is that it can be very expensive when covering large areas of land. Additionally, voles thrive under all types of mulching material. A specific disadvantage of organic mulching is that it needs to be re-applied constantly to keep weeds at bay.

Figure 65 *Felix Riecken mulching his trees with hay at Rieckens Landmilch farm in northern Germany. Photo by Mauricio Sagastuy*

Preventive plant protection measures

Keeping trees well-aerated through pruning allows light and air to dry out the canopy, reducing the risk of scab and other fungal diseases (Tahir, 2014). When pruning, it is important to clean pruning tools with rubbing alcohol to prevent the spread of pests and diseases between trees. It is also beneficial to manage fallen leaves after leaf drop, for example, by shredding them so they decompose quickly and do not spread fungal spores. Remove trees affected by canker and burn them to avoid canker from spreading.

Regularly inspect your trees for harmful insects. Sticky traps help monitor when and which pests are active. Another method is branch tapping, where you gently tap a branch while holding a white tray underneath. This causes insects to fall onto the tray, allowing you to identify both pests and beneficial insects.

Flowering herbs and shrubs attract beneficial insects that can help with pest control. Birdhouses of various models support species that eat pests, such as house sparrows, great tits, blue tits, and nuthatches.

Mixing different species in the same tree rows will reduce the risk of disease outbreaks. However, depending on your management strategy and the laws in your country, you may need to have each species in different rows to facilitate the use of plant protection products and get your farm's subsidies.

Figure 66 *The agroecological fruit orchard La Florentina supports its trees with beneficial insects near Valencia, Spain. Photo by Mauricio Sagastuy*

Nutrient management

Maintaining good soil fertility over time is essential for healthy tree and crop growth. Trees that produce fruits, nuts, and berries require targeted nutrient management to support their yields. Nutrient needs will vary depending on species, soil conditions, and climate, but some general principles apply across most systems.

To begin with, it is important to know the status of the soil and its nutrient profile. **Start by doing a soil test and repeat this process every 2–5 years** to monitor nutrient levels and guide fertilization strategies. Soil testing helps identify deficiencies or imbalances early, allowing you to adjust inputs before they impact your yields negatively.

Nitrogen (N) is essential for vegetative growth and healthy leaf development, especially during the early years of establishment. However, excessive nitrogen – especially later in the season – can delay fruiting and make plants more susceptible to disease. **Phosphorus (P)** is important for root development, flower formation, and energy transfer, while **potassium (K)** enhances fruit quality, disease resistance, and winter hardiness.

In addition to N-P-K, secondary nutrients like **calcium (Ca)** and **magnesium (Mg)** are important for cell wall strength and photosynthesis, particularly in berry crops and pome fruits like apples and pears. **Micronutrients** such as **boron (B)**, **iron (Fe)**, **zinc (Zn)**, and **manganese (Mn)** are also vital in smaller quantities – for example, boron deficiency can lead to poor fruit set in apples and hazelnuts.

The benefit of working with agroforestry is that leaf litter and root turnover from trees contribute to soil organic matter and nutrients over time. Moreover, a diverse planting of deep-rooted trees and shrubs helps to cycle nutrients from deeper soil layers to the surface. Over time, this natural recycling can reduce the need for external input.

In organic systems, nutrients can be supplied using compost, animal manure, seaweed extracts, rock phosphate, basalt dust, and approved foliar sprays. These not only feed the plants but also build up soil organic matter and microbial activity, improving long-term fertility and resilience. Intercropping with **nitrogen-fixing species**, such as clovers or legumes, is another strategy that helps boost soil nitrogen levels naturally, especially when these plants are incorporated into the ground as green manure. If you add mineral fertilizers, make sure to use them carefully to avoid harming soil organisms. **Ideally, fertilization should be targeted, based on soil test results and plant needs.**

Timing and method of nutrient application also matter. Nutrients should be applied when they are most needed, for example, early in the growing season when vegetative growth is most active. Organic materials should be well-composted to prevent nutrient leaching or burning of young plants. Mulching with nutrient-rich organic matter can also help retain moisture and provide a slow, steady release of nutrients over time.

Proper nutrient management supports not only higher yields but also increases a system’s overall health, pest resistance, and resilience to climatic stress.

Pruning

Pruning enhances light penetration, air circulation, and overall plant health. Pruning improves the yields of trees and the quality of their products (e.g., larger fruit size and better wood quality). It also prevents and removes diseases and shapes trees into manageable sizes. Additionally, in agroforestry, pruning helps minimize shade and control the size of trees, which reduces competition between trees and crops.

The best time for pruning depends on the tree species and the intended outcome. For most deciduous trees, pruning during the dormant season – between late fall and early spring – is ideal, as it encourages vigorous growth when the growing season begins. Summer pruning, on the other hand, is used to control excessive growth and remove unwanted shoots. Some fruit and nut trees benefit from post-harvest pruning, which helps them prepare for the next season's production. Stone fruit trees, such as plums (*Prunus domestica*), cherries (*Prunus cerasus*), and peaches (*Prunus persica*), must be pruned in late summer because they tend to "bleed" if pruned in spring. Timing is crucial to avoid stressing the tree or reducing yields.

Figure 67 *Farmer pruning his poplar trees to improve timber quality in Timiș, Romania. Photo by Mauricio Sagastuy*

In agroforestry, pruning strategies should be adapted to the specific function of the trees. Timber trees benefit from early pruning of lower branches to encourage straight trunk growth. Fruit trees require canopy management to optimize fruit production and facilitate harvest. Windbreaks need careful pruning to maintain their protective function without becoming too dense. In alley-cropping, trees may need to be pruned harder to prevent them from overshadowing adjacent crops.

When pruning, it is important to follow proper techniques to maintain tree health. Some key general principles of pruning are:

- **Remove dead or diseased branches** to prevent the spread of infections and improve overall tree health.

- **Shape the tree** to give it the desired form and a good structure for long-term growth and production. Remove narrow branch angles, competing leaders, branches that rub against each other, branches growing inward toward the crown, root shoots, trunk shoots, diseased branches.
- **Thin out overcrowded areas** to allow for better light penetration and air circulation.
- **Avoid over-pruning**, as removing too much foliage can stress the tree and slow its growth.
- **Use proper tools** such as sharp pruning shears, loppers, and saws to ensure clean cuts and minimize damage.

Pruning is not a one-time task but an ongoing process throughout a tree's lifespan. By implementing adequate pruning strategies, you can promote healthier trees, higher yields, and minimize competition between trees and crops.

Harvesting

If you are planning on harvesting products, you need to develop a harvesting plan that includes all the different trees, crops, and animals in the system. In order to do this, you need to **(1) define the different harvesting periods**, **(2) select the right harvesting method for each product**, and **(3) organize each section for efficient management**. Additionally, you need to reflect on how you will store the products once harvested, and whether you want to do post-harvest value addition.

The harvesting period of your products will depend on the chosen species and cultivars, as well as the type of product you want to produce. For example, early harvest grapes (higher acidity, lower sugar) are used for sparkling wines, while later harvest grapes (higher sugar content) are used for sweet wines, such as ice wine. Timber harvested in different periods can also develop different characteristics, for example early harvested oak (*Quercus robur*) is used as flexible wood for barrels or furniture veneer, while older oak is harder and better suited for construction and flooring.

Creating a plan that considers the harvesting time of the different products will make your management more efficient. In the plan, you should outline how often the products will be harvested (e.g. once a year for most fruits and nuts, once every five or fifty years for fuelwood or timber) and the time of the year for the harvest (e.g. August, October, December).

Figure 68 *Vicente Borrás inspects his peaches after harvest at La Florentina, near Valencia, Spain. Photo by Mauricio Sagastuy*

The best harvesting method for your farm depends primarily on the selected species, the available machinery, the type of product you produce, and the scale of the operation. Manual harvesting is common for fruits, nuts, and specialty crops. It preserves product quality but requires significant labor. Mechanized harvesting may be needed for larger operations. Machinery like nut shakers, fruit-picking platforms, or forestry harvesters can improve efficiency. However, to make this investment pay off, you need to produce very large quantities. This method becomes more relevant if you can borrow these machines or if you already own them.

To optimize the harvesting process, it is preferable to separate each section or tree row according to species, cultivars, and harvesting period. With this approach, trees that ripen simultaneously can be harvested more efficiently, reducing labor costs and simplifying transport. However, the downside of this approach is that you lose diversity in each section or tree row, which makes them less resilient and more vulnerable to pests or diseases.

Post harvest handling and adding value

After harvest, you need to think about the post-harvest handling process. How much of it is needed depends on the end-product being sold and who the customer is (e.g. wholesale, value-added products, sold directly to customers). Post-harvesting methods help maintain product quality, reduce losses, and increase profitability.

The first step after harvesting is to sort and clean the harvested products, removing any damaged or diseased items to prevent spoilage. For perishable crops, like fruits and vegetables, immediate cooling through refrigeration slows down ripening and extends shelf life. Nuts often require drying to reduce moisture content, preventing mold and ensuring longer storage, while timber may undergo seasoning or kiln drying to enhance durability. Proper storage conditions, such as humidity control for grains or ventilated spaces for firewood, help preserve quality.

Additionally, you may want to add value to the products after the harvest, such as pressing oils from nuts, fermenting fruits for beverages, or milling timber into processed wood products. These steps not only improve storage efficiency but can also increase their market value.

CHAPTER 10

Economic considerations in agroforestry

Introduction

It is well known that agroforestry is a land-use system that provides many environmental benefits both to the farmers and to the society (Schievano et al., 2022). However, the economic side of agroforestry isn't so well understood. Some people claim that agroforestry is not a financially viable option while others argue that agroforestry will always lead to higher profitability in the-long term. **Whether a farm will become more profitable or not depends on several factors, most of which are context dependent.**

In this chapter, you will learn about some of the key economic principles related to agroforestry, and how your choice of tree species and management strategies affects the economics of your farm. This chapter does not claim to provide robust financial models for agroforestry in Europe and should not be relied upon for that purpose. Commercial agroforestry models are still rare in Europe. Instead, the goal of this chapter is to equip you with the essential tools and information needed to plan an agroforestry system and evaluate its financial performance.

Why can agroforestry be a smart financial decision?

Improved ecosystem services on the farm: Agroforestry enhances ecosystem services by increasing carbon sequestration, promoting biodiversity, reducing erosion, and improving soil quality. These improvements lead to a more resilient agroecosystem, ensuring greater farm stability and profitability over time. Additionally, ecosystem services provide public benefits like flood mitigation, cleaner air, and reduced pollution.

Farmers can also monetize these benefits through programs paying for carbon sequestration, eco-certifications, and marketing environmentally friendly products. Thus, these incentives can add financial value to agroforestry systems.

Higher yield per hectare (Land-Equivalent Ratio): Agroforestry systems often produce a higher yield per hectare compared to monocultural systems due to the symbiotic relationship between trees and crops or animals (Dupraz et al., 2005). In agroforestry, trees usually have a wider distance between each other compared to trees in forests or orchards. Thus, trees have less competition with each other and each tree can therefore grow better. At the same time, trees provide shelter and improve microclimate for crops and animals, which increases their yield compared to monocultural systems.

Extra income from tree products: The most evident economic advantage in agroforestry is the extra revenues that trees generate. Products from trees that have well established markets are fruits, nuts, berries, timber or bioenergy. There are other products from trees that have more niche markets, such as foliage for floristry, biochar or products for the Christmas market, e.g. holly, mistletoe or Christmas trees.

Figure 69 *Tree nursery at Juchowo Farm in north-western Poland. Trees from this nursery are used to replace dead ones in the tree rows. Photo by Mauricio Sagastuy*

Economic differences between agroforestry and conventional farming

The economy of "tree-based" production systems is quite different from the one in annual crops. **Trees usually require a big investment in the establishment phase without generating any profits during the first years**. However, once trees start producing, they tend to generate more valuable products compared to annual crops. Thus, "tree-based" production systems tend to be more profitable in the long run compared to annual crops.

Another difference between "tree-based" production systems and annual crops or livestock, is that the yields from trees will vary over their lifetime. Trees produce lower yields during the first years, then they reach their maximum yield capacity and keep it high for some decades (depending on the tree species), until they finally reach a point where their yield starts to decrease (see Table 10). Fruit trees can take about 5 years to start producing their maximum annual yield, while walnuts can take 15 years to reach their maximum yield potential and for timber, you may have to wait up to 50 years to harvest the wood.

Agroforestry also differs from conventional agriculture in that it isn't always a cash-flow-driven business model. Often, investing in agroforestry is better understood as investing in capital assets. The agroecological benefits of integrating trees tend to emerge over the long-term. Just like purchasing land, stocks, or bonds, the expectation isn't to see a quick return or to sell within a few years. Rather, the goal is to generate long-term economic benefits. Similarly, most agroforestry systems enhance farms' resilience, productivity, and land value over time.

In Europe, agroforestry differs from conventional farming not only in practice but also in how subsidy systems are applied. The types of subsidies that farmers can expect to receive for agroforestry vary from country to country. Additionally, each country has its own definition of agroforestry and its own criteria for when financial support is available. For example, at the time of writing, in Sweden, farmers do not lose their agricultural subsidies if they plant trees on arable land, but they do not receive any additional financial support for doing so. Moreover, agroforestry is not recognized in Sweden if it involves planting shrubs or if it is established on grassland.

In contrast, Germany offers more comprehensive support. In addition to regular agricultural subsidies, German farmers can receive extra financial support for implementing agroforestry on arable land, grassland, or land with permanent crops (such as orchards, berry shrubs, or meadows). They may receive up to €1,290/ha per tree strip for planting short-rotation coppice, and up to €5,000/ha per tree strip for planting trees used for food production, timber, or both – including shrubs planted as ground cover. Additionally, farmers can receive €270/ha per tree strip if more than five woody species are planted per hectare of tree strip within the system.

Before establishing an agroforestry system, it is advisable to consult your local authorities to understand the current regulations and available subsidies in your specific country and region.

Figure 70 *Marcin Przytocki's alley cropping system for grazing and fruit production in north-western Poland. Photo by Mauricio Sagastuy*

Choosing the right tree species and management strategy for your farm

Different trees grow well in different environments. Yet, despite their specific habitat adaptations, all trees need sunlight, water, nutrients, and protection from harmful organisms. The same can be said about the management of trees: even though different species are managed in different ways, there are a few areas of management that most trees share. If these areas are managed well, trees tend to grow better and produce higher yields.

The management methods you decide to use will greatly influence your farm's economy. Some methods pay off only when working with large numbers of trees - for example, investing in rotary harrows to weed newly planted trees. Other management practices may not be necessary in your specific case. For instance, you may be able to skip irrigation if there is constant rainfall in your region, if you have planted drought-tolerant tree species, or if your soil can hold enough moisture, such as clay soils.

The tree species you choose to work with will also greatly influence your management and farm economics. Below, we have categorized tree species into different "production systems". Production systems consist of trees that produce the same type of products. Because they produce the same type of products and grow in similar ways, each production system usually shares similar management needs.

Some tree species can belong to two or more production systems at the same time, because they can produce more than one product from the same tree. For example, walnut trees can provide both nuts and high-quality timber simultaneously. Another example is willow, which can be used as both fodder and biofuel.

Certain management areas are essential for healthy tree growth and usually involve higher costs. These include weeding, water management, protection from wild animals, and management time (the time needed for managing your trees). Make sure to pay special attention to these management areas when choosing your tree species.

The table below provides an overview of the most relevant production systems for European agroforestry. We recommend using it as a general framework for understanding the different "types" of tree species and their management needs. It can help guide your choice of tree species and management strategy for your farm. Before making any final decisions, we suggest consulting an advisor or mentor who can offer a second opinion based on your specific context.

Category	Description of the category	Irrigation	Weed control	Management and harvest	Economics	Examples of tree species for each category:
Fast growing tree species	Fast growing tree species that produce woodchips, bioenergy or timber. These tree species can be planted as cuttings, which makes the planting process quick and effective.	These trees can be established without irrigation.	These trees need the least weed control compared to other types of tree species. They can often be established on a weed free soil without further weed control. However, they will grow better if you control the weeds during the establishment phase.	Usually, these trees do not require any extra nutrients in the soil (fertilizers) or pest control (pesticides). These tree do not need pruning to grow well. However, you may need to prune them depending on the end product you want to produce. If you plant several thousand cuttings and there is low wild animal pressure in your region, you won't need to protect them from wild animals. Few trees may get damaged by wild animals, but the majority will survive. It is recommended to harvest these trees mechanically in large plantations. In smaller plantations it is possible to harvest them manually.	Cuttings from fast growing tree species are very cheap and easy to propagate by yourself. This category of trees works well as a "green infrastructure" in the farm or as windbreaks, due to their quick growth, low costs and little management time.	Willow *(Salix spp.)* Poplar *(Populus spp.)*
Support species	Support species are tree species that generate or improve the ecosystem services on your farm. For example: wind protection, fixing nitrogen in the soils, producing fodder, reducing soil erosion, improving the microclimate, increasing biodiversity, etc.	Some tree species in this category require irrigation during the establishment phase. Resilient tree species can be established without irrigation.	Most tree species in this category need weed control during the establishment phase. Resistant tree species can be established on a weed free soil without the need for further weed control. However, they will grow better if you control the weeds during the establishment phase.	Usually, these trees do not require any extra nutrients in the soil (fertilizers) or pest control (pesticides). Usually, you don't need to prune these trees. Usually, you don't need to harvest any products from tree species in this category.	The purpose isn't necessarily to generate more income in the short term by selling products from the trees. The purpose is to generate more long-term income by improving the health of the agroecosystem, thereby improving the living conditions for your crops and animals. Since your goal isn't to sell something directly from these trees. It would be advisable to NOT invest too much money or management time in them.	Alder *(Alnus spp.)* -> nitrogen fixing Willow *(Salix spp.)* Most tree species that grow in the forests around your region, for example oaks *(Quercus spp.)*, lime trees (Tilia spp.), maples *(Acer spp.)*, beech *(Fagus sylvatica)*, spruce *(Picea spp.)*, pine *(Pinus spp.)*. Be cautious when planting tree species that have invasive tendencies and can propagate through their roots (rhizomes), such as aspen (Populus tremula). Almost all trees and bushes are included in this category as long as they provide a relevant ecosystem service to the farm.

Category	Description of the category	Irrigation	Weed control	Management and harvest	Economics	Examples of tree species for each category:
Timber trees	The purpose is to produce timber from these species.	Some tree species in this category require irrigation during the establishment phase. Resilient tree species can be established without irrigation.	Most tree species in this category need weed control during the establishment phase. Resistant tree species can be established on a weed free soil without the need for further weed control. However, they will grow better if you control the weeds during the establishment phase.	Usually, timber trees do not require any extra nutrients in the soil (fertilizers) or pest control (pesticides). To improve the quality of the timber, you should prune the branches of the first 6–8 meters of the stem.	Due to the long-term presence of these trees (several decades), it would be advisable to plant these trees in a way where they can act as support species by improving the conditions on your farm. Certain tree species produce high quality timber, which can be sold for higher prices.	**High quality timber:** Oak *(Quercus spp.)* Walnut *(European and black) (Juglans regia and Juglans nigra)* Wild cherry (*Prunus avium)* **Other timber species:** Poplar *(Populus spp.* Sweet chestnut *(Castanea sativa* Douglas fir *(Pseudotsuga menziesii)* and other redwoods Several common forest species, such as Alder *(Alnus spp.)*, Beech *(Fagus sylvatica)*, Pines *(Pinus spp.)*, Lime trees *(Tilia spp.)*, etc.
Berry bushes	Shrubs that produce edible berries.	Berry bushes require irrigation during the establishment phase. If you want to produce good reliable yields, then you should irrigate your bushes during their entire lifetime.	Berry bushes require weed control during the establishment phase. Additionally, most berry bushes will produce higher yields if you control the weeds during their entire lifetime.	Require fertilization (enough nutrients in the soil) in order to produce good yields. Require pest control measures. Require continuous pruning in order to produce good yields. It is important to know in advance how you are going to harvest and store the berries.	The purpose is to produce berries in an effective way. Mechanical harvest is needed in large plantations in order to have a profitable enterprise. In smaller plantations it is possible to harvest manually or via u-pick methods.	Saskatoon *(Amelanchier alnifolia)* Sea buckthorn *(Hippophae rhamnoides)* Red or black currant *(Ribes rubrum / Ribes nigrum)* Gooseberry *(Ribes uva-crispa)* Honeyberry *(Lonicera caerulea)* Mulberries *(Morus spp.)*

Category	Description of the category	Irrigation	Weed control	Management and harvest	Economics	Examples of tree species for each category:
Nut trees	Trees and shrubs that produce edible nuts.	Nut trees require irrigation during the establishment phase. Most nut trees will produce higher yields if they are irrigated during their entire lifetime.	Nut trees require weed control during the establishment phase. If you want to produce good reliable yields, then you should control the weeds until the trees have grown enough so that weeds do not affect them.	Require fertilization (enough nutrients in the soil) in order to produce high yields. Require pest control measures. Some species, such as hazelnuts, will produce higher yields if you prune them during their entire lifetime. While other trees, f.ex walnuts, will grow into large trees that require pruning only during the first years before they reach heights where they are hard to prune. It is important to know in advance how you are going to harvest and store the nuts. The upside is that nuts are usually easier to harvest and store compared to fruits or berries.	The benefit of having nut trees is that most species require less management and harvesting time compared to fruit trees or berry bushes. The nuts can be harvested easily once they fall down from the tre-es and there is less need of pruning nut trees compa-red to fruit trees or berry bushes. Another upside of nut trees is that most species have longer lifetimes compared to fruit trees or berry bushes, which allows them to produce high yields for several decades without needing to replant trees after a couple of decades. The downside of having nut trees is that it usually takes a longer time for them to produce compared to fruits or berry bushes.	Hazelnuts *(Corylus avellana)* Chestnuts *(Castanea spp.)* Walnuts *(Juglans regia)* Almonds *(Prunus dulcis)* Pistachios *(Pistacia vera)*
Fruit trees	Trees that produce edible fruits.	Fruit trees require irrigation during the establishment phase. If you want to produce good reliable yields, then you should irrigate your trees during their entire lifetime.	Fruit trees require weed control during the establishment phase. Fruit trees with weak rootstocks require weed control during their entire lifetime. Fruit trees with strong rootstocks do not require weed control after the establishment phase, however they will produce higher yields if you also control the weed after the establishment phase.	Require fertilization (enough nutrients in the soil) in order to produce good yields. Require pest control measures. Require continuous pruning in order to produce good yields. It is important to know in advance how you are going to harvest and store the fruits.	Fruit trees can be managed and harvested manually, while still generating a good profit. In agroforestry, it is usually better to plant fruit trees with strong rootstocks, because they are bigger, more resistant, and they can produce for many more decades compared to trees with weak rootstocks. Fruit trees with weak rootstocks usually require support, irrigation and in general more care during their entire lifetime.	Apples *(Malus domestica)* Pears *(Pyrus communis)* Plums *(Prunus domestica)* Quinces *(Cydonia oblonga)* Olives *(Olea europaea)* Oranges *(Citrus sinensis)*

Category	Description of the category	Irrigation	Weed control	Management and harvest	Economics	Examples of tree species for each category:
Climbing woody perennials	Climbing woody perennials that produce edible berries or fruits.	Climbing woody perennials require irrigation during the establishment phase. If you want to produce good reliable yields, then you should irrigate them during their entire lifetime.	Climbing woody perennials require weed control during the establishment phase. If you want to produce good reliable yields, then you should control the weeds during their entire lifetime.	Require fertilization (enough nutrients in the soil) in order to produce good yields. Require pest control measures. Most species require continuous pruning in order to produce good yields. It is important to know in advance how you are going to harvest and store the fruits or berries. These plants need a structure to climb on.	The goal is to efficiently produce high yields of fruits or berries. Climbing woody perennials often require a lot of care and they usually don't grow well in exposed conditions.	Magnolia-vine *(Schisandra chinensis)* Grape-vine *(Vitis vinifera)* Kiwi *(Actinidia deliciosa)* Hops *(Humulus lupulus)*

Table 9 *Overview of tree species and production systems relevant for agroforestry in Europe.*

There are two key insights you should take away from the table above are:

1. Different tree species have different economic and management needs
2. Some tree species will be better at fulfilling certain functions in your farm than others

For example, tree species categorized as "support species" provide valuable ecosystem services to your farm and they require little management time and low investments. "Fast growing tree species" require even less management time or investments than "support species" while still providing relevant ecosystem services. On the other hand, "fruit trees" or "berry bushes" allow you to generate a good income by selling valuable products. However, these trees will require more management time, better infrastructure, and a larger investment compared to "support species" or "fast growing tree species".

How to budget for a future agroforestry system?

Conducting a financial analysis is essential to evaluate whether implementing agroforestry is a sound economic decision. This process involves forecasting changes to the current economic situation as a result of the proposed system.

The budgeting process begins with an assessment of the existing farm enterprise. This includes determining how many hectares of crops or livestock will be retained and how many hectares will be allocated to agroforestry. Once these areas are defined, financial projections over time can be calculated.

To facilitate these calculations, farms should be divided into different enterprises, defined as any product or service generating sales (see Figure 71 below). Examples include potatoes, oats, milk, fruit, or timber. After dividing the farm into enterprises, the following steps can be taken to conduct a financial analysis.

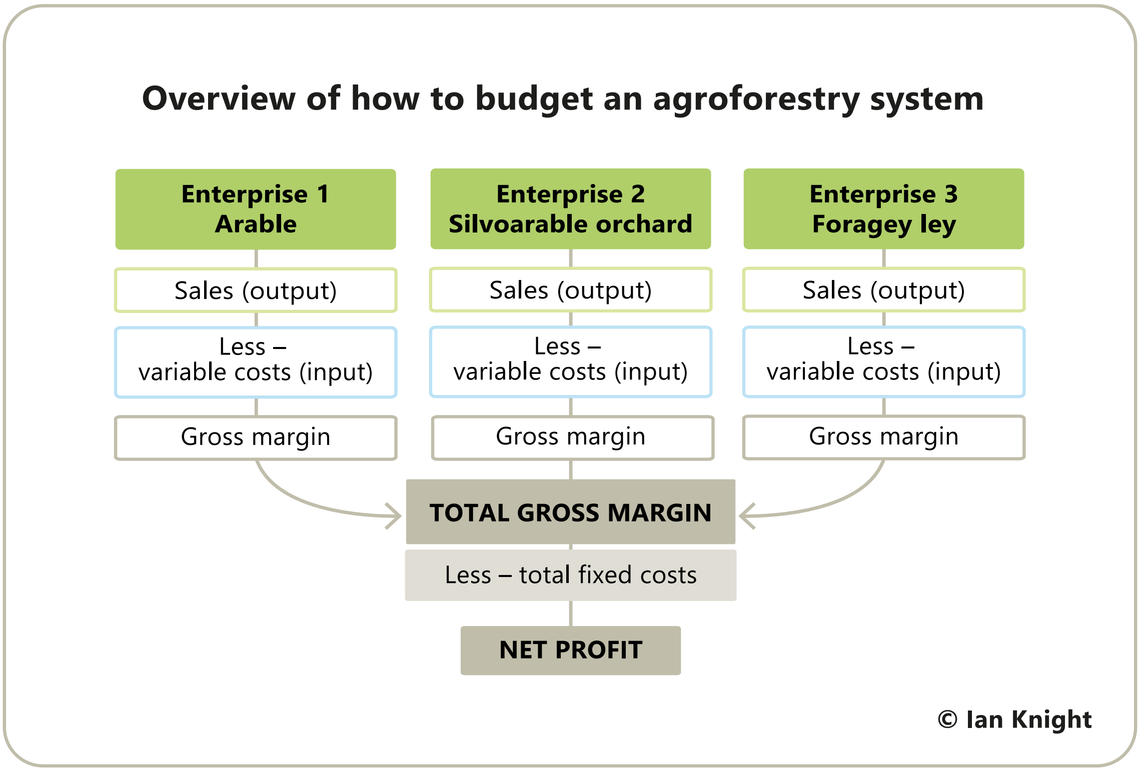

Figure 71 *How to budget the gross margin of different enterprises and the net profit in agroforestry. Adapted from The Agroforestry Handbook: Agroforestry for the UK 1st Edition (July 2019), created by Ian Knight - ABACUS Agriculture.*

Step 1 – calculate the yearly yields of your trees

Write how many years after the establishment of your trees you expect them to produce their maximum yield. Afterwards, you should write the expected yield of the trees before and after they produce their maximum yield. You can write these yields as a percentage of the maximum yield. You can see an example of this on the table below.

Step 2 – expected revenues

List the expected revenues generated from the crop and/or livestock for each year. Afterwards, write the expected yields from your trees for each year and at what price you expect to sell these products (e.g. € per tons of apple, € per cubic meter of wood). Multiply the predicted yields with the price you plan to sell your products to get the expected revenues from your trees.

Step 3 – variable costs

List the variable costs for each enterprise. List these variable costs year by year. For an arable enterprise, fertilizers, seeds and pesticides are considered as variable costs.

Afterwards, list the variable costs of your agroforestry enterprise. Typical variable costs in agroforestry include tree establishment, stakes & ties, tree guards, pruning, pest & disease control, and harvesting. Preferably, write the variable costs per tree or hectare. Then, write the year in which the variable costs occur, for example year one: establishment costs, stakes & ties, tree guards, year three: pruning, year five: pesticides, harvesting.

Step 4 – gross margins

Calculate the gross margin of each enterprise by subtracting the variable costs from the revenues.

Step 5 – your farm’s net profit

Add all the gross margins for each enterprise to get your whole farm’s gross margin. Afterwards, subtract fixed costs, labor, machinery and rent to get the net profit for the entire farm.

A financial analysis of a winter wheat-apple alley cropping system in the UK

Silvoarable – top fruit		
This gross margin sample combines a winter wheat with an apple orchard in year six at 100%. The breakdown of costs are per hectare. In practice this system suits a low-density tree planting of around 85 trees per hectare with a combine harvester or sprayer boom width of 24–36 metres in between the rows, with tree spacing every three m in the row.		
Wheat		
Feed winter wheat		
Production level	**Average**	
	per ha	
Yield: tonne/hectare	8,3	
	€	**€/tonne**
Output at €175/ton	1 463	176
Variable costs €/ha		
Seeds	71	8
Fertilisers	221	27
Sprays	295	35
Total variable costs	**586**	**71**
Gross margin €/ha	**877**	**106**

Apples – orchard system		
Production level	**Average**	
	per ha	
Yield: tonne/hectare	1,7	
	€	**€/tonne**
Output at €1 060/t	1 798	1 058
Variable costs €/ha:		
Orchard depreciation	71	41
Pruning/clearing	59	34
Fertiliser/sprays	95	56
Crop sundries	24	14
Harvesting	137	81
Grading/packing	291	172
Storage/bin hire	167	98
Packaging	130	76
Transport	106	62
Commission/levies	135	80
Total variable costs	**1 215**	**714**
Gross margin €/ha	**583**	**343**
Silvoarable - top fruit gross margin €/ha	**1 459**	**859**

Tree age	Year 1–3	Year 4–5	Year 6–15	Year 16–25
Tree yield	zero	50 %	100 %	75 %

Table 10 *Financial calculations of an apple-winter wheat alley cropping system in year 6, 100 % production. Adapted from The Agroforestry Handbook: Agroforestry for the UK 1st Edition (July 2019), table created by Stephen Briggs - ABACUS Agriculture.*

In the table above, the prices have been converted from pounds to euros at the currency exchange rate for 2 May 2025. It should be noted, however, that the prices have changed over time and the example is not to show the exact figures for each cost and revenue, but to give an idea of how to calculate and compare an agroforestry-based operation against a more traditional farming system.

The budgeting process described above will give you a good overview of the expected economic changes in your farm if you adopt agroforestry practices. If you want to do a more nuanced financial analysis, then you should also include the following aspects:

- cash flow analysis
- grants or changes in subventions due to the introduction of agroforestry practices
- forecasting how the interaction between trees and crops or livestock influences the yields (both positive and negative aspects)

CHAPTER 11

Considerations for urban agroforestry

Introduction

By integrating trees and agricultural methods into urban environments, urban agroforestry provides city planners with creative ways to improve liveability, sustainability, and resilience. Cities that properly include agroforestry into urban development can address environmental concerns, strengthen food security, and improve citizens' general quality of life.

Benefits	Description
Environmental	There are many ecological benefits of integrating trees into urban settings. Trees act as natural air filters, sequestering carbon dioxide and other pollutants, thereby improving air quality. They also offer shade, reducing urban heat islands and lowering energy consumption for cooling purposes. Moreover, urban agroforestry contributes to biodiversity by creating habitats for various species, enhancing ecological balance within cities.
Social and Economic	In addition to its benefits for the environment, urban agroforestry promotes economic growth and social harmony. Community gardens and orchards function as gathering places that promote community involvement, education, and social interaction. Additionally, by selling fresh produce, these areas can increase local food security and generate income through the sale of excess crops.

Challenges and considerations

Urban agroforestry requires careful planning to overcome obstacles such as limited space, soil contamination, and regulatory constraints. City planners must work with communities to locate acceptable places, choose appropriate species, and create maintenance strategies to assure the longevity of these green spaces.
Urban regions frequently confront constraints such as limited and contested spaces. To effectively incorporate agroforestry, planners should look for underutilised spaces like vacant lots, roofs, and street medians to grow trees and produce food.

Identifying underutilized spaces

To effectively incorporate agroforestry, planners should identify underutilized areas such as vacant lots, rooftops, and street medians for tree planting and food production. For instance, the practice of food scaping transforms traditional lawns into productive landscapes, maximizing space for edible plants.

Tree species selection

Choosing the right tree species is critical to the success of urban agroforestry programs. Planners should prioritize species that can withstand urban stressors like pollution and drought while still having development patterns that are suitable with urban infrastructure. Incorporating fruit and nut-bearing trees can boost local food production and improve community wellbeing.

Pollution and drought tolerance

Urban areas can expose trees to high levels of pollution and periods of restricted water availability. The London plane tree (*Platanus × acerifolia*) and several elm cultivars, such as 'Urban' (*Ulmus 'Urban'*), have shown tolerance to these conditions. The 'Urban' elm, for example, was created expressly for its tolerance of poor soils, pollution, and drought, making it ideal for urban landscapes.

Growth patterns and compatibility

The growth habits of selected tree species should align with the spatial constraints of urban areas. Choosing species with controlled growth patterns minimizes conflicts with infrastructure and reduces maintenance requirements. For example, certain elm cultivars have been developed to exhibit desirable growth characteristics suitable for urban settings.

Infrastructure compatibility

Integrating agroforestry into existing urban infrastructure requires rigorous design to create harmony between green zones and developed surroundings. Planners must assess possible consequences to avoid distractions from vital services and improve urban functionality.

Figure 72 *Cows grazing in a silvopastoral system at the land management school of Naturbruksförvaltningen Angereds gård, Sweden Photo: Anna Ternell*

Incorporation of fruit and nut-bearing trees

Integrating fruit and nut-bearing trees into urban landscapes can help to support local food systems while also providing nutritional benefits to people. Community orchards, which are clusters of fruit trees shared by communities in easily accessible regions, act as communal resources that enhance food security and community engagement. Cities such as Beaumont, for example, have built urban orchards to combat food deserts, giving citizens access to fresh vegetables while also encouraging community involvement (Brent, K., 2025).

Multipurpose tree species

Selecting multipurpose tree species can help to maximize the benefits of urban agroforestry. Alder (*Alnus glutinosa*) trees contribute nitrogen fixation, improve soil fertility, and provide shade and ornamentation. Their rapid growth and tolerance to wet soils make them suitable for certain urban contexts, offering ecological and biodiversity benefits.

Strategic placement and design

Thoughtful positioning of trees can significantly enhance urban infrastructure by providing shade, reducing energy consumption, and improving aesthetic appeal.

- **Energy efficiency:** Strategically positioned trees can significantly reduce energy usage in buildings by providing natural shade and minimizing the need for air conditioning during warmer months. According to research, a 10% increase in urban tree canopy can reduce ambient temperatures by 3–4 degrees Celsius, resulting in reduced energy use and fossil fuel use (Gillerot et al., 2024).
- **Urban heat island mitigation:** Urban areas often experience higher temperatures than their rural counterparts, a phenomenon known as the urban heat island effect. Implementing climate-sensitive urban planning through optimized tree placements has been shown to mitigate heat stress and improve thermal comfort in cities.

Figure 73 *Urban agroforestry. Source: Urban Agroforestry,* Freepik.

Mitigation of infrastructure conflicts

To prevent conflicts between tree roots and urban infrastructure, planners should select species with appropriate root structures and implement design solutions like root barriers. This proactive approach minimizes maintenance costs and preserves the integrity of both the trees and the infrastructure.

- **Root barrier implementation:** Installing root barriers is an effective strategy to guide tree roots away from infrastructure such as sidewalks, roads, and underground utilities. Properly installed root barriers protect footpaths, roads, and underground pipes from damage, making them a key solution in urban tree management.
- **Species selection:** Choosing tree species with less aggressive root systems can prevent future infrastructure damage. Certain species, such as willows and poplars, have aggressive root systems likely to invade pipes, foundations, and paved surfaces. In contrast, trees like crepe myrtle, certain magnolia varieties, and smaller ornamental trees have more contained root systems, making them better suited for urban planting near infrastructure.
- **Engineering solutions:** Innovative engineering approaches, such as the use of structural soils and structural cells, can convert spaces beneath hard surfaces into root-friendly zones, thereby reducing the likelihood of root-induced damage to infrastructure. These engineered solutions provide adequate soil volume for root growth while supporting the weight of urban infrastructure.

Community engagement

For urban agroforestry programs to be successful and sustainable, active community involvement is essential. Involving locals, companies, and organisations, promotes a feeling of ownership and guarantees continuous commitment to green projects.

Educational programs and workshops

Implementing educational initiatives, such as workshops and training sessions, empowers community members with the knowledge and skills necessary to participate effectively in agroforestry projects. For instance, urban farms have been instrumental in providing farming education in Gothenburg, Sweden, teaching residents how to cultivate gardens in urban settings (U-garden project 2025).

Collaborative planning and decision-making

Involving community members in the planning and decision-making processes of agroforestry projects ensures that the initiatives reflect local needs and preferences. This collaborative approach enhances community buy-in and the overall success of the projects.

Development of community orchards

One example of community engagement is the creation of community orchards, which are shared groups of fruit trees in easily accessible public areas. In addition to offering fresh produce, these orchards promote community engagement and give opportunities for sustainable agricultural education.

Urban agroforestry initiatives can flourish and provide more resilient and sustainable urban environments by carefully choosing tree species, making sure infrastructure is compatible, and actively involving the community.

Figure 74 *Urban Agroforestry at Brasov, Romania. Photo: Anna Ternell*

Regulations and zoning

Urban agroforestry's success is heavily influenced by local regulations and zoning laws. City planners must navigate and potentially update these regulations to accommodate agroforestry initiatives, fostering sustainable urban development.

Updating zoning laws

Traditional zoning rules sometimes exclude provisions for urban agriculture, posing challenges for agroforestry initiatives. These codes must be revised to allow agricultural activities in residential, commercial, and industrial zones. For example, several towns have adjusted their zoning restrictions to allow urban farming, recognizing its benefits for community health and sustainability. For instance, cities like Barcelona, Lyon, Trieste, and Udine have implemented measures to encourage and regulate various types of urban agriculture, including allotment gardens, community gardens, and controlled environment agriculture. These initiatives highlight the growing recognition of urban farming's role in promoting sustainable urban development and enhancing community well-being (Marini, Caro, & Thomsen, 2023).

Incentives for property owners

To encourage the integration of agroforestry, cities can offer financial incentives such as tax breaks or grants to property owners who implement green infrastructure. For instance, some municipalities provide property tax incentives for landowners using their vacant properties for agricultural production, promoting urban agroforestry practices (Urban Agroforestry, 2025)

Policy support and community engagement

Developing policies that support urban agriculture involves community engagement and education. Cities can promote urban agriculture through educational programs and outreach, fostering a culture that values sustainable practices. For example, initiatives that support community gardens with resources and funding have been successful in promoting urban agriculture (Hagey, Rice, & Flournoy, 2012)

Maintenance and care

Sustaining urban agroforestry systems requires ongoing maintenance to ensure the health and longevity of plantings. This includes regular activities such as pruning, pest management, and irrigation.

Regular maintenance practices

Routine care, including pruning and pest management, is vital for the health of urban forests. For example, initiatives like the Million Tree Initiative involve community members in the maintenance of trees, ensuring their growth and sustainability (MillionTreesNYC 2025).

Community involvement in maintenance

Engaging local communities in the maintenance of urban agroforestry projects fosters a sense of ownership and responsibility. Community involvement ensures that green spaces are well-maintained and valued by residents.

Data and monitoring

Effective monitoring is crucial for assessing the performance and health of urban agroforestry projects. Utilizing data on various environmental parameters helps in making informed decisions and improving management practices.

Utilizing GIS and remote sensing

Geographic Information Systems (GIS) and remote sensing technologies are valuable tools for monitoring urban forests. They assist in mapping tree distributions, assessing health, and planning maintenance activities. For instance, GIS has been used to monitor urban forest health, aiding in the sustainable management of these resources. An example from the article highlights the use of satellite imagery and LiDAR to create accurate spatio-temporal urban forest inventories and species distribution maps (Datta & Dash, 2024).

Importance of regular assessments

Regular assessments of urban agroforestry projects are critical for quick identification of problems and assuring the efficacy of management measures. Regular monitoring detects difficulties early and offers data for evaluating management effectiveness.

By addressing regulations and zoning, ensuring proper maintenance, and implementing robust data monitoring systems, urban agroforestry can thrive, contributing to more sustainable and resilient urban environments.

Climate resilience

Urban agroforestry plays an important role in enhancing climate resilience within urban environments. By integrating trees and vegetation into city landscapes, these practices offer multiple benefits that mitigate the adverse effects of climate change.

Mitigation of urban heat islands

The presence of trees in urban areas significantly reduces the urban heat island effect, where cities experience higher temperatures than their rural surroundings due to extensive concrete and asphalt surfaces. Trees provide shade and facilitate evapotranspiration, leading to cooler ambient temperatures. For instance, the implementation of urban reforestation projects has been associated with decreased energy costs for cooling, as shaded structures require less air conditioning (Reduce Heat Islands, 2025).

Carbon sequestration

Urban agroforestry initiatives, such as those described by Ghale et al. (2022), aim to expand urban tree canopies, thereby enhancing carbon sequestration and contributing to climate change mitigation efforts. Trees act as natural carbon sinks, absorbing carbon dioxide from the atmosphere and storing it in their biomass, which helps reduce greenhouse gas emissions and supports sustainable urban development.

Stormwater management

Integrating trees into urban landscapes helps stormwater management by increasing soil infiltration and decreasing surface runoff. This natural absorption capacity serves to reduce flooding hazards and relieve stress on municipal drainage systems. The concept of “sponge cities,” which use green infrastructure to absorb and retain water, demonstrates this technique.

Equity and access

Promoting social justice and community well-being ensures that everyone has fair access to the advantages of urban agroforestry.

Addressing environmental inequities

In the past, underprivileged communities often did not have enough green areas, which worsened health and environmental imbalances. By adding vegetation that improves air quality, offers shade, and enhances aesthetic appeal, urban agroforestry projects can address these imbalances. To prevent heat islands and advance environmental justice, for instance, cities like Barcelona are aggressively planting trees in underserved communities. These initiatives help mitigate urban heat islands and promote environmental justice by providing cooler, healthier, and more visually appealing urban environments (Rohela et al., 2025).

Enhancing food security

Incorporating fruit and nut-bearing trees into urban landscapes offers residents access to fresh produce, addressing food deserts and improving nutritional outcomes. Initiatives in cities such as Berlin have established green belts of vegetable plots and trees, providing food and cooling urban areas. These projects not only enhance food security but also contribute to the overall well-being of urban communities by creating greener, more sustainable environments (Opitz, Janine, & Monika Egerer, 2025).

Community empowerment

Engaging local communities in planning and implementing agroforestry projects fosters a sense of ownership and empowerment. Participatory approaches ensure that the benefits of green infrastructure are accessible to all residents, promoting social cohesion and resilience. However, challenges such as lack of funding and expertise can hinder these initiatives, especially in smaller or less affluent cities.

Long-term vision

A long-term outlook is necessary for urban agroforestry implementation because the full advantages of these initiatives frequently take time to materialize.

Sustainable urban planning

City planners should integrate agroforestry into broader urban development strategies, considering future climate scenarios and population growth. For instance, cities like Barcelona have developed comprehensive urban greening plans that aim to expand and maintain the city's tree cover, recognizing the long-term environmental and social benefits despite current fiscal challenges. These strategies are part of the EU's broader initiative to promote sustainable land use and nature-based solutions in urban areas (Barcelona City Council, 2020).

Figure 75 *Types of spaces that make up the city's green network. Source: Barcelona green infrastructure and biodiversity plan 2020*

Climate change adaptation

Urban agroforestry serves as a proactive measure for climate change adaptation. By enhancing biodiversity and ecosystem services, these projects increase urban resilience to climate-related stresses such as heatwaves and flooding. The integration of nature-based solutions, like floodable parks and green roofs, helps cities manage excess water and reduce flood risks.

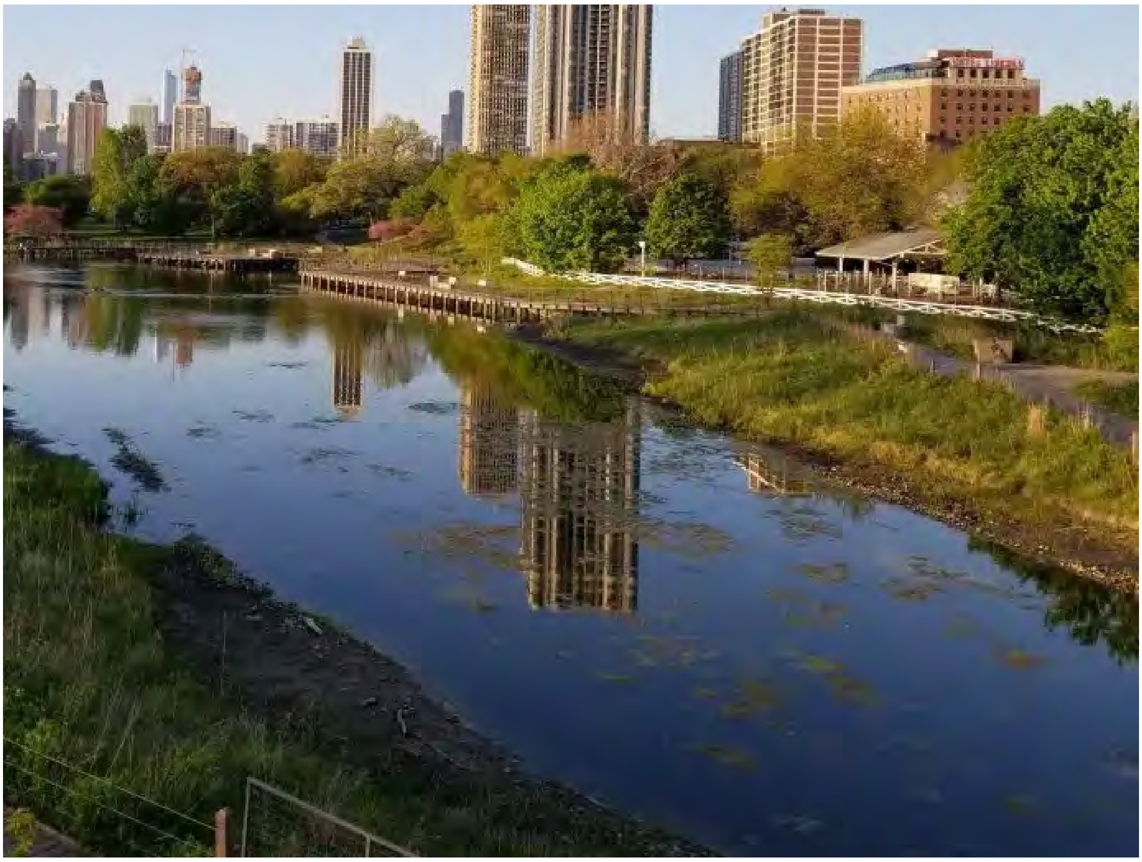

Figure 76 *As the likelihood of both coastal and rainwater flooding increases with climate change and rapid urbanization, floodable parks and other innovative sustainable urban drainage solutions provide one answer for local resilience. Photo: Ranjit Souri on Unsplash*

Policy and funding commitment

Sustained political will and financial investment are crucial for the success of urban agroforestry initiatives. Securing funding, whether through municipal budgets or external grants, ensures the longevity and effectiveness of these projects. For example, the Urban Nature Program aims to facilitate investment by connecting cities with multilateral development banks, addressing funding challenges in urban biodiversity projects. This program supports cities in implementing nature-based solutions, enhancing urban green spaces, and promoting environmental sustainability.

The Urban Nature Program is designed to help cities integrate biodiversity into urban planning and development. It provides technical assistance, funding opportunities, and policy support to ensure that urban areas can develop and maintain green infrastructure. By fostering partnerships with financial institutions and leveraging resources, the program aims to create resilient urban ecosystems that benefit both the environment and the community (European Review, 2023).

Urban agroforestry presents city planners with the opportunity to create more sustainable, resilient, and livable urban environments. However, it requires careful planning, community engagement, and consideration of the unique challenges posed by urban settings. By incorporating agroforestry into urban planning, cities can enhance their overall quality of life while addressing pressing environmental and social issues.

Agroforestry – A world of possibilities

Agroforestry is a flexible land management system that offers a wide range of possibilities. As shown throughout this handbook, agroforestry can be adapted to many different farming systems, landscapes, and climatic conditions. This multifunctionality encourages farmers, landowners, and urban planners to think creatively. Trees provide multiple benefits, and the way they are integrated into the landscape will vary from site to site. Each agroforestry system will reflect the unique needs, goals, and ecological conditions of the individual landholder and their farm. Just as no two farms are alike, no two agroforestry systems will be identical.

This handbook has highlighted the diversity of agroforestry and offered practical tools for designing, implementing, and managing agroforestry systems in Europe. We hope it has provided a deeper and more nuanced understanding of agroforestry. If you feel inspired, we encourage you to begin, even with small steps, and gradually develop your system over time. It will be a journey worth taking. As the proverb says, **“The best time to plant a tree was 20 years ago. The second best time is now.”**

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Anna was the author of Chapter 11 and contributed with text in Chapter 1 and 10, and contributed to the editing of Chapters 2–9.

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