Faculty of Life Sciences

Bachelor Thesis

Ecological and economic investigation of the establishment success of a diverse agroforestry system

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List of abbreviations

AF	Agroforestry
AFS	Agroforestry system/ Agroforestry systems
AG	Agriculture
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft
SA	Syntropic Agriculture
SAF	Syntropic Agroforestry
SAFS	Syntropic Agroforestry system / Syntropic Agroforestry systems
Approx.	Approximately
e.g.	Exempli gratia/ for example

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Abstract

Syntropic agroforestry systems are a form of land use that has attracted increasing international interest in recent decades as a promising approach to regenerative agriculture. However, research on their implementation and success of establishment in the temperate zone remains scarce. This thesis aims to address this research gap by investigating the ecological and economic performance of a syntropic agroforestry system over its first three years of establishment in eastern Germany. A mixed methods approach was employed with data on tree survival and emergence rates collected in the field. Records regarding the input of labor and additional investments after planting were consolidated and analyzed. To put the quantitative data into context, an expert interview was conducted with the manager of the agroforestry system. The results show that certain pioneer species seem to be less suitable for the prevailing environmental conditions at the site, including the Foxglove tree (*Paulownia tomentosa*), possibly due to frost sensitivity and non-compliance with the local soil characteristics. In contrast, species such as Silver birch (*Betula pendula)* and Balsam poplar (*Betula balsamifera)* showed strong growth potential and were therefore classified as good alternatives. Planted fruit trees, including apple, pear, plum and peach showed high levels of vitality and are recommended as viable target crops. The results of the economic investigation reveal that labor costs are considerable. Mechanizing labor-intensive operations is seen as a potential way to reduce costs. The long-term economic viability of the agroforestry system depends on its gradual transition to a low-input, self-sustaining system. Furthermore, practical recommendations for people interested in establishing similar systems are provided.

Keywords

Syntropic agriculture · Syntropic agroforestry · Agroforestry · Tree vitality · Tree mortality

1. Introduction

Agriculture (AG) is both indispensable for global food security and yet responsible for over 10% of global greenhouse gas emissions (Andrade, et al. 2020). The sector's low resilience to climate change (CC) exacerbates its vulnerability, threatening established agricultural systems worldwide (ibid.). Therefore, sustainability in agriculture has gained increasing attention in the last decades, aiming at a greater balance between social, economic and environmental factors (ibid.) as well as sustainable forms of land use to ensure both food production and environmental health (BMEL 2024). Despite of AG's negative environmental impact, it can also be a mean to mitigate CC. Recent studies showed that AG can help to slow CC, by e.g. carbon sequestration. A promising approach towards a more resilient and carbon negative AG is the adoption of agroforestry (AF) (Lengnick 2018).

AF is understood as "a planned and systematic integration of trees (either spatially or temporally) into farming systems in order to derive multiple benefits that include environmental, ecological, economic and social benefits from a unit land area in a sustainable fashion" (Gordon, et al. 2018) (p.xiii). Although AF is a practice deeply rooted in traditional agricultural systems, it has only received increased attention in the last two decades, including from stakeholders of the ecology, socio-economy and politics (ibid.). As the adoption of AF has the potential to both mitigate and adapt to the effects of CC, it has become an active research topic over the last 20 years (Andrade, et al. 2020, Gordon, et al. 2018). However, research on the complex interactions of AF has "just scratched the surface and there is a need for much intensive study" (Hunter, et al. 2017) (p.250). In Germany there are traditional AF systems such as orchards (so-called "Streuobstwiese") as well as more modern SRACS (Short rotation alley cropping systems) (EURAF n.d.). However, AF is still in the niche of German AG, but is intended to be increasingly supported by e.g. public funding (BZL 2024, Ökolandbau.de 2024). Besides the already common forms of AF, there is another that is seen as "a game changer for modern agriculture" and "beyond organic and beyond sustainable" (Gietzen 2016) (p.1).

Syntropic agriculture (SA) is a form of regenerative AG that is designed along the processes found in natural forests, characterized as highly diverse, successional and intensively managed (Kettley 2024). Even though this method was developed in the tropics, it has started to gain attention in Europe. However, literature and data on SA are scarce due to its novelty and specificity, especially in the context of temperate regions and other socio-economic circumstances (ibid.). To promote the dissemination and application of this method, this data gap needs to be filled. Moreover, given its numerous benefits, further investigation into AF is essential to optimize its implementation, understand its full potential across different agroecological zones, develop supportive policies, and scale up adoption globally (Gordon et al. 2018).

This study therefore aims to contribute to this goal, by evaluating the establishment of a syntropic agroforestry system (SAFS) in eastern Germany in its initial years in terms of its ecological and economic performance. This includes examining how the population of planted and direct seeded trees has developed since planting and the ecological explanations for these developments and analyzing the economic expenditures required after the initial investment for establishment in the first three years. Based on this the implications of the findings for practical applications and recommendations are derived.

To approach this topic the research procedure can be subdivided into four steps:

1. A literature review that provides the conceptual background regarding relevant information required for an ecological and economic investigation of an AF, including a description of the concept of SA and Plant Portraits of the further analyzed plant species.
2. Data collection through inventories, economic inputs and a semi-structured interview with a practitioner managing the agroforestry system (AFS) under study.
3. Data analysis in form of a cross-sectional descriptive comparison of both quantitative and qualitative data.
4. Discussion of the results of the inventories and economic analysis with reference to the literature research results and the expert interview.

The results should provide meaningful information on the performance of a SAFS in its early stages. People who are interested in this field can use this study to gain insight into this topic. The results may be of particular interest to people wishing to set up a similar system and dealing with similar environmental and socio-economic conditions, as a basis for planning and orientation.

2. Literature

2.1 Ecological investigation of an agroforestry system

According to Gliessman (2015), an AFS can be classified as an agroecosystem, characterized as a site of agricultural production, such as a farm, that can be understood as an ecosystem. In order to analyze a food production system, this classification is necessary, serving as a framework and considering all its complex interconnections among its system members as well as its wide variety of inputs and outputs (Gliessman 2015).

Agroecosystems differ far from natural ecosystems, because of the induced manipulation and alteration by human activity for the purpose of food production. Nevertheless, the basic structural components of a natural ecosystem, such as the occurrence of biotic and abiotic factors can be applied to an agroecosystem as well. Thereby biotic factors include living organisms like plants and animals. Whereas abiotic factors include nonliving physical and chemical elements of the environment, that interact with the environment. Temperature, moisture, soil and light can be named as examples of abiotic factors, having the characteristic of influencing an ecosystem. However, even if the occurrence of these factors corresponds, their proportion and composition differentiate significantly between the ones of a natural ecosystem and of an agroecosystem. Besides the natural inputs that an agroecosystem is exposed to, humans also provide a whole set of further inputs and outputs (**Fig.1**).

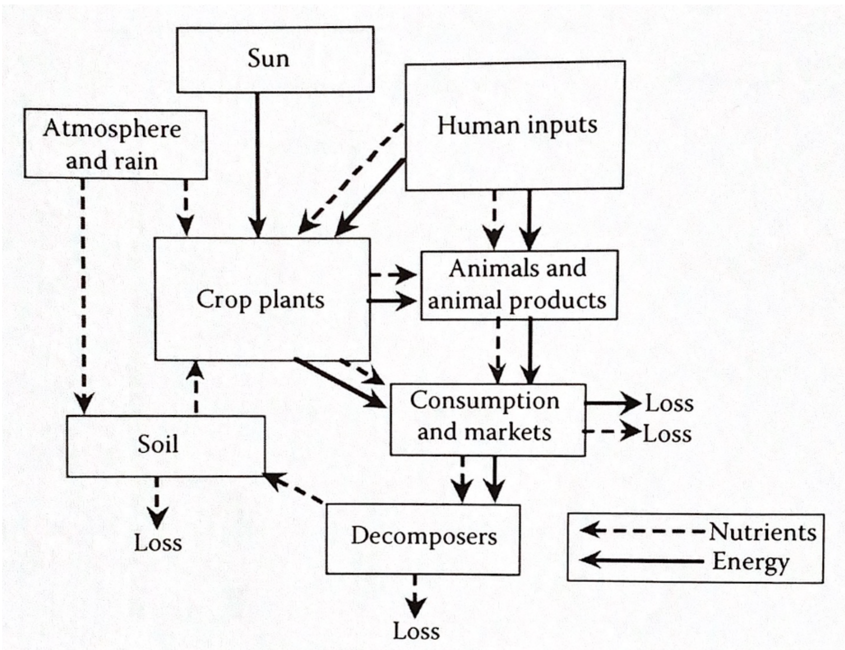

Fig. 1 Functional components of an agroecosystem (Gliessman 2015, p.26)

In general, an agroecosystem consists of many complex interactions between its members, such as soil microorganisms, crop plants, non-crop plants and animals. Those interactions can either be considered as positive, negative or neutral. Thereby, the central component that determines photosynthetic rate and plant growth is the relationship between an individual photosynthesizing plant and its environment. In more detail this includes soil fertility, rainfall, exposure to sunlight, temperature and other physical factors (Gliessman 2015). These factors are essential for plant growth, thus determining the production of biomass in the long term and further contributing a large part to the overall performance of the whole system (Atangana, et al. 2013). Consequently, Atangana et. al. (2013) (p.151) states that “the success of an agroforestry system is highly dependent upon the efficient interactions of the system’s components”.

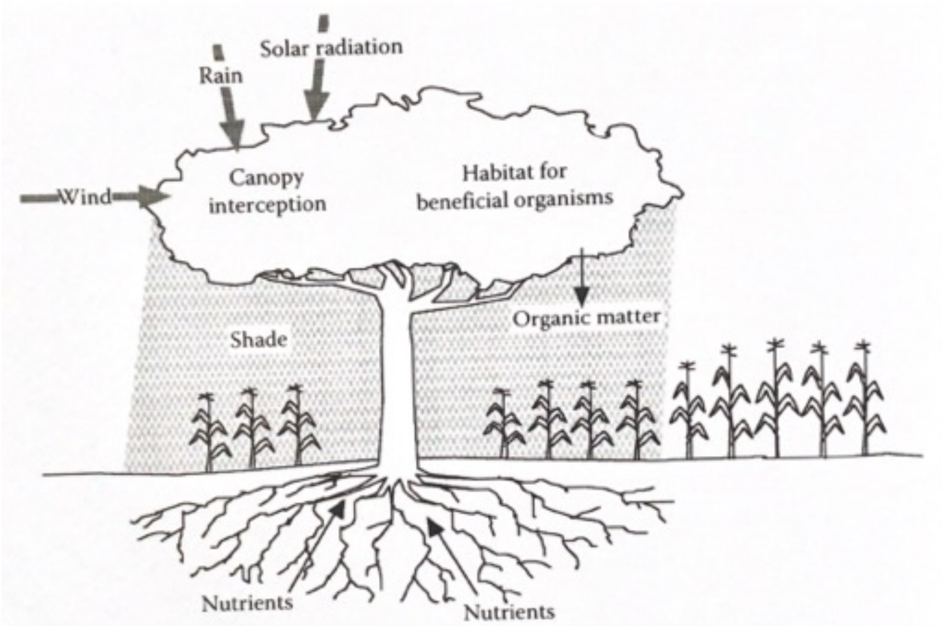

Fig. 2 Effects of a tree on the surrounding agroecosystem (Gliessman 2015, p.230)

In order to establish a successful AFS and to gain efficient interactions among the system’s components, the selection of appropriate tree species is an essential requirement (Atangana, et al. 2013). Trees, among other components, contribute to the overall productivity through soil conservation and fertilization (Jose, et al. 2019). Figure 2 demonstrates the effects of a tree on the surrounding agroecosystem due to its size, root depth and perennial nature. These effects influence many abiotic and biotic interactions within the surrounding agroecosystem. This includes e.g. the interception of water and wind erosion as well as the provision of shade, reducing evapotranspiration and production of organic matter. Trees also form associations with mycorrhiza fungi, improving soil health and moderate soil temperature. Some tree species can also form associations with nitrogen-fixing bacteria, increasing the proportion of plant-available nitrogen within the system (Gliessman 2015). Besides that, trees create numerous ecological niches for organisms, below- as well as above-ground, which are capable of restoring the agroecological balance of nature (Leakey 2014). Their capability of altering an ecosystems environmental conditions can also be seen in the rapid resettlement of soil organisms even in soils that are classified as highly degraded (Sileshi, et al. 2007). Consequently, one can say that trees make a great contribution to the sustainable productivity of AFS, supporting its ecological interactions (Hunter, et al. 2017). However, there are only few studies that examine the interactions occurring in AF, as a result of the long time frame and complexity such an investigation would demand (Kettley 2024).

2.2 Vitality of trees

Through the findings of the previous chapter, it became evident that trees play a fundamental role for the success of an AFS (Atangana, et al. 2013, Jose, et al. 2019). Especially in the first years after planting, trees require intensive care to adapt and develop well (FiBL n.d.). Regular tree inspections are therefore important to ensure a good development of trees. Thereby, tree vitality is assessed, as it is an important indicator of tree health (Klug 2005).

Shigo (1994) describes the term vitality as the ability to thrive within the conditions of a system. This means that vitality determines how successful an individual can survive under the prevailing environmental conditions (Shigo 1994).

As the leaves of a plant are where photosynthesis takes place, leaf green, foliage and the relative leaf size of a tree's leaves are considered as important parameters in assessing its vitality. Circumference growth can only be used to a limited extent as a parameter of tree vitality, as it depends on the tree's ability to expand its crown, the available space and the distance to other trees. Nevertheless, the assessment of tree vitality is a rather relative approach, carried out by comparing trees of the same species, at the same stage of development and growing in the same location. (Klug 2005)

Assessing the future development of trees requires an assessment of their vitality, as low vitality can further lead to susceptible and diseased trees. A simple and common method is to categorize trees into different levels of vitality (**Tab. 1**). According to the overall impression of the tree and by paying special attention to the leaf green, the tree is then placed into one of the categories. (Klug 2017)

Tab. 1 Levels of vitality according to Klug 2017 (p.2)

Level of vitality	**Description**
1 – vital	Crown developed according to species and development phase with corresponding shoot lengths and healthy leaf development
2 – weakened	The shoot length growth and leaf development to be expected for the respective development phase and tree species are slightly reduced. There is a slight crown drought.
3 – very weakened	Leaf development (leaf size, leaf color, relative foliage density) and the expected shoot length growth during the development phase are significantly weakened. In the crown mantle, a dieback of twigs and branches to weak or, in individual cases, coarse branch strength is recognizable. The tree's reaction to injuries to the trunk or crown is rather moderate, with relatively small wound wood or callus formation on former cuts or injuries.
4 - deteriorated	Leaf development (leaf size, leaf color, foliage density) and the expected shoot length growth for the development phase or tree condition are considerably reduced or no longer present. In the crown mantle, entire crown areas or parts of the crown are usually dead, even over the thickness of the branches.
5 - dead	There are no living shoots and leaves existing.

2.3 Tree damages

A tree's level of vitality should not be confused with its state of damage. They are two different parameters that can be the same in many cases but can also be very different in other cases. For instance, there are trees that are severely damaged, but still survive because of their high level of vitality. (Klug 2005)

There are many forms of damage that a tree can suffer. One can be insects that eat certain parts of a tree, according to their preferences. An example of such a phytophagous insect is the aphid. In most cases they cause only little damage to the health of a plant. In severe cases of aphid feeding, the plant will show signs such as stunted or dead shoots, yellow, twisted or curled leaves and poor plant growth. (Hahn 2019)

The lower part of a tree is preferred by larger leaf-eating animals as food. A common problem in AF is damage to trees by root voles. Attracted by the mulch laid in or beside the rows, they like to settle there and damage trees at their roots (FiBL n.d., Reese 2023). Voles often feed on the bark and the roots of trees, causing severe damage and sometimes death. Fruit trees are particularly favored by voles. As a result, in some areas, apple growers consider the animals to be the main cause of economic losses (Adalid, et al. 2021). Disease is another important factor when considering tree health and factors that can damage a tree. There are many different forms of disease and causes, including fungi, bacteria and viruses (Thomas 2000).

In general, a diseased tree can be identified by looking for signs such as necrosis or localized dead plant parts. Necrosis in plants appears in different forms including, cankers, decay, rot, leafspots and lesions (Boa 2003). The cause of a tree damage can also be environmental. Flooding, soil impoverishment, drought, extreme temperatures, lightning, wind or fire are examples of factors that can cause damage to a tree. The onset of cold weather, e.g., can cause frost cracks in the trunk or the death of young trees and small branches. (Thomas 2000) Young shoots, flowers and nearly emerged leaves tend to be more susceptible to frost events than the other parts of a plant. Symptoms of frost damage include browning or blackening and shrinkage of leaf tissue (Steil 2023). Regardless of the cause, damage to a tree can lead to a deterioration in its level of vitality and a reduction in its life expectancy (Böring 2023).

2.4 Tree inventory

A tree inventory can be used to document tree assessments, as it provides an appropriate framework and helps to keep records of tree inspections and maintenance. Thereby, basic descriptive information such as the location, number, size and species of trees are collected. This data can further facilitate the organization of tree management, the allocation of resources as well as the negotiation of tree maintenance budgets. Besides the collection of basic descriptive information, an important part of tree assessment is the identification of defects, that reduce the structural strength of the tree. Such a visual assessment should take between 2- and 20-minutes. The desired data can be collected by either in-house staff, contractors or volunteers. From pencil and paper to dedicated computer hardware, the form of technology used to conduct a tree inventory varies. (Roloff 2016)

2.5 Economic investigation of an agroforestry system

Since AF does not yet belong to the common agricultural cultivation methods, there is a lack of empirical values for an economic evaluation of this land use form, especially in regards to syntropic agroforestry (SAF) (Böhm 2020, Kettley 2024). The long duration of use of the AF land also contributes to the paucity of economic data in this field (Böhm 2020). Mercer et al. (2014) suggest that when assessing the economics of AF, it is important to consider the fact that such systems are managed with multiple inputs, while providing multiple outputs. Additionally, such systems require more time to become self-sustaining, so in most cases the full benefits are realized after 3 to 6 years (Mercer, et al. 2014). The available tools for assessing the economics of AF in Germany are mainly applied to short rotation coppice management and only consider data from arable crops and woodland cutting (Böhm 2020). However, there are some approaches to assessing the economics of AF. Mercer et al. (2014) suggest capital budgeting as a useful tool. It is said to be a simple but powerful tool for comparing the profitability of alternative forms of land uses. As AFSs produce multiple outputs, while using different inputs, capital budgeting is a suitable method as it takes these facts into account. One method of capital budgeting is to determine the Net Present Value (NPV). This is the sum of the discounted net periodic income per unit of land over a given time horizon. The Soil Expectation Value (SEV) is another common capital budgeting tool. It calculates the net return per hectare, assuming that the regimes are repeated in perpetuity (Mercer, et al. 2014). The "Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V." (KTBL) offers several online tools that can be used to determine business parameters, calculate costs and research other useful data. One of these tools is the "KTBL-Feldarbeitsrechner". This tool calculates the machinery costs, diesel requirement and labor requirement for more than 5000 foreign trade operations. The data used to calculate these costs is based on an average of the last three calendar years and is determined annually, taking into account current price developments, and updated quarterly. The purchase prices shown for equipment such as machinery are based on dealer list prices. Prices are reviewed at multi-yearly and annual intervals by machine type. All prices are exclusive of Value Added Tax. The input data that need to be provided for the calculation are divided into data associated with the respective work process and further specifications (**Tab. 2**). (KTBL 2024)

Tab. 2 Required input data for the calculation of operation costs according to the "KTBL-Feldarbeitsrechner"-tool

Work process	Specification
- Process group - Operation - Machine combination	- Field size (ha) - Tillage resistance - Distance to field (km) - Quantity (-/ha) - Working width (m)

Another method of assessing the economics of an AFS is presented in a report by the KTBL. Parallel to the establishment of the AFS under study, data was collected by Finck Stiftung gGmbH on behalf of the KTBL and published in a summary report. This data was collected using the KTBL system and is intended to represent a first scientific approach to data collection in AFSs, with the aim of generating standardized values for future AFSs and at the same time providing farmers with a basis for planning. Part of the report focuses on the costing of the AFS. Costs were categorized into those for seedlings, seeds and operating resources. In some cases, imputed costs were used in the calculation, e.g. the costs of fruit trees, as these were grown in Gut&Bösels's own tree nursery and thus have no market price. Therefore, a standard organic market price for two-year-old trained plants was assumed and incorporated into the analysis. The calculation of labor costs was divided into costs for temporary and fixed labor, and determined using a cost rate set by both the KTBL and Gut&Bösel (**Tab. 3**). (Küsters 2022)

Tab. 3 Labor cost calculation by KTBL system (Küsters, 2022, p.12)

Activity period (30.07.21 – 25.01.22)	**Labor hours Temporary staff**	**Labor hours Permanent staff**
Collecting seeds	131 h	/
Establishing the Agroforestry System	959 h	341 h
Sum	1090 h	341 h
Cost rate KTBL	13,90€	21,00€
Costs according to KTBL	15.151€	7.161€
Cost rate Gut&Bösel	8,10€	21,00€
Costs according to Gut&Bösel	8.829€	7.161€

2.6 Syntropic agroforestry

The AFS under study in this thesis is built on the principles of SA (Boesel 2023). According to Andrade et. al., this form of AG combines elements present in most types of agroecology, including the use of no or low impact technologies, no chemicals and adaptation to the processes of ecological succession. Compared to other agroecological practices, SA differs in that it is based on the concept of syntropy, which determines the choice of management practices and the interpretation of the mechanisms of life. Syntropy is classified as “the tendency complementary to entropy, […], while entropy rules the mechanical and physical world, syntropy governs the biological world.”(Andrade, et al. 2020) (p.22). In contrast to the concept of entropy, which is associated with energy consumption and dissipation, syntropy it is said to be associated with energy accumulation and concentration. The concentration of energy, for instance in the form of organic molecules, leads to increasing differentiation and complexity. Agricultural practices that are based on the concept of syntropy, have their focus on two nature-inspired processes. These include the process of stratification and ecological succession. (ibid.)

When succession is applied in AG, long-term system planning, including the choice of plant species to be introduced into the system, is essential (Kettley 2024). As natural succession describes the tendency of nature to rehabilitate land, one of the main objectives of such a system is to revitalize degraded land by increasing soil fertility over time (Gietzen 2016). As a result, the improvement of soil is accompanied by the progress of succession, which is represented by the growth of placenta, secondary and climax plants. Placenta plants are characterized by a short life span, as in the case of annual or biannual species. Secondary plants include shrubs and trees with short to medium life spans, while climax plants indicate a very long-life span. By introducing such a diversity of plants, the process of succession is facilitated, and the system evolves and changes over time. At the same, time stratification occurs, with different plants occupying different vegetation layers at all successional stages within a system (**Fig. 3**). (Kettley 2024)

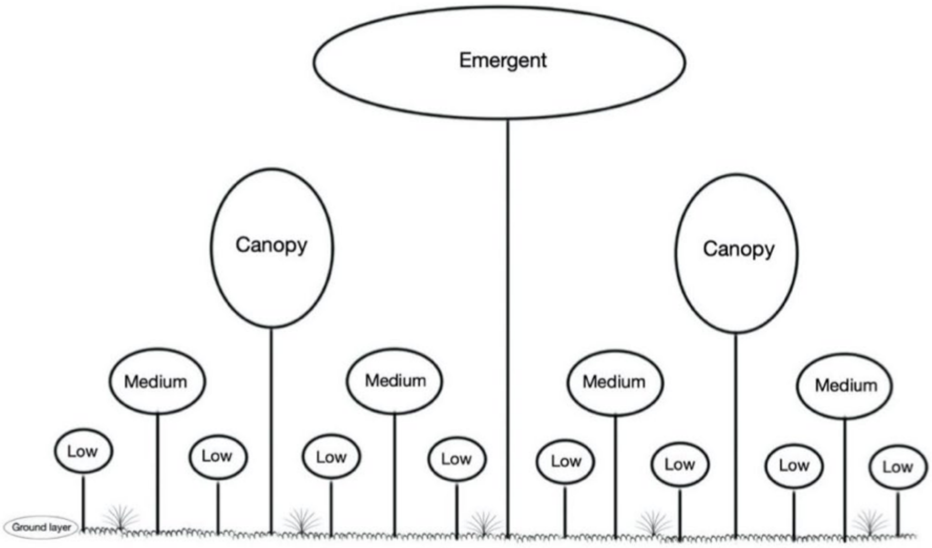

Fig. 3 A visual representation of different stratifications resulting in a maximum utilization of light or solar energy through the deliberate use of space (Andrade 2022, p.2)

The importance of the ground layer should not be overlooked, as it contributes, together with the other layers, to high soil water retention and cooling thermodynamic processes (ibid.).

This form of AF was developed by Ernst Götsch, who sees an AFS as a unified, intelligent living system. Contrary to the beliefs of other natural scientists, he believes that natural succession is not driven by competition, but by cooperation among all members of the system through complex synergetic interactions. As a result, if properly supported, it develops into a strong, healthy, living system. (Gietzen 2016)

In order to mimic the processes of natural succession, a SAFS is composed of two main types of vegetation. The first are plants that are supposed to serve as biomass-plants or pioneer species. These plants do not produce a valuable crop, but they have a positive impact on the system by supporting the growth of target plants and, at the same time, by providing the necessary mulch for the system through regular pruning in strategic time periods. The target plants represent the second type of vegetation, grown for the purpose of producing a valuable crop. The two types of vegetation are grown closely together so that they can grow together and benefit mutually. The planting schemes created in accordance with SAF are structured in a manner that reflects the role of a plant in the natural succession process and its life span. As some plants have a shorter life span compared to others, it is an inherent part of the evolution of such a system that some plants, which initially dominate, will subsequently cease to be present, thereby creating space for other plants to assume their role. (Gietzen 2016)

SA is characterized as labor intensive, especially in its initial implementation. However, the system are expected to be economically feasible, reducing its cost and showing benefits in the long run (Kettley 2024, Nathan 2023).

2.7 Plant Portraits

In the course of this study, the planted tree and shrub species within the investigated AFS are subject to analysis. Thereby, five of the 29 species are analyzed in more detail due to their high mortality rates. To do so, Plant Portraits including their individual site requirements and their possible function within an AFS, if to be found in literature, are described below. In the subsequent sections of this study this information will serve as an important basis for their loss analysis.

<u>Foxglove tree - *Paulownia tomentosa*</u>

The common name of this tree is “Foxglove tree” and belongs to the family of *Paulowniaceae*. It is a deciduous tree that can grow up to 20 meters tall, while developing a bole of around 30 cm in diameter within the first 10 years of planting. It is characterized by its ability of fast growth and developing a timber of good quality. The natural habitat of the Foxglove tree is deciduous montane woodlands at elevations from 1300 to 2000 meters. In AF *Paulownia tomentosa* is introduced due to its fast growth rate and its extensive root system, which is tolerant of poor soil, drought and very acid conditions. The roots, when grown from seed, occupy a different layer than most annual crops. That is why the Foxglove tree is suitable for AF, where yields have been measured to be 16% higher if intercropped with wheat. If propagated by cuttings, the tree loses its ability of deep rooting and tends to form an extensive lateral root system. In literature, the foxglove tree is also characterized as a cold-hardy plant, that tolerates temperatures down to -25 degrees Celsius. However, this refers only to trees whose wood already has been fully ripened. Seedlings of this species that are less than 2 years old, are not as frost hardy, especially as their new growth begins in spring. In areas with hot summer it grows best, since in areas with cooler summers it is not able to fully ripen its wood and is damaged due to frost events over the winter. The species preferences regarding the soil and its location of growth are a well-drained, deep, moderately fertile, and moisture retentive kind of soil at a sunny sheltered spot. However, plants of this species are very susceptible to waterlogged soil and can die if the soil is flooded within a couple of days. In general, *Paulownia tomentosa* grows well in poor soils with a relatively high pH ranging between 5.5 and 7, while also tolerating soils that deviate slightly from this range. (Fern 2022)

<u>White poplar - *Populus alba*</u>

The White poplar is a deciduous tree of the *Salicaceae* family. It can grow up to 20 meters tall and has its natural habitat in forests and along waterways. This species prefers a heavy cold damp, well-drained and deep soil with a pH of 6.0 to 6.8. On soils that are characterized as acidic, rather wet, poor, thin and dry, the growth of white poplar is reduced. It is tolerant of hot and cool summers, but rather dislikes shady locations. (Fern 2022)

Species of the genus *Poplar* are commonly used for the AF purposes worldwide, among others due to their rapid growth and tolerance to root and branch competition (Yao, et al. 2023).

<u>Summer lilac - *Buddleja davidii*</u>

The deciduous to semi-evergreen shrub summer lilac, also called “Butterfly Bush”, belongs to the family of *Scrophulariaceae* and grows up to 4 meters with wide spreading branches. *Buddleja davidii* is said to be tolerant to a broad range of environmental conditions, while growing fast and starting with the production of seed from an early stage. Its natural habitat is found in mountain slopes at elevations from 800 to 3000 meters. Because of its ability to quickly invade disturbed areas, which leads to the buildup of suitable conditions for the growth of trees, summer lilac has a good potential to be used in AFSs. Its ability to grow rapidly on rather poor soils and in dry conditions, makes it a suitable pioneer species with the added purpose of soil restauration. However, if it is planted in an AFS, its tendency to spread and settle in native habitats should be considered. Its location preferences include sunny positions with a rich, loamy, well-drained soils with a pH that ranges between 6 and 8.9. Temperatures as low as -15 degrees Celsius, can occasionally be tolerated by the shrub, as well as dry soils with low fertility. (Fern 2022)

<u>Monarch Birch - *Betula maximowicziana*</u>

The “Monarch Birch” is part of the *Betulaceae* family and is a deciduous tree that reaches heights of up to 30 meters. Besides its ornamental value, the tree is cultivated as a timber producing tree, e.g. in Japan. The natural habitat of the Monarch Birch are mixed, cool, temperate forests at low elevations. In AF, this tree can be planted as a pioneer species, due to its fast growth rate and ability of restoring native woodland. Additionally, compared to other members of the family, this species seems to be more tolerant to drought. (Fern 2022)

Betula maximowicziana grows well in sunny, sheltered locations with well-drained loamy soil that indicates an acidic to slightly alkaline pH value (Benning 2024, Fern 2022). This species is said to be frost hardy, but its new sprouting is rather susceptible towards late frost beginning from mid may. Other conditions that the tree dislike include compacted and light sandy soils. (Leder 2014)

Grey alder - *Alnus incana*

Alnus incana is a deciduous, multi stemmed shrub or tree and a member of the *Betulaceae* family. It is a pioneer species, grows from 5 to 24 meters and indicates a very wide distribution. Besides being grown as an ornamental, Grey alder is also planted for the purpose of re-establishing native woodland. Areas along streams or rivers, or in the mountains belong to its natural habitat. This species is also found in ponds and swamps, which are characterized by wet sandy or gravelly soils. Grey alder is considered to be not competitive in shaded environments, and thus is only found in open sunny locations. In AF, Grey alder is a valuable pioneer species, developing an extensive root system and providing sheltered conditions for the establishment of other trees. As a result of its inability to sustain in shade, *Alnus incana* gradually declines and dies out if other trees establish on its site. Grey alder can grow on poor soils, by forming a symbiotic relationship with atmospheric nitrogen-fixing root bacteria. This also facilitates the growth of other species, as some of this nitrogen is also made available in the soil for other plants. Furthermore, it is very-cold tolerant and grows on a wide range of soil types, including sandy, loamy, gravelly, and clayey, as well as acidic soils with pH levels ranging from 3.4 to 4.0. Compared to other members of the family *Betulaceae,* it can thrive in dry soil and is capable to tolerate occasional periods of drought and flooding. However, it prefers sunny locations with a heavy clay soil. (Fern 2022)

3. Methodology

3.1 Description of study site

The AFS under study was established in 2021, is located in Briesen (Mark). The site is characterized by a continental lowland climate with an average annual temperature of 8.5 degrees and average rainfall of 450 mm. (Küsters 2022) Especially in summer the region is quite dry, e.g. in the summer of 2022, the average temperature in august was approx. 21 degrees with an average rainfall of 34 mm (**Fig. 4**).

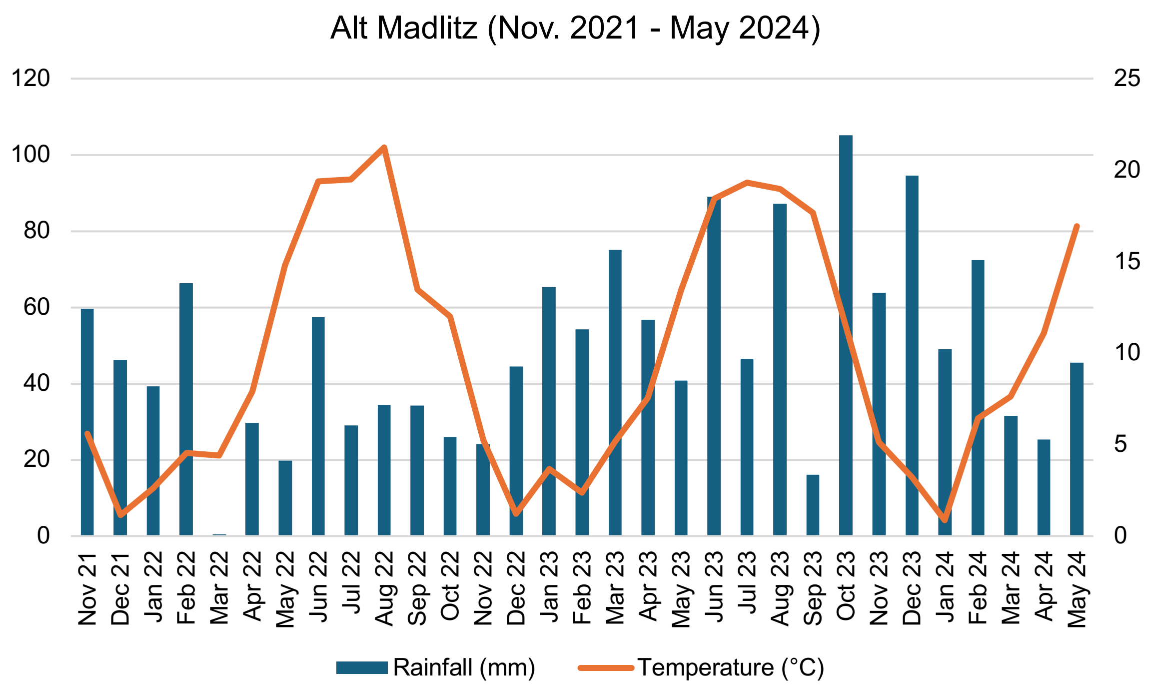

Fig. 4 Climate diagram of Alt Madlitz, (Finck Stiftung Campell Science Weather station 2024)

In addition, further climate data show that the region is quite prone to late frost and severe frosts in winter. In total, 234 days of frost were recorded since the time of establishment of the AFS. Thereby, late frost events (from early April) were documented 24 times (**Tab. 4**).

Tab. 4 Days below zero since time of establishment (Finck Stiftung Campell Science Weather station 2024)

Year	Month	Days below zero
2021	Nov	6
	Dec	21
2022	Jan	18
	Feb	11
	Mar	24
	Apr	7
	Nov	7
	Dec	17
2023	Jan	12
	Feb	19
	Mar	16
	Apr	11
	May	1
	Oct	2
	Nov	12
	Dec	9
2024	Jan	20
	Feb	7
	Mar	9
	Apr	5

Soil sampling, previous to planting (**Tab. 5**), revealed a loamy sand texture and low humus content, hinting at a quickly draining soil with low water and nutrient retention potential (Finck Stiftung 2021). Loamy sand soils belong to the group of light soils (Schmidt n.d.). Light soils are also known as sandy soils, as they have a high sand content and low clay content. Sandy soils are characterized as warm, dry and quick draining (Boughton 2024).

Tab. 5 Results of VDLUFA and Soil balancing. Soil examination from Finck Stiftung 2021

Parameter	Value
pH-value Supply level	6,2 C
P in mg/ 100mg Supply level	6 C
K in mg/ 100mg Supply level	12 D
Mg in mg/ 100mg Supply level	7,8 D
Humus content	1,2%
C/N ratio	6,4
Soil type	Loamy sand
CEC (mmol/ 100g)	6,2

3.2 Design of the syntropic agroforestry system

The AFS covers an area of 2.65 h and consists of 30 rows with a total length of 2689 meters. The tree rows are 1 meter wide, 6.5 meters apart and are laid out according to the principles of keyline design with a headland of 9 meters (see **Fig. 5**, **Fig. 6**). (Küsters 2022)

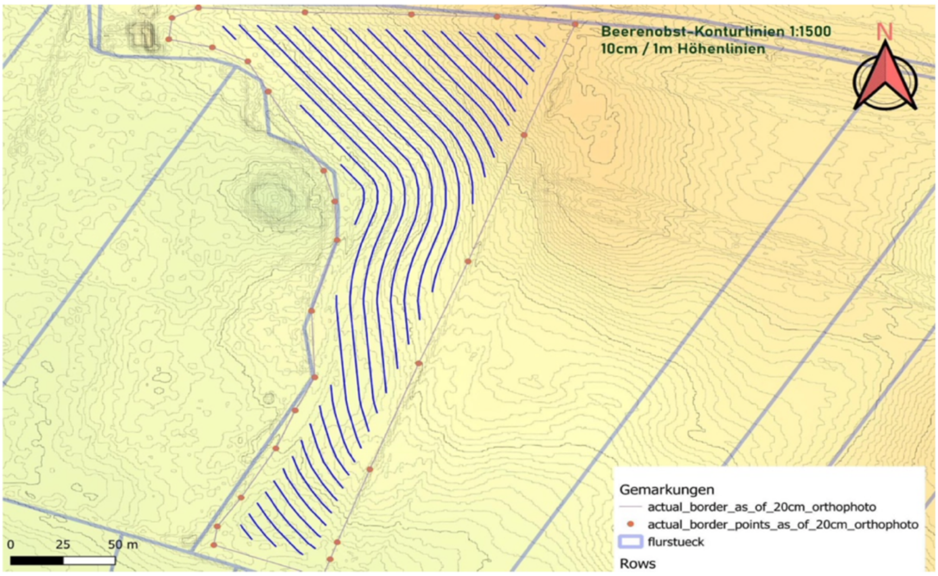

Fig. 5 GIS planning of the system according to the local topography (Küsters 2022)

The keyline technique is a landscaping design used in AF for multiple purposes. It aims at maximizing water catchment and its equal redistribution. Thereby, this technique also is supposed to mitigate soil erosion, by supporting soil water retention and reducing water velocity. (ISA 2019)

Fig. 6 Keyline structure of the agroforestry system

The design of the AFS can be classified as diverse and multi-layered, with rows composed of a variety of woody perennials and forbs, including fruit tree species (Küsters 2022). Between the rows a clover-grass mixture is sown, which is mowed and swathed close to the tree rows 3-4 times during the season, serving as mulch. There is also the potential to use this interrow space for grazing, with introducing mobile chicken coops being declared target. The target crops of the AFS studied are apples, pears, plums and peaches, which were grafted in spring at the farm’s own nursery and then planted out in the system in the fall of the same year. (Interview Hansen 2024)

A variety of valuable woody and herbaceous plants was additionally planted. The aim is to establish a resilient, successional and ecologically and economically valuable system. The density of planting as well as the diversity of species and varieties is rather high. How a row is planted, is determined by the respective target crop within the row. Rows of apples, pears and plums are planted alternately and structured with four layers. A fifth layer of herbs is also sown. (Küsters 2022) The structure of the rows is illustrated in Figures 7,8 and 9.

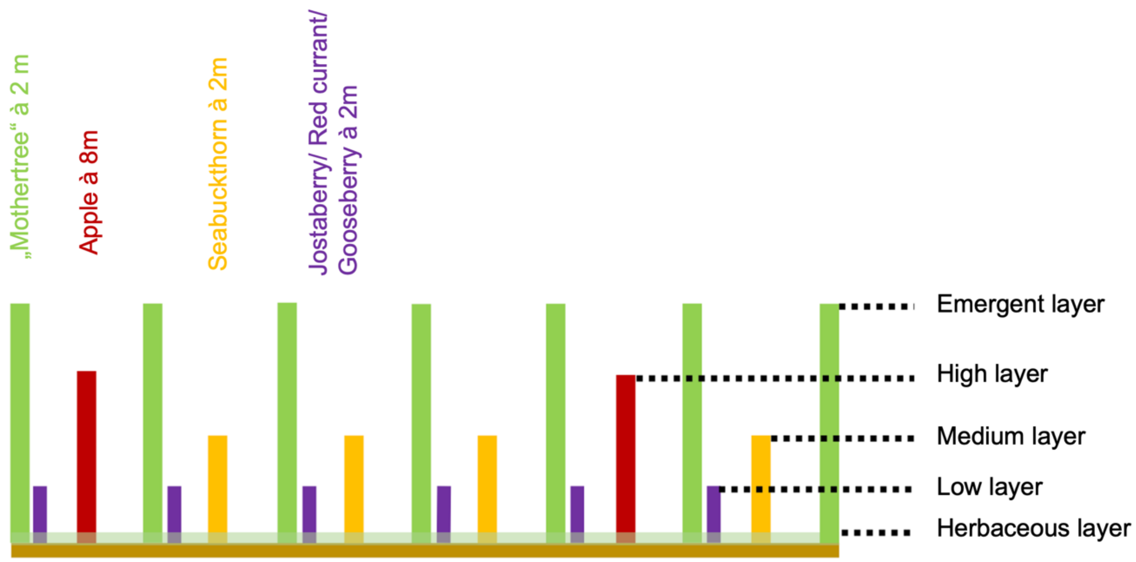

Fig. 7 Structure of a apple row (Küsters 2022, p.6)

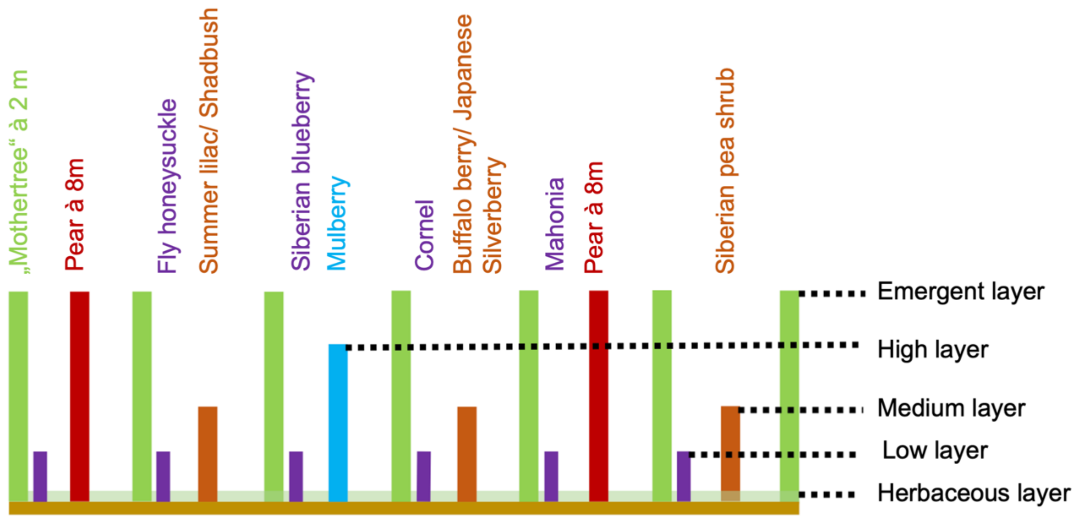

Fig. 8 Structure of a pear row (Küsters 2022, p.6)

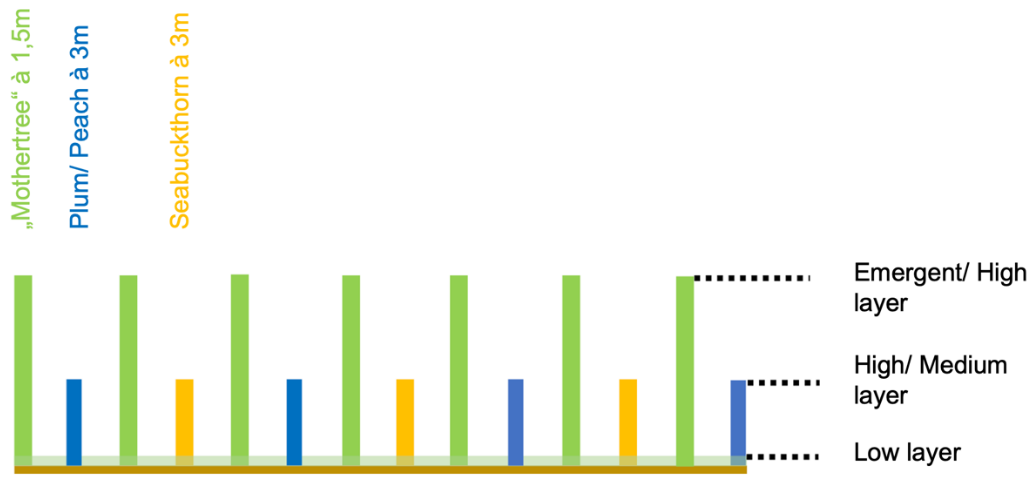

Fig. 9 Structure of a peach row (Küsters 2022, p.7)

Fig. 10 Structure of a peach row in the field

As previously descripted in the literature review part of this thesis on the principles of SA, the design aims to mimic the process of natural succession. This is done to maximize photosynthesis and to establish a rapid growing and resilient AFS. So-called “mother trees” or “pioneer species” e.g. should support the growth of species that do not prefer direct sunlight during establishment (**Tab. 7**). (Küsters 2022) After fulfilling their purpose, after around 5 to 15 years, they will be chopped and used as biomass material or mulch. With this, the soil is meant to be protected against sun radiation as well as wind. At the same time, the actively fed layer mulch serves as a mean to feed the soil biology, increasing activity and accelerating nutrient cycling. (Interview Hansen 2024)

Apart from the planted trees and shrubs, a high amount of around 100 kg of seeds was sown in the rows (**Tab. 6**). A major part was priorly self-collected and included the seeds of herbs, but also of late successional trees. (Küsters 2022)

Tab. 6 Species of introduced seed in syntropic agroforestry system listed according to their function

Function	Species
Herbs	- Artemisia - Mugwort - Mountain Mint - Goldenrod - Burdock - Garlic - Corean mint - Mullein - Lavender - Mallow - Dropping star of Bethlehem - Physalis - Sorrel - Yarrow - Sunflower - Echinacea - Cow parsley - Meadow chervil - Lemon balm
Mother trees	- Maple ash
Late successional trees	- Ash - Pedunculate Oak - Sweet chestnut - Red Oak

Tab. 7 Tree species planted in the syntropic agroforestry system listed according to their function with information on quantity planted, stage of succession and expected time in system

Function	**Species**	**Quantity planted**	**Stage of succession[1]***	**Expected time in System****
Target Fruit crop	Apple (*Malus domestica*)	121	Climax	60-80
	Pear (*Pyrus communis*)	107	Climax	80-100
	Peach (*Prunus persica*)	49	Seconday	20-40
	Plum (*Prunus domestica*)	296	Climax	40-60
Nut crop	Sweet chestnut (*Castanea sativa*)	25	Climax	100+
Berry crop	Buffaloberry (*Spepherdia*)	29	Seconday	15-20
	Shadbush (*Amelanchier lamarckii*)	63	Seconday	20-30
	Red currant (*Ribes rubrum*)	233	Seconday	15-20
	Jostaberry (*Ribes x nidigrolaria*)	96	Seconday	15-20
	Cornel (*Cornus mas*)	105	Climax	60-80
	Japanese Silverberry (*Elaeagnus umbellata*)	67	Seconday	20-30
	Sea buckthorn (*Hippophae rhamnoides*)	628	Seconday	20-30
	Sibirian blueberry (*Lonicera kamtschatica*)	201	Seconday	15-20
	Mulberry (*Morus nigra*)	100	Seconday	40-60
	Gooseberry (*Ribes uva-crispa*)	153	Seconday	15-20
Mother tree	Grey alder (*Alnus incana*)	205	Secondary	5-15
	Balsam poplar (*Populus balsamifera*)	403	Secondary	5-15
	Foxglove tree (*Paulownia tomentosa*)	24	Secondary	5-15

[1] * Categorization according to Ernst Götsch (Rebello & Sakamoto, 2021). For the species planted, the successional stage was defined by the practitioner managing the AF system. Placenta species are herbaceous plants including annuals (sunflower, broad beans) and perennial species (e.g. comfrey, artemisa, sage, lavender). Further Climax species are established by seed.; ** Estimated by practitioner managing the AF system

	Monarch birch (*Betula maximowiziana*)	113	Secondary	5-15
	Silver birch (*Betula pendula*)	191	Seconday	5-15
	White poplar (*Populus alba)*	263	Seconday	5-15
	Aspen (*Populus tremula*)	80	Seconday	5-15
Other	Siberian pea shrub (*Caragana arborescens*)	35	Seconday	15-30
	Mahonia (*Mahonia aquifolium*)	103	Seconday	15-30
	Whitebeam (*Sorbus aria*)	13	Seconday	40-60
	Fly Honeysuckle (*Lonicera xylosteum*)	105	Seconday	15-30
	Goat willow (*Salix caprea*)	123	Seconday	15-30
	Summer lilac (*Buddleja davidii*)	30	Seconday	15-30
	Wild cherry (*Prunus avium*)	91	Climax	60-80

3.3 Study design

In order to study the ecological and economic establishment success of the SAFS, this study uses a cross-sectional descriptive design with a mixed-methods approach. Mixed method designs are characterized by the incorporation of at least one quantitative and one qualitative research component (Schoonenboom and Johnson 2017).

Quantitative data was integrated from tree inventories, a seedling inventory and a cost analysis, while the qualitative data is comprised of an expert interview with a farmer employed in AF. The integration of both qualitative and quantitative data takes place in the results part of this study, where the results of the quantitative data collection are analyzed together with the findings of the qualitative data. The analysis can therefore be classified as qualitative descriptive comparative. This is done to offer an enhanced assessment of both the ecological as well as the economic success of establishment of the examined AFS.

3.4 Data collection

The data collection comprises both primary and secondary data. Primary data was gathered from a tree inventory, a seedling inventory and an expert interview. Secondary data that was used for this study include the data of a previous inventory of 2021, data about the introduced seeds into the AFS, economic data, soil sampling data and climate data of a local weather station.

3.4.1 Ecological parameters

Tree inventory

To allow a comparative analysis of the system’s performance in its initial years after establishment, data on tree survival and establishment was collected in the field in May 2024, including the key parameters of tree vitality and the frequency of damages. Thereby, the existing tree inventory, which was conducted upon the conclusion of planting in 2021/22, was updated with the current status of the planted woody perennials. This assessment occurred visually. The data of 2021 comprises the documentation of the type of shrubs and trees that were planted, their exact position within the tree rows as well as their assigned number. To capture the current status quo of the AFS’s success of establishment, the inventory was conducted in one day. Vitality was assessed visually, and plants categorized as either 'vital', 'low vitality' or 'dead' adapted from the definition by Klug (2017) as defined in Table 8. This straightforward categorization strategy is employed by the agroforestry practitioners at Gut & Bösel / Finck Stiftung for all AF inventories. It is a simplification of the vitality assessment described by Klug (2017), which conveys sufficient information to agroforestry team to base management decisions on.

Tab. 8 Description of the levels of vitality used in tree inventory adapted from Klug (2017)

Level of vitality	**Description**
Vital	Crown developed according to species and development phase with corresponding shoot lengths and healthy leaf development or slightly reduced. A slight crown drought can be identified.
Low vitality	Leaf development (leaf size, leaf color, relative foliage density) and the expected shoot length growth during the development phase are significantly weakened, considerably reduced or no longer present. In the crown mantle, a dieback of twigs and branches to weak or, in individual cases, coarse branch strength is recognizable. In some crown mantles, entire crown areas or parts of the crown are dead, even over the thickness of the branches. The tree's reaction to injuries to the trunk or crown is rather moderate, with relatively small wound wood or callus formation on former cuts or injuries.
Dead	There are no living shoots and leaves existing.

Additionally to tree vitality, damage indicators were recorded when they were observed. Prior to the investigation, four types of damage were defined and described, along with their criteria for their classification, presented in Table 9. In the absence of an unambiguous assignment, no damage was defined.

Tab. 9 Definition of the assessed types of damages and their criteria of classification used in tree inventory

Type of damage	**Criteria of classification**
Voles	Visible damage on bark or root crown. Further root damage was assessed by grabbing the stem and tilting the tree carefully. Vole damaged trees are very loose and tilt readily.
Disease	The tree exhibits dead plants parts or necrosis. Necrosis in the forms of rots and decays, leafspots, lesions or cankers.
Frost	The tree shows shriveling, browning or blackening of its leaf tissue. Terminal bud sprouted and then froze in late frost event in late april. New shoots emerging from axillary or adventitious buds.
Aphid	Aphids or symptoms of aphid damage observed such as characteristically curled, miscolored leaves and shoots.

Seedling inventory

In addition to the above described tree inventory, a seedling inventory was carried out in order to assess the viability of the self-collected seed introduced. This entailed the monitoring of seedling density in sections of the tree rows. The primary data collected comprises the number of emerging seedlings as well as the subsequent calculation of survival rates. For this purpose, secondary data in the form of the quantity of introduced seeds into the AFS in 2021 served as a basis (**Tab. 10**).

Out of the 24 species whose seeds were collected and sown into rows, 4 species were sampled. The selection of the sampled species was based on their ecological and economic importance to the system as well as their relevance in assessing the overall establishment success of the AFS. Thus, the performance of the sown late successional species was subject to analysis, playing an important role in the later stages of the SAFS. These species include Sweet chestnut (*Castanea sativa*), Pedunculate Oak (*Quercus robur*), Red oak (*Quercus rubra*) and Ash (*Fraxinus excelsior*) (**Fig. 11**).

Tab. 10 Seed quantity of sampled species and their Thousand grain weight (Finck Stiftung 2022)

Species	Quantity (g)	Thousand grain weight (g)[2]
Quercus robur	23200	3300 (Herzog 2024)
Quercus rubra	20700	3200 (Herzog 2024)
Fraxinus excelsior	11800	68 (Herzog 2024)
Castanea sativa	30000	4700 (Faust n.d.)

[2] Intraspecific weight of seeds varies depending on tree genetics and environmental conditions. Since weights were not determined empirically for the seeds planted, values based on literature were used to estimate the seeding density.

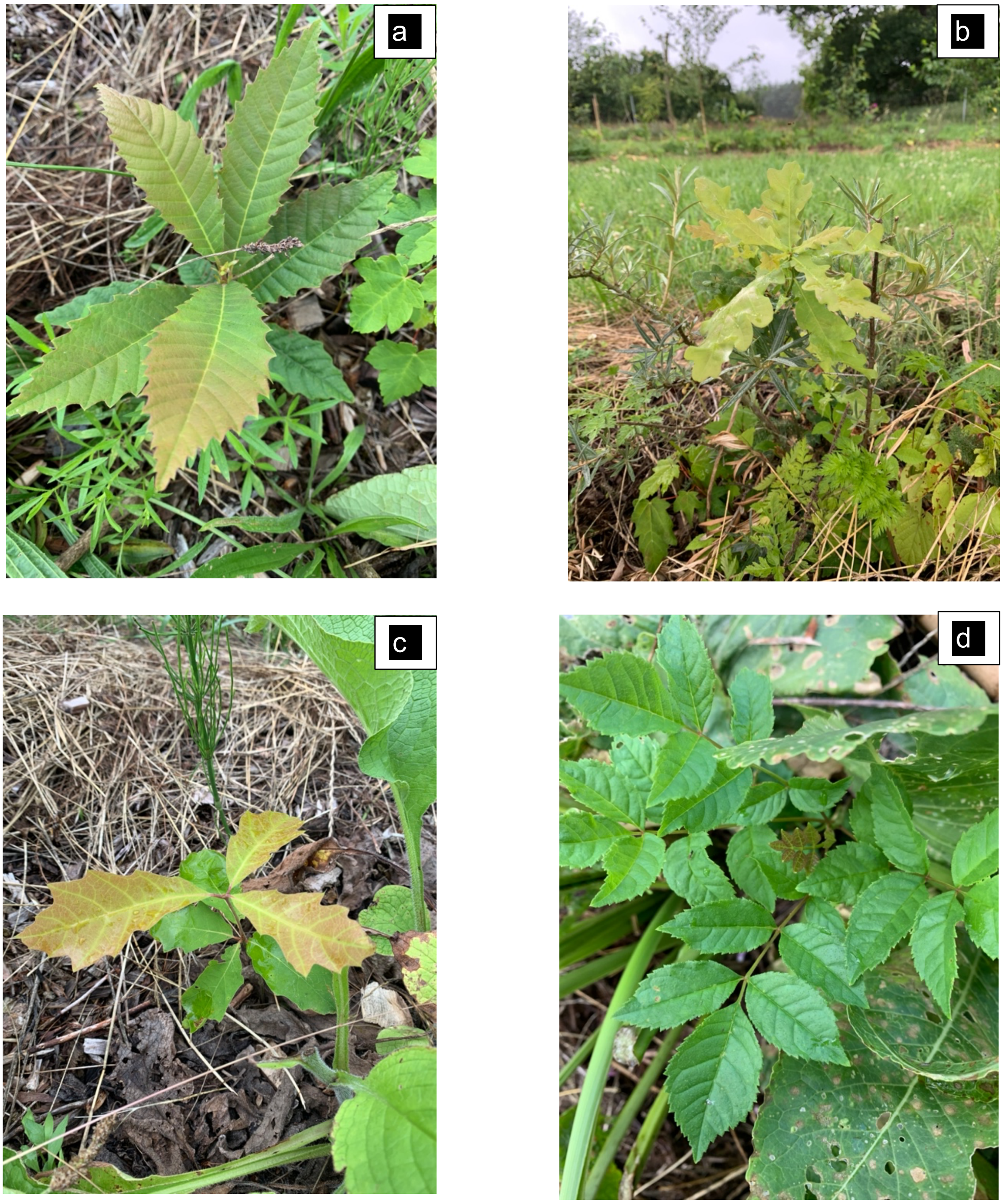

Fig. 11 Seedlings of *Castanea sativa* (a), *Quercus robur* (b), *Quercus rubra* (c) and *Fraxinus excelsior* (d)

The sampling design can be described as follows: In order to generate random sampling points within the tree rows of the AFS, a geographic information system (GIS) – based randomized sampling approach was implemented. The selection of these random points was conducted with the aim of ensuring an unbiased representation of the AFS. For an on-site localization of the 20 selected sample points, their exact positions were overlaid onto a map of the AFS and afterwards transferred to a GPS application called “Emlid (https://emlid.com/)”. The field procedure started with the identification of a randomized sampling point, using the application “Emlid flow” based on their GPS data. Once the location of a point was identified, a 15-meter section was measured out in the direction of north to define the sample section, using a measuring tape. If the distance of a sampling point was smaller than 15 meters to the end of the row, the identification of the sampling section was continued in the subsequent row. To ensure accuracy and be able to recover the sample section, the GPS location of the ending points of the sample sections were marked in the application “Emlid flow”. The location of the sample sections is presented in Figure 12. Within each of the 20 sample sections, the number of the four pre-selected tree species was counted and recorded.

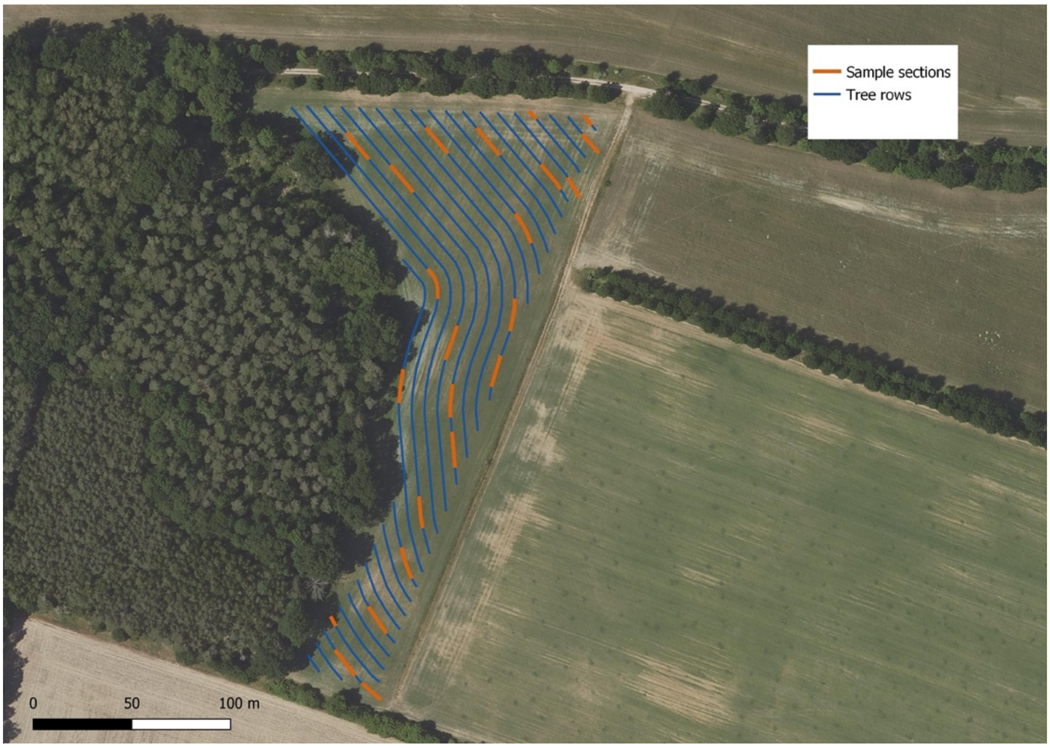

Fig. 12 GIS-Map of the Sample sections of the seedling inventory in the AFS under study (Finck Stiftung 2024)

3.4.2 Economic parameters

Data on the management and maintenance inputs of the SAFS was continuously recorded by the farm team since the time of establishment. Based on the principles of the report of the "Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V." (KTBL) on data collection for the respective SAFS establishment, which provides guidelines for the calculation of agricultural costs in Germany, the economic investigation includes the calculation of two different types of costs. Firstly, the costs associated with labor were calculated. The calculation of labor costs was adapted to the methodology described in the KTBL report (Küsters 2022), summarized priorly in the part "2.5 Economic investigation of an agroforestry system" of this thesis; and based on the provided labor time documentation collected as secondary data (see Appendix 3). This is estimated and logged at the end of each workday by an employee, including the documentation of executed activities, an optional description of the activity (i.e. used equipment).

The calculation of labor costs firstly required the calculation of labor hours, further divided by the two different labor types, including permanent employees and temporary staff. The labor cost rate used or hourly wage rate, was the one suggested by the KTBL and incorporated both permanent employees (21,00€) and temporary labor (13,90€). Even though temporary labor on the farm work without payment, their potential labor costs are included in the calculation to be in accordance with the methodology of the KTBL report.

The second category of costs considered in the economic investigation is the one associated with the operating costs of the AFS. Primary data on operational expenses (i.e. equipment, materials, and frequency) were collected and calculated using the tool called "KTBL-Feldarbeitsrechner", previously described in the part “2.5 Economic investigation of an agroforestry system”. The used input data (e.g. machine types or machine combination) for the calculation was priorly provided by the farm’s research team and made available for the purpose of this thesis. This also includes the frequency of operations and the time required, derived from the labor documentation. The tool only provided a choice of possible data sizes, for the calculation the most appropriate was selected (see Appendix 3). The tool was then used to estimate for the main operating costs associated with the SAFS. It provided information on machinery costs (€/ ha) and diesel requirement (l/ha) for the corresponding operation. The diesel requirement was calculated at a price of €1,15 per liter, based on the suggested price of the tool. Both types of costs were calculated according to the size of the SAFS and then summed up.

Replanting costs are another type of costs that is considered in the economic investigation of the SAFS. These costs above all cover the costs associated with the replanting of fruit trees. As only these target crops are replanted, other plant losses were not considered in the calculation. Nevertheless, the costs for their initial planting are calculated and considered as loss. The calculation of replanting costs was based on the number of losses (trees classified as “dead”), documented during the conducted tree inventory, and the corresponding price of the species, adapted from the price list of initial planting.

The collection of these data sought to gain a more comprehensive understanding of the economic inputs required for the system and served further as a fundamental basis for the evaluation of its economic success.

3.4.3 Expert interview

Qualitative data was gathered through the execution of a semi-structured open interview with the manager of the examined AFS, responsible for its maintenance. The interview sought to gain a deeper insight of the participants’ perspective on the system’s performance both from an ecological and economic point of view. This includes his evaluation of the results of both inventories as well as the identification of factors influencing the system’s success and challenges. After identifying the shrubs and trees with the highest mortality rate, based on the results of the tree inventory, the expert was asked to give his opinion on the possible reasons.

In order to assess the economic performance of the AFS, a part of the expert interview additionally dealt with the economic consequences of tree losses, the assessment of the cost-benefit ratio of self-collecting and sowing seeds in an AFS as well as suggestions for potential areas where labor can be saved. The results of the interview then were used to contextualize the findings gathered through the quantitative data analysis and evaluate the establishment success of the AFS.

In general, an interview is used as a research instrument for a planned procedure with a scientific objective, whereby the interviewee is prompted to give verbal information through communicated stimuli or targeted questions. The selection of interviewees should be based on their relevant knowledge that is important for answering the questions (Scheuch 1973). The type of interview can be classified as semi-structured and open. During the interview, the interviewer has a guideline of questions but can vary the specific wording and sequence. At the same time, the interviewee can answer the questions freely (Mayring 2015).This type of interview was chosen to create a pleasant atmosphere in which the interviewee feels comfortable. The predominantly open questions lead to the interviewee expressing his opinion on the question, interpreting it freely and thus giving the interviewer more insight into the interviewee's understanding of the topic (Kruse 2015). The interview guide was created based on a method developed by Helfferich (2009). His approach encompasses four individual processes: Collecting, checking, sorting and subsuming. Initially, a first set of questions was collected through brainstorming, after that checked for their usefulness and then logically sorted to create a common thread. At the end, the chosen questions were subsumed, so categorized thematically in the guidelines, to create an open but structured questionnaire (Helfferich 2009). The interview guide can be divided into three parts: an introductory part, the main part with the questions for the investigation and a concluding part.

The questions in the main part are divided into five thematically different sections:

- Part A: General information about the farm and the tasks of the interviewee
- Part B: Assessment of the results of tree inventory
- Part C: Assessment of the results of the economic investigation
- Part D: Assessment of the results of seedling inventory
- Part E: Outlook and recommendations

The interview guidelines can be seen in the Annex (**Appendix 1: Interview guidelines**). The expert interview was conducted in July 2024 and, due to distance, via video conference. The interview lasted about 30 minutes, while notes were taken. To ensure that no information was lost and that the interview could be analyzed afterwards, the interview was recorded with the consent of the interviewee.

In the subsequent sections of this thesis, the interview transcript is used as a data source for the analysis of the establishment success of the AFS and cited as "Interview Hansen 2024". To do so, the findings gathered through the interview will be summarized in the results part of this study separately regarding the ecological and economic aspects.

During the ecological investigation, the information obtained from the expert interview was compared with the data from literature. Thus, the experts' assessment of potential causes of plant losses was compared with the optimal site requirements for the studied plant species as described in the relevant literature. In addition, the interview formed the basis for the evaluation of the seeding inventory carried out.

The economic investigation of the establishment success used the information from the interview as a source for evaluating the results, including the economic consequences of tree losses, the assessment of the cost-benefit ratio of self-collecting and sowing seeds in an AFS as well as suggestions regarding potential areas where labor can be saved. To conclude the investigation and provide recommendations for future practice, the data collected from the interview was further analyzed regarding possible management practices than could be improved.

3.5 Representativeness of data

The evaluation of the study's representativeness of data requires first the definition of the population under investigation. The population of this study is represented by an AFS located in Briesen (Mark) together with its stakeholders such as the farm owner and the staff, involved in its establishment and maintenance. The AFS is structured according to the principles of SA and aims to develop into a resilient, long living and valuable system. The study's aim is to investigate the success of establishment from both an ecological and economic point of view. All data were collected within a single geographical area, contributing to the results being comparative and consistent, as the likelihood of significant variation of environmental factors is reduced. However, data of some of the used methodologies may indicate a reduced representativeness. Even though the chosen method of the seedling inventory was designed in a systematic and randomized manner within defined parameters, the sampled intercepts might not represent the condition of the entire AFS. A potential over- or underestimation of success rates and frequencies of seedlings within the tree rows, might also be caused by variations in soil conditions, microclimates and other environmental factors within single tree rows, having different impact on the success of establishment of seedlings. The conducted tree inventory captured the condition of every planted tree and shrub, which suggests that the collected data still give a valid representation of the ecological performance of the system at that time, three years after establishment. However, the inventory was based on visual assessment, which could lead to the introduction of biases due subjectivity.

The basis of the economic investigation in form of the provided labor documentation comprises every operation done on the system together with the respective required labor hours since the system was established. Even though this built a solid foundation for the economic analysis, the representativeness of this data may be reduced due its specificity. The labor cost calculation for instance, considered specific working conditions that might not be applicable to other AFS. In addition, operating costs were calculated using an online tool, whose calculations are based on generalized assumptions leading to a reduced representativeness of collected data. While the sampling might be classified as convenience, the homogeneity of operations done to maintain the system as well as the environmental conditions within the area, contribute to the representativeness of data. Nevertheless, the findings of this study should be interpreted with caution when applied to other AFS or other geographical conditions. The generalizability of the results is limited by the system's specific environmental conditions, economic factors and management practices. In order to extend the applicability and validate the results obtained, further research is needed, involving a broader sampling over a longer period of time.

3.6 Data analysis

3.6.1 Ecological parameters

Tree inventory

The data collected within the framework of the tree inventory was analyzed using the Microsoft Excel software. This entailed aggregating the total number of losses and calculating the percentages of the different levels of vitality to determine the mortality rates of each plant species planted. For a better overview, the examined species were categorized into separate groups according to their function, including fruit trees, mother trees, berries and others (see **Tab. 7**). The data collected through the inventory was employed in a comparative analysis based on the data gathered from the initial inventory carried out. This formed the basis for the identification of trends, mortality rates and species composition in the AFS. The five species with the highest mortality rates, among the 29 assessed, were subjected to further analysis to identify the underlying causes for their significant losses. This was achieved by comparing information obtained through the expert interview and additional soil and climate data with the findings about the species location requirements from the literature review.

Additionally, the incidences of damage were totaled and separately categorized in order to estimate the percentages of occurrence for each type of damage. Furthermore, it was determined which types of trees were affected and whether any specific species were particularly susceptible to damage.

Seedling inventory

The primary goal of the seedling inventory data analysis was to estimate the expected frequency of seedlings in meter within the tree rows of the AFS and to determine the success rate of seedling establishment of each of the before selected tree species. The calculated success rates will additionally be put in relation with the typical germination rates of the respective species (**Tab. 11**).

Tab. 11 Typical seed germination rates of investigated species

Species	**Typical germination rate (%)**
Quercus robur	60-70% (Herzog n.d.)
Quercus rubra	60-70% (Herzog n.d.)
Fraxinus excelsior	65-75% (Herzog n.d.)
Castanea sativa	50-60% (Herzog n.d.)

Out of the total 2689 meters of tree rows, 300 meters were sampled in total. Within these sampled transects, the seedlings of the four different species were counted. These counts provided the raw data needed to calculate the frequency and success rates of the seedlings.

Before determining the expected frequency of seedlings in meters, the frequency of seedlings per meter had to be determined beforehand. This was done by dividing the total number of counted seedlings by the total length of the sampled transects.

$$Frequency\ per\ meter\ = \frac{Counted\ seedlings}{300}$$

To estimate the frequency of seedlings in meters, the inverse of the frequency per meter was calculated:

$$Seedling\ Frequency\ (m)\ = \frac{1}{Frequency\ per\ meter}$$

The calculated value represents the expected distance between individual seedlings of a species within the tree rows.

To determine the success rate of the introduced seeds, it was required to first calculate the total number of seeds that had been sown into the tree rows of the SAFS, using the following formula:

$$Number\ of\ seeds\ sown$$
$$= Number\ of\ seeds\ per\ kg\ of\ seed\ *\ Weight\ of\ introduced\ seeds\ (\mathrm{kg})$$

The estimation of the number of seeds sown presumed the value of two parameters, including the thousand-grain weight (TGW) and the weight of a single seed respective to the sampled tree species. The TGW represents a standard metric to calculate the number of seeds in a given weight.

$$Weight\ of\ single\ seed\ (g) = \frac{TGW}{1000}$$

$$Number\ of\ seeds\ per\ kg\ seed\ = \frac{1000}{Weight\ of\ single\ seed\ (g)}$$

Besides the total number of seeds sown, the calculation of the success rate required the total expected number of seedlings. By using the previously calculated frequency of seedlings per meter, the total expected number of seedlings was determined, using the formula:

$$Total\ expected\ number\ of\ seedlings\ =\ Frequency\ per\ meter * \ 2689$$

Finally, the success rate was calculated using the formula:

$$Success\ rate\ (\%) = \left(\frac{Total\ expected\ number\ of\ seedlings}{Total\ number\ of\ seeds\ sown}\right) * \ 100$$

The obtained value represents the percentage of a tree species seed that successfully germinated and established as seedlings in the SAFS, 3 years after sowing.

3.6.2 Economic parameters

The economic investigation was divided into five parts: labor cost calculation, operating cost calculation, replanting cost calculation, analysis of total costs and the evaluation of the expert interview.

Labor hours were calculated for each operation that has been executed on the AFS. For each of both types of labor (temporary and permanent), the labor hours were calculated separately. The contribution of each operation to the total labor hours was then calculated as a percentage. This was done to identify which type of operation contributed most significantly the overall labor hours and thus to the resulting costs.

Based on the labor hours calculation, labor costs were determined for each year after the year of establishment in 2021. After calculating the total annual labor costs, the analysis focused on the development of the costs over the last three years. This information was crucial for understanding the economic impact of labor on the SAFS.

The operating costs were calculated based on the results of the “KTBL-Feldarbeitsrechner”, which provided the costs associated with each mechanized operation. To estimate the total operating costs, these cost rates were then multiplied by their frequencies of the last three years after establishment.

Afterwards, the costs associated with replanting were calculated. Thereby species were identified that contributed to a big part to this type of costs and the overall proportion to the total costs was estimated additionally.

The following total cost calculation aimed to provide a comprehensive view of the financial performance of the AFS three years after establishment. This included an evaluation of the development of costs in terms of time and their composition. In order to assess the financial trends over time, the annual costs from 2022 to 2024 were calculated, considering labor, operation and replanting costs. Based on this calculation cost fluctuations were examined and any significant changes or patterns that could affect the long-term viability of the system were identified. A specific focus was put on the contribution of replanting costs in the overall expenses, as these costs represent the point of intersection of both the ecological and economic investigation of this study. Evaluating the impact of replanting costs on the overall economic picture was necessary in order to assess the cost-effectiveness of the ongoing management practices.

Another part of the economic investigation was the expert interview, conducted with the aim to gather additional qualitative insights into the economic aspects of the AFS, whit a particular focus on three key areas. The first one includes the economic impact of plant losses, which were identified throughout the inventory analysis. The expert provided an assessment on the financial implications of the plant losses and offered commentary on the effect of such losses on the overall economic performance of the system. Furthermore, the interviewee was asked to evaluate the cost-benefit ratio of the procedure of sowing self-collected seeds within an AFS. The aim of this evaluation was to ascertain whether this practice can be considered as economically viable or if alternative strategies are more recommendable. In addition, the expert provided suggestions regarding potential areas where labor hours could be saved without compromising the overall performance of the system. These recommendations were aimed at identifying strategies to improve the economic efficiency of the AFS and of a similar nature.

3.7 Methodological justification

The design of the methodological approach of this study is based on the research philosophy of pragmatism, which focuses on gaining practical solutions for real-world problems by utilizing multiple sources of data to answer the research question. This approach is particularly suited for sustainability sciences, since it agrees with the objective of this study to explore and enhance sustainable practices within the field of AF. Moreover, the goal of this study is to improve the economic viability as well as foster the success of establishment of AFS/ SAFS and systems of the same kind. This is done by gathering actionable insights and recommendations for the practice.

The generation of knowledge of existing systems in their natural context is classified as an inductive research approach. The existing system under investigation in this study is a diverse AFS. Research was done without changing variables, which allows for a comprehensive understanding of its prevailing dynamics. According to Schoonenboom and Johnson (2017), the methodology of this study therefore can be classified as an applied research methodology, aligning towards providing practical recommendations for improving the performance of the AFS of others of this kind. The implementation of a holistic approach was chosen based on the complex nature of an AFS, as it requires the consideration of various factors and their interdependence.

Throughout the study both quantitative as well as qualitative data were collected and analyzed. The basis for understanding the ecological and economic success of establishment was provided by the collection of quantitative data gathered from inventory assessment, seedling inventory, and an economic analysis. The qualitative data were derived from an expert interview.

To capture the current state of the AFS, the chosen study design as a cross-sectional descriptive design with a mixed methods approach was particularly appropriate, as there was also no need for changes to be implemented. The diagnostic approach of this study was crucial for the identification of potential reasons for the recent performance of the SAFS as well as challenges that could affect the sustainability of the system in the long run.

The justification of the selected methods is based on their capability to effectively address the study's research topic. The pragmatic, inductive and applied research approach is particularly suited due to the complex, real-world context of the examined AFS. The integration of both quantitative and qualitative data offered a holistic and deep understanding of the system, while the use of additional secondary data deepened the analysis. Furthermore, the chosen methodologies allowed the study to generate valuable insights into the ecological and economic success of establishment of the AFS, while providing precious knowledge to the field of AF at the same time.

3.8 Ethical consideration

In the course of the study, confidentiality was maintained, and anonymity of all participants was ensured. The interviewee participated voluntarily and was fully informed about the study process, including its objective and how the collected data would be used. Any sensitive data was anonymized, while personal information was not disclosed in the study findings. To maintain data integrity, the data collected were handled with care and accuracy. Data analysis was done rigorously, paying particular attention to avoidance of misrepresentation. The used secondary data was ensured to be reliable, with reports given about any limitations. The chosen methods of data collection were designed with the aim of minimizing their potential harm to the system under investigation. The tree and seedling inventory were done within at most three days in total, in a non-invasive manner and without disturbing the natural processes within the SAFS.

4. Results

4.1. Ecological parameters

Tree inventory

To investigate how the planted trees established an inventory of the SAFS was conducted as part of this study and results were compared to a first inventory from 2021. The results show that of the 4072 woody perennials planted according to the first inventory from 2021, in the second inventory from 2024, 74 % were categorized as "vital", 4 % as "low vitality" and 22 % as “dead”, representing the third vegetation period after planting. In total more than 800 plants were identified as “dead”. Whereby, the vitality status for each individual species varies (see **Tab. 12**).

The five plant species that indicate the highest percentage of the vitality level "dead" are the following: Foxglove tree, White poplar, Summer lilac, Monarch birch and Grey alder. The lowest percentages at 0.00% is found in the class of berries, which includes Shadbush, Jostaberry, Whitebeam and Japanese Silverberry. The species which shows the highest percentage of "low vitality" is the Mulberry, with a rate of 50.00% (**Tab. 12**).

Tab. 12 Inventory analysis results in percentages: comparison of 2021 inventory with results of 2024 inventory

Species	Quantity	Dead	Low vitality	Vital
Apple (*Malus domestica*)	121	9.09%	5.79%	85.12%
Pear (*Pyrus communis*)	127	12.60%	3.15%	84.25%
Buffaloberry (*Spepherdia*)	29	34.48%	24.14%	41.38%
Siberian pea shrub (*Caragana arborescens*)	35	2.86%	0.00%	97.14%
Sweet chestnut (*Castanea sativa*)	25	16.00%	4.00%	80.00%
Shadbush (*Amelanchier lamarckii*)	63	0.00%	3.17%	96.83%
Grey alder (*Alnus incana*)	205	46.83%	2.44%	50.73%
Balsam poplar (*Populus balsamifera*)	403	29.53%	1.99%	68.49%
Red currant (*Ribes rubrum*)	233	3.86%	2.58%	93.56%
Jostaberry (*Ribes x nidigrolaria*)	96	0.00%	2.08%	97.92%
Foxglove tree (*Paulownia tomentosa*)	24	100.00%	0.00%	0.00%
Cornel (*Cornus mas*)	105	3.81%	4.76%	91.43%
Monarch birch (*Betula maximowiziana*)	113	85.84%	10.62%	3.54%
Mahonia (*Mahonia aquifolium*)	103	4.85%	0.00%	95.15%
Mulberry (*Morus nigra*)	100	45.00%	50.00%	5.00%
Whitebeam (*Sorbus aria*)	13	0.00%	0.00%	100.00%
Japanese Silverberry (*Elaeagnus umbellata*)	67	0.00%	0.00%	100.00%
Peach (*Prunus persica*)	49	20.00%	0.00%	80.00%
Plum (*Prunus domestica*)	296	16.31%	2.15%	81.54%
Fly Honeysuckle (*Lonicera xylosteum*)	105	0.95%	2.86%	96.19%
Goat willow (*Salix caprea*)	123	6.50%	0.00%	93.50%
Silver birch (*Betula pendula*)	191	6.28%	0.52%	93.19%
Sea buckthorn (*Hippophae rhamnoides*)	628	9.55%	6.37%	84.08%
Siberian blueberry (*Lonicera kamtschatica*)	201	2.49%	3.48%	94.03%
Summer lilac (*Buddleja davidii*)	30	90.00%	0.00%	10.00%
Gooseberry (*Ribes uva-crispa*)	153	18.95%	2.61%	78.43%
Wild cherry (*Prunus avium*)	91	6.59%	7.69%	85.71%
White poplar (*Populus alba*)	263	98.86%	0.00%	1.14%
Aspen (*Populus tremula*)	80	20.00%	6.25%	73.75%

The target species of the investigated SAFS are fruit trees and include apples, pears, peaches and plums. Sea buckthorn is included additionally in this group, as it is also one of the species intended for harvesting in year 5 to around 25 of the system (see **Tab. 7**).

The vitality rate of the species in the group of fruit trees is indicated to be at least 80%. The fruit tree with the highest percentage of being "dead" is peach at 20%, followed by plum with approx. 16%. The lowest rate of being "dead" is observed in apples trees (9.09%), followed by a slightly higher percentage in sea buckthorn. While sea buckthorn shows one of the lowest death rates of this group, it indicates the highest rate of "low vitality". Peach trees indicate a "low vitality" rate of 0.00%, which classifies them to be either "vital" or "dead" (**Fig. 13**).

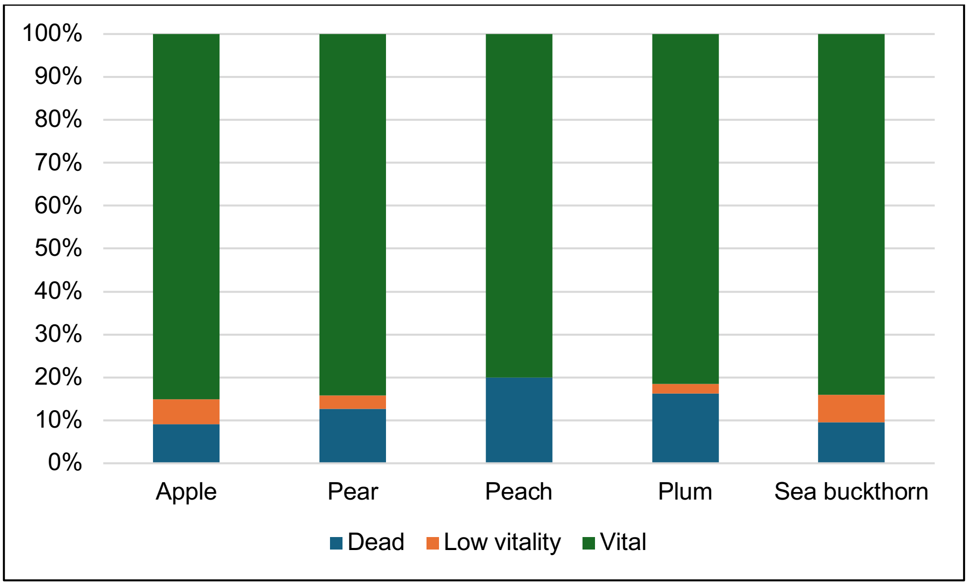

Fig. 13 Vitality status of fruit trees (dead, low vitality, vital) at second tree inventory, described as rate of total planted trees as described in the first tree inventory of 2021

The group of "mother trees" is comprised of eight species of pioneer tree species (see **Tab. 7**) of which several had a high rate of being "dead". This group comprises four of the five species, which indicate the highest rate of being "dead" of the 29 species that have been assessed. Consequently, the results of this group show the lowest rates of tree vitality (**Fig. 14**).

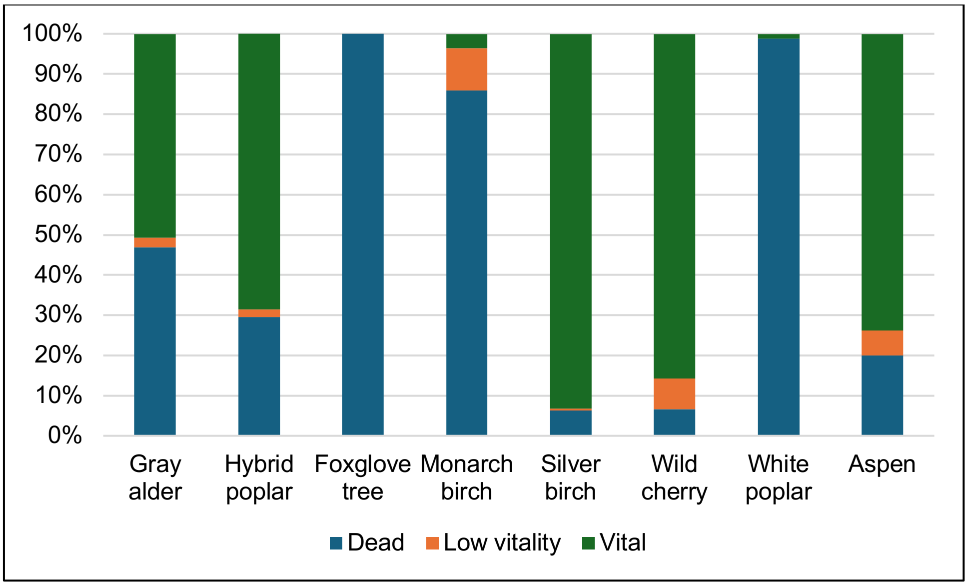

Fig. 14 Vitality status of mother trees (dead, low vitality, vital) at tree second inventory, described as rate of total planted trees as described in the first tree inventory of 2021

The group of berries include nine different species (see **Tab. 7**). The species with the highest "dead" rate in this group is the Buffaloberry with approx. 35%. Compared to the performances of the other berry species this rate can be classified as relatively high. The second highest "dead" rate for instance is lower than 20% and is observed in the species of Gooseberry. The Buffaloberry also shows the highest "low vitality" rate in this group, at approx. 24%. Plants of the species Shadbush, Japanese Silverberry and Jostaberry stand out, as they indicate a "dead" rate of 0%. The Japanese Silverberry also shows a "low vitality" rate of 0%, which means that all the 67 Japanese Silverberries planted were classified as "vital" (**Fig. 15**).

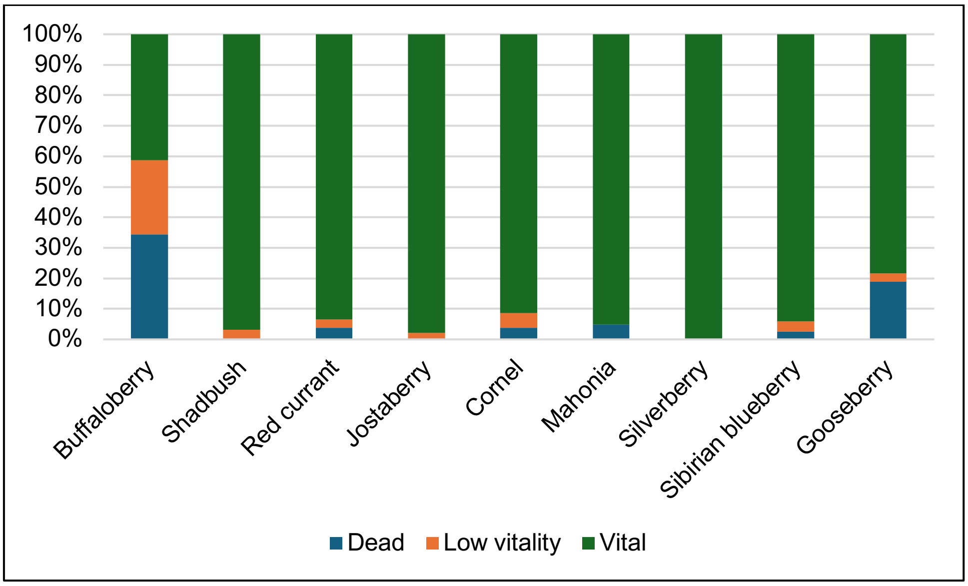

Fig. 15 Vitality status of berries (dead, low vitality, vital) at second tree inventory, described as rate of total planted trees as described in the first tree inventory of 2021

Species that do not belong to either the “Fruit trees”, “Berries” or “Mother trees” groups are grouped under “Others” (see **Tab. 7**) Particularly noticeable in this group, are the performances of Summer lilac, Mulberry and White beam. The first of these indicates the third highest “dead” rate of all the species studied, at 90%. The second is the species with the highest “low vitality” rate at 50%. Whitebeam shows both a “dead” rate as well as a “low vitality” rate of 0% (**Fig. 16**).

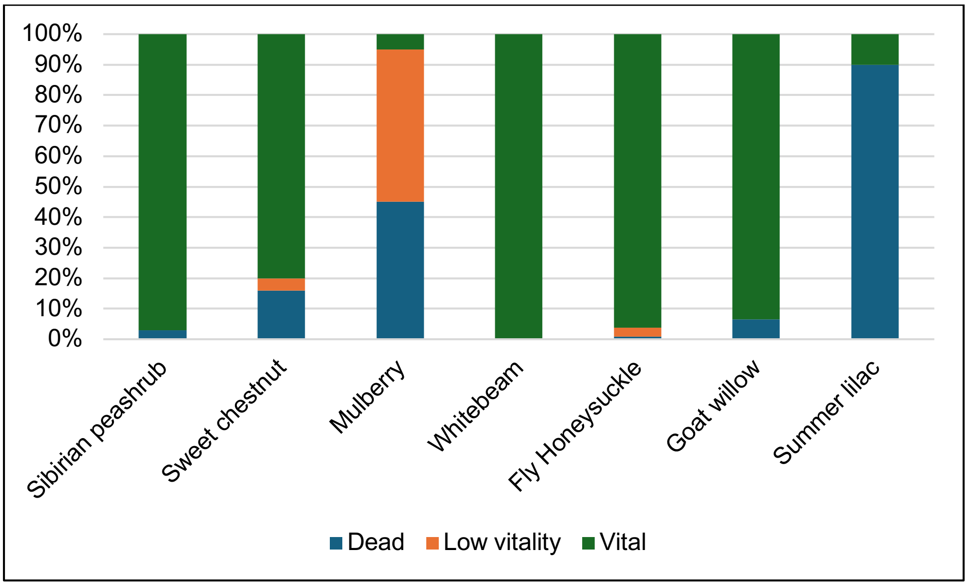

Fig. 16 Vitality status of other planted species (dead, low vitality, vital) at second tree inventory, described as rate of total planted trees as described in the first tree inventory of 2021

In addition to the assessment of plant vitality, the plant's state of damage was determined. The results show that a total of 97 out of 4072 assessed plants were identified as visibly damaged, representing a proportion of 2,4%. Of the 97 damaged plants, 12 were classified as "dead", 32 as "low vitality" and 53 as "vital" (**Tab. 13**).

Tab. 13 Recorded incidences of damage in tree inventory 2024, categorized in type of damage (vole, disease, frost, aphid) and vitality level (vital, low vitality, dead)

	Vital	Low vitality	Dead	Sum
Vole	26	13	11	50
Disease	10	3	1	14
Frost	10	15	0	25
Aphid	7	1	0	8
Sum	53	32	12	97

The most common reason of damaged plants was voles, with a total of 50 cases, accounting for almost half of the total number of damaged plants. Damage due to voles is also the most frequent type of damage, when looking at trees that were classified as damaged and at the same time as being "dead", with a share of more than 90%. Simultaneously, most plants identified as "vital", while being also classified as damaged, are damaged by the presence of voles too. The group of trees that make up the biggest share of plants with visible vole damage are the fruit trees, with a total of 43, giving a percentage of 86%.

More than 25% of all damaged plants and trees are damaged by frost. Most of the frost damaged trees belong to the group of "Mother trees", with 15 out of the total 25 affected trees, belonging to the species of the Monarch birch. Plants with a visible disease were found 14 times, of which 10 were classified as "vital", 3 as "low vitality" and 1 as "dead". 6 of the 14 diseased plants are fruit trees, 4 of which are peach trees. Further 6 diseased plants belong to the species of the Cornel. Aphids visibly damaged a total of 8 trees, of which 7 were classified as "vital" and one tree showing a "low vitality". 6 of the 8 aphid damaged trees belong to the group of fruit trees.

Seedling inventory

To analyze the establishment success of the introduced seeds, the counted numbers of seedlings within the sample sections provided the necessary data for the calculation of important parameters such as success rate and their spacing within the rows.

The evaluation of the seed testing reveals that Sweet Chestnut (*Castanea sativa*) has the highest estimated success rate at 18%, followed by the Pedunculate Oak (*Quercus robur)* with 13%. Seeds of the species Ash (*Fraxinus excelsior)* show the lowest success rate of less than 2%, but at the same time indicate the highest number of expected seedlings in the AFS with more than 2500, which results in an expected frequency of occurrence of about every meter. The lowest number of expected seedlings is that of the Red oak (*Quercus rubra)* with over 700. The expected frequency of occurrence of this species is at about every 3 to 4 meters. Seedlings of *Castanea sativa* and *Quercus robur* can be expected at a spacing of every 2 to 3 meters (**Tab. 14**).

Tab. 14 Collected data and calculated results of the seed testing (including number of counted seedlings, frequency per meter, expected total number, estimated number of spreaded seeds, success rate and their expected frequency in meters)

	Castanea sativa	***Fraxinus excelsior***	***Quercus robur***	***Quercus rubra***
Counted in total (300m)	125	279	102	79
Frequency/ m	0,42	0,93	0,34	0,26
Expected total number	1120	2501	914	708
Estimated number of spreaded seeds (see Tab. 10)	6383	173529	7030	6469
Success rate (%)	18	1,4	13	10,9
Expected frequency in m	2,4	1,1	2,9	3,8

Interview results regarding ecological aspects

According to the interviewee, the reasons for high mortality rates lie above all in the local climatic conditions. Most of the species that showed a high mortality rate are said to be not frost hardy. Other reasons include unsuitable plant material and methods. Losses of fruit trees are explained by the presence of voles. Some of the plants that were planted are considered “experiments”, to see if they can grow in this location and have the potential to be tolerant of a changing climate, including events such as droughts and late frosts. Based on a visual assessment that intends to evaluate which of those “experimental” plants are doing well, and which are not, the appropriate species can be identified and further be used to establish new systems. Overall, the interviewee is positive about the development of the AFS (Interview Hansen 2024).

The seed testing involved the examination of seeds from four trees, belonging to the group of late successional species. Besides their purpose of producing high value timber, these trees are also cultivated for the production of nuts, as in the case of *Castanea sativa*. According to the interviewee, in SA late successional trees are grown to create an emergent canopy, that will intercept 20% of the total light interception. To achieve this, the trees need to be spaced 15 meters apart, as their lateral branches are pruned up to 8 to 10 meters, so that the crown develops at that height. Underneath the emergent layer, fruit trees and other low layers with berry shrubs are supposed to grow. As the results indicate a higher density of seedlings of late successional seedlings than required, the results of the seed testing are evaluated positive by the expert. To reduce the density, it is planned to select seedlings at the desired spacing as target trees. The remaining seedlings will be pruned or pulled out and used as mulch material, which leads to additional labor requirements (Interview Hansen 2024).

When asked about potential suggestions for improvement, the interviewee suggests selecting trees that are proven to be adapted to the local climate. The creation of “seed nests” is another learning outcome, when looking at the overall development of the AFS. It is meant to be a more calculated approach to integrate seeds into an AFS, by sowing the seeds of the desired species already at the required final spacing and then selecting one of the grown seedlings as a “target tree” after germination. This saves the need to go through the rows and mediate which seedling will stay and which will not.

In reply to the question what could have been done differently when setting up the SAFS the interviewee made two suggestions. The choice of a wider spacing between the rows of about 8 to 10 meters is mentioned, as well as an increased distance of the headland, between the fence and the end of the rows to facilitate the turning of a tractor (Interview Hansen 2024). The report on the establishment of the system outlines a target headland of 9 meters (Küsters 2022). The actual headland, however, is now said to be as little as 6 meters, according to the practitioner, with a stated desirable distance of 8-10 meters (Interview Hansen 2024).

4.2 Economic parameters

Labor costs

The labor force on the farm consists of the group of regular employees, also called “permanent labor” and the group of auxiliary staff, also called “temporary labor”, including interns and volunteers. The auxiliary staff usually make up a large part of the working team and therefore execute a large part of the manual work, whereas the permanent labor does operations like mowing and swathing. Most of the labor hours are spent on weeding, which accounts for 43% of the total labor hours, followed by mulching which accounts for 42% (**Fig. 17**).

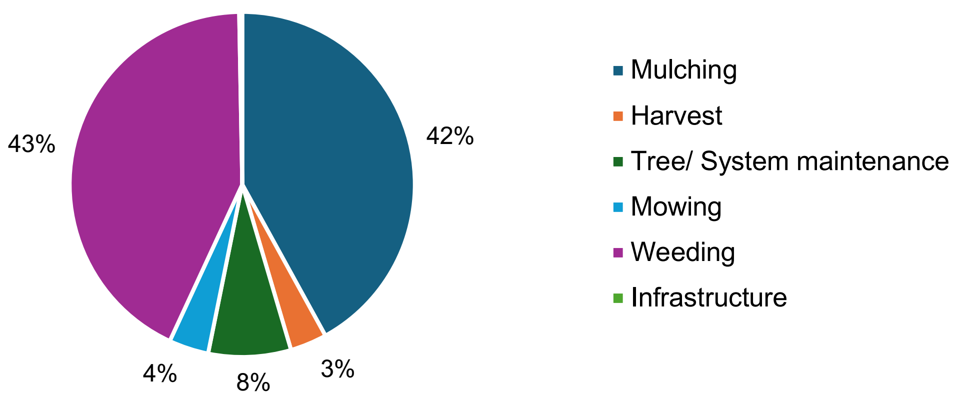

Fig. 17 Percentage distribution of labor hours across operations in the first 3 years after planting (in %)

Managing the system’s infrastructure, mowing and harvesting account for the lowest number of labor hours (**Tab. 15**). Overall, results show that the number of labor hours tends to increase over the last three years, when bearing in mind, that the data for the year 2024 only compromise the period up to inventory (thus January 01, 2024 to May 15, 2024).

Tab. 15 Labor hours divided into Temporary Labor (TL), Permanent Labor (PL), total labor hours (TLH) according to operation type in the first 3 years after planting

Operation	**2022**			**2023**			**2024 (Jan 1- May 15)**			
	TL	PL	Sum	TL	PL	Sum	TL	PL	Sum	TLH
Mulching	86	0	86	191	39.5	230.5	70	48.5	118.5	435
Swathing	0	12	12	0	3	3	0	5	5	20
Harvesting	16	20	36	0	0	0	0	0	0	36
Tree/ System maintenance	13	24.5	37.5	36	7.5	43.5	48	24	72	153
Mowing	0	14	14	14	3	17	8	7	15	46
Weeding	24	9	33	217	88.5	305.5	114	53.5	167.5	506
Infrastructure	0	0	0	0	0	0	2	1	3	3
Sum	139	79.5	218.5	458	141.5	599.5	242	139	381	1199

The evaluation of the labor costs shows that over the last three years the labor costs of the SAFS have increased (**Tab. 16**). The calculation of labor costs estimated with 21,00 € for permanent labor and 13,90€ for temporary labor per hour reveals the following results: The total labor costs (TLC) in 2023 (€9,337.70) are more than twice as high as in the previous year (€3,601.60 in 2022). For the calculated time period of 2024 (January to May 15) the TLC are still almost the same amount as in the previous year, being now €6,282.80. Up to the time of the executed inventory, the system required a total of €19,222.10 in labor costs for its maintenance and care.

Tab. 16 Labor costs in the first 3 years after planting in Euro (€) divided into Temporary Labor (TL), Permanent Labor (PL) and Total labor costs (TLC)

	TL	**PL**	**TLC**
2022	€1,932.10	€1,669.50	€3,601.60
2023	€6,366.20	€2,971.50	€9,337.70
2024	€3,363.80	€2,919.00	€6,282.80
TLC	€11,662.10	€7,560.00	€19,222.10

Operating costs

Most of the work in the SAFS is done manually. The operations that are executed with the help of machines are mowing and swathing. Mowing is done in the area between the tree rows as well as between the ends of the rows and the fence surrounding the system. Swathing is usually done after mowing, in order to distribute the cut grass on the mulch swath next to the rows.

The calculated costs per operation (CpO) for mowing are approx. €60, which include the costs of machinery and the respective diesel requirements (**Tab. 17**). Over the last 3 years mowing has been done five times, resulting therefore in total operating costs of less than €300 (**Tab. 18**). The execution of swathing on the SAFS resulted in costs of about €45 per operation. Due to little growth of gras in November in 2023, swathing was only done once in that year. The total operating costs of swathing, sum up to more than €180. Over the last three years, after the establishment of the SAFS, operating costs sum up to a total of €479.63.

Tab. 17 Machinery costs and diesel demand calculated by KTBL Feldarbeitsrechner per operation (Mowing, Swathing)

	Machinery costs (€/ha)	Diesel demand (l/ha)	Machinery costs total (2,5ha)	Diesel demand total (2,5 ha)	Operating costs total
Mowing	€19.36	€3.85	€48.40	€11.07	€59.47
Swathing	€14.21	€3.32	€35.53	€9.55	€45.07

Tab. 18 Operating costs in the first 3 years after planting (Costs per operation (CpO), Frequency (Fr), Total operating costs (TOC))

		2022		2023		2024 (Jan-May 15)		
	CpO	Fr	Sum	Fr	Sum	Fr	Sum	**TOC**
Mowing	€59.47	2	€118.94	2	€118.94	1	€59.47	€297.35
Swathing	€45.07	2	€90.14	1	€46.07	1	€46.07	€182.28

Replanting costs

The costs of trees for replanting are summed up to the year 2024, as this is when the second inventory was carried out and evaluated. The results of the conducted tree inventory gave evidence about which trees are planned to be replanted. In more detail this means, all fruit trees that were classified as “dead” will be replanted, since fruit trees are the target crop of the studied AFS. The expected related costs were therefore calculated and integrated in the total cost calculation. In total, they amount to a sum of over €3,000 (**Tab. 19**).

Tab. 19 Replanting costs of target crops (fruit trees) in the first 3 years after planting according to their number of losses

Species	Number of lost plants	Costs per plant	Costs
Apples	11	€38.00	€418.00
Pears	16	€38.00	€608.00
Peaches	4	€36.00	€144.00
Plums	53	€36.00	€1,908.00
Sum	**84**	**/**	**€3,078.00**

Most of the fruit trees to be replanted are plums. This is also the fruit tree species with the highest number of trees planted on the AFS. In total there are 53 failed plums, resulting in estimated cost of €1,908.00. All other plants that identified as “dead” are not supposed to be replanted. Therefore, the associated costs of the initial planting of these plants are not included in the material cost calculation but considered as loss. The total loss caused by plants classified as “dead” three years after planting amounts to a sum of more than €2,300, with losses of White poplar, Shadbush and Japanese Silverberry contributing the most to the total loss (**Tab. 20**). For example, 222 trees of white poplar were classified as “dead”, resulting in a total loss of approx. €350. Planted trees of the species of Shadbush caused a loss of more than €335.

Tab. 20 Financial loss associated with dead plants of initial planting in 2021

Species	Number of losses	Costs per plant	Total loss
Buffaloberry	10	€8.40	€84.00
Sibirian peashrub	1	€1.16	€1.16
Sweet chestnut	4	€1.76	€7.04
Grey alder	96	€0.75	€72.00
Balsam poplar	119	€0.75	€89.25
Red currant	9	€2.00	€18.00
Foxglove tree	24	€4.36	€104.64
Cornel	4	€8.75	€35.00
Monarch birch	97	€1.73	€167.81
Mahonia	5	€4.50	€22.50
Mulberry	45	€2.10	€94.50
Fly honeysuckle	1	€1.49	€1.49
Goat willow	8	€1.35	€10.80
Silver birch	12	€1.75	€21.00
Sea buckthorn	60	€1.75	€105.00
Sibirian blueberry	5	€1.50	€7.50
Summer lilac	27	€4.96	€133.92
Whitebeam	13	€1.76	€22.88
Shadbush	63	€5.32	€335.16
Jostaberry	96	€2.50	€240.00
Japanese Silverberry	67	€4.50	€301.5
Gooseberry	29	€2.03	€58.87
Wild cherry	6	€1.76	€10.56
White poplar	222	€1.58	€350.76
Aspen	16	€0.70	€11.20
Sum	**802**	/	**€2,306.54**

Total cost calculation

Over the last three years the costs of maintaining the AFS have increased steadily (**Fig. 18**). The total costs of maintenance three years after establishment sum up to over €22,700. Altogether, labor costs account for the largest share of costs with a share of more than 80%, while operating costs represent only a small part of the total costs of approx. 2%.

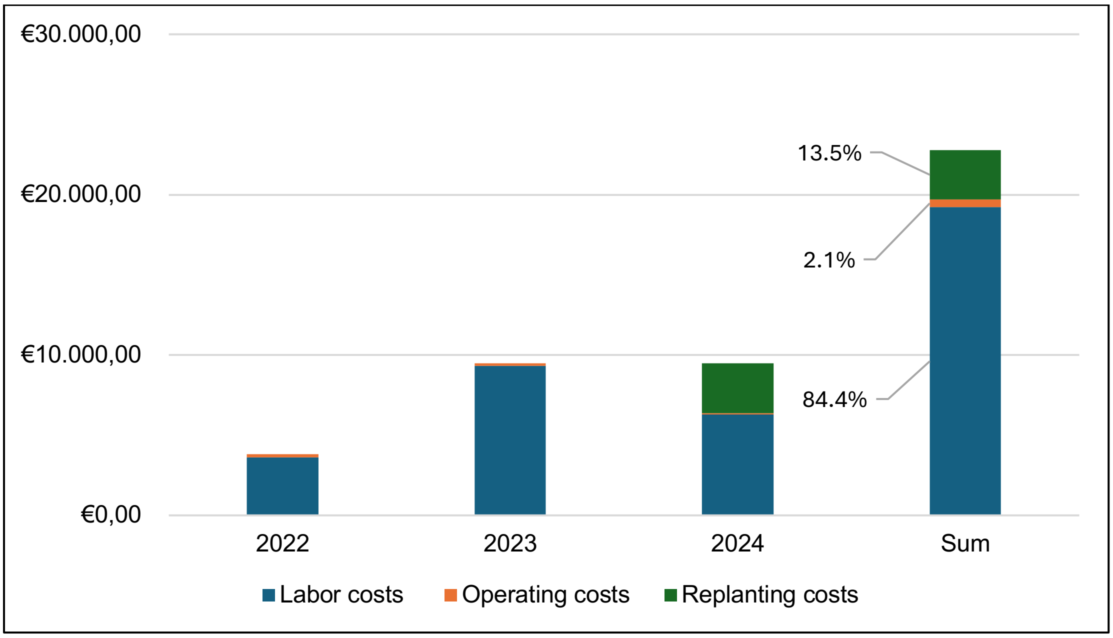

Fig. 18 Development of the maintenance costs in the first 3 years after planting

Labor costs being the most dominant cost factor is also the case when looking at each year separately. In 2023 e.g., labor costs amount to more than €9,300 and operating costs to around €160. Overall, costs associated with replanting represent a proportion of 13,5% of the total costs with approx. €3,000(**Tab. 21**). The total costs of the year 2022 amount to approx. €3,810 while the total costs of the following year (2023) are more than twice as high, being more than €9,500. Even though the total costs for the year 2024 are not yet final, considering only the time period from January to May 15, they are already close to the costs of the previous year.

Tab. 21 Maintenance cost calculation in the first 3 years after planting

	Labour costs	Operating costs	Replanting costs	Total costs
2022	€3,601.60	€209.08	€0.00	€3,810.68
2023	€9,337.70	€164.01	€0.00	€9,501.71
2024	€6,282.80	€104.54	€3,078.00	€9,465.34
Sum	€19,222.10	€477.63	€3,078.00	€22,777.73

Interview results regarding economic aspects

The economic impact of lost trees and plants was evaluated according to their purpose. According to the interviewee, the loss of target woody perennial crops such as fruit trees and sea buckthorn is considered much more economically significant than the loss of support species planted for reasons such as biomass production and soil or biodiversity improvement. Additionally, such plants are planted in a quantity that allows them to fail to a certain extent, as there are also seedlings growing from the direct sowing that can replace them. Thus, their loss does not have a negative effect on the system. One example is ash maple (*Acer negundo*), which was seeded as a potential replacement for planted mother trees. Where planted mother trees failed, an ash maple seedling is now kept, so that no replanting is necessary. However, this does not apply to the target plants, as they are required to be located at a certain distance apart within the tree rows. If they fail, they are replanted, which has an economic impact, as the planting of fruit trees is rather expensive, including the labor hours needed to be invested while planting and coming from the farm's own nursery. Moreover, the harvest time is postponed. The suggestion of increasing the amount of care for the trees and plants planted in the AFS is not seen as economically beneficial overall, as it is said that employees already spend a lot of effort on care and maintenance. Furthermore, the losses of trees due to frost or poor planting material is not seen as factors that can be prevented easily. A possibility to reduce losses due to drought could be watering. However, in the long run, this is rather not considered as worthwhile. To prevent the loss of fruit trees by voles, wire mesh could be used when planting new trees, to protect the roots from being eaten.

According to the interviewee, most working is spent on weeding, which includes pruning the herbaceous layer. This is mainly done manually 4 to 5 times a year.

In the long run, the main input of labor will shift to pruning the trees, starting with the group of mother trees and the training of fruit trees.

Weeding is said to be slowed down by the seedlings of the direct seeding within the tree rows. While weeding, special care must be taken not to damage a potential future target tree such as sweet chestnut. For that reason, a possibility to save labor would be to already select seedlings as target trees at their desired distances, so that the remaining seedlings can be mowed down mechanically together with the herbaceous plants. Another simple option to save labor in this area, would be to reduce the frequency of pruning the herbaceous layer. However, according to the interviewee, reducing the frequency of pruning would then not be in line with the principles of SA, as it states that pruning should take place before the plants start to enter their reproductive phase.

The row layout following a keyline design approach means that each row is not straight-lined but curved. This was evaluated as a complicating factor when using machines such as a tractor for mowing and mulching. As the tree rows are not straight, but adapted to the local topography, such operations must be done more carefully and thus take more time.

Late successional trees have been introduced into the system from seeds that were self-collected and sown by employees of the farm. According to the interviewee, the evaluation of the cost-benefit ratio of this method depends on the type of seed sown. In general, he sees a great advantage in the local adaptation of self-collected seeds and a certain degree of control over their quality, which in the long run leads to a higher vitality of the future trees. However, there are seeds that require more work than others, as they are not easy to collect or require a special treatment to germinate. The lack of respective knowledge and infrastructure means that the introduction of such seeds is regarded as difficult and not worth the effort, favoring their purchase elsewhere. Seeds that are said to be easy to introduce include those of oak, sweet chestnut, maple and ash. The seeds of these species are easy to collect and do not require any special treatment to germinate (Interview Hansen 2024).

5. Discussion

In the following, the results gathered will be interpreted and put into context by explaining their relationships. Thereby, the limitations of the study are described, considered and evaluated. Firstly, the results of the tree inventory conducted are discussed, estimating the suitability of plants to be introduced in a SAFS located in the temperate zone. In addition, the reasons for significant plant losses are determined, taking into consideration difficulties and limitations. The main type of damage will be classified, as well as the impact of damage on the overall ecological performance of the system. To evaluate the ecological performance of the system, the results of the seedling inventory are discussed and contextualized additionally, while also determining the cost-benefit ratio of this planting strategy. Furthermore, the economic success of establishment of the SAFS will be assessed, by interpreting the results of the total cost calculation.

5.1 Plant suitability in temperate SAFS

In general, vitality levels between different plant species vary quite widely. In total around 20% of the trees and shrubs planted were classified as “dead”. This indicates that some of the planted species seem to be more suitable than others for the site, including the prevailing environmental conditions as well as the form of land use. In the following the results of the tree inventory are interpreted to state weather species indicate suitability or seem less suitable. This is done separately for each group of plants. In addition, those species, indicating the highest mortality rates are analyzed in more detail with the aim to find out the underlying causes for their high number of losses. To do so, information that was collected through the expert interview and additional soil and climate data are compared with the information gathered in the literature review.

Target crops (Fruit):

The focus of the SAFS studied is set on the cultivation of fruit trees for the purpose of future fruit harvest. In general, the fruit trees in the AFS indicate a high level of vitality of at least 80%, indicating to seem suitable species. Apple trees showed the highest vitality rate, giving an indication that this species thrives well in the prevailing environmental conditions. Peach trees showed a comparably lower vitality rate. Nevertheless, the number of planted peach trees are less than the one of apple trees, making a reliable statement about the suitability of peach trees difficult.

Mother trees:

The group of mother trees showed the highest mortality rates compared to the other examined groups. Foxglove tree, Monarch birch and White poplar showed mortality rates of above 80%. Their low level of vitality indicates a rather low level of suitability in the context of the system under investigation. In contrast, the most suitable tree species to be used as “Mother trees” in such an AFS, according to their high levels of vitality, seem to be Silver birch, Balsam poplar, Wild cherry and Aspen.

The high mortality of short-lived tree species was also found in a study by Hülsmann (2018), studying the mortality processes in forests of central Europe. In addition, the results of the aforementioned study also indicated strong differences between tree species, whereby less shade tolerant species showed higher mortality rates than shade tolerant species (Hülsmann 2018). This also applies to the results of this study. Vitality levels between species vary, indicating higher mortality rates in tree species that rather prefer sunny locations.

<u>Foxglove tree – *Paulownia tomentosa*</u>

With a mortality rate of 100% the *Paulownia tomentosa* was identified as the tree with the highest mortality rate of all the species planted in the AFS.

When the system was established, this species was planted with young trees of an age of one to two years. According to the interviewee, however, the tree is not frost hardy and young trees in particular are very susceptible to frost. However, in the literature the tree is classified as a very cold hardy species, provided that the wood has been able to fully ripen. Seedlings not older than 2 years are meant to be much more frost tender (Fern 2022), which matches the assessment of the interviewee (Interview Hansen 2024). The results of the soil sampling indicate a pH value of 6.2 (see **Tab. 5**), which is within the preferred range of this species. However, *Paulownia tomentosa* prefers moderately fertile and well-drained soils (Fern 2022), which does not match the characteristics of the local soil type of loamy sand characterized as dry and quick draining (Boughton 2024).

According to Fern (2022) this species prefers sunny sheltered locations. Therefore, the results of the study of Hülsmann (2018), stating that less shade tolerant species show a higher mortality rate compared to shade tolerant short-living species, are inconsistent with one another.

Consequently, frost events as well as the local soil characteristics are considered as one of the main reasons for loss, as the age when planting could not ensure a frost tolerance, and the species soil requirements are not met. The planting of the Foxglove tree seems therefore not to be recommendable in locations with similar conditions. Instead, other species with the same function should be planted, including Silver birch or Aspen.

White poplar – *Populus alba*

According to the results of the interview, *Populus alba* has been planted using self-cut cuttings taken from local trees. However, according to the interviewee, unlike other members of its family, this species cannot be propagated by this method, which may explain the mortality rate of over 98% for this species. In contrast, according to Fern (2022), White poplar can be propagated by taking 20 - 40 cm long cuttings from mature wood of the current season's growth. This should be done in late autumn either placed directly into the soil of the desired location or in a sheltered outdoor bed.

Apart from the pH level, the local soil does not meet the requirements of white poplar for good growth. Since the preferences of this species include a heavy, cold, well-drained soil (Fern 2022).

The identification of the primary cause for the loss of this species is limited. Potential causes include false planting practice and not matching soil requirements. According to the results of the tree inventory, *Populus alba* shows little suitability to be planted in a SAFS in the prevailing conditions of the site. Other pioneer species that showed better performances are therefore recommended to be planted instead, including the Balsam poplar of the same plant family.

Monarch Birch – *Betula maximowizicana*

The Monarch Birch was also planted as one to two year old trees and is considered by the interviewee to be an “experimental plant”. He states that the tree species is supposed to be frost hardy. But young seedlings may not be adapted to the local climate and hence may not be able to tolerate late frosts, which could therefore be the reason for the high mortality rate (Interview Hansen 2024). This assessment, however, is not consistent with the literature reviewed. According to Leder (2014), the Monarch Birch should be a very frost tolerating plant, but who’s new sprouting can be damaged by late frosts from mid-May. However, according to the provided climate data, there have been no frost events from mid-May since the time of establishment (**Tab. 4**). Frost events are therefore not considered as the primary cause for plant loss.

Betula maximowicziana grows best in well-drained loamy soils with a slightly alkaline pH (Benning 2024). In particular, light sandy soils are sites where the Monarch Birch has difficulty growing (Leder 2014). But the soil properties that are found at the location are a dry loamy sand soil, susceptible to dry draining with a neutral pH (**Tab. 5**, Boughton 2024). As a result, the local soil properties seem to be the main cause for the loss of this tree species. Based on the results, the planting of the Monarch birch is therefore rather not recommended, suggesting the use of other plant species that seem to thrive better on site such as Silver birch or Wild cherry.

Grey alder – *Alnus incana*

Alnus incana indicates a mortality rate of about 50% and is a species that is grown in several systems on the farm, where it is said to do well when it grows (Interview Hansen 2024). However, according to the interviewee, it fails quite frequently. A possible explanation that was named by the interviewee, could be that the young trees that were used when planted, not have a high level of tolerance towards planting. If the young plants are rather tender towards planting could not be verifies through literature.

In fact, the comparison of soil preferences of this species and the results of the soil sampling show consistency. At the site of the AFS, the soil is classified as loamy-sandy. Grey alder tolerates a wide range of soils including sandy, loamy as well as dry soils. But, it grows best on heavy clay damp soils (Fern 2022).

Another possible cause for the loss of *Alnus incana* could be its little shade tolerance (Fern 2022), which would correspond with the finding of the study of Hülsmann (2018). However, the identification of a main cause for the loss of *Alnus incana* in the AFS is limited and would require more additional data and analysis to verify. If grey alder is recommendable to be planted in an AFS can therefore not be answered clearly based on the results of this study. According to the interviewee, a good alternative species would be *Robinia pseudoacacia*, also characterized as a nitrogen-fixing plant.

Berry shrubs:

As the AFS intends to produce high value fruit for human consumption as well as potential forage for chickens, a variety of different berry species were also planted (Interview Hansen 2024). The results of the tree inventory indicate that the planted berry shrubs grow well in the SAFS, indicating mortality rates of less than 10%. These include Shadbush, Red currant, Josta berry, Cornel, Mahonia, Japanese Silverberry and Siberian blueberry. Within this group three species showed outstanding results. One of them is the Japanese Silverberry. All the individuals planted were classified as “vital”. The plants of Shadbush and Josta berry indicate a mortality rate of 0%.

As a result, the planted berry shrubs seem to thrive well in the system and can therefore be recommended to be planted within an SAFS in the temperate zone.

Other species

Other species that show a high level of vitality and thus seem to be suitable for introduction in a SAFS in the temperate zone include Siberian pea shrub, Whitebeam, Goat willow and Fly Honeysuckle. Plants of the species Mulberry and Summer lilac appear to be less suitable due to high mortality rates.

Summer lilac – *Buddleja davidii*

Young plants with an age of one to two years, were used for planting *Buddleja davidii.* According to the interviewees’ assessment, this plant is said to be not native to the respective region, giving a hint why losses may be high. According to the interviewee, the high number of losses can also be explained by the poor planting material utilized and the high susceptibility of young plants to frost. Whether the planting material that was used was of poor quality cannot be verified at this stage. However, in literature the plant is classified as tolerant towards occasional frost events, with young plants of this species being more susceptible (Fern 2022), which is in line with the opinion of the interviewee. Frost events could therefore be considered as the most likely reason for the loss of this species. The local soil characteristics show some correspondence with the preferences of the summer lilac. For example, a preference for a pH between 6 and 8.9, as well as a rather dry soil with low fertility. On the other hand, *Buddleja davidii* prefers rich, loamy and well-drained soils (Fern 2022), which does not correspond to the local type of soil (see **Tab. 5**). Consequently, frost events are considered to be the main cause for loss, as the plants were planted into the system before developing stable frost resistance. Therefore, if summer lilac is intended to be planted in an AFS, it should be planted with good planting material as well as in an older stage than 2 years, to ensure frost tolerance.

Summary regarding suitability of trees to site

To sum up, the main cause of death in the assessed tree species is seen in frost events, followed by not matching soil requirements, as results indicate that these two factors show the lowest accordance regarding their site requirements. When the AFS was established, trees and shrubs were planted with young trees of an age of one to two years. In general, such young plants are rather sensitive towards frost (Interview Hansen 2024). Frost as a cause for tree mortality in forests of Central Europe was also described by Hülsmann (2018). The same study also indicated a higher mortality rate in short-living tree species. This could also be seen in the results of this study, as high mortality rates are found especially in the group of "mother trees", characterized by fast growth but a short life span.

As the most common cause of death are frost events, a higher amount of care is seen as not an effective preventive measure by the interviewee (Interview Hansen 2024). However, the planting of alternative species that show better growth is recommended. When considering potential alternatives to the species studied, it was stated that there are usually good options for the group of "Mother trees", which are characterized by a high biomass production rate. *Populus balsamifera,* e.g.*,* could be a possible alternative species to those species that show a high number of losses in the AFS, such as *Paulownia tomentosa* and

Populus alba. Instead of *Alnus incana,* the interviewee suggests other alder species or other nitrogen-fixing trees such as *Robinia pseudoacacia* (Interview Hansen 2024).

Overall, despite some species that do not seem suitable, the total population of the AFS showed high levels of vitality, giving evidence about the applicability of SAFS in eastern Germany in general. The applicability of SA in rather inconvenient sites characterized by e.g. low soil fertility and little rainfall, was also found in case studies from places such as Norway and Mértola (Portugal). This was explained by the high level of flexibility of used species in SAFS (Kettley 2024).

Possible further reasons for plant losses

According to the results, 2,4% of the assessed plants of the AFS were identified as visibly damaged. The low number of records limits this study to give a sound assessment. Further types of damage to plants, other than frost, are therefore not considered as a meaningful contributor to plant losses. To do this, and to evaluate the impact of the other types of damages on the systems' performance, further research dealing with the impact of these damages would be necessary. However, damages caused by voles should not be underestimated. Especially as voles prefer to feed on fruit trees and like to settle in the mulch placed along the tree rows. When planting new fruit trees, the use of vole protection wire is therefore recommended by the interviewee, as a preventive measure.

Other identified causes of tree mortality by other studies like the one of Hülsmann (2018) include drought and competition among the trees. Drought events also happened in the summer of 2022 after the planting on the site (Interview Hansen 2024), with an average temperature of over 21 degrees in august (see **Fig. 4**).

This means that drought could also be a cause of tree mortality, affecting the ecological establishment success of the SAFS. However, irrigation of plants, as a potential measure to prevent losses in a period of drought is possible but regarded as rather challenging to implement and hence not taken into consideration (Interview Hansen 2024). Competition might also affect tree performance. Nevertheless, if drought or competition really had an influence on the tree performance of the studied AFS cannot be verified with the results of this study.

In other regions of the world the main causes for tree mortality in AFS differ. Sileshi et.al. (2007) found that the main cause of tree mortality in AFS in Southern Africa are insects followed by drought, bush fires and browsing by livestock. Several interacting factors should lead to low survival rates of trees, that mutually re-enforced tree mortality (Sileshi, et al. 2007). A study of Somarriba et. al. examined the survival of trees in AFS in Central America. Here, tree management and soil characteristics significantly affected tree growth. The survival of fast growing species was additionally influenced by the plantation type, stating that an ample space supports the tree growth (Somarriba, et al. 2001).

The difference in main causes for tree mortality can be explained by the different prevailing climatic conditions on the site of the study. However, drought, tree competition and plantation type are factors that cannot be excluded to have an impact on the growth of trees in an AFS in the temperate zone as well. Therefore, when establishing or maintaining such a system, these factors should be kept in mind as well. This also shows the need for further studies, analyzing the impact of these factors on tree performance in order to assess their influence on tree mortality.

5.2 Success of introducing self-collected seeds

When the SAFS was established, self-collected seeds were sown in the tree rows. This was done, amongst other things, for the purpose of introducing tree species for the late successional stage of the system. Compared to typical germination rates of the species studied that are above 50% (see **Tab. 11**), the results of the seedling inventory show rather low success rates of less than 20% for the four seeds sampled. Nevertheless, the high seeding density resulted in sufficient late successional seedlings in the system, according to the results of the seedling inventory and the assessment of the AF manager.

As late successional trees are to be spaced 15 meters apart, the estimated frequency is higher than required. As a result, the low success rates turned out to still meet the needs of the system (Interview Hansen 2024). According to the interview results, when collected form trees or shrubs in the local area, such seeds can be expected to show a good adaptation to the local environmental conditions, contributing to a good future development. However, the results of the interview show that self-collected seeds should be introduced in an amount that can equalize low germination rates to ensure a proper density of seedlings. From an ecological point of view, therefore, the strategy of introducing self-collected seeds of late successional species into a SAFS in the temperate zone, can be evaluated as successful.

The evaluation of the cost-benefit ratio of the planting strategy depends on the type of seed in question. As the conducted seedling inventory focused on seeds of late successional tree species, a general evaluation of the strategy is not possible. The results of the interview made it clear that the seeds have different requirements for germination. Seeds that need to be treated prior to sowing, require respective knowledge and an adequate infrastructure to be successfully introduced. Such seeds are therefore regarded as less suitable, as the extra work and the costs involved may not be worthwhile (Interview Hansen 2024). With more knowledge and a better infrastructure other type of seeds could be sown, resulting in a greater variety of potential seeds. However, there are seeds that do not require this kind of effort to germinate. These include the seeds that have been studied. Here the seed collection is considered to be efficient, since they do not need additional treatment after collection in order to be sown. As a result, the seeds of Red Oak, Pedunculata Oak, Ash and Sweet Chestnut seem to be recommendable for this kind of planting strategy. If the sowing other types of seeds is advisable cannot be assessed based on the results of this study, implying the necessity for further research.

The success of introducing self-collected seeds could further be improved by the application of seed nests. Instead of sowing seeds along tree rows, late successional tree species are sown at positions at the desired spacing. The selection of a “target-tree” can then be done more efficiently, eliminating the need of a prior survey of an entire tree row to find well-grown seedlings in the correct distances. (Interview Hansen 2024)

Moreover, this method would facilitate weed management during the early stages of such a system by saving labor hours, as no special attention needs to be paid while weeding.

5.3 Economic performance

Over the first three years of establishment, the number of resources invested into maintaining the SAFS have increased annually. In SA the initial implementation requires intensive time and labor (Nathan 2023). The period of paying costs in SAFS without gaining benefits cannot be accurately determined. According to literature and the comparison of case studies about SA around the world, there is no agreement on the number of years that it takes to see results, depending also on the system. (Kettley 2024)

The type of cost that contributes the most to the total costs in the period three years after establishment is labor costs. As SA is characterized as labor-intensive land use form, this was not an unexpected result. High labor costs in SAFS due to the need of intensive management was also found in the study of Kettley (2024). The results of the economic investigation show that, especially in the first years after establishment, a lot of manual labor such as weeding and mulching is required and thus lead to a high amount of labor costs. Another type of maintenance that requires a high input of labor is tree care, including the pruning of mother and fruit trees. According to the results of the interview, this is also expected to be one of the main operations in the future development of the system. At the same time, as the trees form a canopy, less weeding and herbaceous layer cutting is expected. (Interview Hansen 2024)

Ultimately, the operation of harvest will take up time (Interview Hansen 2024), thus labor hours and costs as well. However, in the long run SA should reduce the amount of labor needed (Nathan 2023), which yet cannot be verified based on the results of this study.

Since machine operations are not performed as frequently as manual operations, operating costs make up a small proportion of the total costs. The small proportion of costs seem to be given by the higher cost efficiency of mechanized operations. Using a machine to perform an operation reduces the number of labor hours or costs (Kettley 2024). It also allows staff to schedule more than one operation to be carried out at the same time, as in most cases mechanized operations only require one person to be present. A reduction of costs is therefore possible, if some of the work that is currently done manually and require a high input of labor hours, such as weeding and mulching, would be mechanized. This was also suggested by the interviewee. Alternatively, another suggestion includes the reduction of labor hours by lowering the frequency of operations (Interview Hansen 2024). However, in the case of weeding e.g., it should be considered that a reduction in frequency could potentially lead to an increase in labor hours per operation.

In addition, it seems like that the keyline design of the system further increases the number of labor hours spent on the execution of operations. The curved tree rows require special attention when weeding or swathing and are therefore considered as rather complicated by the interviewee.

Replanting costs are a rather small but not negligible part of the total costs. Losses of target crops are therefore considered as economically significant (Interview Hansen 2024) and contribute to a substantial part of the costs. This is also since the expected first harvest of a replanted fruit tree is 3 years later than for the trees that survived initially (Interview Hansen 2024).

In order to improve the economic establishment success manual labor task should be mechanized to an extent that both ensures an efficient way to perform a required operation as well as to maintain its quality of execution. Based on the results of this study, it is not possible to give a recommendation regarding the lowering of the frequency of operation. Further research would therefore be necessary to confirm this suggestion.

The results show that the economic performance of the AFS is further influenced by its ecological performance, as losses of target trees result in additional costs for replanting and new planting material. The selection of plants and trees thus seems to be essential for both the ecological and the economic success of an

AFS. Consequently, when establishing or maintain such a system it is recommendable to choose appropriate plant species and planting material to ensure a good ecological performance and reduce additional costs for replanting.

5.4 Outlook and practical implications

The successful establishment of a SAFS requires good planning, above all the right choice of tree species. This is also found by the study of Somarriba (2001), stating that matching tree species to the site conditions is crucial for sound AF production. It is therefore recommended to choose species that are suitable for the local climate and soil conditions. In addition, these species should then be planted in a manner that ensures good development and growth. Species that are rather susceptible to frost at a young age, hence should be planted with caution or at a later stage of age to prevent plant losses.

The results of the interview show also that the creation of seed nests is further recommended when establishing an AFS or a SAFS. This is said to save time and labor when deciding for “target-trees” in the further course of the establishment. (Interview Hansen 2024)

Another possibility to reduce both labor and costs is the mechanization of labor-intensive operations, such as weeding and mulching (Interview Hansen 2024). However, thereby, the quality of care should not be affected. The saved labor could then be used on tasks that require manual work and affect the future development of the AFS. This includes tree care and pruning as well as plant health assessments.

Recommended is also the use of vole protection wire to reduce the number of trees damaged by voles. This is especially recommended, when establishing an AFS with fruit trees to prevent the loss of target crops. In general, the keyline technique is rather not recommended, unless steep slopes make it necessary. Operations such as mowing require more paid attention and therefore time, as the rows are not aligned straightly. In addition, an increased distance between the tree rows is recommended. A favorable distance is said to be approx. between 8 to 10 meters. Furthermore, working on the headlands could be facilitated by an increased size, which is now 9 meters. (Interview Hansen 2024)

5.5 Study limitations

Despite efforts to maintain consistency throughout the study, several limitations of the investigation should be acknowledged. The present study is majorly constrained by its subjectivity of data collection and by its short time frame. Both inventories were carried out at a certain point in time, assessing different levels of plant vitality and visible damages. As a result, seasonal changes and long-term variations are not considered that could influence the ecological and economic performance of the SAFS in the long run. A plant's level of vitality e.g. can change at short notice. This can happen, e.g., due to unfavorable weather conditions that have a negative effect on vitality, limiting the representativeness of the study results. In addition, the long-term viability can only be assessed to a limited extent, as the system is still in its early stages, and it is not yet possible to harvest quantities that can be sold.

The visual assessment of the inventory induced subjectivity, which could lead to individual bias and therefore to a reduced accuracy of the study results and interpretation. This includes e.g. the simple categorization of plants in three different levels of vitality. A tree that got classified as "dead" due to the most applicable criteria of this category, might gave the impression of being dead but was not. Furthermore, the complex interactions of several environmental factors on the level of plant vitality as well as the different planting methods used, limit the ability to determine the exact reasons for plant losses and to compare their performances. In addition, according to Hülsmann (2018) small sample areas can give reliable mortality rates only to a limited extent.

Some trees and shrubs were planted with young individuals, while others were propagated by cuttings, limiting a precise comparison of growth. Furthermore, the analysis of results is based on data collected in a certain time. While the evaluation of the economic data considered data since the time of establishment, the analysis of the tree and seedling inventory only captured the development of the SAFS between two points in time. As a result, the ecological investigation of the establishment success rather represents the performance of the system at the time of the conducted inventory, rather than the consistent development over the last few years since establishment.

Another limitation is the selection of five plants that were analyzed in more detail regarding their potential causes for mortality. The selection of these species was done subjectively based on their calculated "dead" rate. Additionally, this selection did not comprise the economic significant target species. Besides that, the evaluation of the tree inventory results was done in a descriptive manner, comparing the vitality levels of planted species three years after establishment, limiting the accuracy of the results.

Both the ecological and economic investigation of this study further relied on secondary data. The integration of such data may introduce a degree of uncertainty into the analysis, since their completeness and accuracy were not independently verified.

According to the results of the inventory, damage did not contribute significantly to plant losses. Nevertheless, this evaluation is difficult to validate. A plant could have been dead for some time due to damage before the second inventory was conducted. The damage that could cause the plant loss might not have been visible any longer and therefore the plant was only classified as “dead”, with no damage assigned. Aphids and diseases account for the smallest share of damage. The low amount of these types of damage could be due to the fact that, in contrast to the other types of damage, it is rather difficult to assign them precisely. If no reasonable classification of damage was possible, no classification was made, which could decrease the number of aphid and disease damages.

During the seedling inventory, 300 meters of the overall over 2600 meters of tree rows were sampled. Even though the study design was randomized and designed to be representative, the results might not reflect the status quo in other parts of the SAFS. In addition to that, the number of seedlings in the AFS can also be reduced in the three years after sowing by incorrect maintenance or other management practices that unintentionally reduced the number of seedlings. Hence the drawn conclusion can only be generalized to a limited extent.

An important part of this study is the findings gathered from the expert interview. It gave important insights into the ecological and economic performance of the AFS, by providing meaningful qualitative data to support the interpretation of the collected and analyzed quantitative data. However, it is possible that qualitative data may be biased, affecting the representativeness of the study results. Moreover, the interview served as an additional source of information and was not analyzed according to a recognized method. The accuracy of results may also be limited since only one interview was conducted as well as with a person that has started working on the farm later than the system was established.

The economic investigation included several assumptions based on the KTBL system such as the calculation of operating costs, which was done using an online tool provided by the KTBL. These assumptions could affect the accuracy of the study and thus the gained results may not fully reflect the actual conditions, making the drawn conclusion about viability limited. In addition, labor costs for temporary labor were included in the calculation, even though these costs were not paid out but served as a representative cost calculation.

Data availability may also limit the interpretation of this study to a certain degree. For example, the cost calculation could not cover all costs incurred in the last few years. These include the purchase of new work equipment such as work clothes or tools. It also did not include the costs of diesel fuel required for the car used to reach the AFS site. These costs were not considered due to a lack of documentation, impeded by a shared use of equipment on the farm itself.

In addition to the small sampling size, the calculation of the seed success rates is based on secondary data and literature, which could limit the representativeness of the results. Incorrect management practices, which may have influenced the number of seedlings remaining, could also affect the accuracy and interpretation of the results.

5.6 Generalizability of study findings and future research

As the data collected is limited to a specific region and type of AF, the transferability of the study results is limited as well. The generalizability of the seedling inventory sample is limited due to the rather small sample size, making it more difficult to represent the status quo of the whole AFS and apply the results to other AFS where different conditions are prevailing. However, the homogeneity of environmental conditions and management practices within the AFS helps to increase the accuracy of the study results. Future research should therefore increase sample size and analyze the performance of seeds in other AFS.

Another aspect that could affect the generalizability of the study results is the subjectivity inherent in the data collected within the framework of the inventory, e.g, in regard to vitality level assessment. To enhance the reliability of the results, future research should employ standardized valuation methods, thereby reducing the potential for individual bias. In addition, to improve the accuracy of the tree inventory results, future research should perform a statistical analysis, examining relevant parameters such as site requirements and susceptibility to pests, influencing species' performance.

The economic investigation is based on a specific set of data, including the labor documentation and costs that are specific to the region. Consequently, discrepancies in costs in other regions, such as in terms of labor and operations, could affect the generalizability of the results. A comprehensive assessment of the economic viability is not yet possible. In particular SAFS require a significant investment of time in order to realize their full benefits. Most of the costs therefore are incurred after the establishment phase, while the benefits are expected in the long term (Kettley 2024). The system studied is still at an early stage and it is only in the next years few that yield can be expected. Besides that, future research should consider that economic viability can vary in different contexts. The economic viability of a system is contingent upon several factors, including the prevailing economic conditions in the country in question or the availability of financial support, such as for example in the form of subsidy funds.

This study was conducted over a limited period of time, which allows the representation of performance of the AFS at a specific point in time. Nevertheless, due to the evolving and expanding nature of AFS, long-term observations and studies are necessary to gain a deeper understanding of their development and the success of establishment. This applies in particular to the assessment of the target crop suitability, as their degree of suitability highly depends on their yield in the long run. To give more accurate recommendations about the suitability of plant species, their future development should therefore be considered. Thus, future research is encouraged to conduct long-term studies in order to increase generalizability and to be able to apply results to other similar studies.

Future research should additionally increase the number of interviews conducted and perform them together with persons that were involved in the initial establishment of the AFS, enhancing the validity of the interview results.

The results of the study could be of particular interest to researchers and people interested, working with similar systems, implemented in regions that are exposed to similar climatic, soil as well as socio-economic conditions. They provide meaningful insights into the success of establishment and economic challenges of a diverse AFS adapted to the principles of SA. To improve generalizability future research should focus on the success of establishment and performance of such systems in other parts of the world in the long run. More detailed analysis could contribute to an increased accuracy and generalizability of results, for example in assessing plant vitality and economic efficiency. Gathered results from SAFSs in other regions with different environmental as well as economic conditions, may be necessary to validate the interpretation of the results of this study.

6. Conclusion

Despite the limitations of the study, it provided results that can be used to make indicative recommendations for practice. This includes better knowledge for informed future decisions for planting, indicating which species should be monitored closely when planted or examined in future research. The ecological investigation indicated that three years after establishment, 22% of all initially planted plants are “dead”, whereas 78% are “vital”, presenting an overall good development of the AFS population. Based on the results, species that seem to be either suitable or less suitable for establishing in a SAFS in the temperate zone could be identified. However, further indicators should be taken into account by future research to generalize these findings in order to provide accurate recommendations on which species are advisable to be integrated in such a system.

Species that showed low levels of vitality include Foxglove tree, Monarch birch, White poplar, Summer lilac and Grey alder, indicating that in particular species of the group of “mother trees” perform worse than the other groups. The study was not able to provide conclusive reasons for the high number of losses, but it did suggest that the prevailing environmental conditions at the site represent a cause, as they do not meet the species’ requirements. These include the susceptibility to frost and different soil requirements. In total 2.4% of the examined plants was classified as visibly damaged. As a result, damage was not considered as a main cause for plant loss.

While the aforementioned species tended to perform poorly, there are many species that seem to have grown well since the system was established. These include the species of Silver birch, Balsam poplar, Wild cherry and Aspen, which seem to be suitable for use as “Mother trees” in a SAFS. In addition, the results showed that all the fruit tree species planted have high vitality rates. Thus, apple, pear, plum and peach can be classified as species that seem to be suitable with regards to their level of vitality for such a system as well. Considered as target crops, their suitability highly depends on future development, including their start of full crop. Future research is therefore needed to give recommendation on their planting with particular respect to their yield. Most of the cultivated berry species can also be recommended for growing in a SAFS. These include amongst others Shadbush, Red currant and Josta berry. Other species that seem to be suitable for planting in a temperate SAFS, according to their high levels of vitality, are Siberian peashrub, Whitebeam and Goat willow.

The practicality of the planting strategy of using self-collected seed, depends on the type of seed. Seeds that do not require any additional treatment after collection are more recommendable for self-collection and introduction, as additional knowledge and an appropriate infrastructure can be saved. All the examined seeds of Red Oak, Pedunculate Oak, Ash and Sweet Chestnut showed success rates of lower than 20%. However, their calculated expected frequencies within the tree rows are higher than required, due to the high amount of introduced seed. Therefore, if a high number of seed can be ensured to equalize low success rates, the sowing of these seeds can be recommended for the introduction in an SAFS in the temperate zone.

According to the study results, the costs of maintaining the AFS increased significantly from the time of establishment. The total costs, three years after establishment, sum up to over 22,700€. While labor costs account for most of the costs, operating costs represent only a small proportion of the total costs. Costs associated with replanting, make up another rather small proportion of the costs, occurring after about three years after establishment. Areas where costs can be saved are in labor-intensive operations such as weeding and mulching. A mechanization of such operations could reduce the number of labor hours spent and contribute to a reduction in labor costs. However, when looking at the economics of SAF one should not neglect the fact that such systems take time to develop their benefits and become profitable.

Future work is needed to validate the results of this study and to clarify issues that could not be adequately addressed in this study. Subsequent inventories of the AFS could examine the continued growth of trees and shrubs in order to gain a deeper understanding of the development and success of establishment of the system. In addition, the study design of the seedling inventory could be modified by increasing the sample size to increase the representativeness of the data.

Future research is also encouraged to examine the development and composition of costs over the next few years. It would be of particular interest to assess whether labor costs continue to increase and to determine the point at which profits equal costs. This would also be of particular interest to farmers interested in setting up such a system. Thereby, it would also be important to determine the exact point in time at which it would be possible to harvest a quantity that could be sold on the market.

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7. References

Adalid R., Feliu C., Somoano A., Miñarro M., Ventura J., Torres J., Miquel J., Fuentes M.V. (2021) Ecological Analysis of the Helminth Community of Microtus lusitanicus (Gerbe, 1879) (Rodentia) in Asturias (NW Spain). *Animals (Basel)*, 11(11) Available at: https://pubmed.ncbi.nlm.nih.gov/34827787/. Accessed 17.08.2024

Andrade D., Pasini F., Scarano F.R. (2020) Syntropy and innovation in agriculture. *Current Opinion in Environmental Sustainability*, 45:20-24 Available at: https://www.sciencedirect.com/science/article/abs/pii/S1877343520300579. Accessed 24.10.2024

Atangana A., Khasa D., Chang S., Degrande A.: Tropical Agroforestry. Dordrecht, NETHERLANDS, THE: Springer Netherlands; 2013.

Benning J. (2024) Monarch Birch. Available at: http://www.tree-guide.com/monarch-birch. Accessed 02.08.2024

BMEL (2024) Agriculture, climate change mitigation and climate resilience. Available at: https://www.bmel.de/EN/topics/farming/climate-stewardship/agriculture-climate-change-mitigation.html. Accessed 17.09.2024

Boa E. (2003) An illustrated guide to the state of health of trees - Recognition and interpretation of symptoms and damage. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/2a6e76a9-f2ae-4f00-80d2-484ece6cebf2/content. Accessed 17.08.2024

Boesel B. (2023) Gut und Bösel. Available at: https://www.gutundboesel.org/arbeiten/agroforst/. Accessed 23.07.2024

Böhm C., Werwoll, J. (2020) Vergleichende Betriebswirtschaftliche Bewertung von Agroforstwirtschaft und Reinkulturanbau mit Hilfe des Agroforst-Rechners. Available at: https://agroforst-info.de/wp-content/uploads/2021/03/34__Agroforst-Rechner.pdf. Accessed 25.07.2024

Böring K., Tiedemann, O., Janning, J. (2023) Abiotische Schäden an Bäumen. Available at: https://gruener-zweig.de/baumpflege/baumkrankheiten-und-schaedlinge/abiotische-schaeden-an-baeumen/. Accessed 24.07.2024

Boughton (2024) Soil Types. Available at: https://www.boughton.co.uk/products/topsoils/soil-types/#:~:text=Sandy%20Soil%20is%20light%2C%20warm,are%20easy%20to%20work%20with. Accessed 07.08.2024

BZL (2024) Agroforstwirtschaft - ökologisch und ökonomisch vielversprechend. Available at: https://www.praxis-agrar.de/pflanze/ackerbau/agroforstwirtschaft. Accessed 10.11.2024

EURAF (n.d.) Agroforestry in Germany. Available at: https://euraf.isa.utl.pt/countries/germany. Accessed 12.11.2024

Faust K.F., Barbara (n.d.) Genetik und Vermehrungsgut der Esskastanie - LWF Wissen 81. Available at: https://www.lwf.bayern.de/waldbau-bergwald/waldbau/201159/index.php#:~:text=Bei%20der%20Saatgutprüfung%20ergibt%20sich,enthält%20170%20bis%20270%20Kastanien. Accessed 03.09.2024

Fern K. (2022) Useful Temperate Plants Database. Available at: https://temperate.theferns.info. Accessed 01.08.2024

FiBL (n.d.) Agroforst - Von der Idee bis zur Umsetzung - Eine erste Orientierung Available at: https://www.fibl.org/fileadmin/documents/shop/1248-agroforst.pdf. Accessed 24.07.2024

Gietzen R. (2016) Syntropic farming guidebook Work for nature and nature will work for you. Available at: https://bosquedeniebla.com.mx/wp-content/uploads/2019/09/Syntropic-Farming-guide-1.pdf. Accessed 28.05.2024

Gliessman S.R.: Agroecology - The Ecology of Sustainable Food Systems; 2015.

Gordon A., Pablo P., Naresh V N.V., Shibu S., Peter P., Rowan R., Xiaobang X., Christian C., Mohan M., Francis F.: Temperate Agroforestry Systems. Oxford, UNITED KINGDOM: CAB International; 2018.

Hahn J., Wold-Burkness, S. (2019) Aphids in home yards and gardens. Available at: https://extension.umn.edu/yard-and-garden-insects/aphids. Accessed 17.08.2024

Helfferich C.: Das SPSS- Verfahren der Leitfadenentwicklung. In Kruse, J.: Qualitative Interviewforschung. Ein integrativer Ansatz. 2. Auflage, Beltz Juventa; 2009.

Herzog U. (2024) Fraxinus excelsior. Available at: https://shop.herzog-samen.com/en/c/ola1-36/a/ola1-669.html. Accessed 23.10.2024

Herzog U. (2024) Quercus robur. Available at: https://shop.herzog-samen.com/en/c/ola1-61/a/ola1-2944/Quercus/Quercus-robur.html. Accessed 23.10.2024

Herzog U. (2024) Quercus rubra. Available at: https://shop.herzog-samen.com/en/c/ola1-61/a/ola1-2945.html. Accessed 23 .10.2024

Herzog U. (n.d.) Saatgut Laubgehölze. Available at: https://www.herzog-samen.com/fileadmin/pdf/herzog_saatgut_sortiment_laubgehoelze-1.pdf. Accessed 17.11.2024

Hülsmann (2018) Natürliche Baummortalität in Mitteleuropa: Mortalitätsraten und -muster im Vergleich. Available at: https://www.nw-fva.de/fileadmin/nwfva/publikationen/pdf/hulsmann_2018_naturliche.pdf. Accessed 18.11.2024

Hunter D., Guarino L., Spillane C., McKeown P.C.: Routledge Handbook of Agricultural Biodiversity. Oxford, UNITED KINGDOM: Taylor & Francis Group; 2017.

ISA -.U.o.L. (2019) Keyline technique for agroforestry management. Available at: https://medforest.net/2019/12/09/keyline-technique-for-agroforestry-water-management/. Accessed 09.11.2024

Jose S., Walter D., Mohan Kumar B. (2019) Ecological considerations in sustainable silvopasture design and management. *Agroforestry Systems*, 93(1):317-331 Available at: https://doi.org/10.1007/s10457-016-0065-2. Accessed

Kettley A. (2024) What soil is worth: A cost-benefit framework analysis of syntropic farming. Available at:

https://digitalcollections.sit.edu/cgi/viewcontent.cgi?article=4796&context=isp_collection. Accessed 19.10.2024

Klug P. (2005) Vitalität und Entwicklungsphasen bei Bäumen. Available at: https://www.baumpflege-lexikon.de/fileadmin/user_upload/Stadtbaumleben/Fachartikel/Vitalitaet_ProBaum.pdf. Accessed 23.07.2024

Klug P. (2017) Vitalität bei Bäumen. Available at: https://www.baumpflege-lexikon.de/fileadmin/user_upload/Stadtbaumleben/Baumwissen/Arbus_Vitalitaet.pdf. Accessed 23.07.2024

Kruse J.: Qualitative Interviewforschung. Ein integrativer Ansatz. 2. Auflage, Beltz Juventa; 2015.

KTBL (2024) Web-Anwendungen. Available at: https://www.ktbl.de/webanwendungen. Accessed 21.08.2024

Küsters M., KTBL (2022) Abschlussbericht zur Datenerhebung „Erstanlage eines silvopastoralen Agroforstsystems“. Available at: https://finck-stiftung.org/download/4067/?tmstv=1681392161. Accessed 20.08.2024

Leakey R. (2014) The Role of Trees in Agroecology and Sustainable Agriculture in the Tropics. *Annual review of phytopathology*, 52

Leder B., Tennhoff, N. (2014) Kurzportrait Lindenblättrige Birke. Available at: https://www.waldwissen.net/de/waldwirtschaft/waldbau/lindenblaettrige-birke. Accessed 02.08.2024

Lengnick L. (2018) Agriculture as a Means to mitigate Climate Change Available at: https://www.sare.org/publications/climate-risk-management-and-resilience-on-farms-and-ranches/managing-for-climate-resilience/mitigating-climate-change/#:~:text=The%20Intergovernmental%20Panel%20on%20Climate,carbon%20dioxide%20emissions%20could%20be. Accessed 13.11.2024

Mayring P. (2015) Qualitative Inhaltsanalyse - Grundlagen und Techniken. 12. Auflage. Weinheim: Beltz Verlag. Available at:

https://link.springer.com/chapter/10.1007/978-3-658-21308-4_42. Accessed 23.10.2024

Mercer D.E., Frey G.E., Cubbage F.W.: Economics of agroforestry. In: *Handbook of forest resource economics.* Routledge; 2014: 204-225.

Nathan A. (2023) Portugal to New Mexico: Investigating the Applicability of Syntropic Agriculture to a Semi-Arid Continental Climate. Independent Study Project (ISP) Collection. 3698. Available at: https://digitalcollections.sit.edu/cgi/viewcontent.cgi?article=4722&context=isp_collection. Accessed 20.11.2024

Ökolandbau.de (2024) Agroforst - Landnutzungssystem mit Zukunftspotenzial. Available at: https://www.oekolandbau.de/landwirtschaft/oekologischer-pflanzenbau/anbausysteme/agroforst-landnutzungssystem-mit-zukunftspotenzial/#:~:text=In%20Agroforstsystemen%20wird%20Acker%20oder,Trockentoleranz%20und%20den%20Bodenschutz%20verbessern. Accessed 14.11.2024

Reese J. (2023) Voles creating a Furry Underground Fury. Available at: https://www.usu.edu/today/story/voles-creating-a-furry-underground-fury. Accessed 29.08.2024

Roloff A.: Urban Tree Management : For the Sustainable Development of Green Cities. Newark, UNITED STATES: John Wiley & Sons, Incorporated; 2016.

Scheuch E.K.: Das Interview in der Sozialforschung, in: Handbuch der empirischen Sozialforschung Band 2, Teil 3; 1973.

Schmidt G. (n.d.) Bodenarten Available at: https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://ltz.landwirtschaft-bw.de/site/pbs-bw-new/get/documents/MLR.LEL/PB5Documents/ltz_ka/Service/Laborinformationen/Arbeitshilfen%2520f%25C3%25BCr%2520Labore/Bodenuntersuchung_DL/Bodenarten_DL/Schmidt_Poster%2520A0%2520Bodenarten%25201.pdf%3Fattachment%3Dtrue&ved=2ahUKEwjSwMefh56KAxXwqZUCHb5rKW4QFnoECBwQAQ&usg=AOvVaw2Tq4H6GYcRwIEEAuLh5tt_. Accessed 14.12.2024

Schoonenboom J., Johnson R.B. (2017) How to Construct a Mixed Methods Research Design. *KZfSS Kölner Zeitschrift für Soziologie und Sozialpsychologie*, 69(2):107-131 Available at: https://doi.org/10.1007/s11577-017-0454-1. Accessed 25.12.2024

Shigo A.L. (1994) Moderne Baumpflege. Grundlagen der Baumbiologie. Available at: https://www.baumpflege-lexikon.de/fileadmin/user_upload/Stadtbaumleben/Fachartikel/Vitalitaet_ProBaum.pdf. Accessed 25.07.2024

Sileshi G., Kuntashula E., Matakala P., Nkunika P. (2007) Farmers' perceptions of tree mortality, pests and pest management practices in agroforestry in Malawi, Mozambique and Zambia. *Agroforestry Systems*, 72:87-101

Somarriba E., Valdivieso R., Vásquez W., Galloway G. (2001) Survival, growth, timber productivity and site index of Cordia alliodora in forestry and agroforestry systems. *Agroforestry Systems*, 51:111-118

Steil A. (2023) Cold and Freeze Damage to Garden Plants. Available at: https://yardandgarden.extension.iastate.edu/how-to/cold-and-freeze-damage-garden-plants.Accessed 17.08.2024

Thomas P.A.: Trees : Their Natural History. Cambridge, UNITED KINGDOM: Cambridge University Press; 2000.

Yao T., Yuan G., Lu H., Liu Y., Zhang J., Tuskan G.A., Muchero W., Chen J.G., Yang X. (2023) CRISPR/Cas9-based gene activation and base editing in Populus. *Hortic Res*, 10(6):uhad085

Appendix 1: Interview guidelines

Begin of the interview	**Introductory questions** Could you start by describing what your role in the company is and secondly what the intended purposes of the investigated “keyline-system” are? How was the system planted?

Key questions	**Question 1**: In the system there are trees that indicate a higher mortality rate compared to others (such as Paulownia tomentosa, silver poplar, summer lilac, monarch birch and grey alder). What do you think are the reasons for that and how can the mortality rate be minimized? **1.1 Paulownia tomentosa:** 100%. **1.2 Silver poplar:** 98,86%. **1.3 Summer lilac:** 90%. **1.4 Monarch birch (*Betula maximowicziana*):** 85,84%. **1.5 Grey alder:** 46,83%. **Question 2:** As the results of the inventory show, there are more than 800 trees/plants that have been identified as “dead”. From your point of view, how do you evaluate the economic effects of that? **2.1:** Do you think losses of trees/plants could have been prevented, if more time was spent on care after planting? *If so: would it pay off in the end economically?* **Question 3:** When looking at the intended outcomes of the system. Harvesting fruits is one of the main aims. However, some of the fruit trees did not survive after they have been planted. For instance, indicate the peach trees a mortality rate of 20%. What do you think are the reasons for that and how can such losses be prevented? **Question 4:** After talking about the reasons of tree losses. Do you think there are trees that can be used as alternatives to those, which indicated a relatively high mortality rate? *If so, you are welcome to give examples.* **Question 5:** When it comes to the economic performance, one can see that the maintenance overall requires a notably high labour input. Could you firstly name the activities where you think the most working hours occur? **Question 6:** Keeping that in mind, do you think there are areas where labour hours can be saved? **Question 7:** In course of the seedling inventory seeds of four species have been investigated: Sweetchestnut (Castanea sativa), Ash (Fraxinus excelsior), Penduncolate oak (Quercus robur) and Red oak (Quercus rubra). The results of the examination allow us to expect the following frequencies of occurrence inside the rows: Sweetchestnut every 2 to 3 meters; Ash about every meter; Penduncolate oak about every 3 meters and the Red oak every 3 to 4 meters. How do you evaluate the results? Would you say they meet your expectations? **Question 8:** Keeping all this in mind, how do you assess the cost-benefit ratio of collecting and sowing seeds yourself?

	Question 9: As one of my last question I would like to ask you: Looking at how the system has evolved over the last few years since it was established, what would you say are the main lessons you have learnt from it? **9.1:** Having this in mind, do you have any suggestions as on what could have been done differently when the system was created?

Conclusion	Do you see any aspects that have not been addressed in the interview so far, but which are important to you?

Appendix 2: Interview Transcript

A – interviewer, author

B – interviewee (Hansen, P.)

A: First of all, thank you for your participation, I'll give you a short outlook of the topic. So as you know my topic is an ecological and economic investigation of one of your systems. The aim of this interview is mainly to find out the reasons why some trees have a relative high mortality rate compared to others and also I would like to evaluate the resulting economic consequences of that. Therefore I would like to ask you some questions and so that no information is getting lost here I would like to record this. Do you agree to the conversation be recorded?

B: Yes I do.

A: Is there any question from your side before we begin interview?

B: No.

A: Could you start by describing what your role in the company is and secondly what intended purposes of the investigated "keyline-system" are?

B: Yeah absolutely. So I've been working here for 10 months now and I am in charge of designing new agroforestry systems and also maintaining the existing ones doing all kinds of practical work there. As well as all the planning, working with the interns and other colleagues. And for this keyline system it was designed and planted by people that were here before me, with the intended purpose of having an optimal system for chickens as well as integrated fruit and nut production. So there are different fruits mainly sea buckthorn and some berries as well as fruit trees like plums and pears and apples and peach, which are the main perennial tree and shrub crops. And there's lots of other berries that were introduced in the system that could be used as chicken feed or additional chicken feed. The row spacing was chosen to be like 6 meters or 6.5 meters, which is optimal for like small chicken groups that can be rotated through this system, starting in like the third or fourth year after planting. The idea is to have like a perfect habitat for chickens, which prefer to have like some kind of like tree cover or like semi open like woodland which is quite close to kind of habitat that like the original chickens in southeastern Asia used to inhabit. And there's also trees for potential timber production like late successional trees like oaks and chestnut.

A: How was the system planted?

B: So in general the system aims to produce high value fruits for the human consumption, that's why fruit trees are our target crops. Besides that the system intends to create a habitat for chickens, e.g. by introducing mobile chicken coops, so that a variety of different berry species is additionally planted. Most of the trees were planted with biennial trained trees from the farm's own nursery. So, they were grafted in spring and planted in fall of the same year of 2021. Besides that, a lot of seeds were introduced into the system. For example, seeds of herbs and also of trees. In general, we try to introduce as many plants by seeds as possible, because this can be a cost efficient way of establishing an agroforestry system. Moreover, the plants that grow from seed, grow their own tap root, making them more resilient. Also, you do not need to transplant them when they are already growing in the desired location.

A: Alright thank you, coming to my first question. In the system there are trees that indicate a higher mortality rate compared to others those are the Paulownia tomentosa, White popular, Summer lilac, the Monarch birch and Grey Alder. What do you think are the reasons for that and how can mortality rates be minimized? Maybe we can just go through it 1 by 1 and starting with the Paulownia tomentosa, which indicated a mortality rate of 100%.

B: We are here a in a climate, which is quite prone to late frosts and quite strong frost in winter in general it's like the US hardiness zone 7B equivalent here and most likely this tree isn't frost hardy enough to be planted here and especially young trees like pretty young seedlings. When establishing the system young trees were planted that are like one or two years old coming out of the nursery and they're not very frost hardy. So most likely that was the issue.

A: OK and what do you think about the White poplar?

B: That's an interesting one. The idea was to use cuttings from the local hedges or trees. Unfortunately, you can't really propagate White poplar from cuttings like most poplars you can propagate like that ,vegetatively, but White poplar not really. And you see that it hasn't really worked for that reason.

A: Ok and what about the summer lilac indicating a mortality rate of 90%. What do you think are the reasons for that?

B: That's a good question. I don't know for sure, it could be that it was poor planting material, like we just got bad material for planting, or these young plants also weren't super frost hardy, because it's also not really native to this place. So that might be a reason. But also it's not a super important economic plant here, which I guess was planted just for pollinators.

A: Alright. And what about the monarch birch, which indicated a mortality rate of 85.84%?

B: Yeah, another very experimental plant, which is also not native here, it is native in Japan and I think it could also be that it isn't super frost hardy. Supposedly it's a quite frost hardy plant, but again as young seedling it might just not be adapted to this climate or these late frosts that we have here sometimes. So that could have been the reason.

A: Coming to the top five. This was the Grey alder, that showed a mortality rate of 46.83%.

B: That's an interesting tree, because we have it in most of our systems and when it grows it really grows well, and it's quite nice because it’s nitrogen fixing but it does fail quite frequently also in other systems. I don't really know why that is. Why the planted Grey alder don't survive because it is a native plant it should be frost hardy. It might be that it just doesn't really tolerate planting very well, could be a reason.

A: Coming to question number two. The results of the inventory show further that there are more than 800 trees or plants that have been identified as “dead”. From your point of view how do you evaluate the economic effects of that?

B: It really depends on the plants, because lots of plants in the keyline system are introduced for biodiversity reasons for biomass accumulation or as pioneers that help us produce better soil by producing biomass early on, which you can then prune and feed the system. The pioneer species for example are chopped after 5 to 15 years, after they have fulfilled their function. This biomass is than used as biomass material, which helps to protect the soil from sun radiation or wind. This actively feeds the soil mulch layer and helps us to improve soil quality, including soil biology and also it increases activity and accelerates nutrient cycling Usually, we introduce so many of these plants that, if some of them fail, we either have some kind of seedling from the direct seeded plants that can replace that plant or it doesn't really have a negative effect on the system. The ash maple for example can serve as a good replacement tree for failed mother tree species such as poplar. If a planted mother tree failed, an ash maple seedling can replace this tree and no replanting is necessary. But of course, there's lots of costs with planting that many trees, in planting this densely and then when so many fail that is of course quite unfortunate. But I feel like you really have to distinguish. It depends on what kind of tree fails. For us if an apple or pear tree or any target crop tree fails, they are usually more expensive coming out of our own nursery. More work went into them and they are also really important. We want them to be at a certain spacing and we don't want them to fail, so we have to replant them and that's what is economically significant. It costs a lot of money obviously to go in there and dig a hole again and replant them, care for them. So those are the most important ones, like for the pioneer species something like poplar or alder we don't really replant and if some of them fail we might just learn from that. Something like the paulownia, that doesn't work, you probably not gonna try again. It was an experiment in this system. In the next we just gotta stick to hybrid Poplar and Willow for example.

A: Do you think such losses could have been prevented if much more time was spent on care after planting trees?

B: I think for the most part what I outlined, late frosts or you know if you potentially get poor material for planting, then there's not much that can be done. And plants that are adapted to the local climate, the local conditions they will do well. We are already really caring for the plants, putting a lot of work, to prune the herbaceous layer to feed the soil, have an active mulch layer, which also conserves the water. But that being said, after this system was planted, the summer after was very dry. It's usually quite dry here that can be an issue, when you plant these bare rooted plants, that they get too much drought stress in the first year. It means that they don't grow really well. So of course, you could resort to watering, but in this system it would be very challenging, because there's no infrastructure in place. You'd have to come there with a tractor and some kind of tank and water by hand. So, something that we try not to do. But especially if you will be planting like larger fruit trees that’s something that you might have to do, to reduce losses.

A: Do you think however, it would pay off in the end economically? So, if you put more care to the trees?

B: Again I think we already put in a lot of work and if you really had drought stress and you see that you have to water, otherwise you will lose the trees, that might pay off. But in our case the plants, the fruit trees are from our own nursery. They usually have a bale. They are not bare rooted, so they are potted plants and they're pretty small, so usually they don't need watering. I don't think we would have an economic benefit from putting in more work, potentially if we would cut some of the steps or mechanized some of the steps that we’re doing by hand right now, we could improve the outcome of the economic performance of this system.

A: When looking at the intended outcomes of this system harvesting fruits is one of the main aims. However, some of the fruit trees did not survive after they have been planted. For instance, the Peach trees, which showed a mortality rate of 20%. What do you think are the reasons for that and how can such losses be prevented from your point of view?

B: I mean we did the inventory this year and for some of the fruit trees it was quite obvious what had happened. One of the most common reasons is broadens voles, that are eating the roots of our fruit trees. They do like fruit trees more than other trees it seems. So some rows, where we have lots of voles, you have meters and meters of trees in the same row, that have all failed. So that is of course very significant, because this year we lost like 10/15% or even 20% in the case of Peach trees, of our fruit trees. I mean usually they are really prone to vole damage, and they can still bear vole damage for probably five to eight years, and even afterwards it can be a big problem. So that means that I guess for most trees, if every year is as bad as this year, it could be like 40/50%, that fruit trees will die, planting before they are mature due to voles. So what you can do to prevent that is that you use a wire mesh that you dig into the soil, to create some kind of cylinder of wire mesh that protects the roots, because the voles can't go through this mesh. And of course, it is a significant amount of labor that goes into burying this mesh basket in the soil. That's something that we are considering right now, like what is the extra effort and the costs for the material to bury these wire mesh baskets, compared to replanting new trees or replanting a tree after three or four years if it failed. Then you also have to account for the replanted tree that it will take three or four more years, until it goes into production. So this year we are going to replant on the keyline system and we're probably going to use those wire mesh baskets just to make sure that we won't have any further losses there after replanting.

A: OK my next question for you would be then, after talking about the reasons of the tree losses, do you think there are trees that can be used as alternatives to those which indicate a relatively high mortality rate?

B: Absolutely. I think lots of the trees that failed a lot were quite experimental. We do in general experiment a lot and see what kind of trees grow here and might also be promising trees in a changing climate, might tolerate the drought here might tolerate the late frosts here. We keep doing experiments, we are aware that we might have a high failure rate. In the case of for example paulownia, it's not frost hardy, we're not going to use it again, so we might use a different plant that has similar purposes, which is producing lots of biomass early on and can be pruned intensively. So, for paulownia and also White popular we might just use balsam poplar. And for Grey alder, like of course we might use it again, we might try a different type of alder or another nitrogen fixing tree. We have used robinia before, but it comes with different challenges. But usually there are other good options, especially for those mother trees, these early accumulating like biomass species, that you can use that are pretty safe bets. That are not really eaten or don't have any late frost issues.

A: I would like to continue talking with you about the economics of the system now. So, when it comes to the economic performance, we can see that the maintenance over all requires a notably high labour input. Could you firstly name the activities where you think the most working hours occur?

B: Yes, right now it's mainly the pruning of the herbaceous layer which is mainly done by hand, 4 to 5 times a year and then we use this as mulch to feed the soil there and keep an active mulch layer. Additionally, the space between the tree rows is mowed and swathed 3 to 4 times during the season. And as the system matures over the next years, there will be more and more work spent on pruning the trees, like pruning the mother trees and using that as mulch. Also like training the fruit trees. We'll start that in the next couple years, that will be the most labor-intensive activity. Since the meadow growing between tree rows is not very productive, we were lacking sufficient mulch on this system. That is why we decided to add more mulch to our rows this winter. We used woodchips on one side and stable horse manure on the other. Applying the additional mulch by wheelbarrow required lots of additional hours put into this system this winter. That is why the working hours on mulching will appear disproportionate when compared to other activities. In a system where you have vigorous growth between the rows, this step would not be necessary.

A: Keeping that in mind do you think there are areas where labor hours can be saved?

B: For sure. All the pruning of the herbaceous layer is done manually right now. We actively are thinking about already selecting trees for the late succession, which are direct seeded something like chestnuts or oaks. We were planning on selecting the target trees, that look very nice on the right distances and once we have selected these trees then we can potentially mow down those herbaceous plants with something like a hedge cutter, without having to be super careful about it. Because that's what kind of slows us right now, that we have to be really careful not to kill any of the seedlings that are sprouting everywhere. So that can definitely be done. Also, you could think about doing it more extensive, not just cutting the herbaceous layer as often for sure. I guess that could be the main areas where we can save labor.

A: Alright, so you may not miss that another part of the inventory carried out was the examination of the seed you collected and sowed in the rows yourself. Thereby, four species have been investigated, including sweet chestnut, ash, pedunculate oak and also the red oak. The results allow to expect the following frequencies of occurrence inside the rows, so sweet chestnut every two to three meters expected ash about every meter, the pedunculate oak about every 3 meters and the red oak every three to four meters. How do you evaluate these results, and would you say they meet your expectations?

B: So this is very interesting. So, all of these trees are late successional species, and we have them in this system later on, potentially producing nuts in the case of Chestnut or otherwise maybe high value timber. The idea is to have them as an emergent layer so we will branch them up to 8 meters maybe or eight to 10 meters, where we take away all the branches. Then the crown of the tree will be at that height, so underneath you can have the fruit trees and the other layers. The idea in syntropic agroforestry is to have about 20% of the total light interception, the total canopy, being these emergent trees, which for us means that we will have them at a minimal spacing of 15 meters in between like any of those four species that you did the inventory on. So yeah, having two to three or four meters between those trees, they are at a higher density that we need them to be yet. So that's what I mentioned before, we're going to select the target trees in the coming year and check that we have about like one of these trees every 15 meters and the other ones are probably just going to use as biomass, so that their mowed down. So, I think it really worked well. The lesson that we learn here is that it's a lot of work to then go through the system and select the perfect trees and to make sure that there are in a perfect density when you just seed them everywhere. So, starting with the next system we are going to make seed nests where we introduce lots of those seeds at 15 meters spacing. We would make one seed nest and then we select one of those trees, instead of having to go through all the rows and mediate where to have the ultimate trees that we're going to keep.

A: Alright and keeping all this in mind how do you assess the cost benefit ratio of collecting and sowing seeds yourself. You just mentioned that it's worked well but do you think also from an economic perspective?

B: Yeah I mean ecologically and which also will affect probably the performance of the seeds, so the economic performance as well. If you're using seeds that you collected yourself from your area, they should be locally adapted and potentially just have a higher vitality then seeds you introduced from elsewhere, that you buy from sources that might be completely from somewhere else. We also see high failure rates you when they're just not adapted to the local climate. So that's something you have to keep in mind. You have also certain control about seed quality when you collect them yourself. On the other hand, there are some seeds that are like just tricky to collect, tricky to treat. Because if you have different berries or whatever then you have to either ferment the fruit and then you have to get the seeds out of separate seeds and the pulp or the flash and then dry them. And then there are also some seed that need to be stratified in certain ways, so they need to be refrigerated before they germinate or need to get some kind of warm or cold treatment or some kind of scarification, where you need to break some parts of the shell of the seed so it germinates. So, for some of us it's difficult to do and us as farmers we don't really have the infrastructure, the knowledge or the know how to do that. So then it can be easier to buy seeds especially if you can get seeds at a decent price that are adapted to your local conditions. But for other seeds like oaks and chestnuts for example or maples and ash, those are great examples of seeds that are really easy to collect and they germinate quite readily, so there it makes lots of sense. But other trees might be a bit more tricky, like fruit trees for example apple and pear. That is something, that what we're trying out now as well. Stuff like sorbus, these kinds of trees just require a lot more work so it might not be worth it.

A: OK, so as one of my last questions I would like to ask, looking at how the total system has evolved over the last few years since it was established, what would you say are the main lessons you have learned from it?

B: That's a great question. I've already hinted at these seed nests that we're trying for the new systems. Definitely we're going to have a more calculated approach, deciding where are we going to direct seed and where we not going to throw all the seeds everywhere anymore. We gonna be more mindful of what is our final spacing. So where do we want to have certain species. Then of course, like a lot of the plants that we talked about earlier, that were a bit more experimental and the ones that didn't worked out. We might not try again if we see that they're really not adapted to our climate here. And then we have also seen what grows really well and what doesn't grow so well. Based on that visual assessment for the most part we also select species for upcoming systems. I think having the system in a key line shape, it is quite nice. But it creates a little bit of extra work and effort and difficulty when you are mowing it, and doing the mulching with the tractor, because the other lines are straight so you have to be more careful. And also one thing that is tricky here is, that there's not enough space at the end of the rows, between the fence and the end of the rows to turn with the tractor. So probably we would increase that distance. That's from that. I think its looks really nice and I guess I wouldn't do too many things very differently actually. Probably do systems in a similar way but also add a wider spacing between the rows, that's something we have maybe learned as well for having really tall pear and apple trees 6 meters between rows is just a little bit narrow. So probably 8 to 10 meters would be more appropriate.

A: OK, so you already mentioned some of this, but having all that in mind do you have any suggestions on what could have been done differently when the system was created? Maybe you can just summarize this again?

B: Sure. I think I just hinted at most of these things. So, a bit wider row spacing for sure. Leaving more space to turn with the tractor. Maybe selecting trees that are really adapted to the climate. Making seed nests, instead of seeding the late successional species everywhere. And another thing, I mean it's an experimental system to a certain degree, it's like a mixture of some experiments. But also the idea to have it as a first one of our more economical systems that produces lots of food that can actually be sold at the market, and for that purpose, for example to produce juice or whatever. There's lots of different varieties, there's like 20 different varieties of pear and 15 apple varieties that will make it difficult picking.

Appendix 3: Quantitative primary and secondary data used

Tab. 22 Onsite Climate data (2021-2024)

year	month	avg_temperature	total_rainfall
2021	11	5,58	59,68
2021	12	1,16	46,17
2022	1	2,63	39,30
2022	2	4,53	66,33
2022	3	4,40	0,42
2022	4	7,91	29,73
2022	5	14,79	19,75
2022	6	19,38	57,35
2022	7	19,50	29,10
2022	8	21,24	34,33
2022	9	13,45	34,30
2022	10	11,98	25,99
2022	11	5,26	24,12
2022	12	1,21	44,50
2023	1	3,67	65,29
2023	2	2,38	54,26
2023	3	5,19	75,05
2023	4	7,55	56,77
2023	5	13,42	40,73
2023	6	18,45	88,94
2023	7	19,31	46,55
2023	8	18,97	87,10
2023	9	17,66	16,01
2023	10	11,42	105,20
2023	11	5,15	63,82
2023	12	3,23	94,60
2024	1	0,87	49,08
2024	2	6,44	72,37
2024	3	7,61	31,60
2024	4	11,09	25,36
2024	5	16,95	45,55

Tab. 23 Amount of introduced seeds and costs (Finck Stiftung 2024)

Seed (g/quantity)		
Artemisia	65	236 €
Mugwort	610	- €
Mint	10	128 €
Pendunculate Oak	23200	- €
Maple ash	5816	- €
Ash	11800	- €
Sweet chestnut	30000	- €
Golden rod	124	- €
Garlic	140	- €
Burdock	418	- €
Corean mint	50	120 €
Mullein	176	- €
Lavender	200	168 €
Mallow	1628	- €
Dropping star of Bethlehem	600	- €
Red Oak	20700	- €
Sorrel	130	180 €
Sunflower	4200	- €
Echinacea	120	212 €
Cow parsley	344	- €
Lemon Balm	150	96 €
Yarrow	800	51€
Meadow chervil		
Sum	101281	**1.191 €**

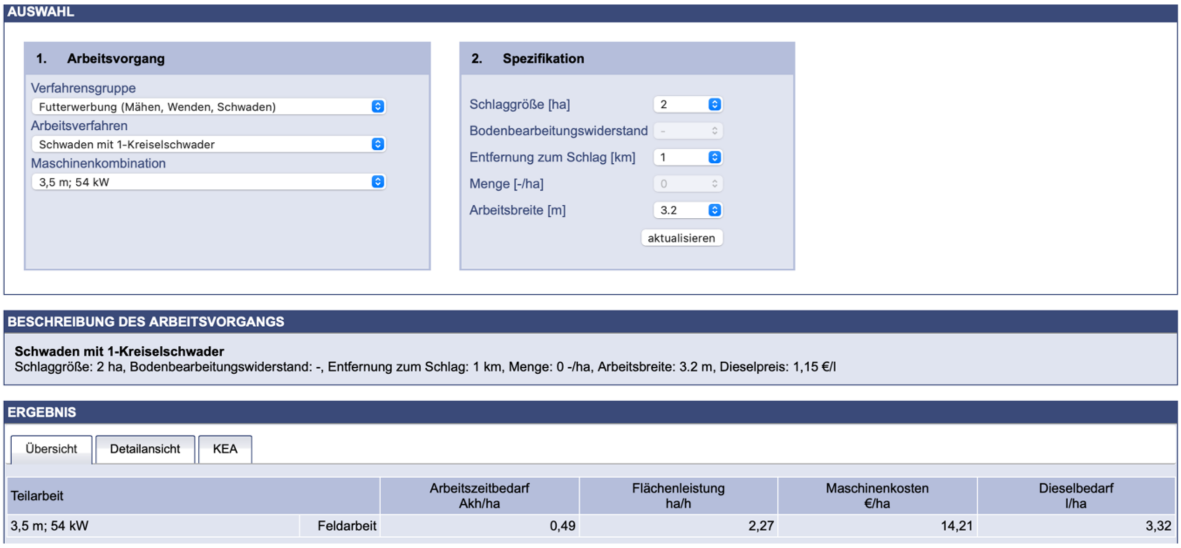
Tab. 24 Prices of planted trees and shrubs in the syntropic agroforestry system

Function	Species	Costs per plant
Target Fruit crop	Apple (*Malus domestica*)	€38.00
	Pear (*Pyrus communis*)	€38.00
	Peach (*Prunus persica*)	€36.00
	Plum (*Prunus domestica*)	€36.00
Nut crop	Sweet chestnut (*Castanea sativa*)	€1.76
Berry crop	Buffaloberry (*Spepherdia*)	€8.40
	Shadbush (*Amelanchier lamarckii*)	€5.32
	Red currant (*Ribes rubrum*)	€2.00
	Jostaberry (*Ribes x nidigrolaria*)	€2.50
	Cornel (*Cornus mas*)	€8.75
	Japanese Silverberry (*Elaeagnus umbellata*)	€4.50
	Sea buckthorn (*Hippophae rhamnoides*)	€1.75
	Sibirian blueberry (*Lonicera kamtschatica*)	€1.50
	Mulberry (*Morus nigra*)	€2.10
	Gooseberry (*Ribes uva-crispa*)	€2.03
Mother tree	Grey alder (*Alnus incana*)	€0.75
	Balsam poplar (*Populus balsamifera*)	€0.75
	Foxglove tree (*Paulownia tomentosa*)	€4.36
	Monarch birch (*Betula maximowiziana*)	€1.73
	Silver birch (*Betula pendula*)	€1.75
	White poplar (*Populus alba)*	€1.58
	Aspen (*Populus tremula*)	€0.70
Other	Siberian pea shrub (*Caragana arborescens*)	€1.16
	Mahonia (*Mahonia aquifolium*)	€4.50
	Whitebeam (*Sorbus aria*)	€1.76
	Fly Honeysuckle (*Lonicera xylosteum*)	€1.49
	Goat willow (*Salix caprea*)	€1.35
	Summer lilac (*Buddleja davidii*)	€4.96
	Wild cherry (*Prunus avium*)	€1.76

Tab.25 Labor documentation (TL= Temporary Labor, PL= Permanent Labor, h= hours, LH= Labor Hours)

Day	Operation	#TL	h. in the field	LH of TL	#PL	h. in the field	LH of PL
24.01.22	Mulching	5	6	30			0
25.01.22	Mulching	7	8	56			0
20.04.22	Harvest	3	2	6	1	1	1
25.04.22	Tree / System maintenance	1	4	4			0
31.05.22	Mulchen			0	1	6	6
02.06.22	Baum-/Systempflege			0	1	8	8
02.06.22	Tree / System maintenance			0			0
10.06.22	Tree / System maintenance	2	3	6	1	3	3
04.07.22	Harvest			0	3	5	15
07.07.22	Mowing			0	2	1,5	3
08.07.22	Harvest	1	4	4	1	4	4
14.07.22	Harvest	2	3	6			0
23.07.22	Tree / System maintenance			0	2	4	8
03.08.22	Tree / System maintenance	1	3	3	1	3	3
17.08.22	Tree / System maintenance			0	1	2,5	2,5
21.08.22	Weeding	2	9	18	1	6	6
14.09.22	Weeding	2	3	6	1	3	3
23.09.22	Mulching			0	1	6	6
02.11.22	Mowing			0	2	5,5	11
19.04.23	Weeding	2	5	10	1	3	3
24.04.23	Weeding	1	2	2	1	2	2
25.04.23	Weeding	1	3,5	3,5	1	3,5	3,5
26.04.23	Weeding	2	2	4	1	2	2
04.05.23	Weeding	4	4	16	2	4	8
05.05.23	Weeding	4	6	24	2	6	12
08.05.23	Weeding	2	8	16	2	8	16
09.05.23	Weeding	2	3	6	1	2	2
15.05.23	Mowing			0	1	3	3
15.05.23	Mulching			0	1	3	3
31.05.23	Mulching	3	6	18	1	2	2
16.06.23	Weeding	7,0	2,5	17,5	2,0	2,5	5
21.06.23	Weeding	5,0	4,0	20	2,0	4,0	8
21.06.23	Mulching	2,0	4,0	8	1,0	4,5	4,5
26.06.23	Weeding	4,0	7,5	30	2,0	7,5	15
03.07.23	Weeding	6,0	7,0	42	1,0	8,0	8
10.07.23	Mulching	3,0	2,0	6	1,0	2,0	2
11.07.23	Mulching	4,0	3,0	12			0
18.07.23	Weeding	3,0	8,0	24	1,0	4,0	4

26.07.23	Mulching	5,0	3,0	15	1,0	3,0	3
25.08.23	Tree / System maintenace	4,0	7,5	30	1,0	7,5	7,5
29.08.23	Tree / System maintenace	3,0	2,0	6			0
07.09.23	Mulching			0	2,0	6,0	12
11.09.23	Mulching			0	1,0	5,0	5
26.10.23	Weeding	1,0	2,0	2			0
01.11.23	Mowing	1,0	7,0	7			0
02.11.23	Mulching	4,0	7,0	28			0
03.11.23	Mulching	5,0	7,0	35			0
03.11.23	Mowing	1,0	7,0	7			0
27.11.23	Mulching	3,0	2,0	6	2,0	2,0	4
29.11.23	Mulching	4,0	2,5	10	2,0	2,5	5
05.12.23	Mulching	5,0	4,0	20	1,0	4,0	4
06.12.23	Mulching	5,0	5,0	25	1,0	5,0	5
22.12.23	Mulching	4,0	2,0	8	1,0	2,0	2
09.01.24	Mulching	5,0	5,0	25	1,0	5,0	5
10.01.24	Mulching	4,0	3,0	12	1,0	3,0	3
12.01.24	Mulching			0	1,0	4,0	4
17.01.24	Mulching	4,0	5,0	20	1,0	3,0	3
11.04.24	Mulching			0	4,0	3,0	12
16.04.24	Weeding	4,0	7,0	28	1,0	10,0	10
16.04.24	Mulching			0	2,0	2,0	4
17.04.24	Weeding	4,0	2,0	8	2,0	2,0	4
19.04.24	Mulching	4,0	1,0	4	2,0	1,0	2
25.04.24	Infracstructure	2,0	1,0	2	1,0	1,0	1
29.04.24	Weeding	3,0	5,0	15	3,0	3,0	9
30.04.24	Weeding	4,0	1,0	4	1,0	1,0	1
06.05.24	Weeding	3,0	3,5	10,5	1,0	4,0	4
10.05.24	Weeding	4,0	2,0	8	1,0	2,0	2
13.05.24	Weeding	3,0	2,0	6	1,0	2,0	2
14.05.24	Mowing			0	1,0	4,0	4
15.05.24	Mowing	1,0	4,0	4			0
15.05.24	Mulching			0	1,0	5,0	5
16.05.24	Mulching	3,0	2,0	6			0
16.05.24	Weeding	1,0	2,0	2			0
21.05.24	Mulching	1,0	3,0	3	3,0	4,5	13,5
10.06.24	Weeding	3,0	2,5	7,5	2,0	2,5	5
11.06.24	Tree/ System maintenace	4,0	4,0	16	2,0	4,0	8
11.06.24	Tree/ System maintenace	2,0	16,0	32	1,0	16,0	16
17.06.24	Mowing			0	1,0	3,0	3
18.06.24	Mowing	1,0	4,0	4			0
18.06.24	Weeding	5,0	5,0	25	3,0	5,5	16,5
21.06.24	Mulching			0	1,0	2,0	2



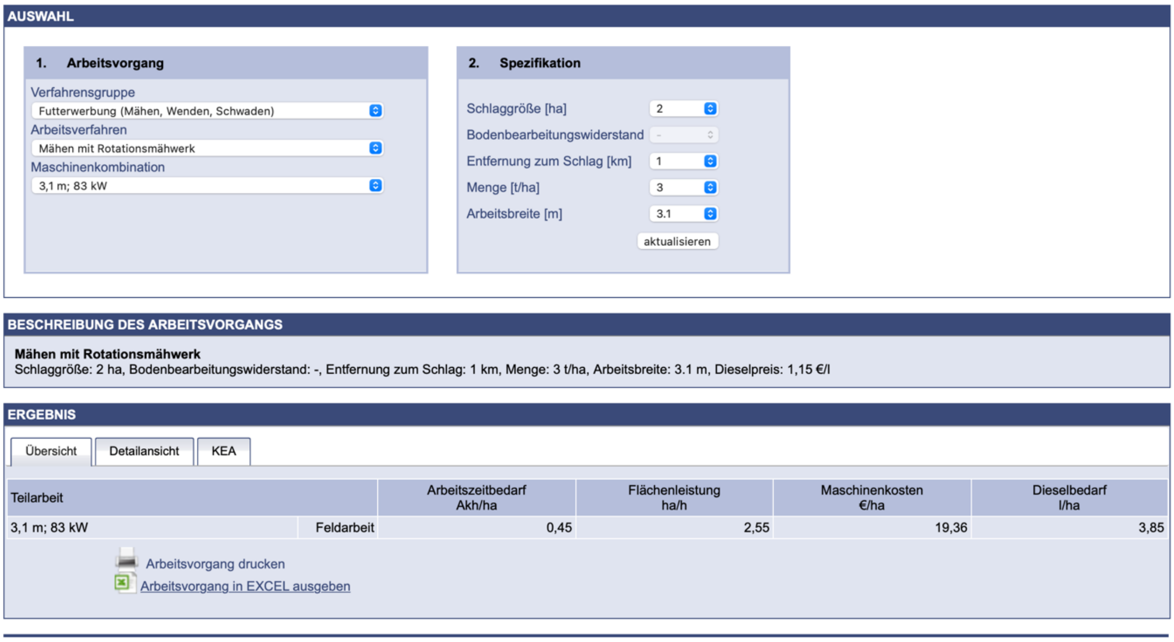


Fig. 19 Operating cost calculation of swathing (above) and nowing (below) (KTBL Feldarbeitsrechner)

Declaration

I, Sina Manuela Weisbrodt, declare that the research work presented here is from the best of my knowledge and belief, original and the result of my own investigations. The cooperation I got for this research work is clearly acknowledged. To the best of my knowledge, it does not contain any materials those are written by others or published already except mentioned with due references in the text as well as with the quotation marks.
This work has not been published, submitted, either in part or whole intended for reward, degree at this or any other University.

Place, Date Signature