THESIS RESEARCH

Exploration of potential silvoarable agroforestry system for horticulture farmers in the Netherlands

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Exploration of potential silvoarable agroforestry system for horticulture farmers in the Netherlands

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Dedication

I would like to dedicate this research to the Almighty God for his grace, my family specially my daughters Arnika and Ronika, and my best friend Elizabeth for their moral support, encouragement, prayers, and motivation during the entire study.

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List of abbreviations

AF	**Agroforestry**
COGS	**Costs of goods sold**
EBITD	**Earnings before interest, tax and depreciation**
P/L	**Profit and loss**
SAF	**Silvoarable agroforestry**
SPS	**Silvopastoral agroforestry system**
SGA	**Selling, general and administrative**

Abstract

Royal Eijkelkamp is a company in the Netherlands that specializes in soil improvement, soil conditions, water preservation, and agricultural research. The company has started an innovation platform in partnership with Van Hall Larenstein University of Applied Sciences that is named InnoFields. The InnoFields platform intends to use agroforestry as one of their innovative pilots where long-term monitoring will take place by using state-of-the-art analysis and technologies (e.g., ground sensor data, soil moisture, soil health/biology). The agroforestry pilot will generate robust scientific information over the effects of crop diversification as well as the interactions between perennial and annual crops in agricultural systems and the delivery and enhancement of ecosystem services. InnoFields allocated one demo plot which will be used to showcase a profitable and environmentally beneficial silvoarable agroforestry system. The company lacks in-depth information about the profitable and environmentally beneficial crop-tree combination that can be used in the company's SAF demo plot. The company will require the crop-tree combination to advise and convince the farmers in the area on transitioning from usual farming systems to agroforestry systems which is profitable and environmentally beneficial.

Agroforestry is defined by the European Commission (2013) as "land-use systems in which trees are farmed alongside agriculture on the same ground." The aim of this study was to investigate if the hazelnut-cabbage combination would be a suitable combination in the SAF system and examine the economic performance of the hazelnut-cabbage combination in terms of profitability through a profit and loss analysis, market channels for the products, and environmental benefit in terms of soil fertility of the crop-tree combination which help with the process of designing a SAF plot in the Gelderland province, the Netherlands.

Five semi-structured interviews, two field observations, and a desk study were used to collect qualitative and quantitative data. Besides, an expert panel with background in agro-ecology, agroforestry, and agriculture was used to evaluate the environmental benefit (soil fertility) of the crop-tree combination.

This research analysis showed that hazelnut and cabbage are compatible in terms of growing requirements, farm management, competition, and synergy. In terms of profitability, this study found that the combination of hazelnut and cabbage in the AF system is more profitable in comparison to their production in the monoculture system. Regarding the market channels of organic cabbage and hazelnut, the results of this study showed that there are two market channels for the products including (a) Farmers sell to cooperatives or other wholesalers, then wholesalers sell to the consumers through chain stores and specific supermarkets such as Odin and Ekoplaza. (b)Farmers sell directly to local consumers to gain more gross margin due to the absence of wholesalers.

This research also found that hazelnut-cabbage combination (SAF system) improves the availability of soil Nitrogen and Phosphorus in the soil, adds to the soil's organic matter, and balances the soil PH compared to the monoculture system.

Despite the limited time of the study that limited the measurement of the environmental benefit of the crop-tree combination and investigation of all aspects of the hazelnut and cabbage compatibility, this study concluded that cabbage and hazelnut are compatible and can be combined in the SAF system. Moreover, the hazelnut-cabbage combination is profitable and environmentally beneficial in terms of soil fertility in comparison to the production of hazelnut and cabbage in the monoculture system. Hence, the hazelnut-cabbage combination can be used in the process of designing the SAF demo plot in the Gelderland province.

Keywords: Agroforestry, Silvoarable agroforestry, Cabbage, Hazelnut, Profitability, Crop-tree combination

Chapter one. Introduction

1.1. Climate change and agriculture: the challenges

A complicated cause-and-effect relationship exists between agriculture and climate change (Agovino *et al*., 2019). Global climate change has resulted in rising temperatures, resulting in heat waves and droughts; increased precipitation, storms, and flood danger; and greater quantities of carbon dioxide in the atmosphere throughout the last century (OECD, 2016). Another number of studies focus on how agriculture contributes to climate change by releasing greenhouse gases, which trap heat in the atmosphere. The agriculture sector, in particular, creates direct GHG emissions through (i) nitrous oxide emissions from soils, (ii) fertilizer applications, (iii) grazing animal dejections, and (iv) ruminant animal methane generation, and changes in land-use, such as land enlargement and deforestation, resulting in both direct and indirect GHG emissions (Hall, Matson and Roth, 1996; Delmas *et al*., 1997; Tilman *et al*., 2002). According to Agovino et al., (2019) agriculture may also help to mitigate climate change by lowering greenhouse gas emissions and sequestering carbon while still producing food. The direction of these impacts is determined by the sort of farming practices used. The positive impacts of farming practices including increasing soil health, farmland protection, and saving energies, etc. Besides, there are a number of challenges that agriculture is facing due to land degradation, intensive farming, water scarcity, etc. (Agovino et al., 2019).

For decades, climate change and land degradation have posed challenges to global agricultural productivity and human food security (Diamond, 2005). Addressing these issues is critical for developing long-term agroecological systems capable of feeding the world's constantly rising population (Webb, et al, 2017). According to Akhtar-Schuster, et al. (2017) since the establishment of the Sustainable Development Goals in 2015, land degradation has resulted in a decline of land performance throughout the world, whether from an ecological or economic aspect, and has played a crucial part in the UN's environmental agenda. This worldwide phenomenon is made by nature, but it is induced by unsustainable management of land as well, and it is accompanied by a series of negative environmental consequences. The most visible repercussions include soil losses that are beyond bearable, as well as soil fertility reductions (Pacheco et al., 2018). Pacheco et al. (2018) report that it's possible that they're linked to lower levels of organic matter and exchangeable nutrients. Degradation of surface and groundwater quality, reduction in biodiversity, and degradation of ecosystem services are among the other consequences.

Cropland expansion and intensification are the primary options for increasing agricultural productivity in response to increased biomass demand, but they are also key causes of biodiversity loss (Zabel et al., 2019). Due to habitat homogenization irrigation, and significant inputs of agrochemicals such as fertilizers and pesticides, land-use intensification postures a threat to several of mostly agricultural species. Meeting future biomass demands while also protecting existing ecosystems and biodiversity is thus a significant problem we confront in the twenty-first century.

Agriculture is the major water user, with farmland irrigation accounting for 70% of all water consumption (McDaniel *et al*., 2017). Rapidly growing populations, along with rising food consumption, necessitate either agricultural area expansion or adequate productivity increases from existing resources (Fitton *et al*., 2019). Fitton *et al*. (2019) also reported that around 11% and 10% of the world's current crop- and grasslands may be vulnerable to water shortages, resulting in the loss of some productive capacity, with Africa and the Middle East, China, Europe, and Asia being the most vulnerable.

Hence, sustainability policies and sustainable farming practices like agroforestry which is using woody vegetation and crops on the same land, are some of the recent approaches that the world is using to be resilient to climate change. To the extent that sustainable agriculture makes efficient use of on-farm resources, respectably uses farmer skills to improve their self-reliance and capacities, and uses external and non-renewable inputs to the extent that these are deficient in the natural environment (Pretty, 1995, Pretty et al., 2000).

1.2. Agroforestry as a climate-adaptive strategy

Agroforestry systems provide resilience to climate change. This research adopts the resilience definition developed by the Resilience Alliance (2021), i.e., a system's ability to withstand perturbation without collapsing into a fundamentally different state governed by 2021 a separate collection of processes. A robust system can absorb shocks and, if required, reconstruct itself (Holling 1973, Gunderson & Holling 2002, Walker *et al*. 2004). Agroforestry systems (AFs), if well managed, can play a key role in improving resilience to extreme weather events and other impacts of climate change. Below is shown all the functions that the implementation of a rational AFs design can provide on the increased resilience to weather- and climate-related extreme events, for example, floods, droughts, and heatwaves.

(a) Microclimate buffering. The use of trees helps to build resilience against for example droughts and heatwaves by the use of trees (Schoeneberger *et al*. 2012). Trees in AFs increase farmer`s resilience to climate variability by modifying temperature, humidity, and wind speed which are examples of the microclimatic conditions (Karvatte *et al*., 2016; Giro *et al*., 2019; Oliveira *et al*., 2019; Pezzopane *et al*., 2019, Karvatte *et al*. 2020). The microclimate controls the amount of moisture in the soil and air available to different ecosystems, the existence of dew and frost, the exact temperatures for growing plants and germination, the resilience of soil biotic life, the capability of soil biota to fix nitrogen, and the presence of pests and diseases. Trees provide a buffer to climate extremes that affect agricultural development, and AFs have a significant influence on agricultural production. The shade effects of trees can help to compensate for temperature and atmospheric saturation deficits, lowering exposure to supra-optimal temperatures, which put physiological and developmental processes and yield at risk (Lott *et al*. 2009). Reduced incidence solar radiation, air, and soil temperature, as well as improved water status, gas exchange, and water usage efficiency are all benefits of trees (Monteith *et al*. 1991).

(b) Regulation of water flow. AFs can provide different mechanisms that can enhance the use of available water more effectively than monocultures and thus increase agroecosystem resilience against for example droughts and heatwaves (van Noordwijk *et al.* 2019). AFs contribute to water recycling by increased rainfall utilization and thus reducing runoff and storing water in deeper layers. Additionally, microclimate changes, as a result of AFs, reduce the evaporation demand and make more water available for transpiration.

(c) Soil health. By maintaining healthy soils AFs cannot only provide the largest store of terrestrial carbon but also soil properties directly influence the presence of dew and frost and the actual temperatures for plant growth and germination, and therefore can contribute to protecting crop productivity against unexpected low or high temperatures. AFs have the potential to improve soil fertility (improvement of soil health and physical properties). Farm trees improve soil structural qualities while facilitating tighter nutrient cycling than monoculture systems. They also replenish the soil with nutrients and organic matter (CGIAR 2016).

(d) Mitigating CO2 emission through Carbon Sequestration. AFs by capturing the CO2 will stimulate plant growth, making it more resilient to warmer weather and drought, and going some way to counterbalance the impacts of climate change. The role of AF regarding the mitigation of CO2 emissions to improve climate change resiliency relates to its capacity, through an adequate management of trees in cultivated land and pasture, of capturing and storing a significant fraction of the atmospheric CO2 in biomass and in soils (Nair *et al*. 2010).

(e) Biodiversity & Pest and disease control. AFs create more diverse ecological communities (plants, animals, etc), this higher biodiversity increases the resistance of such ecosystems to a wide range of climate events (drought, heatwaves, extreme rainfall). Also, by these diverse ecological communities, possible outbreaks of pests and diseases can be controlled by their natural species interactions (Schroth et al. 2000).

(f) Economic stability. AF can enhance farm profitability by improving and diversifying output per unit area of tree/crop/livestock, protecting against detrimental effects of wind or water flow, and adding new products to the financial variability and flexibility of the farming enterprise to increase resilience to extreme weather climate event. AF may result in improved food and fuel security, in addition to the diversification of local goods and economies (Smith 2010).

1.3. Agroforestry in the Netherlands

According to the European Agroforestry Federation (EURAF, 2021), the use of agroforestry in the Netherlands bring new opportunities for increasing resilience in agriculture against extreme weather events, has the potential to diversify the farming revenue while spreading the economic risk, maintain and enhance ecosystem services and fulfill social tasks such as enriching the landscape, opening leisure and connection to nature, both at the regional and national level. However, there are current challenges and bottlenecks, for example, the Netherlands has not accessed the Common Agricultural Policy's (CAP) subsidies that agroforestry farmers are entitled to (via measure sheet 8, article 23; EURAF, 2019), neither structural laws and regulations have been put in place that could facilitate farmers to make a transition from conventional agriculture towards agroforestry as a climate-resilient system (e.g., land use plans sometimes contradicts the implementation of agroforestry, the planting of more than 50 non-fruit trees signifies the devaluation of agricultural land). Interestingly, there are some examples of initiatives that aim at solving some of the bottlenecks, e.g. in the province of North Brabant policymakers and other stakeholders are seeking solutions in the Nature Protection Act; in combination with an exemption from the replanting obligation (EURAF, 2019).

Recently also the Agroforestry Master Plan (Luske *et al*., 2020) was developed by Louis Bolk Institute in which agroforestry has been introduced to the scene as part of land use planning and implementation initiatives. Also, new ideas about developing a reimbursement system for delivering ecosystem services are being developed, such as carbon credits. As a result, there are several potential trends for agroforestry growth in the Netherlands.

1.4. Commissioner (Royal Eijkelkamp)

Royal Eijkelkamp is a company in the Netherlands that specializes in soil improvement, soil conditions, water preservation, and agricultural research. The company has started an innovation platform in partnership with Van Hall Larenstein University of Applied Sciences that is named InnoFields. Royal Eijkelkamp intends to use the Innofields as a hub for innovation and creativity, allowing (agricultural) entrepreneurs and scientists to answer demand-driven inquiries and provide practical information to current and future professional practice. The platform primarily addresses urgent issues such as climate resilience for food security by presenting novel ideas for implementing climate-adaptable agroecosystems. The InnoFields platform intends to use agroforestry as one of their innovative pilots where long-term monitoring will take place by using state-of-the-art analysis and technologies (e.g., ground sensor data, soil moisture, soil health/biology). The agroforestry pilot will generate robust scientific information over the effects of crop diversification as well as the interactions between perennial and annual crops in agricultural systems and the delivery and enhancement of ecosystem services. InnoFields allocated one demo plot which will be used to showcase a profitable and environmentally beneficial silvoarable agroforestry system.

1.5. Problem statement

According to Eijkelkamp (problem owner), the company lacks in-depth information about the profitable and environmentally beneficial crop-tree combination that can be used in the company's SAF demo plot. The company will require the crop-tree combination to advise and convince the farmers in the area on transitioning from usual farming systems to agroforestry systems which is profitable and environmentally beneficial. The research will act as a baseline that will contribute to the process of designing the silvoarable agroforestry demo plot in the Gelderland. However, to obtain realistic and reliable information about the crop-tree combination, this research requires a farmer's situation as a study case.

1.6. Study case

With the consent of the commissioner, a cabbage farmer in the area who would like to plant hazelnut trees on his farm was identified to be used as the study case. Besides, other students from Universities of Applied Sciences (VHL and HAN) will look into other possible combinations for AF system.

1.7. Research objective

To identify if the study case farmer's crop (cabbage) can be combined with hazelnut trees on the farmland that will be profitable and environmentally beneficial and provide recommendations on the combination of the cabbage with hazelnut trees that will help in the process of designing the SAF demo plot.

1.8. Research questions

To what extent is a hazelnut and cabbage co-cultivation suitable as SAF demo plot for Royal Eijkelkamp in Gelderland province?

I. Is cabbage compatible with hazelnut tree in a crop-tree combination?

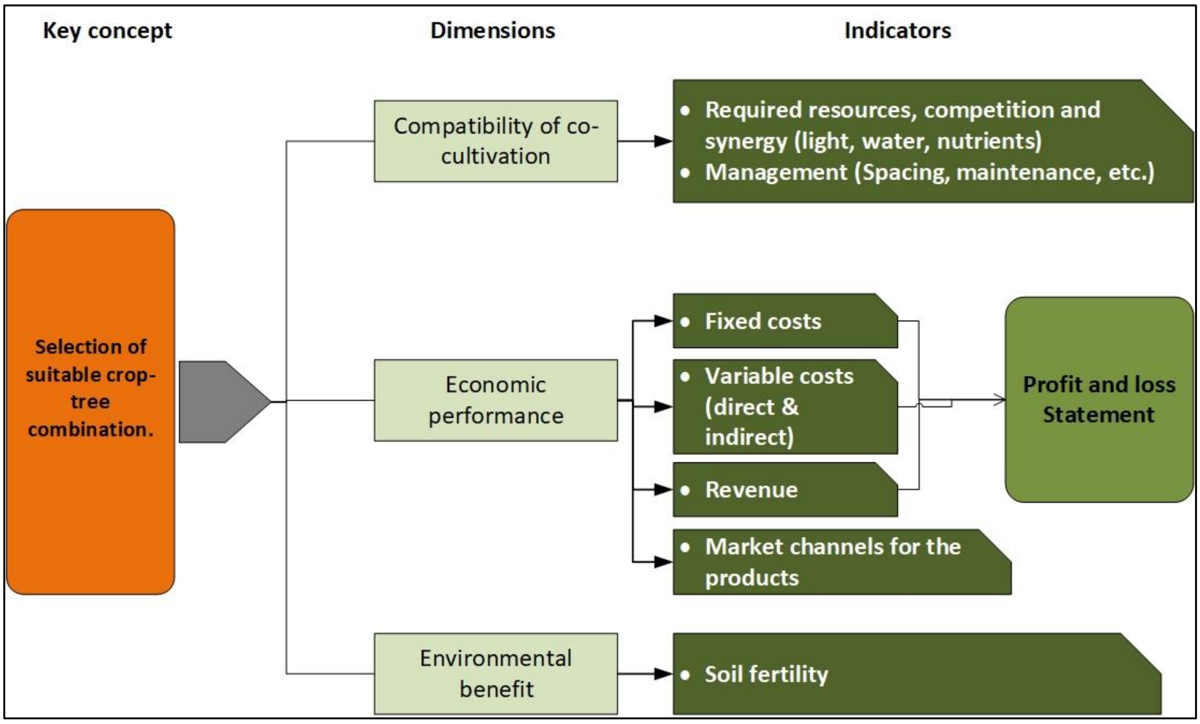
II. What is the economic performance of the hazelnut and cabbage combination in terms of profitability and market channels of the products?

III. What is the environmental benefit in terms of soil fertility of the hazelnut and cabbage incorporation?

1.9. Conceptual framework

Adom, (2018), states "*The conceptual framework explains the path of research and grounds it firmly in theoretical constructs. The overall aim of the framework is to make research findings more meaningful, acceptable to the theoretical constructs in the research field and ensures generalizability*".

Figure 1: Conceptual framework



1.10. Stakeholders

Several institutions, companies, and individuals are affected by this research and its outcomes. Table 1 below illustrates the affected stakeholders and their functions.

Table 1: Stakeholders

Stakeholders	Function	Effect of research
Van Hall Larenstein University of Applied Science	- Provides the education for the student. - It is the lead of the Farmlife project which delivers information on AF systems and their promotion.	Indirectly connected to Royal Eijkelkamp through the student, so any negative outcome or collapse in the research negatively affects the university. And this research affects positively by contribution to farm life project and knowledge for education about AF.
Royal Eijkelkamp	- Provides the research opportunity - Creating connections with farmers in the area that are interested in exploring agroforestry opportunities.	The company observes the results. Positive results will help them redesign their company's portfolio. Negative results might discourage them.
Farmers in contact with Royal Eijkelkamp	- Potential audience and observers of the pilot's success.	Can help other farmers for transition to the AF farming system.
Arable farmers who are not in contact with Royal Eijkelkamp directly.	- Potential audience and observers of the pilot's success.	In case of positive results of the research, other farmers might be convinced to invest in the SAF system through the demo plot.
Agroforestry researchers	- Conduct research in the field of agroforestry	They will find more sample practices if more farmers adopt agroforestry.
Local community	- Products consumers. - Make use of the environment	- See the visual change in the landscape, when trees are added. - Benefit from environmental effects of the agroforestry farming system. - Can benefit from the production

Chapter 2. Literature review

2.1. Agroforestry nomenclature in Europe

According to FAO (2015), animals, crops, and trees, are the three basic components of agroforestry, that can be combined in a variety of spatial and temporal patterns and for a variety of uses, resulting in a wide range of systems. There are three main types of agroforestry: silvopastoral, silvoarable, and agrosilvopastoral (the combination of animals, trees, and crops).

2.1.1. Silvopastoral agroforestry system (SPS)

On the same piece of land, silvopastoral agroforestry systems integrate the management of livestock with trees or other woody perennials. In addition to allowing farmers to diversify their income and reduce inputs, these systems have been proven to provide a number of environmental benefits (Röhrig, Hassler and Roesler, 2020). Pinto-Correia and Mascarenhas (1999) state that the planned integration of trees with grazing animal operations on the same area defines several types of SPS (forest grazing or wood pastures), and they are managed for both forest and fodder products. Moreover, according to Fernández-Núñez and Castro (2016), long-term production (timber and fuelwood) is combined with yearly output in this agroforestry system (hay, meat, milk, eggs, etc.). These systems require a balance of resource utilization between trees and grassland, with the addition of grazing animals, to provide many products in a sustainable manner. As a result, choosing the tree-pasture livestock combination as the first SPS component is critical.

2.1.2. Silvoarable agroforestry system (SAF)

The intentional integration of woody components in different forms (borders, scattered trees, hedgerows, windbreaks, lines) with agriculture is one of the silvoarable techniques. Annual crops intercropped among permanent crops (fruit trees), shrublands with and without limited tree cover, and forests are also used in silvoarable practices. Using the LUCAS (2012) database, the overall area occupied by silvoarable practices in Europe is roughly 360 thousand hectares or less than 0.08 percent of the overall European area. Moreover, Ferreiro-Domínguez and Mosquera-Losada, (2018) state that, agroforestry systems will have a significant influence on many parts of the soil nitrogen dynamic by bringing trees onto an arable field, with significant agronomic and environmental implications.

2.1.3. Agrosilvopastoral agroforestry system

Agrosilvopastoral systems, which integrate agriculture, livestock grazing, and forests in the same land, have been touted as sustainable models (Freitas *et al*., 2020). Ibrahim, *et al*. (2010) state that agrosilvopastoral systems also give many benefits to farming families, such as food, fuel, timber, fruit, and live fences; they are more productive than monocultures, and they have a variety of environmental advantages.

2.2. *Status quo* of agroforestry in Europe

Agroforestry is defined by the European Commission (2013) as "land-use systems in which trees are farmed alongside agriculture on the same ground." Agroforestry, according to another source, is the technique of intentionally combining woody vegetation (trees or shrubs) with agricultural and animal systems in order to benefit from the ecological and economic cooperation that occurs (Burgess et al., 2015). Agroforestry has been accepted in Europe as a viable farming method for nearly half a century (Garrity, 2012).

In accordance with the briefing of the European Parliament over agroforestry in the European Union (2020), agroforestry enjoys EU-level recognition and the benefits are acknowledged. Agroforestry is also supported by the Common Agricultural Policy (CAP). The CAP provides subsidies in which farmers can receive direct payments per hectare of land that is used for agroforestry, it also supports the establishment or maintenance of the agroforestry systems that stem from the rural development strand of the CAP. There is also EU support for innovation and research in the field of agroforestry. Mosquera-Losada et al. (2018) say, facilitating agroforestry in Europe through the CAP should be associated with the knowledge of the extent of agroforestry practices able to operate at the plot level, the main scale on which the CAP operates, Besides, it is also considering national and regional levels, as the CAP is currently used in 118 different European Rural Development programs.

According to Laure and Granier (2020), agroforestry is spread across 19.5 million hectares in Europe, in which the most prominent form is silvopastoralism which accounts for 85%, mostly in the European Southern regions but also in other regions. Moreover, 10% of the current silvopastoralism systems are permanent grasslands in the EU, which shows the big potential of this land use. Also, the home gardens represent an important agroforestry system being the second most significant agroforestry system accounting for 8.3% of the agroforestry lands. Whereas silvoarable systems cover only around half a million hectares, i.e. less than 1% of arable land (Dupra, Gosme and Lawson, 2019).

Agroforestry practices may be found all across Europe, though they are most commonly associated with regions in southern Europe (Mosquera-Losada *et al*., 2018). According to Mosquera-Losada *et al*., (2018), agroforestry methods may be found all throughout Europe, though they are most commonly associated with countries in the south.

2.3. *Status quo* of agroforestry in the Netherlands

The earliest agroforestry operations documented in the Netherlands were the growing of agricultural crops with forest husbandry activities (Rigueiro-Rodróguez and McAdam, 2008). According to the same authors, farmers began undertaking "agroforestry" farming practices about 2500 BC, clearing and burning trees to clear the fields, resulting in agricultural grounds bordered on all sides by forests. By 500 BC forest cover decreased due to the reclamation for permanent farming and the growing population and settlements. After AD 800 reclamation of land by the feudal lords accelerated the forest loss, and by the 17th century, forests had nearly disappeared. Forests were established throughout the nineteenth century. The expansion of forests continued in the 20th century in the polders, the forest law was introduced prohibiting grazing in the forests, agricultural production shifted towards large-scale monoculture production systems with high intensive use of chemical inputs rather than mixing crops or mixing crops with trees (Rigueiro-Rodróguez and McAdam, 2008). The search for alternative ways to produce crops and food has intensified since the negative effects of agricultural practices involving extensive chemical use in large-scale monocultures became undeniable, which leads to green gas emission, climate change, and soil degradation (McAdam, Mosquera-Losada and Rigueiro-Rodríguez, 2008). As a result, experimental agroforestry plots were established throughout the Netherlands, as well as individual farmer efforts using silvoarable and silvopasture as the primary types of agroforestry activities (McAdam, Rigueiro-Rodríguez, and Mosquera-Losada, 2008).

Nowadays, agroforestry in the Netherlands is still limited, however steadily increasing. There is an increasing tendency in using trees as multifunctional natural elements in conjunction with farming activities to mitigate the negative effects of intensive monoculture agricultural land and build resilience to extreme weather events such as the three-year drought (2018-2020) that hit the Netherlands (Bouma, 2020).

According to the Dutch Knowledge and Innovation Agenda Agriculture, Water, Food, agriculture, and nature the Netherlands is planned to be net climate neutral by 2050 (KIA Landbouw, Water, Food, 2019). The European Union has set a target of lowering greenhouse gas emissions by at least 40% by 2030 compared to 1990 as part of the Paris Agreement. The Rutte III cabinet raised, even more, this EU target by putting it at a reduction of 49% by 2030 and to 80% to 95% by 2050. The strategy to reach the aforementioned goals follows the next steps:

• Methane reduction in livestock farming;

• Reduction in the oxidation of peat meadow areas;

• Agricultural soils and open ground cultivation (reduction of nitrous oxide emissions during fertilization and sequestration of carbon in the soil);

• Fixation of carbon in forest and nature;

• Reduction of energy consumption in greenhouse horticulture.

Carola Schouten, the Dutch Minister of Agriculture, Nature, and Food Quality, has recognized that agroforestry can make an important contribution to reach climate-neutral goals. Schouten, in her official response to the written questions over the chances of agroforestry, to make a significant contribution as an agro-ecological form of agriculture raised by Dik-Faber (CU) (submitted on 23 June 2020, reference 2020Z11914) stated the following:

"In the vision and realization plan of the Ministry of Agriculture, Nature and Food Quality, I have indicated that I see agroforestry as a promising form of agriculture in which the reinforcement of agriculture and nature is sought. The Climate Agreement states that agroforestry can be a means of giving substance to the climate policy for trees, forests, and nature on agricultural land. It can also mean a broadening of the farmer's business model. It must be said, however, that the development of agroforestry in the Netherlands is still in its infancy and that more experience with agroforestry is needed to get a more concrete picture of the scope of these benefits. . . In the Forest Strategy (Parliamentary Paper 33 576, no. 186) I have indicated that I see agroforestry as a promising way of realizing trees outside the Nature Network Netherlands. I will elaborate on this in the further development of the forest strategy. " (reply to letter on July 15, 2020, reference DGNVLG-NS / 20184497).

2.4. Profitability of agroforestry systems

Profitability is one of the most important factors in determining whether or not a new land-use system will be adopted (Abadi, 2003). Moreover, Abadi, (2003) states that many current agroforestry techniques have the potential to be used with conventional farming and grazing practices. It's critical to consider the profitability of these agroforestry systems in conjunction with traditional agriculture systems rather than in isolation. Dupraz, and Newman, (1997) report that a system of silvoarable agroforestry can be both ecologically and economically advantageous. This might help to increase agricultural sustainability, diversify farm revenue, supply new products to the wood sector, and create high-value landscapes. According to Graves et al., (2017) and Palma *et al*., (2007), in Europe, SAF's environmental and economic performance is quite varied. However, Palma, *et al* (2007) says that the combination of numerous factors impacting SAF outputs causes this heterogeneity. Because of the diverse combinations of biophysical and managerial circumstances, such as tree and agricultural species selection, national legislation, market circumstances, and regional strategies, various economic and environmental effects are obtained in different European countries. Because of this variability, SAF can be more or less profitable than traditional arable systems; trees can be more or less able to compete with crops, depending on tree species and biophysical conditions, they can have beneficial environmental effects, and in some cases, they may not make a significant difference.

2.5. Crop selection in agroforestry

Different factors are influencing crop selection including resource competition between crops, plant requirements, and management.

2.5.1. Crops growing requirements

The environment has a significant impact on plant development and regional dispersion. A plant's development and/or spread are limited by any environmental condition that is less than optimal. Light, temperature, water, humidity, and nutrition are all variables that influence plant development. It's critical to comprehend how these variables influence plant growth and development (VanDerZanden, 2008). It might be possible to control plants to fit the demands if there is a rudimentary grasp of these variables are better understood, it might be possible to better control the plant developmentto fit the demands in case of environmental stress (VanDerZanden, 2008).

2.5.2. Competition for resources

It is critical to investigate the development and physiological responses of plants resulting from competition across the crop-tree interface in order to enhance the management of temperate alley cropping (Miller and Pallardy, 2001). Thevathasan, *et al*. (2005) state that, in order to effectively design and manage intercropping systems, competitive interactions should always be avoided in order to optimize the significant advantages of tree-based intercropping systems. According to Rao, *et al*. (1997), The examination of numerous complex processes, including those associated with soil conservation, soil fertility, allelopathy, pests and diseases, plant competition (for light, water, and nutrients), and microclimatic changes, is required for investigations of interactions in agroforestry systems. Optimal tree-based intercropping systems will reduce competition between non-woody (annual agricultural crop) and woody (tree) components while maximizing positive interactions (Thevathasan, *et al*., 2005). However, in accordance with Jose, Williams and Zamora (2006), one downside of combining trees with field crops is that they may compete for light, water, and nutrients, particularly in areas where resources are few.

2.5.3. Farm management

When planning an alley cropping strategy, it's important to determine which trees and crops will be planted together and at what spacing (USDA, 1999). Because of the interplay of tree and crop components, as well as the objective of maximizing economic benefit, a combination of trees and companion crops should be established that offers the best return on the landowner's investment. When it comes to developing an alley cropping technique, the spacing between rows and between individual trees is crucial (USDA, 1999). The spacing between rows changes based on a number of management considerations. For example, trees grown for wood fiber production will require less space between rows than trees planted for nut production. Row spacing inside a row varies according to the alley cropping program's goals. Besides, to grow shade-tolerant crops in alleys for more than a few years (five to ten), the alleyways must be broad enough to accommodate growing tree crowns and moisture competition from the trees. To enhance the effectiveness of the management, maintenance, and harvesting operations, alley widths should be set in accordance with the size of the equipment being utilized (USDA, 1999).

2.6. Crop combination profitability

Alley cropping in silvoarable agroforestry might help the farmer make better use of current resources and increase income. (Xu, *et al*. 2019). Alley cropping is an effective land-use strategy because the crop may more than compensate for the loss of tree production in the tree fields (Sida, *et al*. 2018). According to Xu, *et al* (2019), agroforestry economic analysis would provide farmers with reliable information on these activities' potential profitability, but little is known about the effects of companion crops on the net financial benefit.

2.6.1. Revenues and costs in agroforestry

Economic analysis of agroforestry offers a foundation for evaluating financial demands and feasibility, highlighting trade-offs among numerous advantages, and tracking economic efficiency (Godsey, 2000). According to Godsey (2000) because of the extended planning horizon of agroforestry techniques, many of the income and expenses do not happen at periodic or predictable intervals across the whole planning horizon, but rather are irregular. Moreover, there are numerous typical metrics used to assess the economic effects of an agroforestry operation (Godsey, 2000). Godsey (2000) states adding some very simple economic indicators to these standard economic indicators will assist both farmers and economists understand the economic performance of agroforestry techniques.

2.7. Environmental benefits of crop combination

Agroforestry systems are notable for producing ecosystem services such as soil protection, water management, landscape variety, and (functional) biodiversity while concurrently providing food, fodder, and material (Torralba, *et al*., 2016). Torralba, *et al*. (2016) also reports that, in comparison to conventional agriculture and forestry, agroforestry enhances biodiversity and ecosystem service provision in Europe. However, a wide range of evidence suggests that biophysical and land-use characteristics have a substantial role in the response. Besides, intercropping chestnut and walnut systems, as well as introducing trees into arable systems, can increase soil fertility and biodiversity while sustaining agricultural productivity across Atlantic and Continental Europe, according to their research.

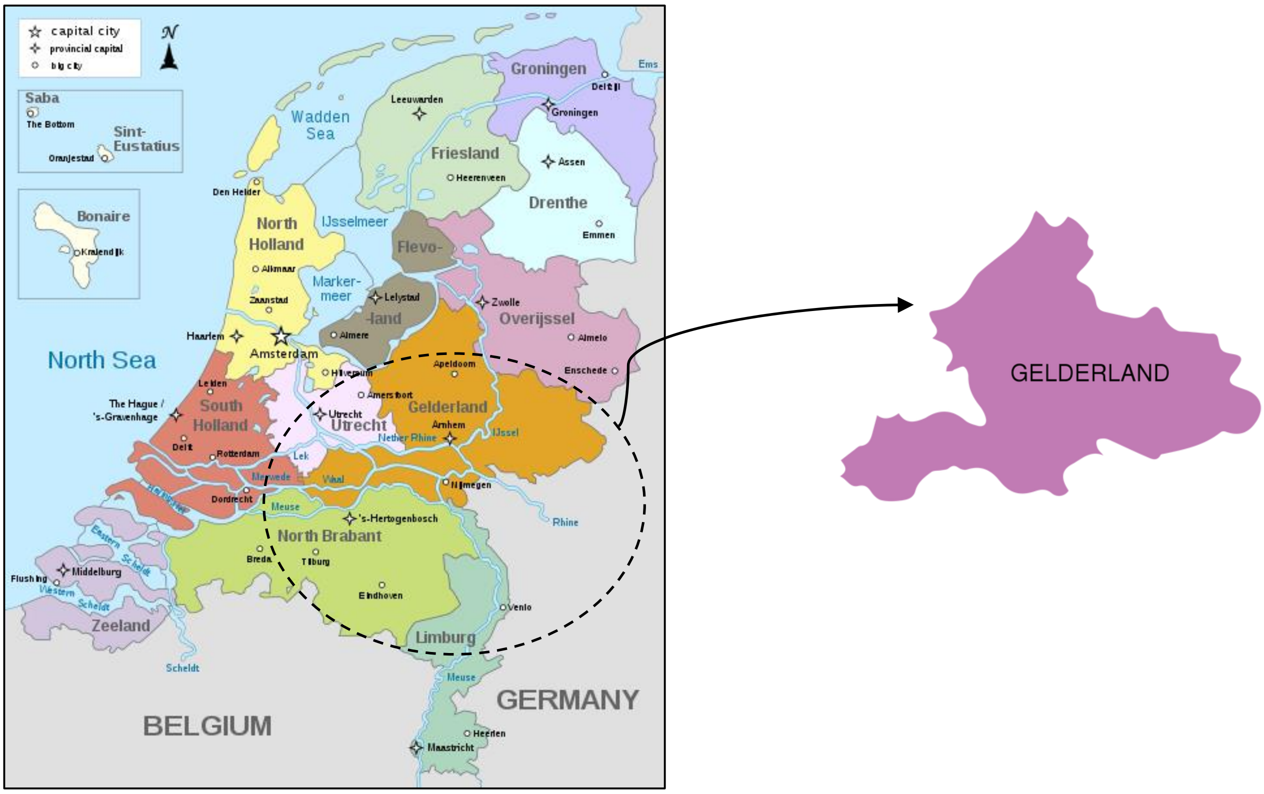
2.7.2. Soil fertility

Based on at least four decades of data acquired from throughout the world, agroforestry as a sustainable land management technique has demonstrated substantial proof of its function in enhancing soil quality and health (Dollinger and Jose, 2018). Incorporating trees into agricultural systems can improve nutrient cycling as well as the chemical and physical characteristics of the soil (Pinho, Miller and Alfaia, 2012). According to Jose, (2009), for decades, both in the tropics and temperate parts of the world, agroforestry methods have been pushed for their claimed benefits of not only increasing soil quality but also delivering other ecosystem services. The potential for agroforestry to increase soil fertility is significant, however, the increase in soil organic matter and biological nitrogen-fixing by tree leguminous plants are the major reasons for this. Trees can improve nutrient cycling and replenish the soil with nutrients and organic matter more than a monocrop system (Lehmann *et al*., 1998). In comparison to the traditional system, Ketema and Yimer (2014) reports improvements in soil characteristics under the agroforestry system, which they attribute to the input of organic matter and less soil disturbance.

Chapter 3. Methodology

3.1. Study area

The Netherlands has a total area of 33,690 km^2, with 17,960 km^2 of agricultural land, comprising arable, permanent crops, and permanent pastures, and 11.2 percent forests (Knoema, 2021). The country is recognized for its intense and specialized agriculture industry, which is well structured and technologically invested. Moreover, being the world's second-largest exporter of agricultural products, the country has a sophisticated and export-oriented agricultural strategy.This research will be conducted in the province of Gelderland, which is located in the Netherlands' center eastern region. Arnhem is the regional capital. Nijmegen, Apeldoorn, and Ede are the other three large cities. Food, agriculture, healthcare, logistics, and electronics are all important sectors in Gelderland. The province, which is the Netherlands' biggest, covers 5,136.5 square kilometers and has a population density of 398 people per square kilometer. The province's three regions are the place of residence for more than 1.9 million people. The Veluwe is home to a variety of agricultural investments, agri-businesses, and major metal-processing companies; the Achterhoek is home to a multitude of agricultural holdings, agri-businesses, and major metal-processing companies; and the Rivierenland is a fruit-growing and transportation and distribution hub (URBACT,2021).



Adopted from: Wikipedia (2021)

3.2. Research strategy

To find answers to the questions of the research, quantitative data including fixed and variable costs, selling prices, plant density, yield volumes, and other economic information of hazelnut and cabbage production and qualitative data including hazelnut and cabbage growing requirements, competition, and synergy level, farm management activities and environmental benefit (soil fertility) of hazelnut and cabbage combination were collected and triangulated. The research aimed to identify if the hazelnut-cabbage combination is profitable and environmentally beneficial to formulate recommendations on the combination that will help in the process of designing the SAF demo plot by Eijkelkamp company. Therefore, the research carried out a desk study to get familiar with the literature about cabbage and hazelnut tree growing requirements, competition between the crop and tree, information that is needed for profit and loss analysis (yield volume, selling price, etc.), and environmental benefit of the crop-tree combination regarding the soil fertility. The instruments included interview checklists which were developed, in addition to desk research. Data collection included semi-structured interviews and farm (study case and hazelnut orchard) observations.

3.3. Target population, sample size, and sampling technique

The target population in this study were the farmer (study case), a hazelnut producer, and experts in the field of agroforestry, agriculture, agribusiness, and ecology. Six key informants' interviews were used to ensure the objective of the research is met. The total was six respondents (see under 3.4.2). Furthermore, data from agroecology, agroforestry, and agriculture experts about soil fertility were collected.

3.4. Data Collection

3.4.1. Desk study

The desk review was from reports, peer-reviewed journals, books, through credible online sources such as Google scholar, Greeni, among others. This was combined with a review of literature that can place the carried out research such as literature on the crop-tree combination, silvoarable agroforestry, and crop-tree combination profitability and environmental benefit in terms of soil fertility.

3.4.2. Interviews for economic and crops' biophysical data

Interviews were done by the researcher via phone call, face to face, or other preferred online means at the comfort of the interviewees to collect the data from the farmer and key informants through semi-structured interviews. Key informant interviews were relevant for collecting qualitative and quantitative data. These were conducted through the use of customized checklists that were administered to different key informants (see annex 26) including the questions that find the answers to the research questions. The key informants included the study case farmer who has planted cabbages and is interested in planting hazelnut trees (Theo Nieuwenhuis), a nut producer including hazelnut (Herman Jansen), an agroforestry expert from company Agrobosbouw (Rene Van Druenen), an agro ecologist (Isabella SelinNoren) and a researcher (Ton Baltissen) from Wageningen University and Research, and an agro economist from VHL University of Applied Sciences (Sebastiaan Masselink). The checklists helped to guide the interviews on the main aspect of the research such as actual data about crop and tree bio-physical requirements, economic information such as, costs, revenues, and market channels that contributed to profit and loss model design and analysis, environmental benefits (soil fertility) of the crop-tree combination, and other information about agroforestry systems.

Furthermore, Through an expert panel, five experts including agroforestry expert (Rene Van Druenen) , agro-ecologists (Isabella SelinNoren, Wijnand Sukkel and Lennart Fuchs), and a researcher (Ton Baltissen) were asked to based on their proficiency and experience compare and give scales to the monoculture systems, and the SAF system environmental benefit in terms of soil fertility. Then, the average given scales for each soil fertility component were used to analyze and compare the effect of the SAF and monoculture systems on soil fertility.

3.4.3. Observations

Two field visits were done by the researcher. The observations were conducted on the selected farms (study case farm and hazelnut producer). The observation method helped to explore the current farm situation and the farmer's capacity in terms of required land, machinery, and equipment. This was useful to have a better view of the study case potential for transitioning the farming system and explore the possible crop-tree combination.

3.4.4. Case study

To obtain realistic and reliable information regarding the crop-tree combination, with the consent of the commissioner a farm situation was used as a study case. The farm is located in the Didam, Gelderland, the Netherlands. The farmer has a total of 50 hectares of land of which 2 hectares are allocated to cabbage cultivation, 4 hectares to fodder beet cultivation, and the rest is only grass for his cattle grazing. The farmer intends to allocate a part of his farm to a silvoarable agroforestry system and he would like to have hazelnut trees on his new farming system. Figure 2 below illustrates the location of the study case farm.

Figure 2: The farm location of the study case

Source: Google maps (2021)

3.5. Data analysis

Collected qualitative and quantitative data through interviews, observations, desk study, and expert panel were analyzed. The analyzed data were descriptive, and narrative of crop and tree growing requirements, resources competition and synergy, farm management and maintenance, fixed costs, variable costs, revenues, net profit, and environmental benefits (soil fertility). Findings were recorded, and data processing was formulated and grouping of data according to different categories. The profit and loss model was used to outline revenues, costs, and net profits over the first 10 years of the crop-tree combination and the monoculture.

3.5.1. Soil fertility data analysis

Spider plots were used to make the visualization of the differences in profitability (i.e. selected economic criteria) and the selected soil fertility components (i.e. availability of Nitrogen and Phosphorus, Organic matter, and balancing the soil PH) among monoculture and SAF systems. Besides, to compare the environmental benefit in terms of soil fertility, four soil fertility components including the availability of Nitrogen, availability of phosphorus, organic matter, and balancing the soil PH were selected and scales 1 to 5 (very low to very high) were allocated to each component.

3.5.1. Profit and Loss model

To convincing farmers to shift their current farming system to a new system it is needed to show the profitability of the new system and compare the current situation and the situation after change economically. The profit and loss model is a tool to analyze and estimate the profitability of a system. Economists use P/L models to demonstrate the costs, revenues, and net profit (Masselink, 2021).

The P/L model includes different parts. The first part is the review that shows a summary of different components of the model such as revenues, costs (costs of goods sold, selling, administrative and general costs, and depreciation and maintenance costs), gross margin, and profit. The second part of the model is revenues which include volume per hectare, number of hectares, selling price, and other revenue sources (Masselink, 2021). The next element of the model is costs of goods sold, this part includes variable costs of production, fixed assets, and the cost of fixed assets such as depreciation and maintenance costs. One important factor in COGS calculation is cost allocation. According to Masselink (2021) "*For instance, in this case, the farmer has 50 hectares in total and he wants to allocate two hectares of his land to the AF system. Hence, the cost of fixed assets should be calculated only for 2 hectares, because the farmer uses the building, machinery, and equipment for 50 hectares as well, not specifically for the 2 hectares. The last part of the model is administrative and general costs including utilities, salaries, insurance, certificates, and other general costs. The cost allocation also is needed in this part because the general costs are not only for allocated land for the AF system*".

In profit and loss analysis, a number of costs such as purchasing seedlings and new required machinery and equipment are depreciated in different years to make a better view of the profitability of the system. Besides, as tax calculation is complicated and the amount of the tax can be changed by the tax authorities based on the farmer's income. Hence, to show the profitability it is recommended to use the net profit before tax for demonstrating the profit (Masselink, 2021).

3.6. Data collection and analysis summary

The sources of data, data collection, and analysis methods were summarized to illustrate an overview of the research methodology. Table 2 below illustrates detailed data collection and analysis based on the sub-questions.

Table 2: Research framework

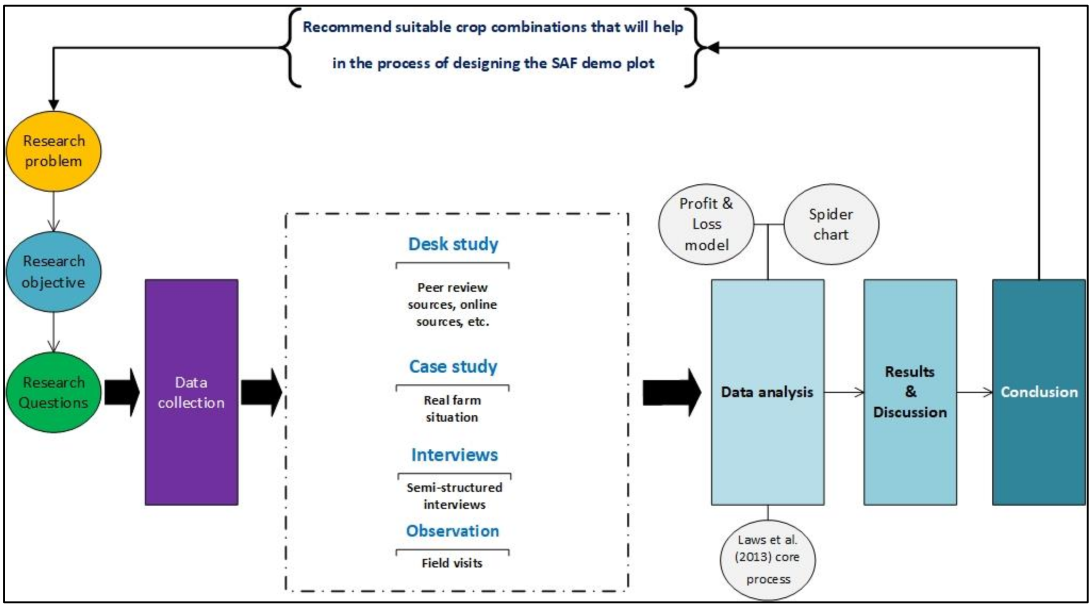
Elements of Sub-questions	Source of data	How to collect data	How to analyze data
Sub-Q I. Crops compatibility	• Literature • Key informants (e.g., farmers, agro-economist, agro-ecologist, and agroforestry expert) • Field visits (study case(cabbage producer) and nut producer)	Desk study Semi-structured interviews Observation	• An excel sheet to categorize findings per crop • Tabular synthesis of all bio-physical requirements per Selected crop(s) • For quantitative interviews data, we use Laws et al. (2013) core process[1] • Qualitative data and observation were used to identify the crops' requirements, farm management, and the potential of SAF system implementation.
Sub-Q II. Crop-tree combination economic performance in terms of profitability and market channels	• Literature • Key informants (e.g., farmers, agro-economist, and agroforestry expert) • Information about P/L model (Agro-economist)	Desk Study to collect secondary info. Semi-structured interviews	• Financial statement(P&L model) for the monoculture systems and crop-tree combination • Spider plots to compare the economic profitability of crop-tree combination and monoculture system • The prices, costs, and revenues were summarized. • Radar Charts were used to see which variables in a dataset are scoring high or low, making them ideal for presenting the differences between mono-crop cultivation and crop-tree combination economic performance.
Sub-Q III. Crop-tree combination environmental benefit in terms of soil fertility	• Literature • Key informants (e.g., farmers, agro-ecologist, and agroforestry expert)	Desk Study to collect secondary info.	• Spider plots to compare crop-tree combination environmental benefit (soil fertility) • Literature review and expert opinion were used to identify, scale and compare environmental benefit in terms of soil fertility between monoculture situation and crop-tree combination.

[1]Laws et al. (2013) core process:

- Making categories of the answers and numbering the interviewees.
- The categories based on the sub-questions and the code of interviewees will be inserted in a table and, each interviewee's responses will be filled horizontally per category.
- The categories will be analyzed in a vertical form, to identify the contradictions and agreements among the interviewee's answers.
- The last step of this process was to analyze to which extent the categories answered the research questions.

3.6.1. Research framework

Figure 3: Research framework



3.8. Research limitations

Due to the limited time of this research, the measurement of the environmental benefit of crop-tree combination measurement was not feasible which influenced answering the third research sub-question. Besides, gathering reliable information of a second annual crop through desk study was not rational, because for P/L Model calculation and assessing the profitability, actual and reliable numbers through a study case are required. Besides, finding another farmer who is cultivating another annual crop was not possible which affected the selection of the second annual crop for crop-tree combination in the SAF system.

Chapter 4. Findings

4.1. Introduction

The information of this chapter was obtained from key informant interviews, field observations, and desk study. Narrative and descriptive data were acquired, analyzed, and summarized to provide a comprehensive picture of crop-tree combination selection, profitability, and its environmental benefit in terms of soil fertility.

4.2. Observations

4.2.1. Hazelnut producer

The nut orchard is located in Huissen, Gelderland, the Netherlands. He is a producer of small quantities of hazelnut and walnut. He produces walnut and hazelnut grafted plants. The farmer has divided his orchard into different sections and allocated each section to experiment with the synergy and competition between different annual crops, shrubs, and trees. The farmer has planted nut trees in rows and is experimenting with different crops cultivation between tree rows. In addition, the nut producer does not use any chemical fertilizer and pesticides because the improved biodiversity helps the biological control of pests and diseases. Besides, combining trees and other plants improves the soil nutrients availability.

Securing hazelnut trees is observed in the orchard by using two posts for each hazelnut tree to keep the tree's shape stable. In the orchard, the farmer has used 6 by 3 meters plant distancing for the hazelnut and he has used different varieties in different planting rows due to the better pollination of hazelnut trees. The farmer does not use machinery for planting and harvesting due to the low quantity of production and he hires laborers to do the mentioned activities manually.

The nut producer has allocated a small building for the processing and selling the nuts, their oil and other products directly to the customers who come to the orchard to visit his experiments about different crops and nut orchards. The farmer has to use this channel because he does not produce in large quantities (see annex 22).

4.2.2. Study case farm

The farm that was decided to be used as a study case in this research is located in Didam, Gelderland, the Netherlands. The farmer is living at the farm with his family. The farmer has 50 hectares of land in total. He allocated 2 hectares in total to white and red cabbage production and 4 hectares to fodder beet production biologically. The rest of the land is grassland. The type of soil in this study case is clay. The farmer has the cattle and uses fodder beet as fodder for his cattle. The farmer cultivates cabbage biologically. He planted cabbages in 3 meters rows and he made a 1,5 meters distance between the rows. He uses this 1.5 meters to plant herbs as biological control of pests and diseases. The farmer is using a drip irrigation system.

According to the observations, the farm has two buildings. they have been constructed by the farmer's own capital. The main building is allocated for administrative activities, meetings, etc. However, the farm has another building next to the main building that is used as storage and a place for tractors and equipment and the building has the capacity for a cooling system installation and storage of more products. The farmer uses part of the land to produce solid manure and compost for his production.

It is observed that the farmer is using the grasslands for his neighbor's cattle grazing and it is a source of money for him. The farmer intends to allocate 13 hectares of his land to the AF system but he wants to experiment in 2 hectares first.

Regarding the machinery and equipment, the farmer has two tractors, a sowing machine, fertilizer spreader, and cultivating machinery. The farmer uses plastic crates for cabbage harvest and hauling (see annex 23).

4.3. Compatibility of cabbage and hazelnut

The information regarding hazelnut and cabbage growing requirements, competition and synergy, and farm management activities were obtained from different literature and the interview with the nut producer (Herman Jansen), cabbage producer (Theo Nieuwenhuis), and agroforestry expert and researcher (Rene Van Druenen and Ton Baltissen).

Currently, most of the experience regarding the combination of annual crops and trees in the Netherlands has just started up by Universities such as the University of Wageningen (Van Druenen, 2021). Experimenting is done with combinations of crops and nuts such as hazelnut and walnut. Hence, there is not a lot of information about a compatible crop with hazelnut trees. In total, there are six producers and 15 hectares of land in the Netherlands that have started experimenting and producing nuts such as hazelnut in arable land.

Hazelnut and walnut are suitable trees for agroforestry systems in the Netherlands based on the climate condition and marketability of the products (Jansen, 2021). In terms of compatibility with vegetables, hazelnut is recommended rather than walnut (Baltissen, 2021). The first reason is the walnut tree's allelopathy which can act as an obstacle to crop growth. The second reason is the canopy diameter. According to Baltissen (2021), the hazelnut has less canopy diameter (1.5 meters on each side) when it is fully grown compared to walnut (3 to 5 meters on each side). In agroforestry systems availability of sunlight is important for the crop which is going to be combined with trees, hence hazelnut is more suitable for combination with vegetables in AF systems. Moreover, hazelnut is recommended for AF systems due to the marketability of hazelnuts in the Netherlands (Baltissen, 2021). Besides, the first harvest time for hazelnut is shorter than walnut which makes it suitable in terms of profitability in AF systems.

Clay soil is very suitable for hazelnut trees and the proper soil PH is between 6 to 6.5 (Jansen, 2021). The water consumption of hazelnut trees depends on the age and size of the trees. Enough availability of water in the first 5 years increases the production. Nematodes and insects are the main pests and diseases that affect production. In hazelnut biological production, natural controls are recommended but some of them such as bird nests are costly. Hazelnut trees are not sensitive to the availability of sunlight and they thrive in mid shade conditions. In organic production, organic fertilizers such as compost can provide essential nutrients for the tree.

Hazelnut varieties selection is important because hazelnut pollination affects the flowering and the yield of the trees. To have a successful hazelnut production, planting different varieties is necessary. Emoa1, 2, or 3, and Corabel are the recommended main varieties due to their compatibility with the Dutch climate condition in terms of frost damage, susceptibility to diseases, and the market demand for round hazelnuts. However, Cosford, Gustav's Zeller, Lang Tidling Zeller, and Riccia di Talanico are the varieties that can be used as pollinators (Wertheim and Baltissen, 2020). For detailed percentage of the main and pollinators varieties in variety selection see annex 1.

Regarding the planting season of hazelnut seedlings, plants grown in pots may be planted at any time of year, although it is ideal to do it during the winter dormant period when the soil is not frozen or waterlogged. Late autumn or early spring is the best time to plant bare-root trees. Regarding the harvesting season, autumn is the common harvesting time for hazelnut in the Netherlands.

One of the important factors in hazelnut production management is spacing. The proper space in the agroforestry system is 6×6 and 6×5 meters and 6×3 meters is suitable for monoculture system (Baltissen, 2021). In this planting space, the competition between trees will be less. Besides, the planting of the pollinator varieties among the main varieties needs to be considered. Another important factor in management is pruning (Jansen, 2021). Hazelnut tree tends to be a bush, hence, regular pruning is necessary, especially in the first 6 years of the tree life when it comes to the crop-tree combination. Pruning labor cost is one of the main variable costs in hazelnut production but it is essential because in agroforestry systems the shape of the tree is important. According to Jansen (2021), hazelnut trees are sensitive to the wind in the first years of their life, so it is also recommended that plant some pollinator trees is planted as windbreaker trees in the hazelnut orchard.

The pre-planting activities for hazelnut production are land preparation such as soil test, weeds elimination, planting spots allocation, orchard design in terms of location of different varieties, spacing and rows allocation for the annual crop, and seedlings purchase. The main planting activities are digging holes (60cm depth), mixing compost with the soil (4 to 6 kg per tree), planting the trees, and securing the trees with posts. The main variable cost for hazelnut production is labor. When farmers want to order the seedlings, they need to consider 5 to 10 percent more seedlings as a substitution for the trees that failed to grow in the second year. According to the nut producer, the required equipment and machinery depends on the AF system and the availability of space for the machinery movement. For instance, if the space between the trees and the annual crop allows the farmer to use the harvesting machinery the harvesting labor cost will be decreased.

Table 3 below illustrates a summary of gathered information about hazelnut growing requirements and farm management activities through desk study.

Table 3: Hazelnut growing requirements (source: Desk study)

GROWING REQUIREMENTS	
SOIL TYPE	• Well-drained soil is about 1.8 m deep (Snare, 2008). • Heavy clays and very sandy soils should be avoided and a deep loam is preferred (Snare, 2008). • Fertile soils are considered essential for profitable commercial production (Snare, 2008). • High organic matter soil is preferred (İSLAM, 2018).
SOIL PH	• A neutral to slightly acid soil (pH of about 6) is suitable (Snare, 2008).
WATER	• Hazelnut trees need around 80 to 100 mm of water monthly from the end of April to the end of August (Germain and Sarraquigne, 2004). • More than 750 mm annual rainfall is required for good production, and supplementary irrigation is useful during the establishment stage (Snare, 2008).
CLIMATE	• Hazelnut needs a temperate climate for good development and productivity (İSLAM, 2018). • Temperatures below -8 °C and above +36 °C adversely affect cultivation(İSLAM, 2018). • Long periods of chilling are required to ensure fruitfulness and reliable hazelnut yields. Chilling requirements vary for male catkins, female flowers and leaf buds but about 1200 hours between 5°C and 7°C is suitable (İSLAM, 2018). • Hazelnuts do not tolerate windy conditions combined with high summer temperatures and low humidity (İSLAM, 2018).
NUTRITION	• Hazelnuts benefit from a balanced nutritional program such as annual applications of a complete NPK fertilizer (Snare, 2008). • Nitrogen, potassium and boron are the elements most commonly found deficient in hazelnuts (Snare, 2008).
MANAGEMENT	
PLANTING DISTANCE	• The selection of tree planting distances should take into account the relative vigour of the variety, the soil type and the width of implements available for use in the orchard (Snare, 2008). • 6×3m in monoculture, 6×6m and 6×5m in crop-tree combination are the preferred plant distances (Wertheim and Baltissen, 2020).
PRUNING	• Pruning in the next 2–5 years is used to produce a modified leader tree with 3–5 main branches (İSLAM, 2018).

	• With mature trees insufficient pruning can reduce shoot vigour and diminish cropping potential (İSLAM, 2018). • Hazelnut pruning operations are made in different times such as planting pruning, shape pruning, yield pruning, winter, and summer pruning two times per year (Roversi, Malvicini, Mozzone and Dilmacunal, 2009).
HARVESTING	• Harvesting time in the Netherlands is late Summer and early Autumn (Wertheim and Baltissen, 2020). • Manually by labor and using machinery such as picking machine are the common ways of harvesting (Wertheim and Baltissen, 2020).

The planting season of the white cabbage seedlings is in late May and they are harvested in September and October. The optimum soil PH for cabbage Is between 6 to 6.5 and it grows properly in clay soil. Weekly irrigation is needed for cabbage cultivation. Regarding the pests and diseases fungus, some bacteria, snails, and rabbits affect the yield which is controlled with biological control and fencing. According to the cabbage farmer, 5 to 6 hours of sunlight is needed for the cabbages and the cabbage taste then becomes sweeter which makes it more marketable. The main farm management activities of cabbage production are land preparation for transplanting the purchased seedlings, irrigation, and regular weeding.

NPK are the main required nutrients for the cabbage which are provided for the plant through using compost and solid manure in organic production. The optimum temperature for cabbage growing is between 10 to 20 ^{0}C. According to the cabbage producer planting vegetables including cabbage in SAF system is possible due to the shallow root system of these crops and after harvesting the residues of the crops can add organic matter to the soil.

Table 4 shows the summary of gathered information about cabbage growing requirements and farm management activities through desk study.

Table 4: Cabbage growing requirements (source: Desk study)

GROWING REQUIREMENTS	
SOIL TYPE	• Cabbages grow well on a wide range of soils from light sand to heavier clays. Soils with high organic matter content give the best yields (Murison, 2005). • Good drainage is important, and soils that become waterlogged after heavy rain or irrigation are unsuitable (Murison, 2005).
SOIL PH	• Cabbages require soil with a pH of 6.0–6.5 for best growth.
WATER	• Cabbages need regular irrigation to ensure rapid growth and evenness of maturity. • Soil type and weather will also influence the frequency of irrigation.
CLIMATE	The optimum temperature range for cabbage production is 15 to 20°C. Above 25°C, growth stops. • The proper temperature to grow cabbage is 55-75 °F degrees (12-23 °C) (Kelley, MacDonald and B. Adams, 2006). • The planting season is late spring (Kelley, MacDonald and B. Adams, 2006).
NUTRITION	• Soil analysis prior to applying fertilizers is strongly advisable (Murison, 2005). • As cabbages benefit from high levels of organic matter, it is suggested that animal manure (if available) be the basis of the fertilizer program (Murison, 2005).

	• Phosphorus (as superphosphate) is essential and must be applied in the root zone before transplanting (Murison, 2005). • Nitrogen, Phosphorus and Potassium are the main required nutrients (Kelley, MacDonald and B. Adams, 2006).
MANAGEMENT	
PLANTING DISTANCE	• A spacing of 40–60 cm is used on single-row plantings where the rows are 1 m apart. Narrower plantings are used where smaller-sized cabbages are produced. A favored density is 20,000 plants/ha (Murison, 2005).
TRANSPLANTING	• Transplanting is carried out by machines and manually by labor (Murison, 2005). • A good watering immediately after transplanting is essential to ensure that the young plants become well established (Murison, 2005).
WEED CONTROL	• By hand in biological production.
HARVESTING	• Harvesting time is late Summer and early Autumn (Murison, 2005). • A cabbage is mature when the head is firm to the touch. Heads firm gradually until they become hard. After a period they will split and the cabbage is then not suitable for sale (Murison, 2005). • Cutting is usually carried out in the morning when the cabbage is at its coolest temperature (Murison, 2005). •

In terms of competition and synergy of the hazelnut tree and cabbage, according to Baltissen (2021), there is limited competition for water and nutrients because the crop and the tree have different root systems. The synergy can be the improvement of the soil quality by hazelnut tree which makes the situation appropriate for the cabbage to grow better. Of course, all these assumptions are in the situation that the soil is fertile and water is available for both tree and crop. According to agroforestry expert (Van Druenen, 2021), falling tree leaves and also the crop residues after annual harvesting add organic matter to the soil which after decomposition in the soil provides nutrients such as nitrogen and micronutrients for cabbages and hazelnut trees. Another synergy that is expected from the crop-tree combination is biodiversity in the farm which helps to control pests and diseases in a biological situation.

4.4. Economic performance of hazelnut and cabbage combination in terms of profitability

Shifting to an agroforestry system needs a lot of investment such as new machinery, labor costs, and seedling, but after 8 or 10 years these systems will be profitable (Baltissen, 2021). Farmers, through these systems, cannot gain profit from the hazelnut production in the first couple of years, so the cultivation of an annual crop can compensate for a part of their investment in these systems.

In hazelnut production, in the third and fourth year, the trees start the production but only 10% of the fully grown tree. After the 7th year, they will have full production. According to the nut producer Jansen (2021), if the hazelnut tree grows in fertile soil and water is available for the tree, the average yield in a monoculture orchard situation is between 3 to 4 kg per tree when the trees are fully grown. But in an organic AF system which is, the production is expected to be between 3 to 3.5 kg per tree. Also, in general, the weight percentage of the nuts shell is between 40 to 60 percent (50% on average). According to (Baltissen, 2021), the wholesale price in the Netherlands for hazelnut with shell is 4 Euros/kg and for hazelnut without shell is 10 Euros/kg on average. If the farmers do some processing such as shelling the nuts and package them to sell directly to the local consumers the average price per kg will be 18-19 Euros per kg. Depending on the farmers' financial situation that whether they can invest in machinery and equipment, there are several ways of processing and adding value to the hazelnut. One of which is processing the nuts to hazelnut oil. To produce one-liter hazelnut oil which should be done by cold press machine to gain a high-quality oil, 20kg hazelnut without shell is needed. The price of hazelnut oil is 40-50 Euros per liter.

According to Wertheim and Baltissen (2020), to obtain optimum production in a monoculture system, the proper planting distance is 6×3 meters and for the crop-tree combination, the proper plant distancing is 6×5 or 6×6 meters. In the crop-tree combination, the distance is recommended to be increased to reduce the competition between annual crops and trees.

Seedling purchase and labor costs are the main costs of hazelnut cultivation. According to Wertheim and Baltissen (2020) and Jansen (2021), the average price of two years old grafted trees in the pot in the Netherlands is 11.25 Euros per tree. Besides, transplanting and Pruning are labor-intensive activities in hazelnut production.

Table 5 below shows different labor costs per hectare for different stages and years of hazelnut production based on Jansen's experience and the information that is gathered within the last five years by Wertheim and Baltissen (2020) . The numbers are based on 6 by 6 plant distancing and 556 trees per hectare.

Table 5: Labor costs in hazelnut production

Activity	Required hours	Price/hour	Amount/hectare
Cleaning the orchard	2	€ 20,00	€ 40
Digging and planting	16	€ 20,00	€ 320
Secure the trees Year 1	6	€ 20,00	€ 120
Secure the trees Year 2-6	2	€ 20,00	€ 40
Fertilization First year	3	€ 20,00	€ 60
Fertilization Year 2 afterwards	2	€ 20,00	€ 40
Weeding	6	€ 20,00	€ 120
Pruning year 1 to 5	24	€ 30,00	€ 720
Pruning year 5 afterwards	20	€ 30,00	€ 600
Harvesting year 4	2	€ 30,00	€ 60
Harvesting year 5	4	€ 30,00	€ 120
Harvesting year 6	6	€ 30,00	€ 180
Harvesting year 7	9	€ 30,00	€ 270
Harvesting full production	12	€ 30,00	€ 360

Source: (Wertheim and Baltissen, 2020); (Jansen, 2021); compiled by the author

The cabbage farmer (study case) has planted 2 hectares of white and red cabbages in total, 4 hectares of fodder beet for his cattle and the rest of the farm is grass. The total land is 50 hectares. He would like to allocate 2 hectares of his land to the agroforestry system and he is willing to plant hazelnut trees. He would like to plant cabbages in between tree rows in the agroforestry system because he has experience in cabbage cultivation.

The expected yield for cabbage is 30 to 35 tons of cabbages per hectare in the monocropping system. If the nutrients, water, and light are available for cabbage, the yield in the crop-tree combination will be the same as the monoculture system. The farmer would like to plant annual crops (cabbage) in the agroforestry system because he thinks that trees take time to reach the full production stage and there is a need for planting annual crops between rows in the SAF system to compensate for the investment in planting trees economically.

The farmer would like to invest 20,000 to 25,000 Euros in the agroforestry system with his capital. He is the owner of the land and he does not use any mortgage. The farm has two buildings that can be used as storage for hazelnuts and cabbages. Regarding the machinery, the farmer has two tractors which he bought for 25,000 Euros in total. In addition, he has other equipment such as a sowing machine, cultivating machinery, and manure spreader that are worth 11,000 Euros in total. The farmer has two buildings constructed and he invested 450,000 Euros for them. For biological production, the farmer pays 1200 Euros annually for 50 hectares of land for the certificate and he does not pay anything for insurances. Regarding the harvesting equipment, the farmer has crates and scissors which he bought for 250 Euros in total. Besides he needs to invest in hazelnut harvesting equipment and machinery such as shelling machine, picking machine, etc. for the agroforestry system. According to the farmer, labor cost is a big part of the cabbage production costs. He hires 7 temporary laborers (30 Euros/hour) for 2 hectares transplanting cabbage plants and it takes two days, each day 8 hours. Besides, he hires 8 temporary laborers (30 Euros/hour) for 2 hectares harvesting the cabbages and it takes two days, each day 8 hours. Weeding is also a part of labor cost which needs 2 temporary laborers (20 Euros/hour) each of which works 4 hours for one hectare. The total costs for utility expenses like fuel, electricity, etc. for 2 ha/year is € 748 (see annex 24).

The farmer buys 37,000 cabbage seedlings for transplanting, 4,000 of which is considered as replacement. He pays 5,800 Euros for two hectares of cabbage planting material per year. The plant spacing that he uses is 50×60 cm to obtain bigger cabbages. The land preparation, leveling, making rows, and spreading the fertilizers (compost and solid manure) for transplanting is done by the tractor.

After harvesting, the weight of each cabbage is 1,200 grams on average and they are sold to a cooperative for 0.35 Euros per cabbage. Besides, the farmer also receives 250 Euros per hectare agriculture subsidy from the Government which applies to all Dutch farmers in the Netherlands. According to the farmer, due to biological production, 5% of production is lost. After deduction of the yield loss, he sells 62 to 63 thousand cabbages per year for 2 hectares in total to the cooperative. The farmer does not pay for transportation and the cooperative collects the cabbages from the farm gate by itself and it pays after the collection. The cooperative then distributes among retailers by itself.

4.5. Profit and loss model

The P/L model was designed to calculate and compare the profitability of hazelnut and cabbage in the monoculture farming system and SAF system through the actual data gathered from the study case and nut producer interviews and observations. But, the information from the key informant interview with the agro-economist about the model was used to calculate profit and loss accurately.

Assumptions and allocations: Table 6 below illustrates the assumptions in the profit and loss model and their sources. The rest of the used numbers in the profit and loss model are the actual numbers gathered through interviews and observations.

Table 6:P/L model assumptions

Assumption	Source of data
5 % yield loss	• (Nieuwenhuis, 2021) • (Wertheim and Baltissen, 2020)
Irrigation system and its annual cost	• (Netafim company, 2021)
Tree stakes	• (Target.com, 2021)
Shelling machine	• (Shellingmachine.com, 2021)
Picking machine	• (Agriexpo.online, 2021)
Hazelnut pruning equipment	• (Target.com, 2021)
Accountant yearly salary in the Netherlands	• (Glassdoor.nl, 2021)

Regarding the allocations, the study case has 50 hectares of land in total and the farmer intends to allocate 2 hectares of land to the AF system, Hence a number of costs such as depreciation and maintenance costs, accountant salary, and utility costs were calculated based on *4 percent allocation*. Moreover, in the hazelnut monoculture and crop-tree combination P/L models, the costs of required seedlings and the new machinery and equipment for hazelnut harvesting and cracking the nuts were depreciated (annualized) to the number of years (10 years for seedlings and 6 years for machinery and equipment) to show the overall profitability of the system.

4.5.1. Hazelnut monoculture system P/L model

The hazelnut in a monoculture system P/L model was designed based on gathered information from Jansen (2021) and Wertheim and Balitssen (2020), calculated and compiled by the author. There are two different scenarios for hazelnut production in a monoculture system including hazelnut with shell and without shell. In the monoculture system, the optimum planting distance is 6×3m (556 trees/ha) to achieve the highest production (Jansen, 2021).

4.5.1.1. Annual revenues (hazelnut with shell)

Table 7 below shows the calculation of **hazelnut with shell** yield per hectare and in total for 2 hectares in different years.

Table 7:Hazelnut with shell yield (monoculture system)

Hazelnut yield		**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
Item	**Unit**				(10%)	(30%)	(60%)	(80%)	(100%)	(100%)	(100%)
Volume	Kg/tree	0	0	0	0,3	0,9	2	2,6	3,3	3,3	3,3
Land	Ha	2	2	2	2	2	2	2	2	2	2
No. of trees	Number	556	556	556	556	556	556	556	556	556	556
Yield loss (5%)	Kg/ha	0	0	0	8	25	56	72	92	92	92
Total volume/ha	Kg	0	0	0	158	475	1.056	1.373	1.743	1.743	1.743
Total volume	Kg	**0**	**0**	**0**	**317**	**951**	**2.113**	**2.747**	**3.486**	**3.486**	**3.486**

Source: (Baltissen, 2021); (Jansen, 2021); (Nieuwenhuis, 2021); (Wertheim and Baltissen, 2020), compiled by the author

According to Wertheim and Balitssen (2020) and Jansen (2021) the lowest wholesale price of hazelnut with shell per kg (**€ 3,50**) and the highest wholesale price per kg (**€ 4,50**). The average of two prices is **€ 4,00** per kg**.**

The total annual revenues of hazelnut **with shell** per year for the first period of 10 years was calculated based on the price per kg, total yield for 2 hectares of land for the first 10 years of production, and a subsidy received yearly for the land. According to Nieuwenhuis (2021), 250 Euros is received as a subsidy for the land per hectare. Table 8 shows the total revenues per year of hazelnut with shell production in the monoculture system.

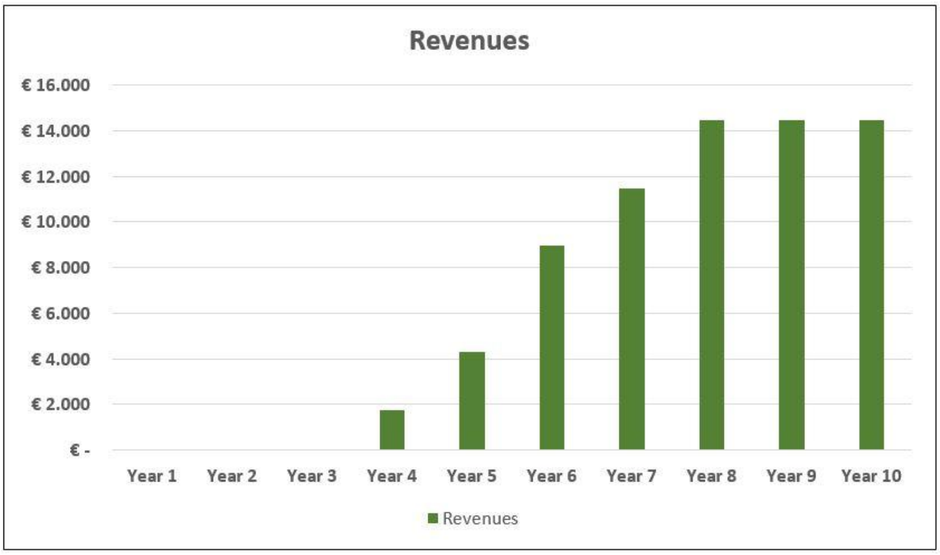
Table 8:Hazelnut with shell total revenues/year (monoculture system)

Hazelnut total revenues/year		**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
					(10%)	(30%)	(60%)	(80%)	(100%)	(100%)	(100%)
Annual revenue		0	0	0	€ 1.268	€ 3.803	€ 8.451	€ 10.987	€ 13.944	€ 13.944	€ 13.944
Subsidy for 2 hectares		€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500
Total Revenues		**€ 500**	**€ 500**	**€ 500**	**€ 1.768**	**€ 4.303**	**€ 8.951**	**€ 11.487**	**€ 14.444**	**€ 14.444**	**€ 14.444**

Source: Compiled by the author

Figure 4 below illustrates the trend of annual revenues of hazelnut **with shell** in the monoculture system for the first period of 10 years because the revenues of the first years are very different from other 10 years periods.

Figure 4: Hazelnut with shell annual revenue trend (monoculture system)



There is no production in the first three years so there is no revenue. The production starts in the fourth year with 10% of the fully grown tree production and increases annually up to the 8th year, where the production of hazelnut trees remains constant until year 10.

4.5.1.2. Annual revenues (hazelnut without shell)

According to Jansen (2021), the weight of hazelnut without shell is about 50 percent of the hazelnut with shell. The yield of hazelnut without shell in the monoculture system was calculated separately to obtain the total volume of hazelnut after shelling for 2 hectares of land. Table 9 illustrates the calculation of hazelnut without shell yield per hectare and in total for 2 hectares for the first period of 10 years.

Table 9: Hazelnut without shell yield (monoculture system)

Hazelnut yield		**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
Item	Unit				(10%)	(30%)	(60%)	(80%)	(100%)	(100%)	(100%)
Volume	Kg/tree	0	0	0	0,16	0,48	0,96	1,3	1,6	1,6	1,6
Land	Ha	2	2	2	2	2	2	2	2	2	2
No. of trees	Number	556	556	556	556	556	556	556	556	556	556
Yield loss (5%)	Kg/ha	0	0	0	4	13	27	36	44	44	44
Total volume/ha	Kg	0	0	0	85	254	507	687	845	845	845
Total volume	Kg	**0**	**0**	**0**	**169**	**507**	**1.014**	**1.373**	**1.690**	**1.690**	**1.690**

Source: (Baltissen, 2021); (Jansen, 2021); (Nieuwenhuis, 2021); (Wertheim and Baltissen, 2020), compiled by the author

The lowest (**€ 9,00**) and the highest (**€ 11,00**) are the wholesale price of hazelnut without shell per kg in the Netherlands (Wertheim and Balitssen, 2020) and (Jansen, 2021). The average of two prices (**€ 10,00/kg**) was used as the wholesale price in the hazelnut monoculture system's P/L model calculations.

The total annual revenues of hazelnut without shell per year for the first period of 10 years was calculated based on the price per kg, total yield for 2 hectares of land, and a subsidy received yearly for the land. According to Nieuwenhuis (2021), 250 Euros is received as a subsidy for the land per hectare.

Table 10 illustrates the total revenues per year of hazelnut without shell production in the monoculture system.

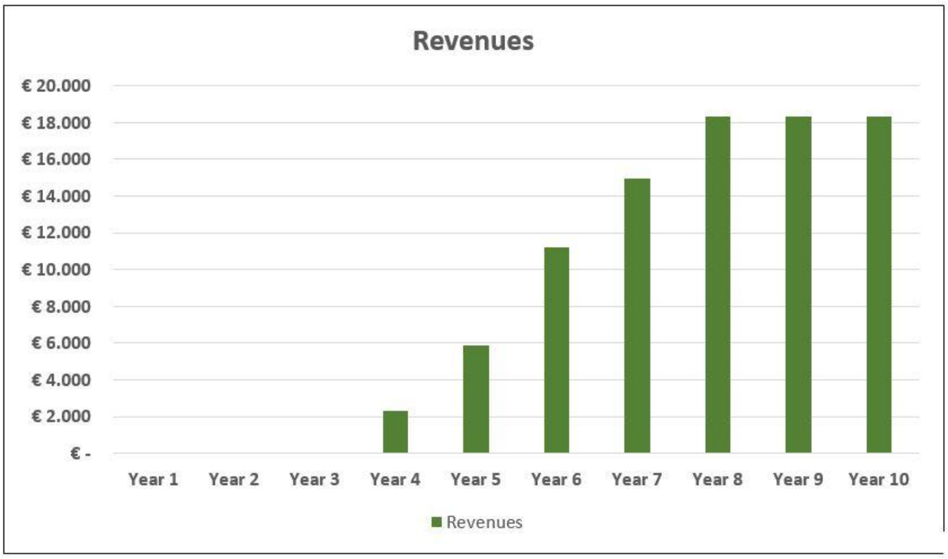
Table 10: Hazelnut without shell total revenues/year (monoculture system)

Hazelnut total revenues/year	**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
				(10%)	(30%)	(60%)	(80%)	(100%)	(100%)	(100%)
Annual revenue	0	0	0	€ 1.779	€ 5.338	€ 10.675	€ 14.456	€ 17.792	€ 17.792	€ 17.792
Subsidy for 2 hectares	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500
Total Revenues	**€ 500**	**€ 500**	**€ 500**	**€ 2.279**	**€ 5.838**	**€ 11.175**	**€ 14.956**	**€ 18.292**	**€ 18.292**	**€ 18.292**

Source: Compiled by the author

Figure 5 below shows the trend of annual revenues of hazelnut **without shell** in the monoculture system for the first period of 10 years because the revenues of the first years are very different from other 10 years periods.

Figure 5:Hazelnut without shell annual revenue trend (monoculture system)



There is no production in the first three years so there is no revenue. The production starts in the fourth year with 10% of the fully grown tree production and increases annually up to the 8th year, where the production of hazelnut trees remains constant until year 10.

4.5.1.3. Annual costs and net profit (hazelnut with shell)

The annual cost of goods sold (COGS) for 2 hectares of land was calculated based on the information gathered from Wertheim and Balitssen (2020) and Jansen (2021). The calculated annual COGS includes purchases (**€ 25.069**) and labor costs (**€ 6.100**) for different required activities of different years (see annex 2).

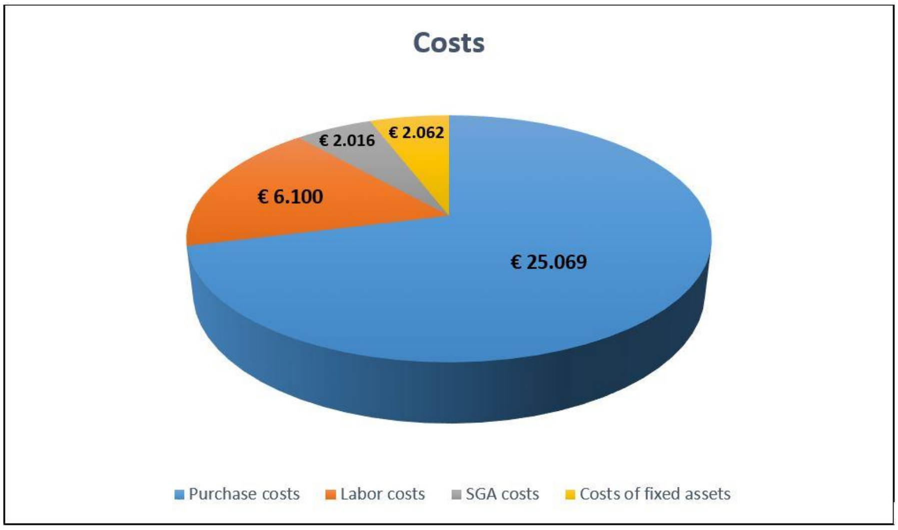
In order to calculate the costs of fixed assets in the hazelnut with shell scenario, data were gathered from different sources (Nieuwenhuis, 2021, Netafim company, 2021, Agriexpo.online, 2021 and Target.com, 2021), see annex 3. The total fixed assets of the farmer were found to be **€ 674.410** by the author.

The annual costs for fixed assets (**€ 2.062**) for hazelnut with shell scenario, depreciation (**€ 1.418**) and maintenance (**€ 644**), were calculated per year based on the value of the assets, the expected life of the assets, maintenance cost percentage, and the allocation percent for 2 hectares of land (see annex 4).

The selling, general, and administrative (SGA) annual costs (**€ 2.016**) including utility (**€ 748**) and other general and administrative costs (**€ 1.268**) per year were calculated based on the information gathered from the farmer (study case) and allocation percent for 2 hectares of land (see annex 5).

Figure 6 shows the different types of costs for hazelnut production **with shell** in the monoculture system per year. Purchase (71%) and labor costs (17.30%) are the main costs incurred.

Figure 6:Hazelnut with shell production costs per year per 2ha (monoculture system)



The total annual costs for the first period of 10 years were calculated based on the annual COGS costs which are annualized (see annex 25), annual costs of the fixed assets, and annual SGA costs.

Table 11 shows the total annual costs of hazelnut **with shell** production in a monoculture system.

Table 11: Hazelnut with shell total annual costs (monoculture system)

	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
COGS	€ 4.282	€ 4.678	€ 4.678	€ 5.598	€ 5.218	€ 5.018	€ 5.198	€ 5.378	€ 5.378	€ 5.378
SGA costs	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016
Depreciation and maintenance	€ 1.522	€ 1.522	€ 1.522	€ 2.062	€ 2.062	€ 2.062	€ 2.062	€ 2.062	€ 2.062	€ 2.062
Total costs	**€ 7.820**	**€ 8.216**	**€ 8.216**	**€ 9.676**	**€ 9.296**	**€ 9.096**	**€ 9.276**	**€ 9.456**	**€ 9.456**	**€ 9.456**

Source: Compiled by the author

The annual gross margin for a period of 10 years was calculated based on the annual revenues and annual COGS. Table 12 shows the annual gross margin of hazelnut **with shell** production in a monoculture system.

Table 12: Annual gross margin for hazelnut with shell (monoculture system)

	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
Revenues	€ 500	€ 500	€ 500	€ 1.768	€ 4.303	€ 8.951	€11.487	€14.444	€14.444	€14.444
COGS	€ 4.282	€ 4.678	€ 4.678	€ 5.598	€ 5.218	€ 5.018	€ 5.198	€ 5.378	€ 5.378	€ 5.378
Gross margin	**€ -3.782**	**€ -4.178**	**€ -4.178**	**€ -3.831**	**€ -915**	**€ 3.933**	**€ 6.288**	**€ 9.066**	**€ 9.066**	**€ 9.066**

Calculated annual gross margin, COGS, SGA costs, and costs of fixed assets were used to calculate the annual net profit before tax and cost price of hazelnut with shell production in the monoculture system. Table 13 illustrates an overview of the P/L model of the hazelnut with shell production in a monoculture system for 10 years.

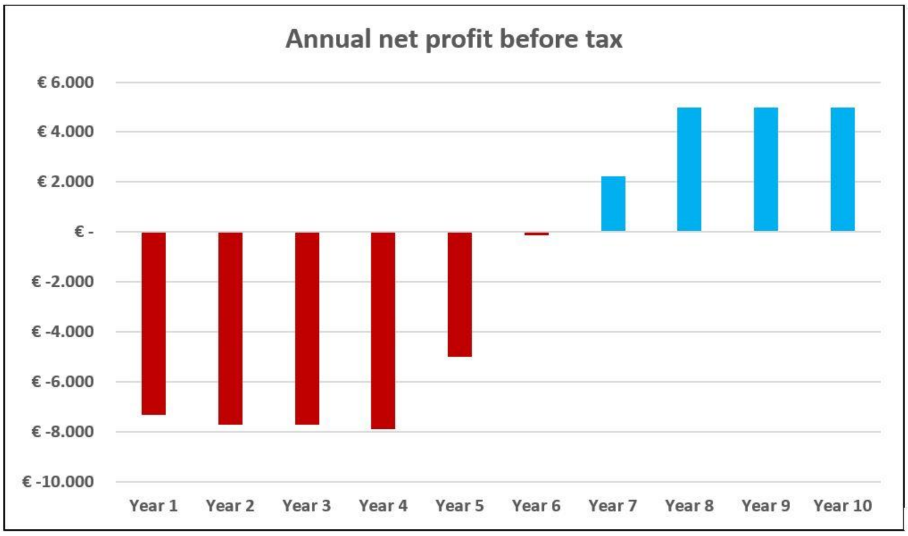
Table 13:Hazelnut with shell production P/L model overview

Overview	**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
Revenues	€ 500	€ 500	€ 500	€ 1.768	€ 4.303	€ 8.951	€ 11.487	€ 14.444	€ 14.444	€ 14.444
COGS	€ 4.282	€ 4.678	€ 4.678	€ 5.598	€ 5.218	€ 5.018	€ 5.198	€ 5.378	€ 5.378	€ 5.378
Gross margin	€ -3.782	€ -4.178	€ -4.178	€ -3.831	€ -915	€ 3.933	€ 6.288	€ 9.066	€ 9.066	€ 9.066
SGA costs	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016
Earnings before interest, tax and depreciation (EBITD)	€ -5.798	€ -6.194	€ -6.194	€ -5.846	€ -2.931	€ 1.917	€ 4.273	€ 7.051	€ 7.051	€ 7.051
Depreciation and maintenance	€ 1.522	€ 1.522	€ 1.522	€ 2.062	€ 2.062	€ 2.062	€ 2.062	€ 2.062	€ 2.062	€ 2.062
Net profit before Tax	**€ -7.320**	**€ -7.716**	**€ -7.716**	**€-7.908**	**€-4.993**	**€ -145**	**€ 2.211**	**€ 4.989**	**€ 4.989**	**€4.989**
Cost price/kg	N/A	N/A	N/A	€ 24.02	€ 7.61	€ 3.33	€ 2.63	€ 2.12	€ 2.12	€ 2.12

Source: Compiled by the author

Figure 7 illustrates the trend of annual net profit before tax of hazelnut with shell production for a period of 10 years in the monoculture system. The annual net profit before tax for the first 6 years of hazelnut with shell production in the monoculture system is negative due to the low production and high costs of labor and purchases. The production of hazelnut trees starts from the 4th year and the revenues cover the annual costs of production. Hence, the annual net profit before tax after the 7th year becomes positive and after the 8th year remains constant. Moreover, 14 years after planting the trees is the pay-back point, after which the farmer is compensated for earlier loss.

Figure 7:Annual net profit before tax of hazelnut with shell production (monoculture system)



4.5.1.4. Annual costs and net profit (hazelnut without shell)

The annual COGS for 2 hectares of land in the hazelnut without shell scenario was also calculated based on the information gathered from Wertheim and Balitssen (2020) and Jansen (2021). The calculated annual COGS includes purchases (**€ 27.069**) and labor costs (**€ 6.100**) for different required activities of different years (see annex 6). These costs were higher due to the costs for shelling.

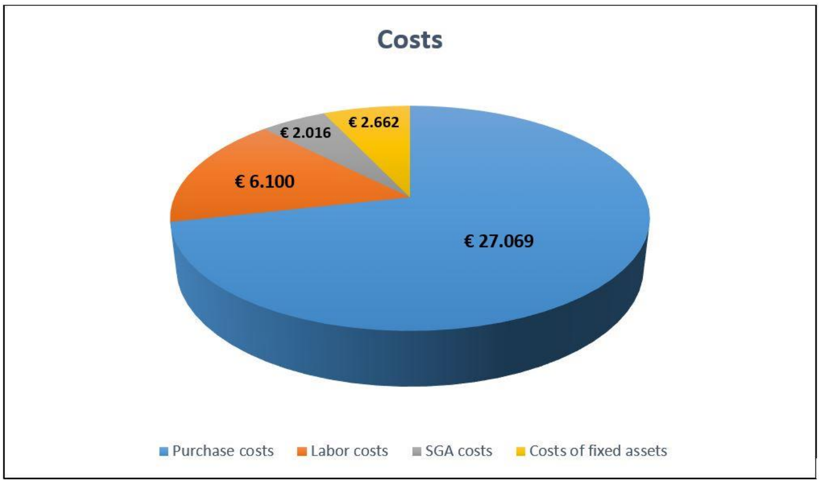
In order to calculate the costs of fixed assets in hazelnut without shell scenario, the information as shown in annex 7 was gathered from different sources (Nieuwenhuis, 2021, Netafim company, 2021, Agriexpo.online, 2021, Shellingmachine.com, 2021 and Target.com, 2021) which was later compiled by the author to give the summary of the total fixed assets of the farmer (**€ 676.410**).

The annual costs of fixed assets (**€ 2.662**) including depreciation (**€ 1.818**) and maintenance (**€ 844**) were calculated per year based on the value of the assets, the expected life of the assets, maintenance cost percentage, and the allocation percent for 2 hectares of land (see annex 8).

The SGA annual costs including utility (**€ 748**) and other general and administrative costs (**€ 1.268**) per year were calculated based on the information gathered from the farmer (study case) and allocation percent for 2 hectares of land (see annex 9).

Figure 8 shows the different costs of hazelnut **without shell** production in the monoculture system. Purchase and labor costs.

Figure 8:Hazelnut without shell production costs per year per 2ha (monoculture system)



The total annual costs for the first period of 10 years were calculated based on the annual COGS costs which are annualized (see annex 25), annual costs of the fixed assets, and annual SGA costs. Table 16 shows the total annual costs of hazelnut without shell production in a monoculture system.

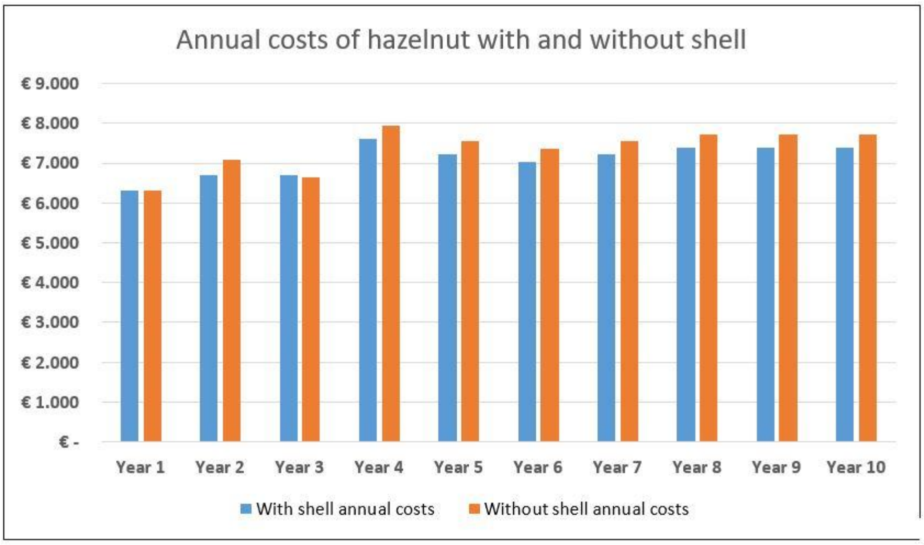
Table 14:Hazelnut without shell total annual costs (monoculture system)

	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
COGS	€4.282	€ 5.072	€ 4.622	€ 5.932	€ 5.552	€ 5.352	€ 5.532	€5.712	€ 5.712	€5.712
SGA costs	€2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€2.016	€2.016
Depreciation and maintenance	€1.522	€ 1.522	€ 1.522	€ 2.662	€ 2.662	€ 2.662	€ 2.662	€ 2.662	€ 2.662	€2.662
Total costs	**€7.820**	**€8.216**	**€8.216**	**€9.676**	**€9.296**	**€9.096**	**€9.276**	**€9.456**	**€9.456**	**€9.456**

Hazelnut annual costs comparison

Figure 9 illustrates the annual total costs of hazelnut production in the monoculture system and two different scenarios (with and without shell). The total cost of hazelnut without shell production is more than hazelnut with shell due to the purchase of additional machinery such as shelling machine. Besides, the total costs in year 4 are the highest in two scenarios due to the start of production which requires labor, purchases, and equipment costs

Figure 9:Annual total costs of hazelnut (with and without shell) production (monoculture system)



The annual gross margin for the first period of 10 years was calculated based on the annual revenues and annual COGS. Table 15 shows the annual gross margin of hazelnut **without shell** production in a monoculture system.

Table 15: Annual gross margin for hazelnut without shell (monoculture system)

	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
Revenues	€ 500	€ 500	€ 500	€ 2.279	€ 5.838	€11.175	€ 14.956	€ 18.292	€ 18.292	€ 18.292
COGS	€ 4.282	€ 5.072	€ 4.622	€ 5.932	€ 5.552	€ 5.352	€ 5.532	€ 5.712	€ 5.712	€ 5.712
Gross margin	**€-3.782**	**€-4.572**	**€-4.122**	**€-3.652**	**€ 286**	**€ 5.824**	**€ 9.424**	**€ 12.580**	**€ 12.580**	**€ 12.580**

Calculated annual gross margin, COGS, SGA costs, and costs of fixed assets were used to calculate the annual net profit before tax and cost price of hazelnut without shell production in the monoculture system. Table 16 shows an overview of the P/L model of the hazelnut **without shell** production in a monoculture system for the first 10 years.

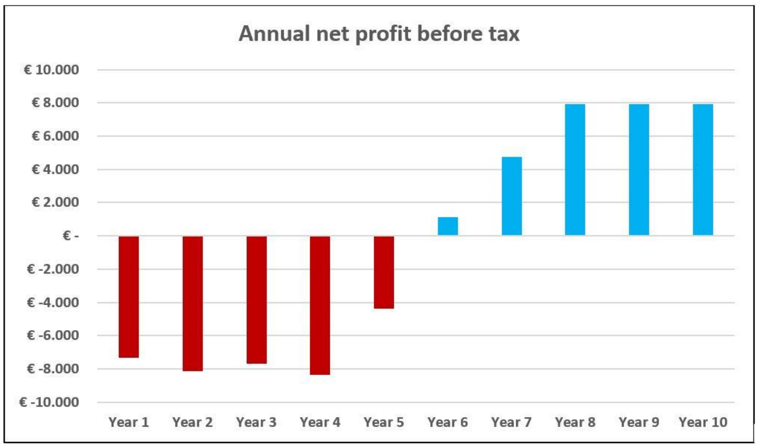
Table 16: Hazelnut without shell production P/L model overview

Overview	**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
Revenues	€ 500	€ 500	€ 500	€ 2.279	€ 5.838	€ 11.175	€ 14.956	€ 18.292	€ 18.292	€ 18.292
COGS	€ 4.282	€ 5.072	€ 4.622	€ 5.932	€ 5.552	€ 5.352	€ 5.532	€ 5.712	€ 5.712	€ 5.712
Gross margin	€ - 3.782	€ - 4.572	€ -4.122	€ -3.652	€ 286	€ 5.824	€ 9.424	€ 12.580	€ 12.580	€ 12.580
SGA costs	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016
EBITD	€ - 5.798	€ - 6.588	€ -6.138	€ -5.668	€ -1.730	€ 3.808	€ 7.409	€ 10.565	€ 10.565	€ 10.565
Depreciation and maintenance	€ 1.522	€ 1.522	€ 1.522	€ 2.662	€ 2.662	€ 2.662	€ 2.662	€ 2.662	€ 2.662	€ 2.662
Net profit before Tax	**€- 7.320**	**€- 8.110**	**€ -7.660**	**€-8.330**	**€-4.392**	**€ 1.146**	**€ 4.747**	**€ 7.903**	**€ 7.903**	**€ 7.903**
Cost price/kg	N/A	N/A	N/A	€ 45,05	€ 14,27	€ 6,94	€ 5,25	€ 4,37	€ 4,37	**€ 4,37**

Source: Compiled by the author

Figure 10 illustrates the trend of annual net profit before tax of hazelnut without shell production for a period of 10 years in the monoculture system. The annual net profit before tax for the first 5 years of hazelnut without shell production in the monoculture system is negative due to the low production and high costs of labor and purchases. The production of hazelnut trees starts from the 4th year and the revenues cover the annual costs of production. Hence, the annual net profit before tax after the 6th year becomes positive and after the 8th year remains constant. Due to the higher price of hazelnut without shell, the positive net profit begins in the 6th year compared to hazelnut with shell production for which the positive net profit starts later, namely in the 7th year. Besides, 11 years after planting the trees is the pay-back point after which the farmer is compensated for earlier loss.

Figure 10:Annual net profit before tax of hazelnut without shell production (monoculture system)



4.5.2. Cabbage monoculture P/L model

Cabbage annual production in a monoculture system P/L model was designed based on the gathered information from Nieuwenhuis (2021), calculated and compiled by the author. To obtain optimum cabbage production, the proper planting distance is 50×60 cm and the width of the rows is 3 meters (Nieuwenhuis, 2021).

Annual revenues of cabbage production (monoculture system)

Table 17 below shows the calculation of cabbage annual yield per hectare and in total for 2 hectares in the monoculture system.

Table 17: Cabbage total annual yield (monoculture system)

Cabbage yield		**Annually**
Item	**Unit**	
Volume	head/ha	33,000
Land	Ha	2
Yield loss (5%)	Kg/ha	1,650
Total volume/ha	head	31,350
Total volume	Kg	**62,700**

Source: (Nieuwenhuis, 2021), compiled by the author

According to Nieuwenhuis (2021), one head of cabbage (1200 grams on average) is sold to a cooperative for **€ 0.35**. Hence*,* the total annual revenues of cabbage production were calculated based on the price per kg, total yield for 2 hectares of land, and a subsidy received yearly for the land. According to Nieuwenhuis (2021), 250 Euros is received as a subsidy for the land per hectare. Table 18 illustrates the total revenues per year of cabbage production in the monoculture system.

Table 18: Cabbage total revenues/year (monoculture system)

Cabbage total revenues/year	**Annually**
Cabbage	€ 21.945
Subsidy for 2 hectares	€ 500
Total Revenues	**€ 22.445**

Source: Compiled by the author

Annual costs and net profit of cabbage production (monoculture system)

The annual COGS for 2 hectares of land was calculated based on the information gathered from Nieuwenhuis (2021). The calculated annual COGS includes purchases (**€ 7.280**) and labor costs (**€ 3.920**) for different required activities of production (see annex 10).

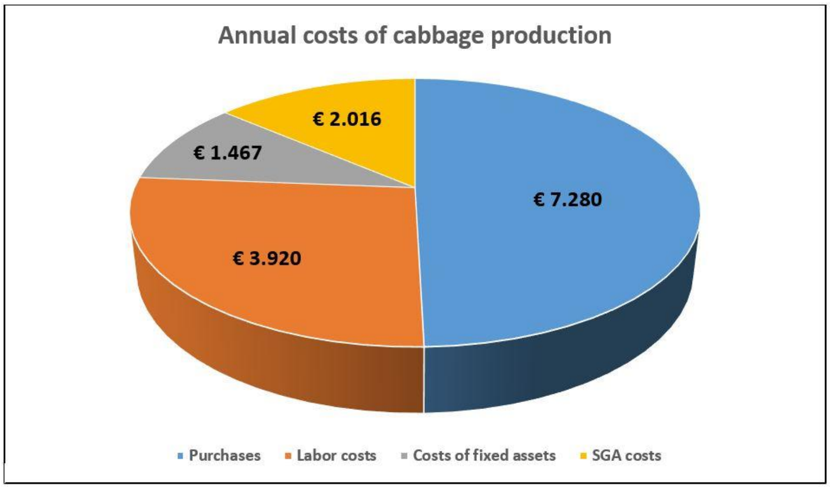
In order to calculate the costs of fixed assets, the information as illustrated in annex 11 was gathered from different sources (Nieuwenhuis, 2021 and Netafim company, 2021) which was later compiled by the author to give the summary of the total fixed assets of the farmer.

The annual costs of fixed assets (**€ 1.467**) including depreciation (**€ 1.018**) and maintenance (**€ 449**) were calculated based on the value of the assets, the expected life of the assets, maintenance cost percentage, and the allocation percent for 2 hectares of land (see annex 12).

The SGA annual costs (**€ 2.016**) including utility (**€ 748**) and other general and administrative costs (**€ 1.268**) per year were calculated based on the information gathered from the farmer (study case) and allocation percent for 2 hectares of land (see annex 13).

Figure 10 shows the different costs of cabbage production in the monoculture system. Purchase (49%) and labor costs (26.7%) are the main costs incurred in cabbage production in the monoculture system.

Figure 10:Annual costs of cabbage production (monoculture system)



The total annual costs for cabbage production were calculated based on the annual COGS costs, annual costs of the fixed assets, and annual SGA costs. Table 19 shows the total annual costs of hazelnut without shell production in a monoculture system.

Table 19: Cabbage production total annual costs (monoculture system)

	Annually
COGS	€ 11.200
SGA costs	€ 2.016
Depreciation and maintenance	€ 1.467
Total costs	**€ 14.683**

Source: Compiled by the author

The annual gross margin was calculated based on the annual revenues and annual COGS. Table 20 shows the annual gross margin of hazelnut without shell production in a monoculture system.

Table 20: Annual gross margin for cabbage production (monoculture system)

	Annually
Revenues	€ 22.445
COGS	€ 11.200
Gross margin	**€ 11.245**

Calculated annual gross margin, COGS, SGA costs, and costs of fixed assets were used to calculate the annual net profit before tax and cost price of cabbage production in the monoculture system. Table 23 demonstrates an overview of the P/L model of cabbage production in the monoculture system.

Table 21: Cabbage production P/L model overview

Overview	**Annually**
Revenues	€ 22.445
COGS	€ 11.200
Gross margin	€ 11.245
SGA costs	€ 2.016
EBITD	€ 9.229
Depreciation and maintenance	€ 1.467
Net profit before Tax	**€ 7.762**
Cost price/cabbage	**€ 13,21**

Source: Compiled by the author

4.5.3. Hazelnut and cabbage combination P/L Model

In crop-tree combination to prevent the competition between trees and the annual crop, the hazelnut trees planting distance has been increased from 6×3m in monoculture situation to 6×5m (Wertheim and Baltissen, 2020). Moreover, due to the allocation of more space for the tree's canopy in the future to make sunlight available for the cabbages when trees become mature, only 3 meters of the 6 meters distance between tree rows was allocated to the cabbage row. Hence, the calculated land for the cabbages is 0.9 hectare with a plant density of 33,000. The P/L model for hazelnut and cabbage combination was calculated based on two different scenarios which were hazelnut with shell and cabbage combination and hazelnut without shell and cabbage combination.

4.5.3.1. Annual revenues of the crop-tree combination (hazelnut with shell)

Table 22 below demonstrates the total annual yield of the hazelnut **with shell** and cabbage combination in the SAF system per hectare and in total for 2 hectares of allocated land for the SAF system for the period of 10 years.

Table 22: Hazelnut with shell and cabbage combination total annual yield (SAF system)

Annual crop-tree combination yield		Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
Item	**Unit**				(10%)	(30%)	(60%)	(80%)	(100%)	(100%)	(100%)
Volume											
Hazelnut	Kg/tree	0	0	0	0,3	0,9	2	2,6	3,3	3,3	3,3
Cabbage	Heads	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000
Land											
Hazelnut	Ha	2	2	2	2	2	2	2	2	2	2
Cabbage	Ha	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
No. of trees	Number	333	333	333	333	333	333	333	333	333	333
No. of plants	Number	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000
Yield loss (5%)	Kg/ha										
Hazelnut	Kg/tree				5	15	33	43	55	55	55
Cabbage	Heads	1,650	1,650	1,650	1,650	1,650	1,650	1,650	1,650	1,650	1,650
Total volume/ha											
Hazelnut	Kg	0	0	0	95	285	633	823	1.044	1.044	1.044
Cabbage	Kg	31,350	31,350	31,350	31,350	31,350	31,350	31,350	31,350	31,350	31,350
Total volume (Hazelnut)	**Kg**				**190**	**569**	**1.265**	**1.645**	**2.088**	**2.088**	**2.088**
Total volume (Cabbage)	**Kg**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**

Source: (Baltissen, 2021); (Jansen, 2021); (Nieuwenhuis, 2021); (Wertheim and Baltissen, 2020), compiled by the author

The average of € 3,50 (the lowest price) and € 4,50 (the highest price) of hazelnut **with shell** (€ 4,00/kg) (Baltissen, 2021, Jansen, 2021, Wertheim and Baltissen, 2020) and € 0.35 per head of cabbage (Nieuwenhuis, 2021) (1200 grams on average) was used as the wholesale price for hazelnut with shell and cabbage in SAF system's P/L model calculations.

The total annual revenues of hazelnut **with shell** and cabbage per year for the first period of 10 years was calculated based on the price per kg, total yield for 2 hectares of land, and a subsidy received yearly for the land. According to Nieuwenhuis (2021), 250 Euros is received as a subsidy for the land per hectare. Table 23 illustrates the total revenues per year of hazelnut with shell and cabbage combination in the SAF system.

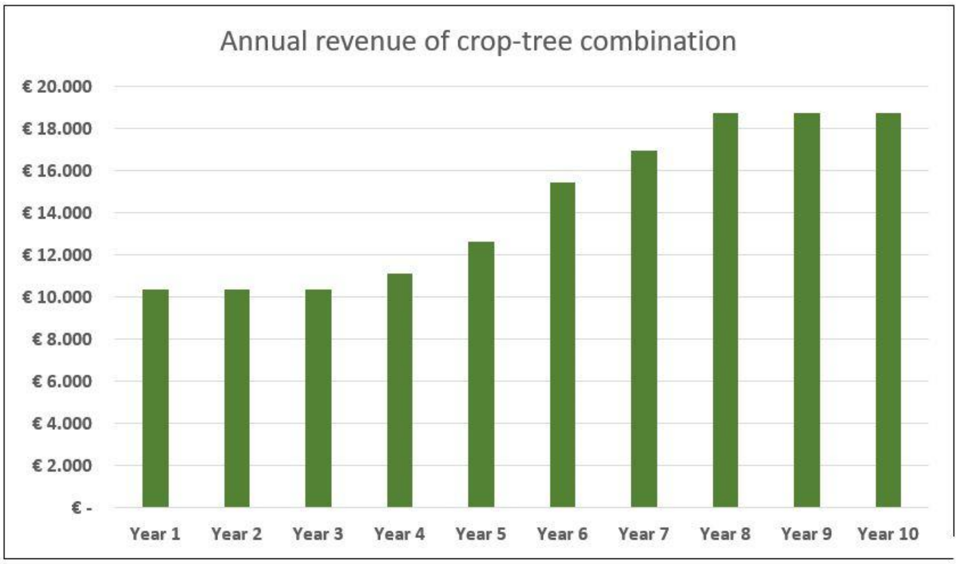
Table 23:Hazelnut with shell and cabbage combination total annual revenues (SAF system)

Hazelnut+Cabbage total revenues/year	**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
				(10%)	(30%)	(60%)	(80%)	(100%)	(100%)	(100%)
Annual revenue										
Hazelnut+Cabbage	€9.875	€9.875	€9.875	€10.634	€12.153	€14.937	€16.455	€18.227	€18.227	€ 18.227
Subsidy for 2 hectares	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500
Total Revenues	**€10.375**	**€10.375**	**€10.375**	**€11.134**	**€12.653**	**€15.437**	**€16.955**	**€18.727**	**€18.727**	**€ 18.727**

Source: Compiled by the author

Figure 11 below demonstrates the trend of annual revenues of hazelnut **with shell** and cabbage combination in the SAF system for a period of 10 years. The revenues in the SAF system start from the first year due to the cultivation of cabbages between the tree rows.

Figure 11:Annual revenues of hazelnut with shell and cabbage combination (SAF system)



4.5.3.2. Annual revenues of the crop-tree combination (hazelnut without shell)

Table 24 below illustrates the total annual yield of the hazelnut **without shell** and cabbage combination in the SAF system per hectare and in total for 2 hectares of allocated land for the SAF system for the period of 10 years.

Table 24: Hazelnut without shell and cabbage combination total annual yield (SAF system)

Hazelnut yield		**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
Item	**Unit**				(10%)	(30%)	(60%)	(80%)	(100%)	(100%)	(100%)
Volume											
Hazelnut	Kg/tree	0	0	0	0,16	0,48	0,96	1,3	1,6	1,6	1,6
Cabbage	Heads	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000
Land											
Hazelnut	Ha	2	2	2	2	2	2	2	2	2	2
Cabbage	Ha	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
No. of trees	Number	333	333	333	333	333	333	333	333	333	333
No. of plants	Number	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000
Yield loss (5%)	Kg/ha										
Hazelnut	Kg/tree				3	8	16	22	27	27	27
Cabbage	Heads	1,650	1,650	1,650	1,650	1,650	1,650	1,650	1,650	1,650	1,650
Total volume/ha											
Hazelnut	Kg	0	0	0	51	152	304	411	506	506	506
Cabbage	Kg	31,350	31,350	31,350	31,350	31,350	31,350	31,350	31,350	31,350	31,350
Total volume (Hazelnut)	**Kg**				101	304	607	823	1.012	1.012	1.012
Total volume (Cabbage)	**Kg**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**	**28,215**

Source: (Baltissen, 2021); (Jansen, 2021); (Nieuwenhuis, 2021); (Wertheim and Baltissen, 2020) and compiled by the author

The average of € 9,00 (the lowest price) and € 11.00 (the highest price) of hazelnut **without shell** (€ 10,00/kg) (Baltissen, 2021, Jansen, 2021, Wertheim and Baltissen, 2020) and € 0.35 per head of cabbage (Nieuwenhuis, 2021) (1200 grams on average) was used as the wholesale price for hazelnut with shell and cabbage in SAF system's P/L model calculations.

The total annual revenues of hazelnut **without shell** and cabbage per year for a period of 10 years was calculated based on the price per kg, total yield for 2 hectares of land, and a subsidy received yearly for the land. According to Nieuwenhuis (2021), 250 Euros is received as a subsidy for the land per hectare. Table 25 illustrates the total revenues per year of hazelnut without shell and cabbage combination in the SAF system.

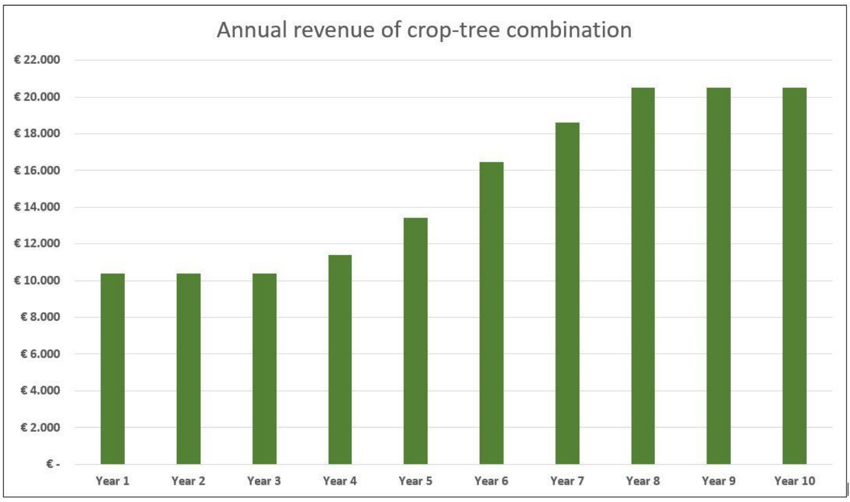
Table 25: Hazelnut without shell and cabbage combination total annual revenues (SAF system)

Hazelnut+Cabbage total revenues/year	**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
				(10%)	(30%)	(60%)	(80%)	(100%)	(100%)	(100%)
Annual revenue										
Hazelnut+Cabbage	€9.875	€9.875	€9.875	€ 10.720	€ 12.411	€ 14.946	€16.742	€ 18.326	€ 18.326	€ 18.326
Subsidy for 2 hectares	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500
Total Revenues	**€10.375**	**€10.375**	**€10.375**	**€11.388**	**€13.412**	**€16.449**	**€18.600**	**€20.498**	**€20.498**	**€20.498**

Source: Compiled by the author

Figure 12 below demonstrates the trend of annual revenues of hazelnut **without shell** and cabbage combination in the SAF system for a period of 10 years. The revenues in SAF system start from the first year due to the cultivation of cabbages between the tree rows. The revenues of this scenario (without shell) are higher than the with shell scenario due to the higher price of hazelnut without shell.

Figure 12:Annual revenues of hazelnut without shell and cabbage combination (SAF system)



4.5.3.3. Annual costs of the crop-tree combination (hazelnut with shell)

The annual COGS for 2 hectares of land was calculated based on the information gathered from Wertheim and Balitssen (2020), Jansen (2021), and Nieuwenhuis (2021). The calculated annual COGS includes purchases (**€ 19.481**) and labor costs (**€ 6.780**) for different required activities of crop and tree of different years (see annex 14).

In order to calculate the costs of fixed assets in hazelnut with shell and cabbage combination scenario, the information as shown in annex 15 was gathered from different sources (Nieuwenhuis, 2021, Netafim company, 2021, Agriexpo.online, 2021 and Target.com, 2021) which was later compiled by the author to give the summary of the total fixed assets of the farmer.

The annual costs of fixed assets including depreciation (**€ 1.468**) and maintenance (**€ 674**) were calculated per year based on the value of the assets, the expected life of the assets, maintenance cost percentage, and the allocation percent for 2 hectares of land (see annex 16).

The SGA annual costs (**€ 2.016**) including utility (**€ 748**) and other general and administrative costs (**€ 1.268**) per year were calculated based on the information gathered from the farmer (study case) and allocation percent for 2 hectares of land (see annex 17).

Figure 13 shows the different costs of hazelnut with shell and cabbage combination production in the SAF system. Purchase and labor costs are the main costs incurred in hazelnut without shell and cabbage combination in the SAF system which is the same as the monoculture system.

Figure 13:Hazelnut with shell and cabbage combination production costs (SAF system)

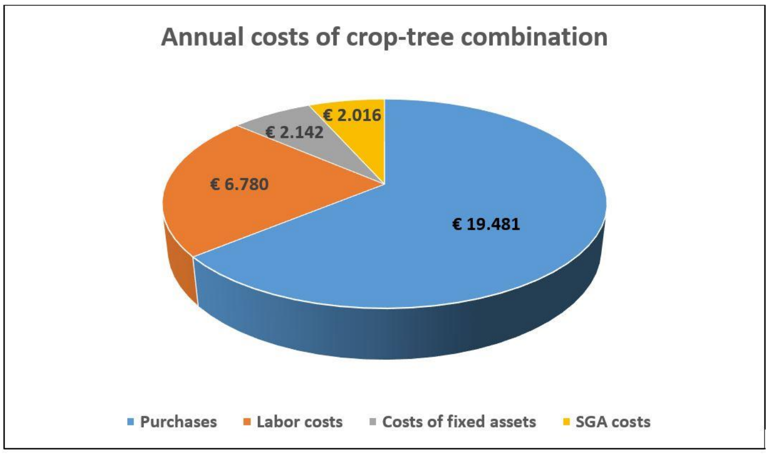


Table 26 below illustrates the total annual costs of hazelnut **with shell** and cabbage combination for the first period of 10 years. The COGS are annualized (see annex 25).

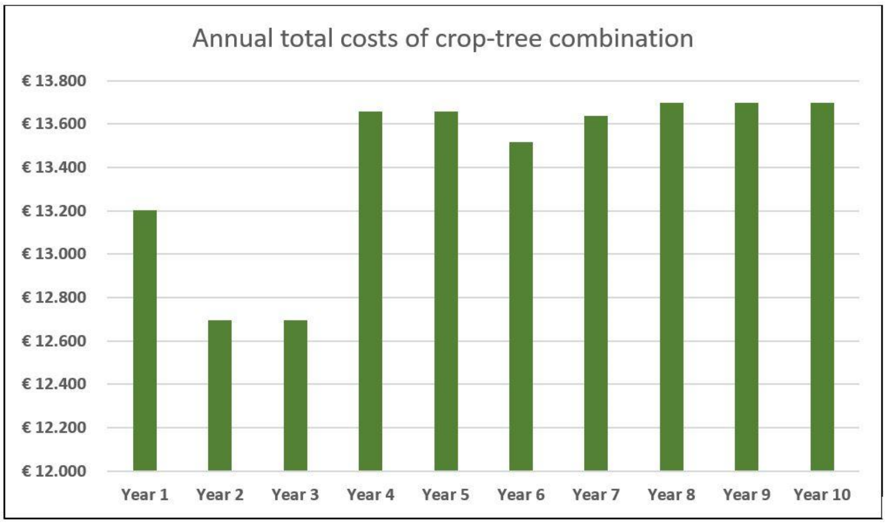
Table 26: Hazelnut with shell and Cabbage combination total annual costs (SAF system)

	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
COGS	€9.583	€9.079	€ 9.079	€9.499	€9.499	€9.359	€9.479	€9.539	€9.539	€9.539
SGA costs	€2.016	€ 2.016	€ 2.016	€ 2.016	€2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016
Depreciation and maintenance	€1.602	€1.602	€1.602	€2.142	€2.142	€2.142	€2.142	€2.142	€2.142	€2.142
Total costs	**€13.201**	**€12.697**	**€12.697**	**€13.657**	**€13.657**	**€13.517**	**€13.637**	**€13.697**	**€13.697**	**€13.697**

Source: Compiled by the author

Figure 14 demonstrates the total annual costs of production for hazelnut with shell and cabbage combination in the SAF system. The total cost in the first year is high due to the tree's transplanting labor costs in the first year.

Figure 14:Total annual costs of production for hazelnut with shell and cabbage combination (SAF system)



The annual gross margin for a period of 10 years was calculated based on the annual revenues and annual COGS. Table 27 shows the annual gross margin of crop-tree combination (hazelnut with shell) in SAF system. Table X below illustrates the annual gross margin for

Table 27: Annual gross margin of crop-tree combination (hazelnut with shell)*)*

	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
Revenues	€10.375	€10.375	€10.375	€11.134	€12.653	€15.437	€16.955	€18.727	€18.727	€18.727
COGS	€ 9.583	€ 9.079	€ 9.079	€ 9.499	€ 9.499	€ 9.359	€ 9.479	€ 9.539	€ 9.539	€ 9.539
Gross margin	**€ 792**	**€ 1.296**	**€ 1.296**	**€ 1.635**	**€ 3.154**	**€ 6.078**	**€ 7.476**	**€ 9.188**	**€ 9.188**	**€ 9.188**

4.5.3.4. Crop-tree combination P/L model overview (hazelnut with shell)

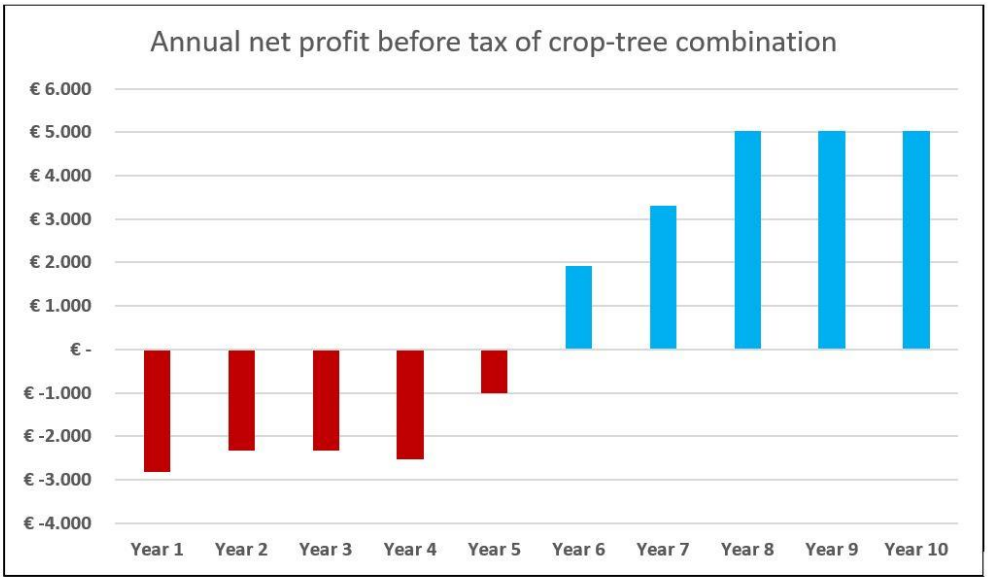
Calculated annual gross margin, COGS, SGA costs, and costs of fixed assets were used to calculate the annual net profit before tax and cost price of hazelnut with shell and cabbage production in the SAF system. Table 28 illustrates an overview of the P/L model of the hazelnut with shell and cabbage combination in the SAF system for 10 years.

Table 28: Hazelnut with shell and cabbage combination P/L model overview

Overview	**Y 1**	**Y 2**	**Y 3**	**Y 4**	**Y 5**	**Y 6**	**Y 7**	**Y 8**	**Y 9**	**Y 10**
Revenues	€ 10.375	€ 10.375	€ 10.375	€ 11.134	€ 12.653	€ 15.437	€ 16.955	€ 18.727	€ 18.727	€ 18.727
COGS	€ 9.583	€ 9.079	€9.079	€ 9.499	€ 9.499	€9.359	€ 9.479	€ 9.539	€ 9.539	€ 9.539
Gross margin	€ 792	€ 1.296	€ 1.296	€ 1.635	€ 3.154	€ 6.078	€ 7.476	€ 9.188	€ 9.188	€ 9.188
SGA costs	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016
EBITD	€ -1.224	€-720	€-720	€-381	€ 1.138	€ 4.062	€ 5.460	€ 7.172	€ 7.172	€ 7.172
Depreciation and maintenance	€ 1.602	€ 1.602	€ 1.602	€ 2.142	€ 2.142	€ 2.142	€ 2.142	€ 2.142	€ 2.142	€ 2.142
Net profit before Tax	**€ -2.826**	**€ -2.322**	**€ -2.322**	**€ -2.523**	**€ -1.004**	**€ 1.920**	**€ 3.318**	**€ 5.030**	**€ 5.030**	**€ 5.030**

Figure 15 illustrates the trend of annual net profit before tax of hazelnut **with shell** and cabbage combination production for a period of 10 years in the SAF system. The annual net profit before tax for the first 5 years of hazelnut with shell and cabbage combination in the SAF system is negative due to the low production of trees and high costs of labor and purchases. The production of hazelnut trees starts from the 4th year and the revenues of the combination cover the annual costs of production. Hence, the annual net profit before tax after the 6th year becomes positive and after the 8th year remains constant. Due to the cultivation of cabbages in SAF system, the positive net profit begins in the 6th year compared to hazelnut with shell production in the monoculture system that the positive net profit starts in the 7th year. Besides, the 8th year after planting the trees and cabbages in the SAF system is the pay-back point after which the farmer is compensated for the earlier loss.

Figure 15:Annual net profit before tax of hazelnut with shell and cabbage combination (SAF system)



4.5.3.5. Annual costs of the crop-tree combination (hazelnut without shell)

The annual COGS for 2 hectares of land was calculated based on the information gathered from Wertheim and Balitssen (2020), Jansen (2021), and Nieuwenhuis (2021). The calculated annual COGS includes purchases (**€ 21.481**) and labor costs (**€ 6.780**) for different required activities of crop and tree of different years (see annex 18).
In order to calculate the costs of fixed assets in hazelnut with shell and cabbage combination scenario, the information as illustrated in annex 19 was gathered from different sources (Nieuwenhuis, 2021, Netafim company, 2021, Agriexpo.online, 2021 and Target.com, 2021) which was later compiled by the author to give the summary of the total fixed assets of the farmer.

The annual costs of fixed assets (**€ 2.742**) including depreciation (**€ 1.868**) and maintenance (**€ 874**) were calculated per year based on the value of the assets, the expected life of the assets, maintenance cost percentage, and the allocation percent for 2 hectares of land (see annex 20).
The SGA annual costs including utility (**€ 748**) and other general and administrative costs (**€ 1.268**) per year were calculated based on the information gathered from the farmer (study case) and allocation percent for 2 hectares of land. Table 50 shows the total SGA costs per year for 2 hectares of land in the SAF system (see annex 21).
Figure 16 demonstrates the different costs of hazelnut **without shell** and cabbage combination production in the SAF system. Purchase and labor costs are the main costs incurred in hazelnut without shell and cabbage combination in the SAF system which is the same as the monoculture system.

Figure 16:Hazelnut without shell and cabbage combination production costs (SAF system)

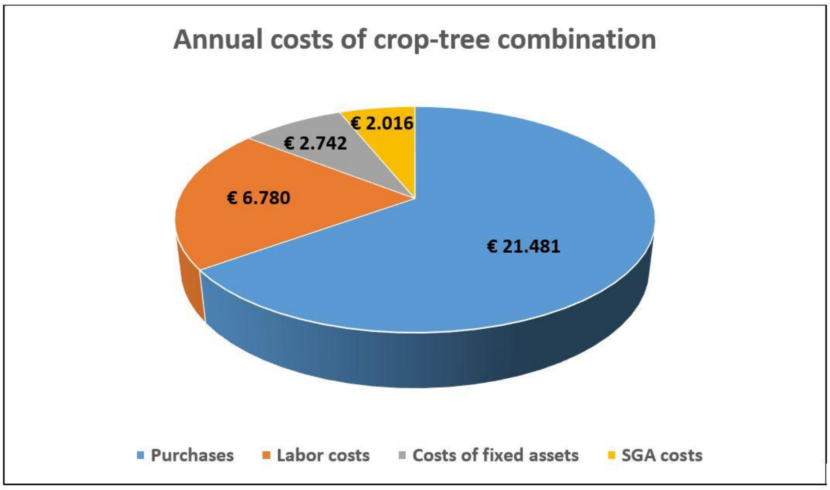


Table 29 below illustrates the total annual costs of hazelnut **without shell** and cabbage combination for the first period of 10 years. The COGS are annualized (see annex 25).

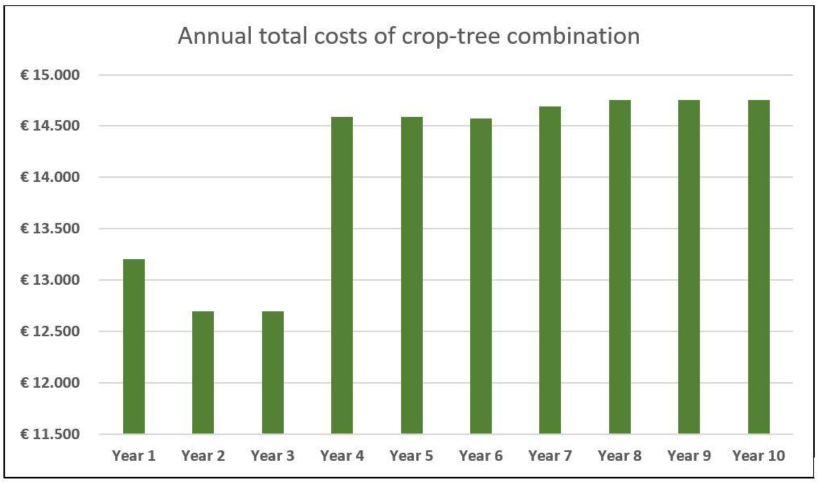
Table 29: Hazelnut without shell and Cabbage combination total annual costs (SAF system)

	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
COGS	€ 9.583	€ 9.079	€ 9.079	€ 9.833	€ 9.833	€ 9.813	€9.933	€9.993	€9.993	€9.993
SGA costs	€ 2.016	€2.016	€ 2.016	€ 2.016	€ 2.016	€2.016	€2.016	€2.016	€2.016	€2.016
Depreciation and maintenance	€ 1.602	€1.602	€ 1.602	€ 2.742	€ 2.742	€ 2.742	€2.742	€2.742	€2.742	€2.742
Total costs	**€13.201**	**€12.697**	**€12.697**	**€14.590**	**€14.590**	**€14.570**	**€14.690**	**€14.750**	**€14.750**	**€14.750**

Source: Compiled by the author

Figure 17 demonstrates the total annual costs of production for hazelnut with shell and cabbage combination in the SAF system. The total cost in the first year is high due to the tree's transplanting labor costs in the first year. Besides, the total costs in without shell scenario crop-tree combination are higher than the with shell scenario due to the purchase cost of the additional machinery such as shelling machine.

Figure 17:Total annual costs of production for hazelnut with shell and cabbage combination (SAF system)



The annual gross margin for a period of 10 years was calculated based on the annual revenues and annual COGS. Table 30 shows the annual gross margin of crop-tree combination (hazelnut with shell) in SAF system.

Table 30: Annual gross margin of crop-tree combination (hazelnut without shell)

	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
Revenues	€10.375	€10.375	€10.375	€11.388	€13.412	€16.449	€18.600	€20.498	€20.498	€20.498
COGS	€ 9.583	€ 9.079	€ 9.079	€ 9.833	€ 9.833	€9.813	€9.933	€9.993	€9.993	€ 9.993
Gross margin	**€ 792**	**€1.296**	**€1.296**	**€1.555**	**€3.580**	**€6.636**	**€8.668**	**€10.506**	**€10.506**	**€10.506**

4.5.3.6. Crop-tree combination P/L model overview (hazelnut without shell)

Calculated annual gross margin, COGS, SGA costs, and costs of fixed assets were used to calculate the annual net profit before tax and cost price of hazelnut **without shell** and cabbage production in the SAF system. Table 31 illustrates an overview of the P/L model of the hazelnut with shell and cabbage combination in the SAF system for the first 10 years.

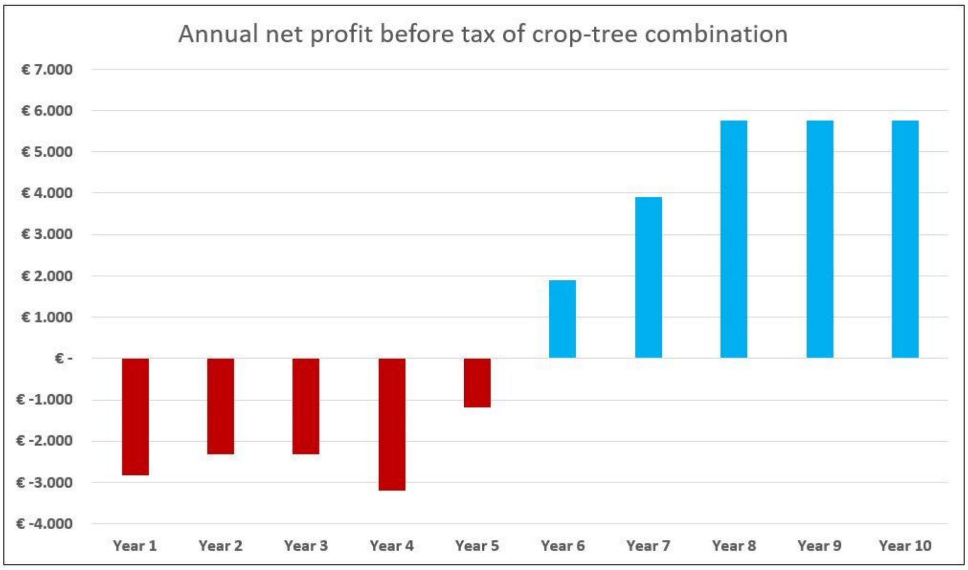
Table 31: Hazelnut without shell and cabbage combination P/L model overview

Overview	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y 10
Revenues	€ 10.375	€ 10.375	€ 10.375	€ 11.220	€ 12.911	€ 15.446	€ 17.242	€ 18.826	€ 18.826	€ 18.826
COGS	€ 9.583	€ 9.079	€ 9.079	€ 9.833	€ 9.833	€ 9.813	€ 9.933	€ 9.993	€ 9.993	€ 9.993
Gross margin	€ 792	€1.296	€1.296	€1.555	€3.580	€6.636	€8.668	€10.506	€10.506	€10.506
SGA costs	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016	€ 2.016
EBITD	€ -1.224	€ -720	€ -720	€ -461	€ 1.564	€ 4.621	€ 6.652	€ 8.490	€ 8.490	€ 8.490
Depreciation and maintenance	€ 1.602	€ 1.602	€ 1.602	€ 2.742	€ 2.742	€ 2.742	€ 2.742	€ 2.742	€ 2.742	€ 2.742
Net profit before Tax	**€ -2.826**	**€ -2.322**	**€ -2.322**	**€ -3.203**	**€ -1.178**	**€ 1.897**	**€ 3.910**	**€ 5.748**	**€ 5.748**	**€ 5.748**

Source: Compiled by the author

Figure 18 illustrates the trend of annual net profit before tax of hazelnut **without shell** and cabbage combination production for a period of 10 years in the SAF system. The annual net profit before tax for the first 5 years of hazelnut with shell and cabbage combination in the SAF system is negative due to the low production of trees and high costs of labor and purchases. The production of hazelnut trees starts from the 4th year and the revenues of the combination cover the annual costs of production. Hence, the annual net profit before tax after the 6th year becomes positive and after the 8th year remains constant. Due to the cultivation of cabbages in the SAF system, the positive net profit begins in the 6th year which is the same as hazelnut without shell production in the monoculture system. Moreover, the 8th year after planting the trees is the pay-back point after which the farmer is compensated for the earlier loss.

Figure 18:Annual net profit before tax of hazelnut without shell and cabbage combination (SAF system)



4.5.4. Monoculture and AF systems economic performance comparison

To demonstrate the differences in the economic performance of monoculture system and SAF system, the average of 10 years total annual revenue, Annual costs, annual total costs, annual gross margin, and annual net profit before tax were calculated in the P/L model. A spider chart and bar charts were used to illustrate the differences between monoculture systems and AF system economic performance.

Figure 19 shows the differences in average annual revenue, annual gross margin, annual total costs, and annual net profit between monoculture system and AF system for both (with shell and with out shell) scenarios.

Figure 19:Monoculture and SAF systems economic performance comparison

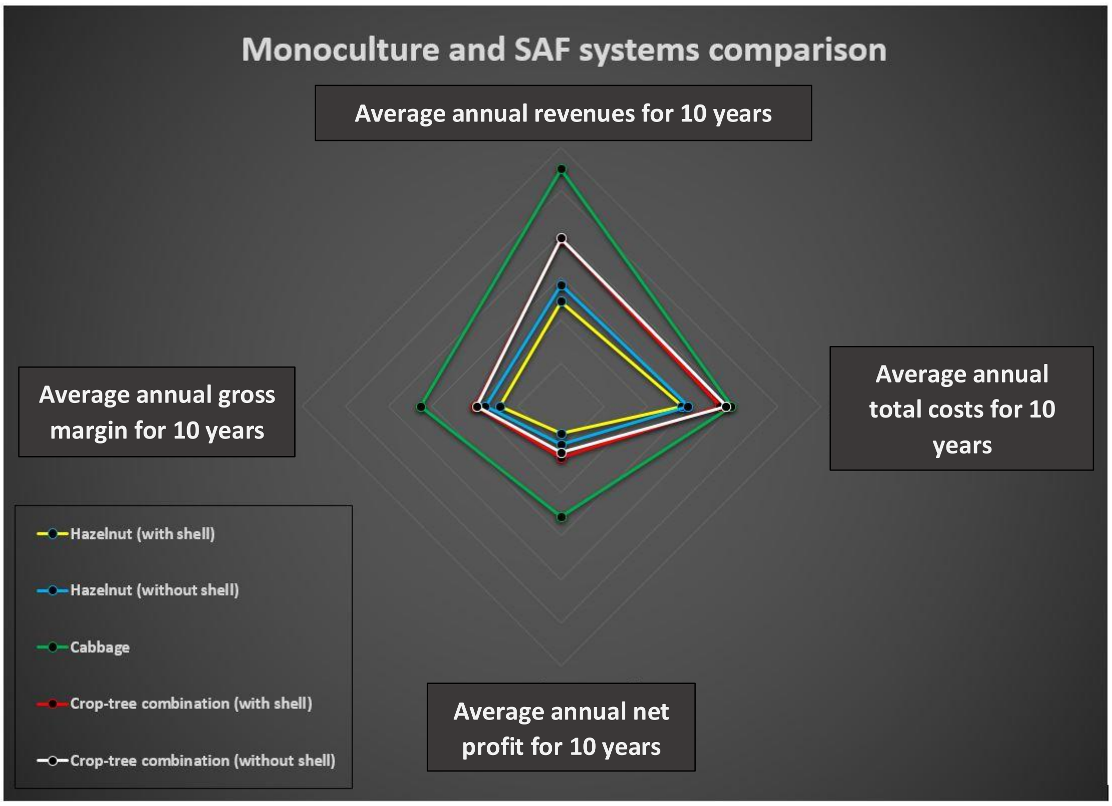


Figure 20 illustrates the differences in average annual revenues, annual gross margin, annual total costs, and annual net profit between the monoculture system and AF system for the hazelnut **with shell** scenario. It is seen that the average net profit before tax of the crop-tree combination is positive compared to hazelnut with shell production in the monoculture system. However, it is negative compared to cabbage production in monoculture system.

Figure 20:Monoculture and SAF systems economic performance comparison for hazelnut with shell scenario

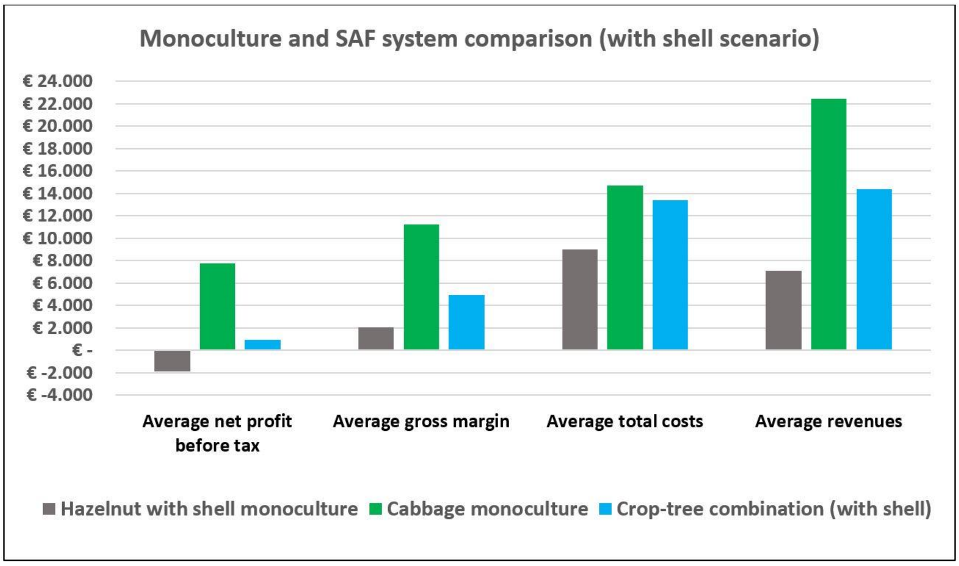


Figure 21 illustrates the differences in average annual revenues, annual gross margin, annual total costs, and annual net profit between the monoculture system and AF system for the hazelnut **without shell** scenario. It is seen that the average net profit before tax of the crop-tree combination is also positive compared to hazelnut without shell production in the monoculture system. However, it is still negative compared to cabbage production in monoculture system.

Figure 21:Monoculture and SAF systems economic performance comparison for hazelnut without shell scenario

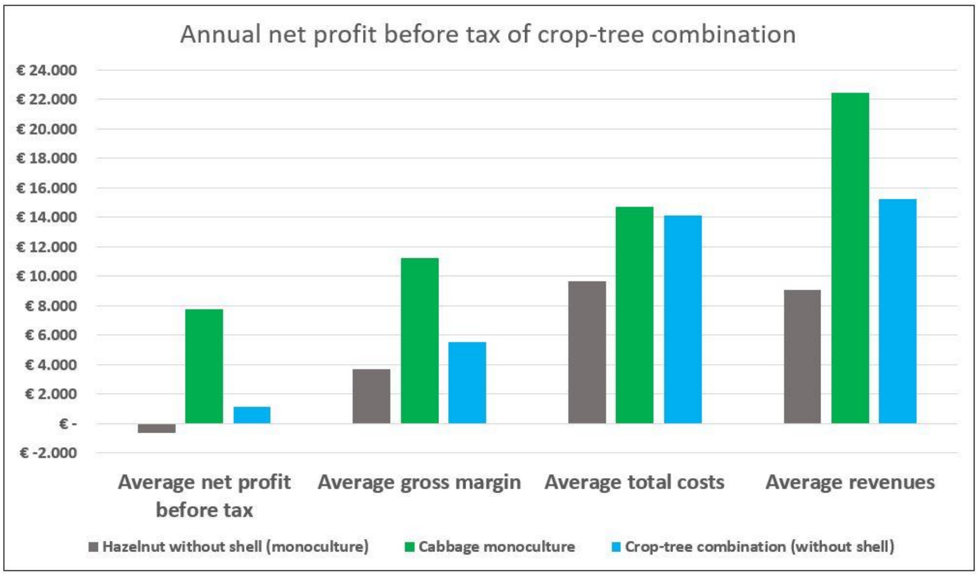


Figure 22 shows the differences in production costs between the monoculture system and AF system for the hazelnut **with shell** scenario. It is seen that the purchase cost in the hazelnut monoculture production is lower than the SAF system due to the increase in distance between trees thus a decrease in the number of trees per hectare. However, the labor cost due to the combination of cabbage and hazelnut in the SAF system is higher than the hazelnut production in the monoculture system.

Figure 22:Monoculture and SAF systems costs comparison for hazelnut with shell scenario

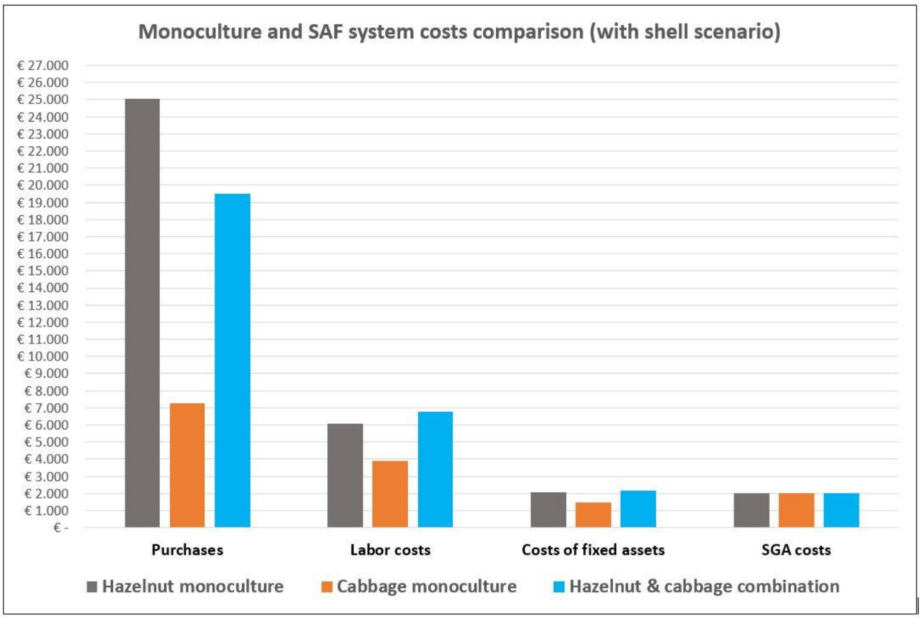
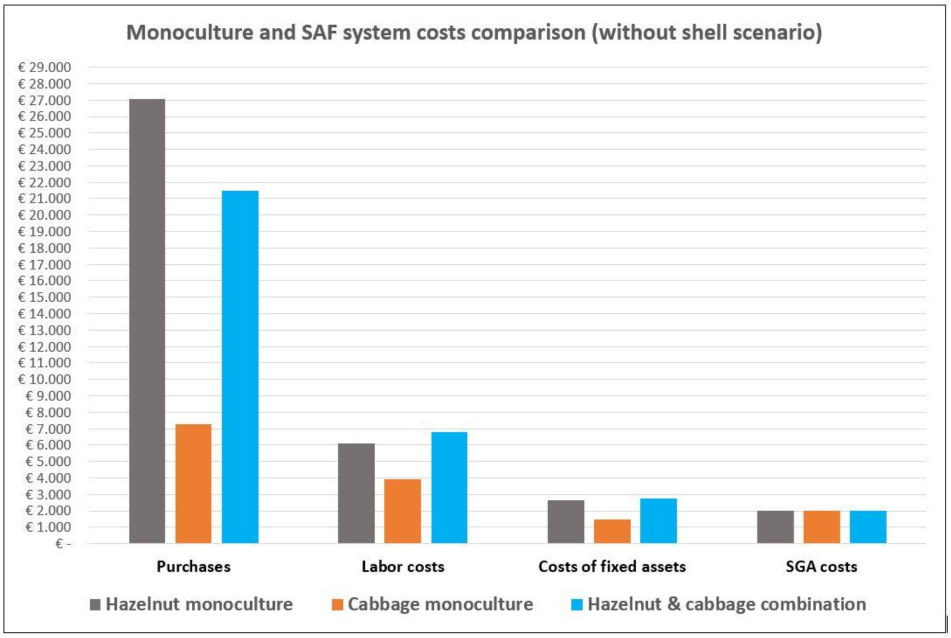


Figure 23 shows the differences in production costs between the monoculture system and AF system for the hazelnut **without shell** scenario. In general, the costs of production in without shell scenario is higher than with shell scenario due to the purchase of additional machinery such as shelling machine. Besides, It is seen that the purchase cost in the hazelnut monoculture production is lower than the SAF system due to the increase in distance between trees thus a decrease in the number of trees per hectare. However, the labor cost due to the combination of cabbage and hazelnut in the SAF system is higher than the hazelnut production in the monoculture system.

Figure 23:Monoculture and SAF systems costs comparison for hazelnut without shell scenario



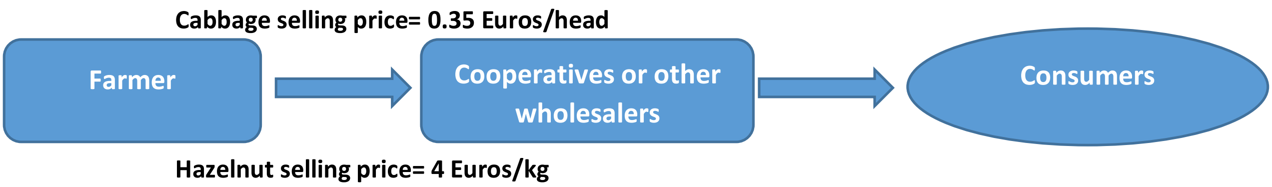
4.6. Economic performance of hazelnut and cabbage combination in terms of products market channels

Regarding the market channels for the hazelnut in the Netherlands, there is no difference between the price of hazelnut produced in agroforestry and monoculture system. According to Baltissen (2021), Currently, there is no settled value chain for the hazelnut produced in the agroforestry system because farmers still have no production of nuts due to being in the production period. The market of organic/conventional hazelnut in the Netherlands depends on the production volume, quality, and year-round delivery. In the Netherlands, most farmers due to the low production volume and insufficient storage equipment cannot meet the big buyer companies' requirements in terms of volume and year-round delivery (Baltissen, 2021). Hence the only option that they have is selling directly to the consumers or selling at a lower price to a limited number of wholesalers. But if the farmers can produce in large quantities, they can sell their hazelnuts to big buyer companies such as Tony's chocolate, Odin, Ekoplaza, and Bakeries (Baltissen, 2021 and Jansen, 2021). According to Baltissen (2021)," *one farmer sells nuts to Tony's chocolate and another to ODIN (an EKO supermarket) in Belgium. Both farmers have approximately 5 to 6 hectares of hazelnuts (not agroforestry but full field production), which means that they have thousands of kilograms (5 to 6 tons for instance) that they can deliver nuts to these companies year-round*". However, the mentioned farmers have planted hazelnut trees in the monoculture system, Therefore the agroforestry system where the production is lower due to the less trees, more land is needed in order to produce in large quantities.
Regarding the market channels for cabbage in the Netherlands, according to Nieuwenhuis (2021), the channel that most of the farmers use is selling to cooperatives and the selling price in this channel does not favor the cabbage grower.

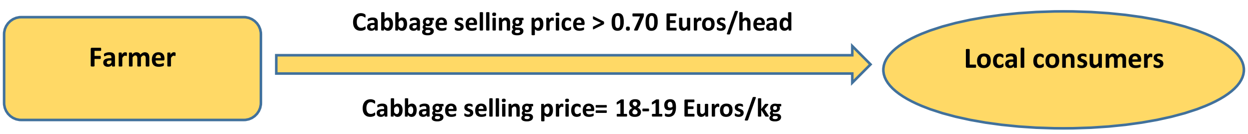
Figure 24 below illustrates the two different market channels.

Figure 24: Market channels

1. Farmers sell to cooperatives or other wholesalers, then wholesalers sell to the consumers through chain stores and specific supermarkets such as Odin and Ekoplaza.



2. Farmers sell directly to local consumers to gain more gross margin due to the absence of wholesalers.



Source: Baltissen (2021); Jansen (2021); Nieuwenhuis (2021); Wertheim and Baltissen (2020) and compiled by the author

Moreover, the difference between the two market channels is in the selling price. In the channel which includes the wholesalers and cooperatives, the farmers sell their products at a lower price compared to the channel that farmers sell their products directly to the consumers.

4.7. Environmental benefit (soil fertility) of hazelnut and cabbage combination

Netherlands soil health is important for future generations, and due to the intensive farming in the country shifting to a sustainable farming system like the AF system is essential (Van Druenen, 2021).

Some researches have been done in the field of environmental benefits of AF systems, most of which focused on biodiversity improvement. Regarding soil fertility, assessing the benefit of the crop-tree combination needs a couple of years of monitoring and assessment of the soil and its components (Selin Noren, 2021). According to Roest (2020), the existence of hazelnut has a negative impact on the soil PH and causes a reduction in the soil PH couple of years after planting. However, the combination of annual crops and trees has positive environmental effects. The deep root system of trees improves the health of the soil in different layers of soil. Besides, the annual crop residues add organic matter to the soil, Consequently, soil water holding capacity, soil organic matter, soil nitrogen availability, soil PH balance, and soil carbon sequestration improve.

Situations description:

1. Hazelnut monoculture system: Planting distance=6×3. The number of trees/ha=556 and the soil is clay.

2. Cabbage monoculture system: Planting distance=50×60 cm. Distance between rows 1.5 meters. And the soil is clay.

3. Hazelnut and cabbage combination (SAF system): Hazelnut planting distance=6×6. Cabbage row is 3 meters between tree rows. The number of trees/ha=278 and the soil is clay.

Table 32 below illustrates the effect of the monoculture system and SAF system on the soil fertility selected components according to the consulted experts. The scales include 1 (very low), 2 (low), 3 (medium), 4 (high) and 5 (very high). The average score of each farming system was used to demonstrate the differences between the monoculture and SAF systems.

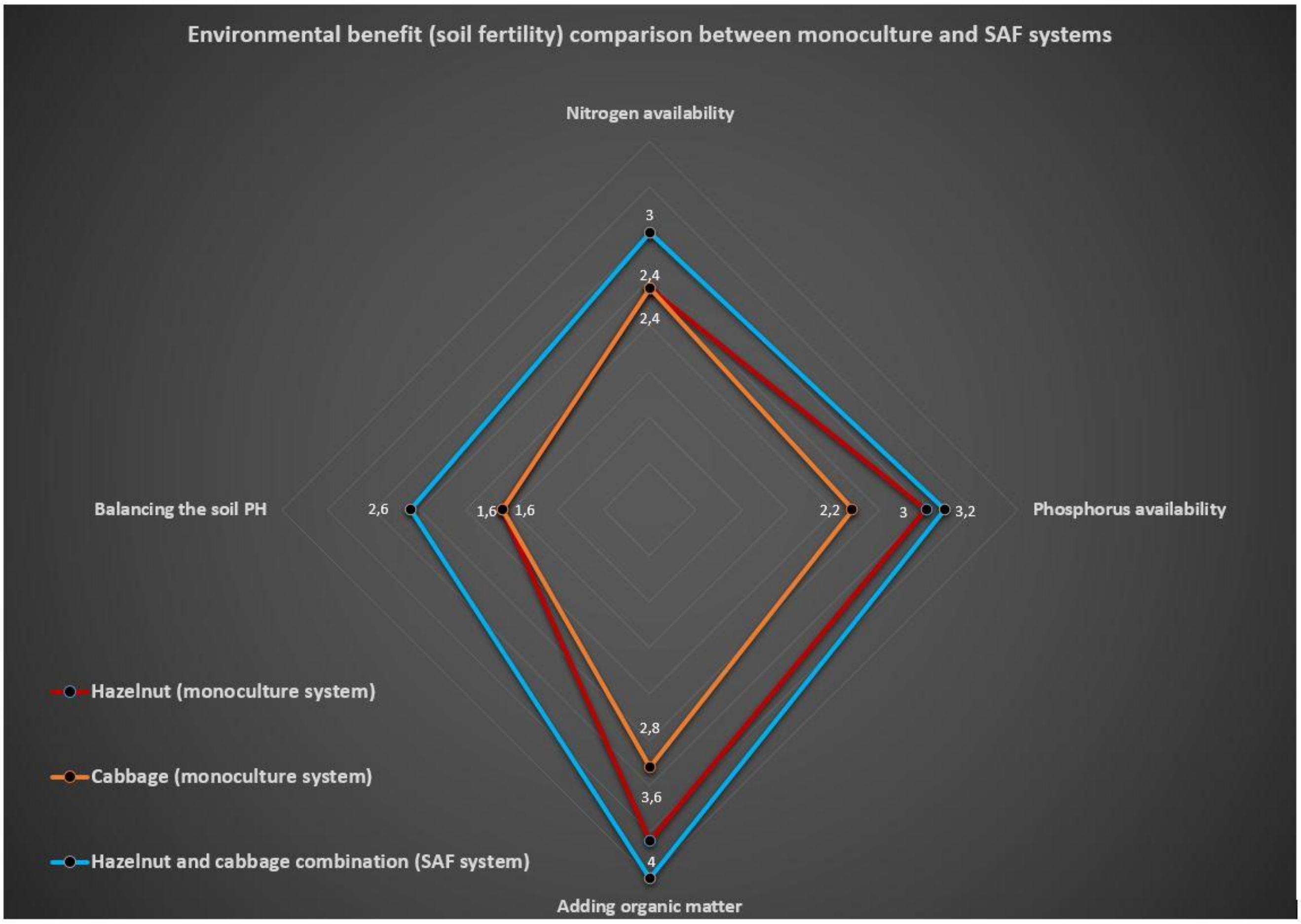
Table 32:Environmental benefit (soil fertility) of monoculture and SAF systems.

Crop/tree	Soil nitrogen availability	Soil phosphorus availability	Adding organic matter to the soil	Balancing the soil PH
Hazelnut monoculture				
Agroforestry expert (René van Druenen)	2	3	4	2
Agro-ecologist (Isabella Selin Noren)	3	3	4	2
Agriculture expert (Ton Balitssen)	3	4	4	2
Agro-ecologist (Wijnand Sukkel)	2	2	3	1
Agro-ecologist (Lennart Fuchs)	2	3	3	1
Average score	**2.4**	**3**	**3.6**	**1.6**
Cabbage Monoculture				
Agroforestry expert	2	2	4	3

(René van Druenen)				
Agro-ecologist (Isabella Selin Noren)	4	4	2	3
Agriculture expert (Ton Balitssen)	4	3	4	3
Agro-ecologist (Wijnand Sukkel)	1	1	2	1
Agro-ecologist (Lennart Fuchs)	1	1	2	1
Average score	**2.4**	**2.2**	**2.8**	**1.6**
Hazelnut & cabbage combination				
Agroforestry expert (René van Druenen)	2	4	4	4
Agro-ecologist (Isabella Selin Noren)	5	5	5	3
Agriculture expert (Ton Balitssen)	4	3	5	4
Agro-ecologist (Wijnand Sukkel)	2	2	3	1
Agro-ecologist (Lennart Fuchs)	2	2	3	1
Average score	**3**	**3.2**	**4**	**2.6**

Figure 25 illustrates the environmental benefit (soil fertility) comparison by the experts between the monoculture and the SAF system. It is seen that the effect of the hazelnut and cabbage combination on the soil fertility components is considered more than their cultivation in the monoculture system.

Figure 25:Evrionmental benefit (soil fertility) comparison between monoculture and SAF systems



Chapter 5. Discussion

The purpose of this research was to identify is cabbage a suitable crop that can be combined with hazelnut trees on the farmland that is profitable and environmentally beneficial and provide recommendations on the combination of the crop with hazelnut trees that will help in the process of designing the SAF demo plot. For this research, it was analyzed if cabbage would be a suitable crop to combine with hazelnut.

This chapter includes a discussion of findings as related to the literature on the annual crop (cabbage in this study) and hazelnut tree growing requirements, competition and synergy, farm management activities, the profitability of the crop-tree combination, market channels of the crop-tree combination products and environmental benefit in terms of soil fertility of the crop-tree combination (SAF system).

5.1. Compatibility of hazelnut and cabbage

The first question in this study sought to determine the growing requirements, competition and synergy and farm management of cabbage and hazelnut cultivation to determine the level of compatibility of the crop and tree.

5.1.1. Hazelnut

The current study found that trees that can be used in the SAF system in the Netherlands are hazelnut and walnut which is consistent with that of De Visser *et al*. (2015) who stated hazelnut and walnut are among indigenous nuts in most parts of Europe, including the Netherlands, where it is endemic. Moreover, another important finding was the experiments on the crops and trees combination. There are six producers and 15 hectares of land in the Netherlands that have started experimenting and producing nuts such as hazelnut in arable land. There is not yet enough information regarding the compatible crops with nut trees including hazelnut in the Netherlands. This result is in agreement with Rombouts (2021) findings which showed Wageningen University & Research in Lelystad, the Netherlands, is developing the country's first large-scale (15 hectares) multidisciplinary agroforestry research facility which is a multi-year research project in which Wageningen University, in collaboration with arable farmers and business leaders, investigates the possibilities of agroforestry in the Netherlands.

Another finding was that the hazelnut variety selection is important because hazelnut pollination affects the flowering and the yield of the trees. Hence, to have a successful hazelnut production, planting different varieties is necessary. Emoa1, 2, or 3, and Corabel are the recommended main varieties due to their compatibility with the Netherlands climate condition, frost damage, susceptibility to diseases, and the market demand for round hazelnuts. Besides, Cosford, Gustav's Zeller, Lang Tidling Zeller, and Riccia di Talanico are the varieties that can be used as pollinators. It is encouraging to compare this finding with that found by Wertheim and Baltissen (2020) who stated that the mentioned hazelnut varieties have been experimented with and are compatible with the Netherlands climate condition.

The results of this study show that the pre-planting activities for hazelnut production are land preparation such as soil test, weeds elimination, planting spots allocation, orchard design in terms of location of different varieties, spacing and rows allocation for the annual crop, and seedling purchase. One of the important factors in hazelnut production management is spacing. The proper space in the agroforestry system is 6×6 meters. Another important factor in management is pruning. Mature trees' insufficient pruning can reduce shoot vigor and diminish cropping potential (İSLAM, 2018). Hazelnut tree tends to be a bush, hence, regular pruning is necessary especially in the first 6 years of the tree life when it comes to the crop-tree combination. Pruning labor cost is one of the higher variable costs in hazelnut production but it is essential because in agroforestry systems the shape of the tree is important. In accordance with the study results, previous studies have demonstrated that land preparation, weeding, planting space (Wertheim and Baltissen, 2020), and pruning (Reddy, 2020) are the main farm management activities for hazelnut production.

5.1.2. Cabbage

Regarding the cabbage, this study found that cabbage planting season is in late May and they are harvested in September and October. The optimum soil PH for cabbage Is between 6 to 6.5 and it grows properly in clay soil. Weekly irrigation is needed for cabbage cultivation. The optimum temperature for cabbage growing is between 10 to 20 ^{0}C and 5 to 6 hours of sunlight is needed for the cabbages, so the cabbage taste becomes sweeter which makes it more marketable. Nitrogen, Phosphorus, and Potassium are the main required nutrients (Kelley, MacDonald and B. Adams, 2006) which can be provided for the plant through using compost and solid manure. A spacing of 40–60 cm is used on single-row plantings (Murison, 2005). The main farm management activities of cabbage production are land preparation for transplanting, transplanting, irrigation, and regular weeding. These results seem to be consistent with other literature that stated for cabbage cultivation, the soil ph level should be between 5.5 and 6.5. Early mature seedlings can be planted in August-September, whereas late mature seedlings are planted in September-October. Temperatures between 10 and 20 ^{0}C are ideal for growing cabbage. Plant spacing is 45 cm and row spacing is 60 cm. Besides, the weeds mostly harm the cabbage roots (Oscar, 2018).

These results may support the hypothesis that in general hazelnut and cabbage are compatible in terms of growing requirements and farm management. However, to have a better view of the compatibility of hazelnut and cabbage, a further study with a more detailed focus is therefore suggested to look at the growing requirements and management activities. Because hazelnut as a perennial crop has a long life cycle and it may require a different level of nutrients, climate condition, and management activities in different stages of its life. However, due to the shortage of time, this research was not able to investigate the aspect of pest and disease management in crop-tree compatibility which is also an important factor that needs to be taken into account in further studies.

5.1.3. Competition and synergy

In terms of competition and synergy of the hazelnut tree and cabbage, the current study found that in case of the availability of water and nutrients in the soil, there is limited competition for water and nutrients between hazelnut and cabbage due to the different root systems of cabbage and hazelnut which are in accord with studies indicating that cabbage has a shallow root system that varies between 45 and 90 cm deep (Lires, 2020) and hazelnut can grow vigorous root systems to depths of 1.8–3 meters (Olsen, 2013). With respect to the first research question, it was found that generally, the growing requirements of cabbage and hazelnut are in the same range. Therefore it can be assumed that the competition between hazelnut and cabbage is limited. However, these results are based on assumptions, so it would be better to investigate and monitor the above and below ground crop-tree competition for a long period to accept the hypothesis that there is indeed limited competition between hazelnut and cabbage.

Another important finding was that the synergy of the cabbage and hazelnut tree can be the improvement of the soil quality by hazelnut tree which makes the situation appropriate for the crop to grow better. Besides, falling tree leaves and also the annual crop residues after harvesting annually add organic matter to the soil which after decomposition in the soil provides nutrients such as nitrogen and micronutrients for cabbages and hazelnut trees. Moreover, another synergy that is expected from the crop-tree combination is biodiversity in the farm which helps to control pests and diseases in a biological situation. These results seem to be consistent with other studies which found that plant nutrients are recycled from deeper soil layers through the use of green manure for annual crops and creating a suitable environment for soil microorganisms and improvement of biodiversity (Bhattarai et al., 2016). However, further research needs to be undertaken to investigate and monitor these synergies in a long-term period which this study was not able to undertake due to the time limit.

5.2. Economic performance of the crop-tree combination (P/L Model)

The current study found that In hazelnut production, in the third and fourth year, the trees start the production but only 10% of the fully grown tree. After the 7th year, they will have full production, This finding was also reported by Wertheim and Baltissen (2020). Besides, the average yield in the hazelnut monoculture system is between 3 to 4 kg per tree when the trees are fully grown. But in organic production, the production is expected to be between 3 to 3.5 kg per tree. This finding is consistent with that of Demiryurek and Ceyhan (2009) who stated that organic hazelnut growers' yields were roughly 5% lower than conventional hazelnut producers' yields.

Another important finding was that the wholesale price in the Netherlands for hazelnut with shell is 4 Euros/kg and for hazelnut without shell is 10 Euros/kg on average (Baltissen, 2021, Wertheim and Baltissen, 2020 and Jansen, 2021). Moreover, according to Wertheim and Baltissen (2020), the average price of two years old grafted trees in the pod in the Netherlands is 11.25 Euros per tree. Besides, If the farmers do some processing such as shelling the nuts and package them to sell directly to the local consumers the average price per kg will be 18-19 Euros per kg. Depending whether the farmers’ financial situation enables the farmers to invest in machinery and equipment, there are several ways of processing and adding value to the hazelnut, one of which is hazelnut oil. To produce one-liter hazelnut oil which should be done by cold press machine to gain a high-quality oil, 20kg hazelnut without shell is needed. The price of hazelnut oil is 40-50 Euros per liter (Baltissen, 2021). Also, this study found that the price of a head of cabbage is 0.35 cents (selling to the cooperative) and 5,400 seedlings are needed for two hectares of cabbage cultivation. Besides, the price of cabbage seedlings in the Netherlands is 0.17 cents/plant (Nieuwenhuis, 2021).

The results of this study indicate that the total yield per hectare of hazelnut in the monoculture system (556 trees/ha) for the fully grown tree in the 8th year is 1,743 kg/ha (with shell) and 845 kg/ha (without shell). Besides, the total yield per hectare of hazelnut in the SAF system (333 trees/ha) for the fully grown tree in the 8th year is 1,044 kg/ha (with shell) and 506 kg/ha (without shell). The difference between the yield of hazelnut between monoculture and SAF system is due to the increase in the distance between trees in the SAF system which leads to a reduction in the number of trees and total yield per hectare. It means, if the farmer wants to produce hazelnut in the SAF system in more quantities needs to allocate more land to the SAF system to compensate for the difference between yields. However, expanding the SAF system requires an additional investment that at this time based on the farmer's available capital is not possible.

The current study found that the total yield of cabbage in the monoculture system is 33,000 heads per hectare. Besides, the cabbage total yield per hectare in the SAF system is the same as the monoculture system due to the limited competition between hazelnut and cabbage. Though, the yield of hazelnut and cabbage might be lower or higher in practice. Hence, these data must be interpreted with caution because the information regarding the prices and yields is gathered from only one hazelnut producer and one cabbage producer. It would be better to have more resources for these data to make the information more reliable.

Another finding was that the average of 10 years total annual revenues for 2 hectares of the hazelnut production in the monoculture system is 7,134 euros (with shell) and 9,062 euros (without shell). The difference between with shell and without shell average revenue is due to the higher selling price of hazelnut without shell (10 euros/kg) in comparison to the hazelnut with shell (4 euros/kg). Also, this study found that the annual revenue of the cabbage in the monoculture system is 22,445 euros in comparison to the SAF system which is 10,375 euros. This result may be explained by the fact that the allocated land for the cabbage in the SAF system (0,9 ha) is less than the monoculture system (2 ha) due to the allocated space for hazelnut trees.

What is important is that the average of 10 years total annual revenues for 2 hectares of the hazelnut and cabbage combination (SAF system) is 14,349 euros (with shell) and 15,247 euros (without shell). The observed increase in average total annual revenues of the hazelnut could be attributed to the combination of the cabbage revenues in the SAF system especially in the first 3 years that the hazelnut does not have revenues due to the zero production of trees.

Another finding of this study was that the costs of fixed assets are almost equal between the monoculture system and the SAF system. This finding is consistent with that of Kurtz, Garrett, Slusher and Osburn (1996) who stated that in agroforestry systems the fixed costs are shared between crop and tree because of the joint-production relationship in these farming systems.

The most important finding was that the total annual cost of cabbage production in the monoculture system is 14,683 euros and the average of 10 years total annual cost for hazelnut is 8,996 euros (with shell) and 9,683 euros (without shell). Besides, the average of 10 years' total annual cost of the cabbage and hazelnut combination is 13,415 euros (with shell) and 14,129 euros (without shell). These results may be explained by the fact that the annual costs of the production of cabbage and hazelnut in the monoculture systems are compiled in the SAF system which is in agreement with Lehmann *et al*.(2020) who mentioned the high cost of the establishment of crop-tree combination in AF systems. There is an assumption that the total annual cost can be decreased by using the machinery for cabbage transplanting and harvesting and hazelnut harvesting that leads to a decrease in labor costs. However, In future investigations, it might be possible to use the P/L model to calculate the total annual costs based on the new study case which has machinery for the mentioned activities to have a reliable view of the assumption.

The results of this study show that the annual net profit before tax of cabbage production in the monoculture system is 7,762 euros. Besides, the average annual net profit before tax for hazelnut production in the monoculture system is -1,862 euros (with shell) and -621 euros (without shell). These results may be explained by the calculations of the P/L model which shows the annual net profit in hazelnut production becomes positive after the 5th year in without shell scenario and 6th year in with shell scenario. Hence, the average net profit of a period of 10 years becomes negative due to the negative net profit in the first 4 to 5 years of production. These results reflect those of Wang Mei Hua, Warren-Thomas and Cherico Wanger (2019) who also found that the profit of planting trees in the first years is negative due to low production and high costs of orchard establishment.

The most important finding was that the average annual net profit before tax for hazelnut and cabbage combination is 933 euros (with shell) and 314 euros (without shell). There are several possible explanations for this result. One of which is the effect of cabbage revenues which compensates the initial costs and negative net profit of hazelnut production in the first 4 years of the SAF system.

One of the main results of the study was that the combination of hazelnut and cabbage combination (SAF system) is more profitable in comparison to the hazelnut production in the monoculture system. Besides, the profitability of cabbage in the monoculture system is more than the SAF system. Though, the environmental benefits and the sustainability of the SAF system need to be considered as well because economic profitability is not the only aim of transitioning to the AF system. However, this study was able to analyze the profitability of the system for 10 years, but the life cycle of the hazelnut tree is more than 10 years which means for a better understanding of the profitability of cabbage and hazelnut there is a need for long term economic analysis.

5.3. Market channels of the crop-tree combination products

Regarding the market channels of hazelnut and cabbage combination, the interesting finding was that there is no difference between the price of hazelnut produced in agroforestry and monoculture system. Currently, there is no settled value chain for the hazelnut produced in the agroforestry system, because farmers still have no production of nuts due to being in the production period. Besides, the market depends on the production volume, quality, and year-round delivery. In the Netherlands most farmers due to the low production volume cannot meet the big companies' requirements in terms of volume, hence the only option that they have is selling directly to the consumers or selling at a lower price to a limited number of wholesalers. But if the farmers can produce in large quantities which is more than 3 tons in more than 3 hectares of land in the AF system (Baltissen, 2021) and invest in storage equipment like a cooling system that enables them to deliver year-round, they can sell their hazelnuts to the big companies such as Tony's chocolate, Odin, Ekoplaza, and Bakeries. These results are in agreement with De Visser *et al*. (2015) findings which showed that neither scientific information nor general FAO statistics could be obtained for hazelnut production in the Netherlands, leading to the perception that Dutch hazelnut production plays a small part in the Dutch and international economies. Nonetheless, hazelnut producers persist in the Netherlands, even if their trading capability is confined to regional and national scales. De Visser *et al*. (2015) also found that in the Netherlands, hazelnut growers typically process and/or sell their goods directly, or supply them to firms that aren't focused on processing, distribution, or retailing but perform several roles.

Regarding the market channels for cabbage in the Netherlands, the current study found that the channel that most of the farmers use is selling to cooperatives. The selling price in this channel does not favor the farmers, so farmers need to invest in marketing and required equipment to be able to sell directly to the consumers due to the higher margin of this channel (Nieuwenhuis, 2021 and Van Druenen, 2021).

The results of this study show that there are two main market channels for organic cabbage and hazelnut in the Netherlands including (a) Farmers sell to cooperatives or other wholesalers, then wholesalers sell to the consumers through chain stores and specific supermarkets such as Odin and Ekoplaza. (b) Farmers sell directly to local consumers to gain more gross margin which may be due to the absence of wholesalers in this channel. This study has been unable to demonstrate that all cabbage and hazelnut producers in the Netherlands sell their products through the mentioned channels, hence, further research should be undertaken to investigate the existing market channels and supply chains for organic cabbage and hazelnut in the Netherlands.

5.4. Environmental benefit in terms of soil fertility of the crop-tree combination

In the current study, comparing hazelnut and cabbage production in the monoculture system with the hazelnut and cabbage combination in the SAF system showed that experts believe the environmental benefit of hazelnut and cabbage combination (SAF system) in terms of soil fertility including the availability of Nitrogen and phosphorus, balancing the soil PH, and adding organic matter to the soil is higher in comparison to production in the monoculture system. This result may be explained by the fact that the combination of hazelnut and cabbage adds organic matter to the soil through cabbage residues after harvesting and hazelnut tree litter and pruning. Hence, the availability of nutrients in the soil improves and the soil PH is balanced. Another possible reason for this is that the hazelnut root system expands to the deeper layers of the soil which improves the soil structure, soil texture, and health. This is in agreement with Batish (2008) findings which showed the impact of the crop-tree combination on the soil including nutrient release through tree litter and prunings, Phosphorus input via mycorrhizal relationships, decreased soil erosion and nutrient leaching, and nutrient absorption from the subsoil via deep-rooted trees. This finding was also reported by Palma, Paulo, and Sendim (2014) that In terms of organic matter rate and soil structure, nutrient content, and soil biology, trees have a critical influence on soil quality.

However, due to the limited time of the research, the measurement of soil fertility components was not possible. Hence, agro ecologists and agroforestry expert's experiences were used to compare the environmental benefit (soil fertility) of the cultivation of hazelnut and cabbage in the monoculture system and SAF system. To develop a full picture of the environmental benefit of crop-tree combination in the SAF system, additional studies will be needed that monitor the soil nutrients, PH, and organic matter in both systems for several years.

5.5. Reflection on methodology

Methodology refers to the technical "how" of any particular piece of research. It refers to how a study prepares an investigation in a systematic way to ensure that the results are accurate and reliable, as well as that the study's aims and objectives are accomplished (Jansen and Warren, 2021).To achieve the aim of this study was to investigate if the hazelnut-cabbage combination would be a suitable combination in the SAF system and examine the economic performance and environmental benefit in terms of soil fertility of the combination, five semi-structured interviews, desk study, and two field observations were used to collect data. Besides P/L model and expert panel were used to analyze the profitability and environmental benefit of the crop-tree combination.

The process of data collection took 4 weeks, within these four weeks, five semi-structured interviews with key informants were conducted. The first challenge of this method was the formulation of question checklists to assure to collect sufficient information that enables analysis and answer the research questions. The language barrier was the second challenge because the cabbage grower was not able to express himself in English, hence the communication had to be via email to give time to the interviewee to focus on his answers and required information. Hence, to conduct an interview in a country in which the national language is not English, I need native person as a translator needs to be used. Another challenge that affected the research process was having access to key informants who were engaged in the market channels of the products most of which were not available or did not want to participate in the research due to personal issues. As a result, the information gathered regarding the market channels was not sufficient to be generalized, hence an overall view of the current market channels was used to answer the research question.

A desk study was used to collect secondary qualitative and quantitative data. The challenge of this method for me as a researcher was the literature most of which was in Dutch and needed to be translated. Also, the information about a compatible crop with hazelnut trees was not sufficient because according to Van Druenen (2021), the experience regarding the combination of annual crops and trees in the Netherlands has just been started up by Universities such as the University of Wageningen. However, it was tried to review the available literature as much as possible to obtain reliable information that helped to answer the research questions.

During the research design, field observation is essential to have a proper view of the hazelnut and cabbage grower situation. Actually, the gathered information through observations was not sufficient to help me to answer the research questions. So it would be better to use another method like two more interviews with other farmers to collect more reliable quantitative data for P/L analysis.

The P/L model is an interesting model to calculate and analyze the profitability of a system for a long-term period. Besides, it enables the researcher to evaluate the profitability in different situations and estimate the future changes in the economic performance of the system. However, this model requires large numbers of quantitative data and assumptions which makes the data collection difficult and affects the validity and reliability of the analysis.

The biggest challenge of this study was the assessment of the environmental benefit in terms of soil fertility. Finding and having access to experts who are willing to participate, the expert's bias in scaling, and generalization of the given scales were the factors that might affect the results. But, due to the limited time of the study, this method was the only method that could be used to answer the research question regarding the environmental benefit in terms of soil fertility.

The last challenge of the research methodology was conflicting of the data collection time with summer holidays in the Netherlands. However, in spite of the difficulties it was possible to schedule and conduct the interviews and observations within the allocated time for data collection in the research planning.

Chapter 6. Conclusions and Recommendations

The purpose of the current study was to investigate if the hazelnut-cabbage combination would be a suitable combination in the SAF system and examine the economic performance of the hazelnut-cabbage combination in terms of profitability, market channels for the products, and environmental benefit in terms of soil fertility of the combination.

This study has identified that the hazelnut and cabbage are compatible with the Netherlands climate condition based on their growing requirements. The research has also shown that the selection of different varieties of hazelnut which are compatible with the main varieties for pollination is essential due to the effect of hazelnut pollination on production. Another finding was that regarding the farm management activities, transplanting, pruning, are the main, important, and labor-intensive activities for hazelnut production, and land preparation, transplanting, weeding, irrigation, and harvesting are the main farm management activities in cabbage production.

Regarding the competition and synergy between hazelnut and cabbage, the results of this research show that due to the different root systems of cabbage and hazelnut, there is limited competition for water and nutrients in the soil when water and nutrients are available and sufficient. Moreover, the enhancement of soil quality by the hazelnut tree, which makes the condition suitable for the crop to develop better, might be the synergy of the cabbage and hazelnut tree. Additionally, after yearly annual crop harvesting, leftovers and tree litter provide organic matter to the soil, which supplies nutrients such as Nitrogen and micronutrients to cabbage and hazelnut trees after decomposition. Another synergy from the hazelnut and cabbage combination is an increase in agricultural biodiversity, which aids in pest and disease management in a biological condition.

Regarding the economic performance of hazelnut and cabbage combination, this study has indicated that the total yield per hectare of hazelnut in the monoculture system is more than the total yield per hectare in the SAF system. Besides, the total yield of cabbage in the SAF system is the same as the monoculture system. This study has also identified that the annual revenue in the hazelnut without shell scenario is higher than with shell scenario. Moreover, in comparison to the SAF system, the annual revenue of cabbage in the monoculture system is higher. The research has also shown that due to the cabbage revenues contribution in the SAF system, especially in the first three years when the hazelnut has no revenues due to zero tree production the average total annual revenues for 2 hectares of hazelnut and cabbage combination (SAF system) are higher than the monoculture system over the first 10 years.

Another major finding was that the main costs incurred in the monoculture and SAF systems are the purchase of seedlings and required equipment for harvesting and pruning, as well as labor costs for weeding, planting, and pruning for hazelnut and purchase of seedlings, irrigation system establishment and labor costs for cabbage. Besides, due to shared fixed costs and a joint-production relationship in SAF systems, the costs of fixed assets are nearly similar in the monoculture and SAF systems.

The P/L analysis in this study showed that the average of 10 years' total annual cost of cabbage and hazelnut combination is higher in comparison to the total annual cost of cabbage production and the average of 10 years' total annual cost of hazelnut production in monoculture systems. The fact that the annual costs of producing cabbage and hazelnut in monoculture systems are gathered in the SAF system may explain these result.

The results have also shown that in both the with and without shell hazelnut scenarios, the average annual net profit before tax for hazelnut production in the monoculture system is negative, that can be explained by the P/L model calculations, which showed that the annual net profit in hazelnut production becomes positive after the 5th year in the without shell scenario and after the 6th year in the with shell scenario. As a result of the negative net profit in the first 4 to 5 years of production due to low production and high costs of orchard establishment, the average net profit over the first 10-year period becomes negative.

The most important finding to emerge from this study is that in both the with and without shell hazelnut scenarios, the average annual net profit before tax is positive, indicating that cabbage income covers the initial expenses and negative net profit of hazelnut production in the first four years of the SAF system establishment.

As a result, it can be stated that the SAF system's mix of hazelnut and cabbage is more profitable than the monoculture system's hazelnut production. However, cabbage is more profitable in a monoculture system than in a SAF system. Though, the SAF system's environmental advantages and long-term sustainability should also be taken into account.

On the subject of the market channels of hazelnut and cabbage combination products, this study has found that generally there is no difference between the price of hazelnut produced in agroforestry and monoculture system. Furthermore, there is currently no established value chain for the hazelnut produced in an agroforestry system, as growers are still in the process of producing nuts. Additionally, the market is dependent on the volume of production, quality, and year-round delivery. Because most farmers in the Netherlands cannot fulfill the big companies' requirements due to low production volumes and lack of storage capacity for round-year delivery, their only choice is to sell directly to customers or sell at a lower price to a small number of wholesalers. The current study also found that the majority of farmers sell cabbage to cooperatives as a selling channel. Because the selling price in this channel does not benefit farmers, farmers can spend on marketing and the necessary equipment in order to sell directly to consumers, where the margin is higher. Therefore, this study has identified two main market channels for organic cabbage and hazelnut in the Netherlands including (a) Farmers sell to cooperatives or other wholesalers, then wholesalers sell to the consumers through chain stores and specific supermarkets such as Odin and Ekoplaza. (b) Farmers sell directly to local consumers to gain more gross margin which may be due to the absence of wholesalers in this channel. However, this study has been unable to demonstrate that all cabbage and hazelnut producers in the Netherlands sell their products through the mentioned channels, hence, Further research should be undertaken to investigate the existed market channels and supply chains for organic cabbage and hazelnut in the Netherlands.

In terms of the environmental benefit of hazelnut and cabbage production on soil fertility, the findings of this study showed that the effect of hazelnut and cabbage production on soil fertility, including Nitrogen and Phosphorus availability, balancing the soil PH, and adding organic matter to the soil in SAF system, is higher than in monoculture system. This finding might be explained by the fact that the hazelnut and cabbage combination contributes organic matter to the soil via cabbage leftovers after harvesting and hazelnut tree litter and pruning. As a result, the soil's nutrient availability improves, and the PH balance is maintained. Besides, the hazelnut root system expands to the deeper layers of the soil which improves the soil structure, soil texture, and health.

However, the measuring of soil fertility components was not achievable due to the research's timing constraints. As a result, more studies that monitor soil nutrients, PH, and organic matter in both systems for multiple years will be required to provide a complete picture of the environmental benefit of crop-tree combination in the SAF system.

Overall, the results of this study indicated that cabbage and hazelnut are compatible and can be combined in the SAF system. Moreover, the evaluation of the economic performance and environmental benefit in terms of soil fertility of the hazelnut-cabbage combination showed that the combination is profitable and environmentally beneficial in terms of soil fertility in comparison to the production of hazelnut but not cabbage in the monoculture system. However, the combination is indeed still profitable. Hence, the hazelnut-cabbage combination can help in the process of designing the SAF demo plot in the Gelderland province.

Recommendations

The recommendations presented in this chapter are meant to help the commissioner (Royal Eijkelkamp) in the process of designing the SAF demo plot and farmers for transitioning to the AF system.

Royal Eijkelkamp company

- It is recommended to use hazelnut-cabbage combination for their AF demo plot. However, due to the limited time of the research, analysis the environmental benefit in terms of soil fertility measurement was not feasible. In addition, further experimental investigations are needed to measure and monitor the soil fertility components for a long-term period to have a better view of the environmental benefit of the selected crop-tree combination.
- The initial required investment for the establishment of the SAF system is high. Hence it is recommended to explore the funding opportunities for the farmers who do not have access to the required money for initial expenses in the first 4 to 5 years of the SAF system.

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- This research was able to determine and analyze only one annual crop (cabbage) for the combination with hazelnut trees in the SAF system due to the limited time of the study. Due to the importance of crop rotation in AF systems further studies need to be carried out in order to determine another annual crop that is compatible with the hazelnut tree.
- Further research could also be conducted to determine the supply chain and all market channels of organic cabbage and hazelnut in the Netherlands through investigation among involved actors in the market.

Farmers Eijkelkamp is in contact with

- The P/L Model calculations show that the higher gross margin of processed products that are sold directly to the consumers will be able to cover the investment in purchased equipment and marketing activities. It is recommended to invest in processing equipment, marketing, and advertisement.

Cabbage grower (study case)

- Due to the profitability and environmental benefit in terms of (soil fertility) of cabbage-hazelnut combination and the financial situation of the farmer, it is recommended to start the SAF system trial on 2 hectares that are allocated to the system.

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Annexes:

Annex 1: Hazelnut variety selection

Variety	Percentage
Main varieties	
Emoa 1, 2 or 3	40%
Corabel	40%
Pollinators	
Cosford	5%
Gustav's Zeller	5%
Lang Tidling Zeller	5%
Riccia di Talanico	5%

Source: Wertheim and Baltissen (2020)

Annex 2: Hazelnut with shell (monoculture system) annual COGS

Item	Unit	Price/unit	Quantity	Amount
Purchases				
Purchase seedlings (one year tree)	Num	€ 11,25	611	€ 13.748
Purchase compost	Kg	N/A	N/A	N/A
Purchase solid manure	Kg	N/A	N/A	N/A
Irrigation system	Num	€ 580	1	€ 1.160
Irrigation system annual cost	Num	€ 370	1	€ 740
Tree stakes (two per tree)	Num	€ 3	1112	€ 6.672
Crates for harvesting	Num	€ 5	100	€ 500
Picking machine	Num	€ 1.800	1	€ 1.800
Lopper	Num	€ 90	3	€ 270
Rop saw	Num	€ 20	3	€ 60
Pruning saw	Num	€ 40	3	€ 120
			Total purchases costs	**€ 25.069**
Labor costs				
Cleaning the orchard	Hours	€ 20,00	2	€ 80
Digging and planting	Hours	€ 20,00	16	€ 640
Secure the trees Year 1	Hours	€ 20,00	6	€ 240
Secure the trees Year 2-6	Hours	€ 20,00	2	€ 80
Secure the trees Year 6 to 10	Hours	€ 20,00	N/A	N/A
Fertilization First year	Hours	€ 20,00	3	€ 120
Fertilization Year 2 afterward	Hours	€ 20,00	2	€ 80
Weeding	Hours	€ 20,00	6	€ 240
Pruning year 2 to 5	Hours	€ 30,00	24	€ 1.440
Pruning year 6 afterward	Hours	€ 30,00	20	€ 1.200
Harvesting year 4	Hours	€ 30,00	2	€ 120
Harvesting year 5	Hours	€ 30,00	4	€ 240
Harvesting year 6	Hours	€ 30,00	6	€ 360
Harvesting year 7	Hours	€ 30,00	9	€ 540
Harvesting full production	Hours	€ 30,00	12	€ 720
			Total labor costs	**€ 6.100**

Source: (Baltissen, 2021); (Jansen, 2021); (Wertheim and Baltissen, 2020), (Netafim company, 2021); (Agriexpo.online, 2021) and (Target.com, 2021) compiled by the author

Annex 3: The farmer (study case) fixed assets (with shell scenario)

Fixed assets				
Item	**Unit**	**Price/unit**	**Quantity**	**Amount**
Buildings (life span 30 years)	Num	€ 450.000	1	€ 450.000
Tractors	Num	€ 25.000	2	€ 50.000
Land	Num	€ 80.000	2	€ 160.000
Equipment	Num	€ 11.000	1	€ 11.000
Irrigation system	Num	€ 580	2	€ 1.160
Picking machine	Num	€ 1.800	1	€ 1.800
Harvesting equipment	Num	€ 450	1	€ 450
			Total fixed assets	**€ 674.410**

Source: (Nieuwenhuis 2021); (Netafim company, 2021); (Agriexpo.online, 2021) and (Target.com, 2021) compiled by the author

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Annex 4: Hazelnut with shell (monoculture system) annual costs of fixed assets

Costs of Fixed assets			
Depreciation	**Amount**	**Allocation %**	**Final amount**
Buildings (life span 30 years)	€ 15.000	4%	€ 600
Machinery (life span 7 years)	€ 7.000	4%	€ 280
Picking machine (life span 5 years)	€ 360	100%	€ 360
Equipment (life span 5 years)	€ 2.200	4%	€ 88
Harvesting equipment (life span 5 years)	€ 90	100%	€ 90
		Total depreciation	**€ 1.418**
Maintenance	**Amount**	**Allocation %**	**Final amount**
Buildings	€ 4.500	4%	€ 180
Harvesting equipment	€ 40	100%	€ 40
Machinery	€ 5.000	4%	€ 200
Picking machine	€ 180	100%	€ 180
Equipment	€ 1.100	4%	€ 44
		Total maintenance	**€ 644**
		Total annual costs of fixed assets	**€ 2.062**

Source: Compiled by the author

Annex 5: Hazelnut with shell (monoculture system) annual SGA costs

SGA annual costs			
Utility	**Amount/year**	**Allocation %**	**Final amount/year**
Gas	€ 4.800	4%	€ 192
Water	€ 500	4%	€ 20
Electrisity	€ 6.000	4%	€ 240
sewer	€ 167	4%	€ 7
Mobile/Phone bills	€ 300	4%	€ 12
Internet	€ 928	4%	€ 37
Fuel	€ 6.000	4%	€ 240
		Total utility costs/year	**€ 748**
Others	**Amount/year**	**Allocation %**	**Final amount/year**
Bilogical production certificate	€ 1.200	4%	€ 48
Accountant salary	€ 61.000	4%	€ 1.220
		Total SGA annual costs	**€ 2.016**

Source: Nieuwenhuis (2021)

Annex 6: Hazelnut without shell (monoculture system) annual COGS

Item	Unit	Price/unit	Quantity	Amount
Purchases				
Purchase seedlings (one year tree)	Num	€ 11,25	611	€ 13.748
Purchase compost	Kg	N/A	N/A	N/A
Purchase solid manure	Kg	N/A	N/A	N/A
Irrigation system	Num	€ 580	1	€ 1.160
Irrigation system annual cost	Num	€ 370	1	€ 740
Tree stakes (two per tree)	Num	€ 3	1112	€ 6.672
Crates for harvesting	Num	€ 5	100	€ 500
Picking machine	Num	€ 1.800	1	€ 1.800
Shelling machine	Num	€ 2.000	1	€ 2.000
Lopper	Num	€ 90	3	€ 270
Rop saw	Num	€ 20	3	€ 60
Pruning saw	Num	€ 40	3	€ 120
			Total purchases costs	**€ 27.069**
Labor costs				
Cleaning the orchard	Hours	€ 20,00	2	€ 80
Digging and planting	Hours	€ 20,00	16	€ 640
Secure the trees Year 1	Hours	€ 20,00	6	€ 240
Secure the trees Year 2-6	Hours	€ 20,00	2	€ 80
Secure the trees Year 6 to 10	Hours	€ 20,00	N/A	N/A
Fertilization First year	Hours	€ 20,00	3	€ 120
Fertilization Year 2 afterward	Hours	€ 20,00	2	€ 80
Weeding	Hours	€ 20,00	6	€ 240
Pruning year 2 to 5	Hours	€ 30,00	24	€ 1.440
Pruning year 6 afterward	Hours	€ 30,00	20	€ 1.200
Harvesting year 4	Hours	€ 30,00	2	€ 120
Harvesting year 5	Hours	€ 30,00	4	€ 240
Harvesting year 6	Hours	€ 30,00	6	€ 360
Harvesting year 7	Hours	€ 30,00	9	€ 540
Harvesting full production	Hours	€ 30,00	12	€ 720
			Total labor costs	**€ 6.100**

Source: (Baltissen, 2021); (Jansen, 2021); (Wertheim and Baltissen, 2020), (Netafim company, 2021); (Agriexpo.online, 2021) and (Target.com, 2021) compiled by the author

Annex 7: The farmer (study case) fixed assets (without shell scenario)

Fixed assets				
Item	**Unit**	**Price/unit**	**Quantity**	**Amount**
Buildings	Num	€ 450.000	1	€ 450.000
Tractors	Num	€ 25.000	2	€ 50.000
Land	Num	€ 80.000	2	€ 160.000
Equipment	Num	€ 11.000	1	€ 11.000
Irrigation system	Num	€ 580	2	€ 1.160
Picking machine	Num	€ 1.800	1	€ 1.800
Shelling machine	Num	€ 2.000	1	€ 2.000
Harvesting equipment	Num	€ 450	1	€ 450
			Total fixed assets	**€ 676.410**

Source: (Nieuwenhuis 2021); (Netafim company, 2021); (Agriexpo.online, 2021) and (Target.com, 2021) compiled by the author

Annex 8: Hazelnut without shell (monoculture system) annual costs of fixed assets

Costs of Fixed assets			
Depreciation	**Amount**	**Allocation %**	**Final amount**
Buildings (life span 30 years)	€ 15.000	4%	€ 600
Machinery (life span 7 years)	€ 7.000	4%	€ 280
Picking machine (life span 5 years)	€ 360	100%	€ 360
Equipment (life span 5 years)	€ 400	100%	€ 400
Harvesting equipment (life span 5 years)	€ 2.200	4%	€ 88
Buildings (life span 30 years)	€ 90	100%	€ 90
		Total depreciation	**€ 1.818**
Maintenance	**Amount**	**Allocation %**	**Final amount**
Buildings	€ 4.500	4%	€ 180
Harvesting equipment	€ 40	100%	€ 40
Machinery	€ 5.000	4%	€ 200
Picking machine	€ 180	100%	€ 180
Shelling machine	€ 200	100%	€ 200
Equipment	€ 1.100	4%	€ 44
		Total maintenance	**€ 844**
		Total costs of fixed assets	**€ 2.662**

Source: Compiled by the author

Annex 9: Hazelnut without shell (monoculture system) annual SGA costs

SGA expenses			
Utility	**Amount/year**	**Allocation %**	**Final amount/year**
Gas	€ 4.800	4%	€ 192
Water	€ 500	4%	€ 20
Electrisity	€ 6.000	4%	€ 240
sewer	€ 167	4%	€ 7
Mobile/Phone bills	€ 300	4%	€ 12
Internet	€ 928	4%	€ 37
Fuel	€ 6.000	4%	€ 240
		Total utility costs/year	**€ 748**
Others	**Amount/year**	**Allocation %**	**Final amount/year**
Bilogical production certificate	€ 1.200	4%	€ 48
Accountant salary	€ 61.000	4%	€ 1.220
		Total SGA expenses	**€ 2.016**

Source: (Nieuwenhuis, 2021)

Annex 10: Cabbage production (monoculture system) annual COGS

Item	Unit	Price/unit	Quantity	Amount
Purchases				
Purchase plant material	Num/ha	€ 2.900	2	€ 5.800
Purchase compost (kg)	Kg	N/A	N/A	N/A
Purchase solid manure (kg)	Kg	N/A	N/A	N/A
Irrigation system setup	Num	€ 370	1	€ 740
Irrigation system removal after harvest	Num	€ 370	1	€ 740
			Total purchases costs	**€ 7.280**
Labor costs				
Weeding	Hours	€ 20,00	8	€ 320
Transplanting	Hours	€ 30,00	28	€ 1.680
Harvesting	Hours	€ 30,00	32	€ 1.920
			Total labor costs	**€ 3.920**

Source: (Nieuwenhuis, 2021); (Netafim company, 2021); (Agriexpo.online, 2021); (Target.com, 2021) and compiled by the author

Annex 11: The farmer (study case) fixed assets (cabbage production)

Fixed assets				
Item	**Unit**	**Price/unit**	**Quantity**	**Amount**
Buildings	Num	€ 450.000	1	€ 450.000
Tractors	Num	€ 25.000	2	€ 50.000
Land	Num	€ 80.000	2	€ 160.000
Equipment	Num	€ 11.000	1	€ 11.000
Irrigation system	Num	€ 580	2	€ 1.160
Harvesting equipment	Num	€ 250	1	€ 700
			Total fixed assets	**€ 672.410**

Source: (Nieuwenhuis 2021); (Netafim company, 2021); compiled by the author

Annex 12: Cabbage production (monoculture system) annual costs of fixed assets

Costs of Fixed assets			
Depreciation	**Amount**	**Allocation %**	**Final amount**
Buildings (life span 30 years)	€ 15.000	4%	€ 600
Machinery (life span 7 years)	€ 7.000	4%	€ 280
Equipment (life span 5 years)	€ 2.200	4%	€ 88
Harvesting equipment (life span 5 years)	€ 50	100%	€ 50
		Total depreciation	**€ 1.018**
Maintenance	**Amount**	**Allocation %**	**Final amount**
Buildings	€ 4.500	4%	€ 180
Harvesting equipment	€ 25	100%	€ 25
Machinery	€ 5.000	4%	€ 200
Equipment	€ 1.100	4%	€ 44
		Total maintenance	**€ 449**
		Total costs of fixed assets	**€ 1.467**

Source: Compiled by the author

Annex 13: Cabbage production (monoculture system) annual SGA costs

SGA expenses			
Utility	**Amount/year**	**Allocation %**	**Final amount/year**
Gas	€ 4.800	4%	€ 192
Water	€ 500	4%	€ 20
Electrisity	€ 6.000	4%	€ 240
sewer	€ 167	4%	€ 7
Mobile/Phone bills	€ 300	4%	€ 12
Internet	€ 928	4%	€ 37
Fuel	€ 6.000	4%	€ 240
		Total utility costs/year	**€ 748**
Others	**Amount/year**	**Allocation %**	**Final amount/year**
Bilogical production certificate	€ 1.200	4%	€ 48
Accountant salary	€ 61.000	4%	€ 1.220
		Total SGA expenses	**€ 2.016**

Source: (Nieuwenhuis, 2021) and compiled by the author

Annex 14: Crop-tree combination annual COGS (hazelnut with shell)

Item	Unit	Price/unit	Quantity	Amount
Purchases				
Purchase seedlings (one year tree)	Num	€ 11,25	366	€ 8.235
Purchase cabbage seedlings	Num	€ 2.600	1	€ 2.600
Purchase compost	Kg	N/A	N/A	N/A
Purchase solid manure	Kg	N/A	N/A	N/A
Irrigation system	Num	€ 580	1	€ 1.160
Irrigation system annual cost	Num	€ 370	1	€ 740
Tree stakes (two per tree)	Num	€ 3	1112	€ 6.672
Crates for harvesting	Num	€ 5	100	€ 500
Picking machine	Num	€ 1.800	1	€ 1.800
Lopper	Num	€ 90	3	€ 270
Rop saw	Num	€ 20	3	€ 60

Pruning saw	Num	€ 40	3	€ 120
			Total purchases costs	**€ 19.481**
Labor costs				
Cleaning the orchard	Hours	€ 20,00	2	€ 80
Digging and planting	Hours	€ 20,00	8	€ 320
Secure the trees Year 1	Hours	€ 20,00	3	€ 120
Secure the trees Year 2-6	Hours	€ 20,00	2	€ 80
Secure the trees Year 6 to 10	Hours	€ 20,00	0	N/A
Fertilization First year	Hours	€ 20,00	3	€ 120
Fertilization Year 2 afterward	Hours	€ 20,00	2	€ 80
Weeding	Hours	€ 20,00	3	€ 120
Pruning year 2 to 5	Hours	€ 30,00	12	€ 720
Pruning year 6 afterward	Hours	€ 30,00	10	€ 600
Harvesting year 4	Hours	€ 30,00	2	€ 120
Harvesting year 5	Hours	€ 30,00	2	€ 120
Harvesting year 6	Hours	€ 30,00	3	€ 180
Harvesting year 7	Hours	€ 30,00	5	€ 300
Harvesting full production	Hours	€ 30,00	6	€ 360
Cabbage weeding	Hours	€ 20,00	7	€ 280
Cabbage transplanting	Hours	€ 30,00	25	€ 1.500
Cabbage harvesting	Hours	€ 30,00	28	€ 1.680
			Total labor costs	**€ 6.780**

Source: (Baltissen, 2021); (Jansen, 2021); (Nieuwenhuis, 2021); (Wertheim and Baltissen, 2020), (Netafim company, 2021); (Agriexpo.online, 2021); (Target.com, 2021) and compiled by the author

Annex 15: Crop-tree combination fixed assets (hazelnut with shell)

Fixed assets				
Item	**Unit**	**Price/unit**	**Quantity**	**Amount**
Buildings	Num	€ 450.000	1	€ 450.000
Tractors	Num	€ 25.000	2	€ 50.000
Land	Num	€ 80.000	2	€ 160.000
Equipment	Num	€ 11.000	1	€ 11.000
Irrigation system	Num	€ 580	2	€ 1.160
Picking machine	Num	€ 1.800	1	€ 1.800
Harvesting equipment	Num	€ 700	1	€ 700
			Total fixed assets	**€ 675.110**

Source: (Nieuwenhuis, 2021) and compiled by the author

Annex 16: Crop-tree combination annual costs of fixed assets (hazelnut with shell)

Costs of Fixed assets			
Depreciation	**Amount**	**Allocation %**	**Final amount**
Buildings (life span 30 years)	€ 15.000	4%	€ 600
Machinery (life span 7 years)	€ 7.000	4%	€ 280
Picking machine (life span 5 years)	€ 360	100%	€ 360
Equipment (life span 5 years)	€ 2.200	4%	€ 88

Harvesting equipment (life span 5 years)	€ 140	100%	€ 140
		Total depreciation	**€ 1.468**
Maintenance	**Amount**	**Allocation %**	**Final amount**
Buildings	€ 4.500	4%	€ 180
Harvesting equipment	€ 70	100%	€ 70
Machinery	€ 5.000	4%	€ 200
Picking machine	€ 180	100%	€ 180
Equipment	€ 1.100	4%	€ 44
		Total maintenance	**€ 674**
		Total costs of fixed assets	**€ 2.142**

Source: Compiled by the author

Annex 17: Crop-tree combination (hazelnut with shell) annual SGA costs

SGA expenses			
Utility	**Amount/year**	**Allocation %**	**Final amount/year**
Gas	€ 4.800	4%	€ 192
Water	€ 500	4%	€ 20
Electrisity	€ 6.000	4%	€ 240
sewer	€ 167	4%	€ 7
Mobile/Phone bills	€ 300	4%	€ 12
Internet	€ 928	4%	€ 37
Fuel	€ 6.000	4%	€ 240
		Total utility costs/year	**€ 748**
Others	**Amount/year**	**Allocation %**	**Final amount/year**
Bilogical production certificate	€ 1.200	4%	€ 48
Accountant salary	€ 61.000	4%	€ 1.220
		Total SGA expenses	**€ 2.016**

Source: (Nieuwenhuis, 2021) and compiled by the autho

Annex 18: Crop-tree combination (hazelnut without shell) annual COGS

Item	Unit	Price/unit	Quantity	Amount
Purchases				
Purchase seedlings (one year tree)	Num	€ 11,25	366	€ 8.235
Purchase cabbage seedlings	Num	€ 2.600	1	€ 2.600
Purchase compost	Kg	N/A	N/A	N/A
Purchase solid manure	Kg	N/A	N/A	N/A
Irrigation system	Num	€ 580	1	€ 1.160
Irrigation system annual cost	Num	€ 370	1	€ 740
Tree stakes (two per tree)	Num	€ 3	1112	€ 6.672
Crates for harvesting	Num	€ 5	100	€ 500
Picking machine	Num	€ 1.800	1	€ 1.800
Shelling machine	Num	€ 2.000	1	€ 2.000
Lopper	Num	€ 90	3	€ 270
Rop saw	Num	€ 20	3	€ 60
Pruning saw	Num	€ 40	3	€ 120
			Total purchases costs	**€ 21.481**

Labor costs				
Cleaning the orchard	Hours	€ 20,00	2	€ 80
Digging and planting	Hours	€ 20,00	8	€ 320
Secure the trees Year 1	Hours	€ 20,00	3	€ 120
Secure the trees Year 2-6	Hours	€ 20,00	2	€ 80
Secure the trees Year 6 to 10	Hours	€ 20,00	0	N/A
Fertilization First year	Hours	€ 20,00	3	€ 120
Fertilization Year 2 afterward	Hours	€ 20,00	2	€ 80
Weeding	Hours	€ 20,00	3	€ 120
Pruning year 2 to 5	Hours	€ 30,00	12	€ 720
Pruning year 6 afterward	Hours	€ 30,00	10	€ 600
Harvesting year 4	Hours	€ 30,00	2	€ 120
Harvesting year 5	Hours	€ 30,00	2	€ 120
Harvesting year 6	Hours	€ 30,00	3	€ 180
Harvesting year 7	Hours	€ 30,00	5	€ 300
Harvesting full production	Hours	€ 30,00	6	€ 360
Cabbage weeding	Hours	€ 20,00	7	€ 280
Cabbage transplanting	Hours	€ 30,00	25	€ 1.500
Cabbage harvesting	Hours	€ 30,00	28	€ 1.680
			Total labor costs	**€ 6.780**

Source: (Baltissen, 2021); (Jansen, 2021); (Nieuwenhuis, 2021); (Wertheim and Baltissen, 2020), (Netafim company, 2021); (Agriexpo.online, 2021); (Target.com, 2021) and compiled by the author

Annex 19: Crop-tree combination fixed assets (hazelnut without shell)

Fixed assets				
Item	**Unit**	**Price/unit**	**Quantity**	**Amount**
Buildings	Num	€ 450.000	1	€ 450.000
Tractors	Num	€ 25.000	2	€ 50.000
Land	Num	€ 80.000	2	€ 160.000
Equipment	Num	€ 11.000	1	€ 11.000
Irrigation system	Num	€ 580	2	€ 1.160
Picking machine	Num	€ 1.800	1	€ 1.800
Shelling machine	Num	€ 2.000	1	€ 2.000
Harvesting equipment	Num	€ 450	1	€ 450
			Total fixed assets	**€ 676.410**

Source: (Nieuwenhuis, 2021) and compiled by the author

Annex 20: Crop-tree combination annual costs of fixed assets (hazelnut without shell)

Costs of Fixed assets			
Depreciation	**Amount**	**Allocation %**	**Final amount**
Buildings (life span 30 years)	€ 15.000	4%	€ 600
Machinery (life span 7 years)	€ 7.000	4%	€ 280
Picking machine (life span 5 years)	€ 360	100%	€ 360
Shelling machine (life span 5 years)	€ 400	100%	€ 400
Equipment (life span 5 years)	€ 2.200	4%	€ 88
Harvesting equipment (life span 5 years)	€ 140	100%	€ 140
		Total depreciation	**€ 1.868**
Maintenance	**Amount**	**Allocation %**	**Final amount**
Buildings	€ 4.500	4%	€ 180
Harvesting equipment	€ 70	100%	€ 70
Machinery	€ 5.000	4%	€ 200
Picking machine	€ 180	100%	€ 180
Shelling machine	€ 200	100%	€ 200
Equipment	€ 1.100	4%	€ 44
		Total maintenance	**€ 874**
		Total costs of fixed assets	**€ 2.742**

Source: Compiled by the author

Annex 21: Crop-tree combination (hazelnut without shell) annual SGA costs

SGA expenses			
Utility	**Amount/year**	**Allocation %**	**Final amount/year**
Gas	€ 4.800	4%	€ 192
Water	€ 500	4%	€ 20
Electrisity	€ 6.000	4%	€ 240
sewer	€ 167	4%	€ 7
Mobile/Phone bills	€ 300	4%	€ 12
Internet	€ 928	4%	€ 37
Fuel	€ 6.000	4%	€ 240
		Total utility costs/year	**€ 748**
Others	**Amount/year**	**Allocation %**	**Final amount/year**
Bilogical production certificate	€ 1.200	4%	€ 48
Accountant salary	€ 61.000	4%	€ 1.220
		Total SGA expenses	**€ 2.016**

Source: (Nieuwenhuis, 2021) and compiled by the author

Annex 22: Observation pictures (hazelnut producer)





Annex 23: Observation pictures (study case farm)

Annex 24: Utility expenses of study case farm

Utilities	Cost for 50ha/year	2 ha cost allocation percentage	Cost for 2ha land/year
Gas	€ 4,800	4%	€ 192
Electricity	€ 6,000	4%	€ 240
Water	€ 500	4%	€ 20
Sewer	€ 167	4%	€ 7
Fuel	€ 6,000	4%	€ 240
Mobile/phone bills	€ 300	4%	€ 12
Internet	€ 928	4%	€ 37

Source: (Nieuwenhuis, 2021), compiled by the author

Annex 25: COGS annualization

Item	Price	Annualized amount	Explanation
Seedlings	€ 8.235	€ 824	Purchased in the first year, divided by 10
Posts	€ 3.996	€ 400	Purchased in the first year/ divided by 10
Shelling	€ 2.000	€ 333	Purchased in the fourth year/ divided by 6
Picking	€ 1.800	€ 300	Purchased in the fourth year/ divided by 6
Lopper	€ 270	€ 34	Purchased in the second year/ divided by 8
Rop saw	€ 60	€ 8	Purchased in the second year/ divided by 8
Pruning saw	€ 120	€ 15	Purchased in the second year/ divided by 8

Annex 26: Interview checklists

Interview checklist 1

Respondent's name: Herman Jansen Date: 14/07/2021

Proficiency/Experience: Farmer (Hazelnut producer)

1. Production

- **Between walnut and hazelnut, which one do you suggest for an agroforestry system?**

Hazelnut

- **Which varieties are proper for silvoarable agroforestry in the Netherlands?**

The main tree varieties are:

Emoa 1, 2 or 3 and Corabel= 40% each

The pollinators that can be used are:

Cosford, Gustav's Zeller, Lang Tidling Zeller and Riccia di Talanico= 5% each

The reasons for the selection of these varieties are:

The nut has a round shape which is demanded by the market in the Netherlands. Moreover, these varieties have less susceptibility to diseases and frost damage which makes them suitable for agroforestry systems.

- **Growing requirements and characteristics of the variety:**
  - **What are the planting and harvesting seasons?**

  In the case of using one year or two years old grafted trees the planting season is not important. And harvesting time is the Autumn which begins in September.

  - **What is the proper soil PH?**

  The proper soil PH for the hazelnut tree is 6 to 6.5.

  - **What is needed to make clay soil proper in terms of fertility and PH for tree growth?**

  Clay soils are very good for hazelnut production and the tree has a good performance in clay soils.

  - **Water consumption per tree/day in different ages of tree**

  It depends on the size and age of the trees. In August and July the evaporation is high and in April and October is low. The table below illustrates the water consumption (Liter/tree/day) in different ages of the tree:

  - **What are the main pest and diseases and the required actions in different ages of the tree?**

  The main pests and diseases are Nut weevil and Mites. As the selected farm is doing biological production so the control will be biological control. Moreover, insects are also a problem that is recommended to use birdnest in the farm which is costly. And for Nematodes, there are several natural control ways.

  - **What kind of fertilizer do you use? How many KG per tree? How many times per year, And the price per KG.**

  As the farm is going to have biological production, the compost and organic matter will be mixed with the soil before planting and the first few years. Once the trees are in production, fertilization will be carried out based on soil and leaf analysis.

  - **To what extent hazelnut trees are sensitive to sunlight?**

  Hazelnut trees are not sensitive to the sunlight, and they thrive in mid shade situations.

  - **What are the necessary nutrients (NPK) for hazelnut trees?** The amount per tree

  Organic fertilizers can be used because they provide all the necessary nutrients for the trees.

  - **What is the optimum temperature for a hazelnut tree to grow well in different stages? And What is the effect of frost and temperature change on the yield and trees?**

  The optimum temperature is 13 to 20 ^{0}C. In the flowering time, the tree is sensitive to frost damage (less than -10 ^{0}C which is in January and February.

- **How many years does it take for the trees to start production and when is the full production?**

If a good seedling is bought by the farmers, in the third and fourth year the trees start the production but 10% of the fully grown tree. After the 7th year, they will have full production.

- **What is the average yield per tree for the matured hazelnut tree as monocrop (with shell and without shell)? And what will be the yield when it combines with another crop? (with/without shell)**

In case of the availability of water and fertile soil, the average yield per tree in monocropping is 3 to 4 kg when the tree is fully grown. So in the 4th year, the estimated yield can be 0.4 kg per tree which is 10% of the fully grown tree. Moreover, the weight of the shell is 50% of the nut. So the yield without the shell will be 50% of the yield with the shell.

- **What are the important factors in hazelnut farm management in the agroforestry system?**
    - Spacing and what does it look like
      The proper spacing for the agroforestry system is 6*6 which gives space to the tree and crops to grow.
    - Plant density
      278 trees per hectare.
    - Pruning
      Pruning is very important. Because hazelnut trees tend to be bush, so regular pruning is needed. Hence, purchasing tree shape seedlings is recommended to reduce labor costs.
    - Any other factor

      Planting hazelnut trees that can be pollinators varieties or other trees as wind breaker is also recommended, because it may affect the shape of the trees.
- **If you grow hazelnut organically, what other/extra production measures are required? Does this bring along any additional costs?**
- **Based on your experience, what challenges do you think need to be considered when hazelnut combine with another crop?**

  The possible challenges are competition and pests and diseases, if the combination's advantage is more than a disadvantage, it means there will be no problem.
- **What are the expenses regarding hazelnut production? (per hectare/tree)**

Land preparation

- What are the activities for land preparation

Order plants
Eliminate perennial weeds
Eliminate compaction
Soil sample, and address any deficiencies of P, K, and non-leachable micronutrients
Lime if needed to raise the pH to 6.0
Build soil organic matter with compost, manure and/or cover crops
Establish permanent vegetation in alleys
Till the planting strip in the summer or fall

Seedling

- To plant a hazelnut production area, how many seedlings do you need to buy and per hectare
  Based on the spacing which is 6*6, 278 seedlings from different varieties per hectare are needed plus 5% additional as an alternative for replacement.
- How much do seedlings costs if you purchase them in larger quantities?
  Between 8 to 12 Euros

Fertilizer

- What kind of fertilizer do you use?
  In organic production only compost, manure, and liquid organic fertilizers in some cases.
- How many KG per tree?

One or two full shovels compost in the hole and mix with the soil

Equipment & Machinery

- What kind of equipment is needed?
  Harvesting and pruning machines and equipment

Farm management (pruning, harvesting, etc.)

- How many times per year pruning is needed and for how many years?
  In case of purchasing tree shape hazelnut seedling which is expensive and difficult to get, pruning will not be necessary. But if the tree is vase shape the yearly pruning in December and February is needed up to the 4th year.
- The cost of labor for pruning and harvesting per tree?
  The estimated time is 5min per tree and the labor cost is 20 to 30 Euros per hour.
- How do you harvest and how much is the labor cost?
  If the farmer is able to buy harvesting machinery and the farming system allows machinery movement, the labor needed is less. But if the situation needs manual harvesting then labor for harvest will be needed.

➢ **Do you sell hazelnut with or without shells?**

Both have their own customers and are possible to sell.

➢ **What is your suggestion about the premium and normal price for the AF hazelnut (with and without shell)?**

Due to the quantity, mostly farmers sell directly to the consumer or local market. The price with shell is 4 Euros/kg and without shell is 10 Euros/kg. But the organic nuts can be sold at higher prices.

➢ **Would you consider process the hazelnut (i.e. turn them into hazelnut oil, etc.) before selling them? Why would you, why not? If you treat them, what kind of investments are needed? Machinery?**

Considering the farmer's financial situation, processing the nuts is recommended due to the added value. It can be cracked and extract the oil. This process needs to be done by cold press machines to have high oil quality. The price for the oil is **40-50 Euros** per liter. And one kilogram of the kernel can produce **50 ml** of oil.

➢ **What are the market channels and customer segments for agroforestry hazelnut?**

Basically, there is no value chain for hazelnut in the Netherlands, and farmers produce and sell directly to the consumer if the production volume is small, or if the volume is high they can sell to the big companies like Tony's chocolate, Odin, Eco plaza and bakeries.

➢ **What is the environmental benefit of hazelnut trees in terms of soil fertility?**

- Nitrogen
- Phosphorus
- Organic matter
- Soil PH
  Due to the presence of trees, it will not possible to disturb the soil, so soil quality will be better. And due to the organic matter added to the soil, all elements will improve like PH, water holding capacity, and nutrients like Nitrogen and Phosphorus. All of these benefits will help Carbon sequestration.

- **What is the level of competition and synergy of hazelnut trees when they incorporate with annual crops?**
  - For sunlight= Before the tree is fully grown there will not be that much competition for the light. And when the tree is fully grown if the distance between rows has been taken into the consideration there will not be competition.
  - For water= In the first three years that the tree needs water the competition for water will exist.
  - For nutrients= If the soil has good condition, there is not too much competition because the root system of the tree is different from the annual crop.
- **What are the possible crops that are suitable to combine with hazelnut trees?**
  Based on the advantages and disadvantages of the combination, there are a lot of combinations. In my opinion cabbages and beans can be good options.

Interview Checklist 2

Respondent's name: Theo Nieuwenhuis Date: 15/07/2021

Study case: Farmer

1. Production

- **What are the current cultivated crops? (their species)**

  Red and White cabbages and fodder beet, also grass and herbs.
- **What is the crop that you would like to use in the AF system?**

  Cabbages and beans
- **What is the acreage that you have allocated to each crop?**

  2 hectares for cabbages and 4 hectares for fodder beet.
- **How many times in a year and when do you harvest? (per crop/per harvest season)**

  One time and in September. We planted in late May.
- **How many kg per hectare do you harvest? (per crop/per harvest season)**

  30 to 35 tons per hectare
- **What are the growing requirements and characteristics of the crops?**
  - **What are the planting and harvesting seasons?**
    Spring (May) is the planting season and early autumn (September) is harvesting season.
  - **What is the proper soil PH?**
    PH should be between 6 to 6.5
  - **What is needed to make clay soil proper for the cabbages?**
    Cabbage does not have any problem with clay soils and it grows well in this type of soil.
  - **Water consumption per ha/day?**
    Weekly irrigation or rainfall is needed. For irrigation 1-2 inches per day
  - **What are the main pest and diseases and the required actions?**

Fungus, some bacteria, and pests cause problems that in an organic situation can be controlled.

- **To what extent cabbages are sensitive to the available light?**
  It needs 5-6 hours of sunlight to grow well and the taste will be sweet.
- **What are the necessary nutrients for cabbages growth? How do you provide them in the organic situation?**
  The necessary nutrients are NPK, and with compost and solid manure, the plant will gain the required nutrients.
- **What is the optimum Temperature for Cabbages to grow well in different stages?**
  Cabbage can grow well in between 10 to 22 degrees.
- **What will be the level of competition and synergy if the cabbages combine with hazelnut trees?**
  Generally, vegetable cultivation in agroforestry systems is possible because they have shallow root systems and they do not have competition underground with trees. Moreover, they can add to soil organic matter if we leave the leaves on the farm.

➢ **Which annual/perennial crops would you like to plant for the agroforestry plot?**

Annual crops can be cabbages and beans. And perennial can be walnut, hazelnut or apricot.

➢ **How many hectares of your farm do you want to allocate to plant trees?**

2 hectare

➢ **How do you want to invest (own capital or by loan) in it?**

I will use my saving money to invest in agroforestry system. 20,000 to 25.000 Euros.

3. Costs

3.1. Fixed costs

➢ **Land ownership (ownership or lease)**

I owned the land and I do not use any mortgage.

➢ **Do you have storage space for products? (hazelnut, cabbage, etc.).**

Yes, we have a building that wants to make it storage for our products. Moreover, we are trying to buy a cooling system for the cabbages that we want to store.

➢ **What kinds of machinery do you have?**

Two tractors, sowing machine, manure spreader and cultivation machines

➢ **Do you currently have an irrigation system? And can you use it for the agroforestry system?**

Or do you have to invest in a new additional irrigation system for the agroforestry?

Yes, I have an irrigation system that can be used for the agroforestry system.

➢ **Insurance, certificates (including biological certificate), and legal expenses related to the cabbage production and the agroforestry system?**

1200 Euros per year

- **Will you use any machines, equipment, or tools for agroforestry? Do you already own this? Or do you have to invest in those, if yes how much is the investment, and in how many years do you write these off?**

  I will need machinery for harvesting the hazelnuts, and shelling the nuts if I decide to sell directly to the customers.

- **Labor cost and salaries related to cabbage production. (man/hour needed per year, hourly Euro price, annual salary contract)**

  We used 7 people for planting two hectares cabbages for two days, each day 8 hours and 30 Euros per hour

- **Do you have any other fixed costs?**

  No

3.2. Variable costs

- **How much do you spend on the below items per year:**
  - **Cabbage: how much (KG) of seeds or plants per hectare do you buy annually?**

    We buy 37,000 seedlings. 33,000 plus 10% as a replacement.5800 Euros.

    50*60 is spacing to have bigger cabbages.

  - **How many hectares will you plant Cabbage on? What are the costs of seeds per hectare or in total?**

    The land is 2 ha, if we deduct the distance between rows which is 1.5 meters for herbs and grasses for biological control, the planted area will be 2.3 ha.

  - **Does the land need any special preparation to grow Cabbage (or other new crops), and which additional costs do this cause, other than labor?**

    First, we do the leveling and then making rows for planting the seedlings. Planting needs labor which is 2 days for 2 hectares and 7 people, 8 hrs per day.

  - **Utility expenses for the current situation and you will need to pay for agroforestry system per year.**

    ✓ Electricity 500 Euros/month
    ✓ Gas 400 Euros/month
    ✓ Fuel 6000 Euros/year
    ✓ Water 500 Euros/year
    ✓ Sewer 167 Euros/year
    ✓ Mobile /phone bills 300 Euros/year
    ✓ Internet 928 Euros/year

  - **Are products sold off-premises? If not, how are they transported to the point of sales?**

    It is sold off-premises to the cooperative with 32 cents per cabbage (1200grams)

- **Do you as a farmer pay any trucking costs? If so, what are the annual trucking costs? EUR/KG/KM.**

  No, they come and take the cabbages.

- **If you use temporary labor (Man/hour per year, hourly Euro, etc.) and specify if you use labor for a specific purpose.**

  Only for planting cabbages and harvesting, sometimes for weeding.

➢ **Have you made any investments in cabbage production yet? If yes, how and for what?**

We invested to buy compost, solid manure, and seedlings (37,000 cabbages for one hectare)

4. Revenues

➢ **In which market would you sell the cabbage? direct sales to consumers? To wholesalers? To restaurants?**

We sell to a cooperative, but we intend to have a system to be able to sell directly to the consumer to have more margin.

➢ **What's your expected distribution channel?**

Directly to the customer, have a package with different vegetables and sell it directly.

➢ **Do you receive any subsidy currently? (the type and the amount)**

Yes, 250 Euros per hectare per year.

➢ **Who are the customers and what are the market channels for the product?**

Currently, we sell to the cooperative, but we plan to sell directly to the customer which needs equipment such as a cooling system for storage of the cabbages.

Interview Checklist 3

Respondent's name: Rene Van Druenen Date: 14/08/2021

Study case: Agroforestry expert

Questions:

1. What are the annual crops that can be combined with hazelnut trees?
2. How do you show the profitability of a system to the farmers to convince them for farming system transition?
3. What are the environmental benefits of crop tree combination?
4. What are the market channels for cabbage and hazelnut that are produced in the AF system?

Answers:

Currently, the most experience regarding the combination of annual crops and trees in the Netherlands has just started up by Universities such as the University of Wageningen. They are experimenting combination of crops and nuts such as hazelnut and walnut. Hence, there is not a lot of information about a compatible crop with hazelnut trees. In total, there are six producers and 50 hectares of land in the Netherlands that have started experimenting and producing nuts such as hazelnut in arable land. There is more experience in other EU countries like England. In general, experts in agroforestry systems use the concept of land equivalent ratio to show the productivity of crop-tree combinations and compare it to the production of the same crop or tree in the same area in a monocropping system. Experts use this concept to convince farmers about the new farming systems and the benefits of shifting to a new system. In the Netherlands, there is a lack of data regarding crop-tree combinations.

Regarding the competition and synergy between hazelnut trees and cabbage, the tree and the crop have different root systems (deep root system of hazelnut and shallow root system of cabbage) there will be the least competition for water and nutrients between them. On the other hand, falling tree leaves and also the annual crop residues after harvesting annually add organic matter to the soil which after decomposition in the soil provides nutrients such as nitrogen and micronutrients for cabbages and hazelnut trees. Another synergy that is expected from the crop-tree combination is biodiversity in the farm which helps to control pests and dieseases in a biological situation. tree itself.

Reagarding the economic performance of crop-tree combinations, shifting to an agroforestry system needs lots of investment such as new machinery, labor costs, and seedling, but after 8 or 10 years these systems will be profitable. Farmers, through these systems, cannot gain profit in the first couple of years, so the cultivation of an annual crop can compensate for a part of their investment in these systems.

In terms of the environmental benefits of the crop-tree combination, in the Netherlands soil Nitrogen is not a big problem but soil health is important for future generations, and due to the intensive farming in the country shifting to a sustainable farming system like the AF system is essential. Combining trees and annual crops increases the amount of organic matter in the soil and makes soil healthier, Consequently, healthy soil has a better texture and capacity to hold water. Also, adding organic matter to the soil increases the amount of nitrogen in the soil and balance the soil PH. Another environmental benefit of the trees is due to their root system that increases the availability of phosphorus in the soil.

The market of agroforestry products in the Netherlands is in the development stage and it is gaining. Currently, most AF products are going to local consumers. Odin and Ekoplaza are the main buyers of organically produced products in the AF systems but they purchase in large quantities. Framers prefer to sell their products directly to the consumer due to the higher margin of this market channel.

Interview Checklist 4

Respondent's name: Isabella Selin Noren Date: 13/07/2021

Study case: Agro-ecologist

Questions:

1. What are the main environmental benefits of crop-tree combination?
2. How to assess the environmental benefit of crop-tree combination?
3. How to scale and analyse the environmental benefits?
4. What are the competitions and synergies of hazelnut and cabbage combination in the AF system?

Answers:

Some researches have been done in the field of environmental benefits of AF systems, most of which focused on the biodiversity improvement aspect. Regarding soil fertility, assessing the benefit of the crop-tree combination needs a couple of years of monitoring and assessment of the soil and its components. According to the agro-ecologist, the combination of annual crops and trees has positive environmental effects. The deep root system of trees improves the health of the soil in different layers of soil and on the other hand, the annual crop residues add organic matter to the soil, Consequently, soil water holding capacity, soil organic matter, soil nitrogen, and phosphorus availability, soil PH balance, and soil carbon sequestration improve.

Having access to reliable and measured numbers for soil fertility in a short time is not possible. But it is possible to ask agro ecologists and experts to allocate scales to the effect of the cropping system on the soil fertility selected components. According to the agro-ecologist, to have a better result the situation's explanation is essential because experts will give different scales based on the land area, soil type, plant density, etc. It is recommended to allocate scales for the effects 1 to 5 which are very low, low, medium, high, and very high. Then the gathered numbers can be averaged and with this method, the environmental benefit (soil fertility) of different farming systems can be shown to the farmers to inform them about the benefits of crop-tree combinations. In addition, some literature regarding the effect of the crop-tree combination, hazelnut tree, and vegetables such as cabbage can be used to support and justify the gathered scales.