CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Agroforestry in the Limburg province of the Netherlands

MASTER'S THESIS

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Author: Benjamin van Leeuwen, BSc

Supervisor: prof. Ing. Bohdan Lojka, Ph.D

Declaration

I hereby declare that I have done this thesis entitled "Agroforestry in the Limburg province of the Netherlands independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague on 21^{st} of April 2023

Benjamin van Leeuwen

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Abstract

Agroforestry as a sustainable farming system is increasingly receiving attention from farmers and institutions. This thesis reviews the current extend of agroforestry practices in the Limburg province of the Netherlands and the farmers‘ perspective on agroforestry. For the first research objective, the LUCAS database was used. Seven locations indicating agroforestry were found: three of these systems were found to be silvopastoral sytems and four sytems were found to be high value tree agroforestry. The total extend of agroforestry in Limburg was estimated to be 5,004 hectare, 2.26% of total area and 3.2% of UUA. A concentration of agroforestry was found in the southern region of the province. For the second research objective, key informants and farmer survey was used. The current scale of agroforestry was described as experimental, but there are also examples of traditional agroforestry practices in the region. The main benefits of agroforestry systems mentioned were biodiversity improvement, landscape embellishment and business opportunities. Farmers were generally positive about implementing novel agroforestry systems, but have several concerns related to the a lack of agrotechnical research, competition for resources and the business model. The results from our study for the extend of agroforesty in Limburg were higher than was expected based on comparable research using LUCAS and a national inventory. However, Limburg is known to have more than average tree cover and traditional landscapes. It should also be noted that LUCAS is less reliable in smaller datasets and homogenous landscapes. However, this is the first study to approach the scale of agroforestry in the region using secondary data. It effectively shows the extend of agroforestry to be much higher would be expected based on primary data. We conclude that agroforestry shows potential for further implementation in Limburg. It positively relates to regional challenges, such as drought and loss of traditional landscapes. The region also attracts tourism, which can serve as a consumer base for added-value products. We recommend further research should focus on further defining agroforestry in the regional context of Limburg. Applied research on regional demonstration farms with region-specific crops will further help to spread the awareness of agroforestry.

Keywords: LUCAS, permanent crops, silvoarable, silvopastoral, silviculture, tree crops

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List of abbreviations

AF:	Agroforestry
AFNL:	Agroforestry NL, Dutch representative of European Agroforestry Federation
CAP:	Common agricultural policy
CBS:	Central organization for societal statistics
EURAF:	European Agroforestry Federation
EU:	European Union
FAO:	Food and Agriculture organization of the United Nations
LUCAS:	Land Use and Cover Frame Area survey
ICRAF:	World agroforestry association
UUA:	Utilized agricultural area

1. Introduction

The agricultural sector in the Netherlands is under pressure. Current research shows several trends that negatively impact agriculture from both inside and outside the sector. Hamers et al (2021) researched land-use in the Netherlands and observed the amount agricultural land has been steadily decreasing to make place for urban areas and nature. Research done by Stigas (2021), a semi-governmental organisation for company statistics, shows the farmer population is aging and there is a lack of successors. Research by van der Meulen et al (2020) showed the profitability of farming to be under pressure, which also hampers a transition to sustainable farming methods. Witte et al. (2020) describes the reality of climate change for farmers and calls for a transformation of agricultural operations, with ever increasing drought. Lastly, Verhue et al (2011) researched migration and rural land abandonment and showed an increasing rift between urban consumers and agriculture.

Agroforestry is proposed as a land-use method to counter these trends. Agroforestry is the deliberate integration of crops and/or livestock either simultaneously or sequentially on the same unit of land, as per definition by Nair (1993). There are different categories of agroforestry systems, including wood pastures, windbreaks, riparian buffers, grazed orchards, intercropped orchards, and forest grazing. The intentional interaction of elements is also what defines agroforestry (Nair, 1993). Agroforestry is said to have the potential to re-invigorate rural areas by providing additional employment opportunities in agriculture, attracting innovators to the sector, and improving farm profitability, all while promoting biodiversity on farms as was shown by Prins et al. (2023). It also elaborates on the need to make agricultural systems climate adaptive, with preliminary research showing a higher resilience to drought, for example in Portugal in research done by Castro (2008). It has the potential to make farmers break their current strategy of cost-price reduction and specialization and adopt a strategy of risk-management by diversification (Prins et al., 2023). In this context, agroforestry has gained a lot of attention recently, by institutional support in the form of (planned) government subsidies, as discussed by Bouwmeester (2023) and a growing number of farmer experiments, as described by Hilberink, (2023) & Wouda, (2023). However, agroforestry is not new. There are several traditional farming methods and landscapes that follow the same principle as agroforestry, which can help to bridge the disconnect between hesitant farmers and ‘modern’ agroforestry. These traditional farming methods have been mainly abandoned due to low profitability, however, in the abandonment also the benefits of trees and shrubs in agricultural systems were lost and forgotten, as discussed in Aarts (2021) and Vandenabeele (2021).

The scale of these experiments, together with the relics of traditional landscapes was researched by den Herder et al (2017) on an EU-level, but an accurate estimate for agroforestry in the regional context of Limburg is lacking. Furthermore, current estimates are usually based on inventories of modern applications of agroforestry using primary data, which disregards the traditional aspects and is assumed to underestimate the total extend of agroforestry in the region. This study aims to quantify the scale of agroforestry systems, both traditional and novel, in the Limburg province of the Netherlands, using secondary data from LUCAS. An accurate estimate will aid in the recognition of agroforestry as a vital part of the current agricultural landscape. Furthermore, a survey among farmers further helped to understand the farmers perspective on planting woody plants on their farms. Understanding the farmer perspective, in combination with the estimate, will help to show policy makers the importance of agroforestry.

2. Literature Review

2.1. Definition of Agroforestry

According to the FAO, Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement of temporal sequence (FAO, 2022). Secondly, agroforestry is multifunctional and provides a range of economic, sociocultural, and environmental benefits. AGROFORWARD, an EU-project for the stratification of agroforestry in the union, has defined agroforestry as:

''The practice of deliberately integrating woody vegetation with crop and/or livestock production systems to benefit from the resulting ecological and economic interactions'' (Agforward, 2017).

A wide range of possibilities and component combinations is commonly mentioned. The intentional combination of production systems is considered a key concept in agroforestry.

In the context of the European Union, for the purpose of grants and funding for agroforestry farmers, the following definition was adopted:

'Land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same parcel of land management unit without the intention to establish a remaining forest stand.' (European Union, 2020)

This definition implies that:

- Agroforestry involves two or more species of plants (or plants and livestock), at least one of which is a woody perennial.
- An agroforestry system always has two or more inputs.
- Even the simplest agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system

2.2. Categorization and classification of agroforestry systems

Agroforestry is characterized by the interaction of crops/livestock with woody components, producing products that can be grown in an agricultural setting but also a forestry setting. Traditionally, in European land cover analysis ‘farmland’ and ‘forestry’ are defined by whether there is a tillage regime or tree cover. The two classes are mutually exclusive. Because of this, historical inventories of agroforestry are lacking as they were made to fit one of these categories in land surveying.

Different approaches can be followed to categorize agroforestry systems. Most research uses a principal classification based on structural components, but secondary classification varies by area of application. Elaborate research was done by McAdam et al. (2008) on this topic. In McAdam et al. (2008), four different approaches we described: A structural basis, a functional basis, a social basis, and an agro-ecological basis.

Structural basis – nature and arrangement of components

In this approach, we define the agroforestry system based on its components and their spatial distribution or temporal sequence. The most basic categorization (as followed by the FAO) of agroforestry systems by spatial structure is silvoarable (crops and trees), silvopastoral (trees and livestock) and agrosilvopastoral (crops, trees, and livestock). Some researche, such as Rosa Mosquera-Losada et al. (2018), further specify practices with specific structure; for example, home gardens (highly diverse combination of crops, trees, and livestock) and forest farming (overrepresentation of the forest component). Temporal structure of the agroforestry system can be coincident, with trees and crops at the same time in the field, or sequentially separated in time. Temporal-sequence agroforestry systems such as improved fallow and shifting cultivation are not common in European countries. However, there are traditions in orchard establishment where the space in between establishing trees was used for pasturing, which can be considered a sequential agroforestry system (Pré-vergers in France: (Pointereau, 2015), Blijver-Wijker system in the Netherlands.

In McAdam et al. (2008) & Norgrove & Beck (2016), the components and their structural arrangements were described on a continuum scale, as it also explains the interactions between components. Recent research for the AGFORWARD project, which aims to stratify and quantify agroforestry in the European Union, also follows this methodology. The figure below (figure 1) shows this continuum scale.

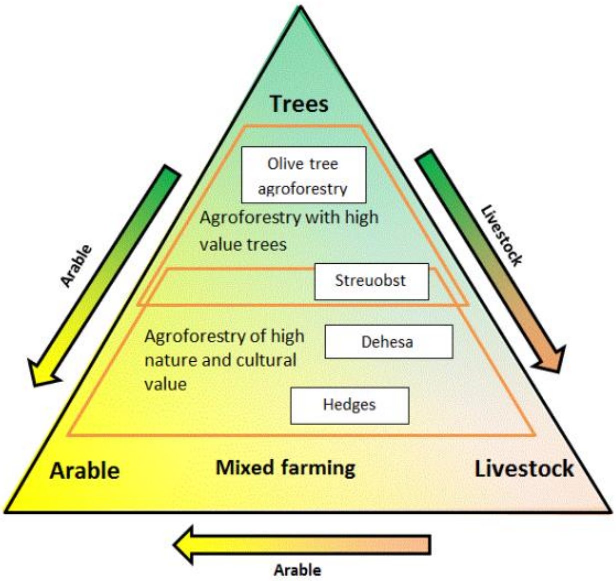

Figure 1. example of different agroforestry practices on a continuum scale, according to den Herder et al (2015)

On the continuum scale, the AGROFORWARD stakeholders described three main practices, agrisilvicultural, silvopastoral and agrosilvopastoral, and additionally, two types of practices with specific elements (agroforestry with high value trees and agroforestry of high natural or cultural value). In the table below (table 1), an example is shown for classification of agroforestry based on structural grouping.

Table 1. Structural grouping of agroforestry systems for the purpose of classification, adapted from McAdam et Al (2008)

Nature of components	**Based on arrangement of components**
Agrisilvicultural (crops + trees) Silvopastoral (livestock + trees) Agrosilvopastoral (crops + livestock + trees) Others: multipurpose trees, apiculture with trees, aquaculture with trees	Spatial: densely mixed, scattered trees, strip planting, boundary planting In time: Coincident, overlapping, in sequence

Functional basis

In using a functional approach, we refer to the primary/secondary functions the agroforestry system provides. This approach disregards the components in the system. We can group systems on functional basis into productive systems, protective systems, multifunctional systems, ecological systems, and recreational systems. In some research, this approach is used for secondary classification, for example, a silvopastoral system (structural) with productive function (functional). Some examples of functional grouping of agroforestry systems are shown in table 2.

Table 2. Classification of agroforestry system following a functional grouping, adopted from McAdam et al., (2008)

Function	**Productive**	**Protective/regulatory**	**Wildlife habitat**	**Recreational**	**Cultural**	**Mixed function**
Examples	Fodder, fuel, fuelwood, food producing systems	Riparian strips, windbreaks, shelterbelts, soil conservation planting	Highly biodiverse habitats for wildlife	Municipal parks with multipurpose trees, petting zoo, allotments	Traditional agroforestry systems for conservation	Mix of functions

Socio-economics

In this approach, special regard is given to socio-economic parameters of the system, for example, scale (large, medium, small plots), intensity of management (highly managed, little managed), use of inputs (no inputs, high use of inputs), commercial orientation (subsistence, commercial, intermediate), technology input (mechanized, no mechanization). This approach is often taken in areas where the aim of research is to highlight socio-economic circumstances. For example, in Mukhlis et al., (2022), where it was researched what agroforestry can contribute income of smallholder farmers in developing countries.

Agro-ecological zone

This last approach considers environmental conditions and their relation to the system as a basis for categorization. It describes and categorizes based on the different environmental conditions, such as highland, lowland, dry region. It is sometimes used to distinguish agroforestry practices in the Mediterranean ecological zone from those practiced elsewhere (McAdam et al., 2008).

Furthermore, in classification, also level of analysis should be considered (see figure 2). Combining crops and/or animals with trees on field-level (e.g., alley cropping) is a relatively known agroforestry practice. In farm-scale agroforestry systems, fields may be homogenously cropped, and trees incorporated on designated parts (for example in buffer strips on boundaries). In this farming system, the interaction between the crops is not always clear and these systems might be overlooked in agroforestry inventories, as discussed by Den Herder et al. (2015).

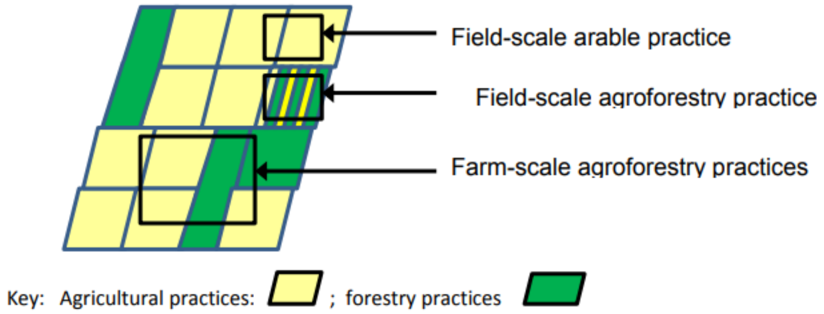

Figure 2. Schematic overview of scale levels of agroforestry practices as described in Den Herder et al. (2015)

In more recent agroforestry research, systems classification as proposed by Dupraz et al. (2018) is commonly used. The same classification was also used by Mantazanas et al. (2017) & Mosquera-Losada et al. (2018) & Lojka et al. (2022). In this classification, a distinction is made for agroforestry on agricultural land and on forest land. Secondly, the classification also differentiates on the location of the trees to also include farm-level agroforestry (e.g., trees between parcels). This classification is shown in the table below (table 3).

Table 3. Classification of agrforestry systems as proposed by Durpraz et al. (2018)

Tree Location	Agroforestry System	Agricultural Land	Forest Land
Trees inside parcels	Silvopastoral AF	Wood pasture	Forest grazing
	Silvoarable AF	Tree alley cropping Coppice alley cropping Multi-layer tree-gardens	Forest farming (including food forests)
	Permanent crop AF	Orchard intercropping Orchard grazing	
	Agrosilvopastoral AF	Alternating cropping and grazing	
Trees between parcels	Field boundary AF (Tree landscape features)	Wooded hedges	
		Windbreaks and shelterbelts Trees in lines Riparian tree buffer zones	
Trees in settlements	Urban AF	Homegardens, allotments, etc.	

This method of classification was developed to make it easier for lawmakers and policy makers to develop legislation and policies for agroforestry, and secondly, to make it easier for agroforestry-farmers to receive subsidies and lesson administrative burden. An example of this is the direct payments in the previous common agricultural policy (CAP). All farmers managing agricultural land are entitled to a payment per hectare under CAP Pillar one. In the CAP, three distinct types of land are described: arable land, permanent grassland, and permanent crops. If a farmer were to integrate trees or woody perennials in an arable system, a higher number than 100 trees per hectare will make the farmer no longer eligible to receive payments for arable land. There are measures under the CAP second pillar payments, however, the rules governing agroforestry are complex, as discussed by Granier (2020). In the following paragraphs, we will describe different agroforestry systems and show examples as found in the temperate region, based on the classification as shown in table 3.

2.3. Trees inside parcels

2.3.1. Silvopastoral systems

This group of agroforestry systems combines trees and livestock components. Traditional forms of silvopastoralism include cattle in pastures with scattered trees and traditional woodland farming systems. In Western-Europe, because of intensification in agriculture, wooded pastures were often cleared for homogenous pasture of perennial ryegrass (*Lollium perenne* L.). The trees were often seen as competitor for the grass production and were removed for optimal feed production. Specific benefits of trees in silvopastoral systems are improved animal welfare by providing shade and shelter, higher production of grasses or through additional tree production and more effective nutrient recycling (Hermansen et al. 2017). The main challenge for many silvopastoral systems is the protection of young trees against damage from livestock (Hermansen et al. 2017).

The systems in this group can include cattle, sheep, poultry, pigs, or other types of livestock. The pastures can be intensively managed by planting and fertilizing or unmanaged and allowed to develop naturally. A traditional combination is wooded cattle pastures. Wooded pastures, also sometimes referred to as parkland systems, stem back from a period where the tree cover was much less, and wood was still a valued fuel and construction material. Pastures would have few scattered trees, and which would be coppiced routinely for fuelwood. Browsing pressure from cattle caused little regeneration to occur.

A novel application of agroforestry in poultry farming is the development of wooded pasture for free-range poultry. The growing awareness into animal welfare has led to more livestock farmers adopting free-range concepts, as researched by Bestman & Bloksma (2015). In the research, chicken behaviour in relation to tree cover was researched. According to local regulation, the free-range chickens should have at least four-square meters. When the pastures were not planted, predatory birds resulted in a significant loss of chickens. Furthermore, the chickens were less likely to move into the pasture further away from the coup. When the pastures are planted, the chickens feel more secure and will spread more evenly, feel less stress, and show more natural behaviour. Furthermore, recent research by Bracke et al. (2020) also suggests a lower risk for bird flu transmission as the habitat is less favourable for geese and ducks, which serve as a vector in bird flu transmission.

Figure 3. Silvopastoral combination of chickens and walnuts in Flanders, example from ILVO (2020)

2.3.2. Silvoarable systems

Systems based on annual/perennial crops in combination with trees are considered silvoarable agroforestry systems. The combination is based on the assumption that the combination leads to a higher land-use factor; the combined yield of the two crops is higher than the yield of both cultivated separately. Next to a possible higher land-use factor, trees may yield other benefits. Specific benefits in the combination of crops and trees are microclimate buffering effects, more effective fertilizer use, improved carbon sequestration in soil and improved soil fertility. In a research done in the Southern part of France by Panozzo et al. (2022), the microclimate buffering ability of trees was shown in an alley-cropped orchard; in comparison to the full-sun comparison, the agroforestry system had significantly lower wind speed (-85%--99%) and a more gradual diurnal temperature cycle (+1.7 degrees Celsius during the night, -3.2 degrees Celsius during the day). The physical shading effect also leads to lower temperature on soil level, especially valid in deciduous trees: tree trees will yield most shade in summer, when the rainfall is lowest and temperature stress is most likely to occur. For practical purposes, trees are usually planted in lines to allow for mechanical handling of the arable crop. A lot of research was done into this topic in the tropics and in the Mediterranean. An interesting example is found in France, described by Gosme & Meziere (2016), where walnut and cereals are combined. The timber tree varieties are specifically selected to be late flushing to extend the favourable sunny conditions for the cereal crop, which will already be past the active growing stage when the canopy of the timber trees reaches the highest shade cover in summer (Gosme & Meziere 2016). Similar experimental plots are found in Italy, as described by Paris et al. (2016), where poplars are planted in combination with cereals. Other combinations that are currently being researched are walnuts & common beans in Greece (Mantazanas et al. 2017), Paulownia and alfalfa in Hungary (Vityi et al. 2015) and poplar, willow, locust, and alder combined with arable crops, among others, beets, maize, barley, alfalfa, and potato (Mirck et al. 2015).

2.3.3. Permanent crop agroforestry – silvoarable

This category of agroforestry systems includes traditional systems where trees, usually fruit-producing trees, are planted scattered in pastures, which are intercropped with crops. The tradition of Streuobst is an example of these in European context and was described by Westeringh (1975). Steuobst culture is a practice that is estimate to originates around 15th century. It included trees, 20 to 100, of varied species, varieties, and age, usually in a scattered pattern. In silvoarable permanent crop agroforestry, the trees are intercropped with vegetable crops such as potatoes, cabbages, and lettuce. The category differs from pure silvoarable systems in the structure and type of productive trees.

2.3.4. Permanent crop agroforestry – silvopastoral

This category of agroforestry systems includes traditional systems where trees, usually fruit-producing trees, are planted scattered in pastures which are also used by livestock. As with the prior category, it was traditionally practiced in Europe as Streuobst. It included trees, 20 to 100, of different species, varieties and age scattered in pastures. In silvopastoral permanent crop agroforestry, the space in between the trees is pasture and used for pasturing livestock. The category differs from pure silvopastoral systems in the structure and type of productive trees.

Figure 4. Example of a tradional streuobst silvopastoral system (source: author)

2.3.5. Agrosilvopastoral agroforestry

The last category in the category of trees within parcels is the most diverse in components and application. A combination is made between agricultural crops, livestock and tree components. Trees may be incorporated in lines and small plots inbetween are used for

Figure 5. Example of an agrosilvopastoral system where cattle is introduced to pasture after cropping cycle, taken from corpoguajira (2017)

pasturing or cropping alternatively or in an intentional rotation. With the right timing, livestock can be used to clean up harvests and transform crop remnants into fertile manure for the next crop. According to Russo (1996), the practice is well established in South America and highly productive multispecific farms were once the norm for efficient land-use. It is also found in areas where fallow periods are practiced. To make use of the land during fallow, livestock may be introduced to the fallow pasture (Russo, 1996).

2.4. Trees between parcels

2.4.1. Field boundary AF

This group of agroforestry systems can also be referred to as farm-level agroforestry. There are numerous mentions of traditional practices and modern adaptations of linear features with trees in Europe. The remnants of these can still be found in some agricultural areas where small-scale agriculture is still practiced (Oosterbaan & Raap, 2011). In recent times, many of these features have been removed to increase the area for a primary crop and being able to upscale (Aarts, 2021; Oosterbaan & Kuiters, 2008). Furthermore, previous CAP-payments we primarily based on area under cultivation of certain crops, further discouraging farmers to maintain the features. Different traditions recorded from history are for example:

Riparian strips along bodies of water

This practice is mentioned as a way to protect the agricultural fields bordering the river from flooding and soil erosion (Wigboldus et al., 2022). In more recent literature (Rosa Mosquera-Losada et al., 2018), the function of the riparian buffer to also protect the water quality is mentioned: for example, it captures runoff from the field and acts as green filter and regulator for water temperature and light penetration. It also serves as green corridor for amphibians and aquatic fauna in agricultural landscapes.

Figure 6. Example of field boundary agroforestry: riparian buffer along river, taken from Delso (2022)

Windbreaks and shelterbelts

This practice is traditionally practiced in flat areas where wind hampers the development of crops (Rosa Mosquera-Losada et al., 2018). They are commonly planted along fields where high-value trees are grown, for example, in apple orchard to protect the blossom from frost.

Figure 7. Examples of field boundary agrforestry: windbreaks on plain landscapes in the Netherlands, taken from Landschapsbeheer Groningen (2020)

The use of windbraks is well documented thoughout history. They are also applied on slopes and keep the soil in place by their roots, as described by Oosterbaan (2011).

Hedgerows

Another similar practice is the use of hedgerows along fields and pastures (Rosa Mosquera-Losada et al., 2018) They are typically planted with thorny species of shrubbery and trees to form a barrier for either cattle or to designate a boundary between farms.

Figure 8. Example of field boundary agrforestry: hedgerow along pasture, also incorporating tree lines (Source: author)

2.5. Trees in settlements

2.5.1. Urban AF: allotments and homegardens

Urban agroforestry can be characterized by small scale plots where a diverse range of crops is grown for primarily subsistence use. They can be individual allotments, homegarden, urban food forests, productive urban spaces or community gardens. They are comparable in components to other agroforestry systems, but also include a social element (also due to the urban setting). They offer a wide range of ecological benefits in an area that usually doesn't provide much of ecological niches. For example, the urban environment usually offers few habitats for native biodiversity and it was shown urban agroforests can be a method to increase biodiversity in these landscapes, as researched by Taylor & Lovell (2021). Additionally found from Taylor & Lovell (2021) was a benefit specific to urban agroforests, namely, the potential to recycle urban waste; the organic waste from households may be collected and be composted in the urban agroforest. However, there were also challenges identified specific to urban areas: there might be more resistance from surrounding communities and due to biophysical characters, the area might be warmer and drier

Figure 9. Example of urban food forest in Den Bosch (source: author)

The interest in urban agroforestry is growing as it also serves as a leisure activity for people living in these areas. There has been a clear trend in recent years in food forest initiatives that serve a social function, as described by van Gent (2019).

2.6. Study area

This study was done in the Limburg province of the Netherlands. The name Limburg also refers to the larger region, a part of which is part of Belgium. For practical reasons, only the Dutch part of the province is chosen as study site. In the following paragraphs, different parameters of the region are described.

2.6.1. Geographical conditions

Location

The province is in the South-Eastern part of the Netherlands. The characteristic shapes can be recognized as panhandle. The southern region contains the biggest city, Maastricht, and harbours most of the population (around 600,000). The middle and northern regions contain respectively 239,000 and 282,000 inhabitants. The total number of inhabitants was 1,117,201 in January 2022 (CBS, 2022). The total area of the province is 220,985 hectares. The regional capital is Maastricht.

Figure 10. Location of Limburg (in red)

The region borders the German governmental districts of Dusseldorf and Keulen, the latter of which is also known as the Ruhr area. The Ruhr area is a highly industrialized area of Southern-Germany, where a lot of the country's heavy industry is located. On the south and western sides, Limburg borders the Belgian provinces of Luik and Limburg. There are close cultural ties with the Belgian Limburg province, with many similarities in traditions, language, and folklore.

Hydrology

The biggest river in the province is the Maas. The Maas originates in France and enters the Netherlands in the region of Maastricht. The Rhine (the second biggest river in the Netherlands) has historically deposited many layers of sediment on floodplains along the river, forming rich deposits of gravel and coarse sand which served as a basis for the concrete industry (as described by Berendsen, 2011). The fertile silt was usually carried further along the river but sometimes sedimented on plains in the event of flooding. The current river run of the Rhine River shifted north and no longer enters the province of Limburg. There are obvious signs the Maas and Rhine have left in the landscape, with numerous horseshow lakes along the current river run.

Soils

The most prevalent soil type in the region is sandy soils and loamy sand in the south (Alterra, 2006). These soils were formed by sand deposits from the Maas River. In the area surrounding Maastricht, there are also limestone deposits from the Chalk era. In the middle and southern area of Limburg, there are also deposits of coal dating back to the Carbon era. In regions where the soils were previously waterlogged, acid bogs formed. The bogs gave rise to typical nature reserves called 'Peel' areas, the development was described by Provincie Limburg, 1967). The word 'Peel' stems from pael, a historical word for border markings; these areas are found in the border region of Belgium and the Netherlands.

Climate

The climate is comparable to the rest of the Netherlands and is considered a temperate climate. The climatic extremes are mediated by the influence of sea and wind currents. The mean winter temperature is 3°C and mean summer temperature is 17°C. Because of the southernmost location of Limburg, the average temperatures are on average slightly higher. The annual precipitation is on average 721 mm, with a significant peak in summer and fall (Harris et al., 2020). In the climate diagram below (figure 12), a schematic overview of the regional climate can be seen (Climate-Data.org, 2023)

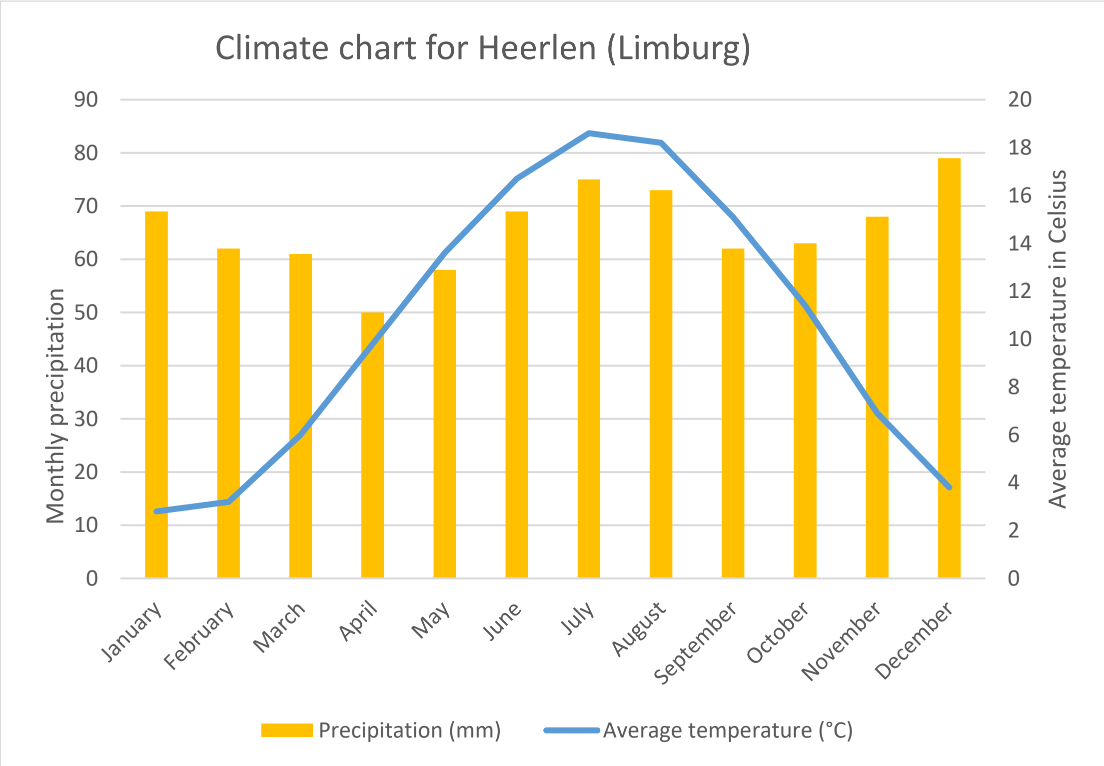

Figure 11. Climate diagram for Heerlen, Limburg (Climatedata.org, 2022)

2.6.2. Historical context

The history of the region has been extensively researched and was compiled into a book by van der Woude et al. (1992). The history of the region differs from national history in several key events, which will be highlighted in the following chapter. The province has existed in its current form since 1867 after the treaty of London. The region was historically part of the Spanish Empire, French Empire, Prussian kingdom and eventually split into a Belgian and Dutch province. This is also reflected in a powerful sense of regional nationality and identity: there are numerous local traditions and dialects that natives celebrate to this day.

Early Middle Ages to early modern time

The region is known to be colonized by the Romans (500 years B.C. till 395 A.D). Tichelman (2013) mentions the cities of Heerlen, Maastricht, Venlo, Blerick, Heel and Melick were founded by the Romans. It also describes these to function as outposts for the border with the Batavian and Germanic tribes. The cities of Heerlen and Maastricht are mentioned as part of Via Belgica, an important trade route connecting Koln to Boulognese-sur-mer. In the Middle Ages (500-1500), the region remained scarcely populated and the population consisted of subsistence farmers. By early modern times (1500-1800), Maastricht was cemented as the regional capital and had maintained its prominent position for trade, as was discussed by Arts et al. (2007) & Albers et al. (1974). The French revolutionary army took control of the region in 1794. The region was formally annexed into the France 1795 and remained part of the French republic until 1814 (Arts et al., 2007). After several setbacks, Napoleon and the revolutionary army was forced to take seat at the congress of Vienna for peace talks. On the congress of Vienna in 1815, the allies agreed the republic of the Netherlands should be united with the Austrian Netherlands in the south (currently known as Belgium) to form a buffer state for the French and Prussian (formalized in the Vienna congress, (1815). This resulted in the creation of the United Kingdom of the Netherlands, which separated in 1830 into Belgium and The Netherlands (the former Republic of the Netherlands). It was only after the treaty of London in 1867 that the Dutch part of Limburg could formally be considered as province of the Netherlands due to a historical obligation towards the German Union, which was dissolved in 1866 (Alberts et al., 1964). Under French rule (1795-1815), formal law and a constitution were installed. In van der Woude et al. (1992), the significance of these is discussed in relation to reclamation of heathlands and bogs.

History of farming in the region

Farming in the region has a long history. In the larger area of Maastricht, many remains of medieval farms were found in proximity of the city, which were intended to supply the city. This region is known for sandy soils and yields were generally low compared to the fertile floodplains of the provinces of Brabant and Holland. During the French rule, farmers were heavily stimulated to grow crops suited for human consumption, as discussed in van der Woude et al. (1992). In historical documentation reviewed by van der Woude et al. (1992), there was stated the traditional migratory systems for cattle were primitive and were to be abandoned for the most part. However, in doing so, the French created a shortage of fertilizers. For additional fertilizer, heathland was cut and applied to the fields. These heathlands covered vast stretches of land and were primarily the result of rampant deforestation in the centuries before. The primary intention of the French was to make farming systems more efficient and make them produce food. Subsistence farming was abandoned for the most part and instead larger operations focussing on cereals, fruits, cattle, and vegetables started to appear. Before the period of French influence, small-scale reclamation projects were undertaken by villagers primarily to establish subsistence plots. The French considered the reclamation as a method to expand the agricultural acreage and started to promote this by legislation and bounties for reclaimed areas. During the French influence, legislation was installed that aimed to limit the amount of land owned by the ‘gemeende,’ (the villagers as a whole) and to promote individual land ownership, also as a method to increase agricultural acreage. Another objective was to avoid land-use conflicts on these no-mans-lands that were increasingly occurring over reclaimed heathland. Heathlands and bogs not used by specific villagers were sold by the municipality to private individuals. Other than land-use conflict avoidance, this was done with the aim to raise money for the building of churches and municipalities and the development of the region, as discussed in van der Woude et al. (1992). In 1811, a decree was signed that required annual reclamation of 10% of the heathlands within ownership (van der Woude et al., 1992). The initial success of the legislation was limited. Small-scale reclamation was undertaken, but the reclaimed lands were often poor and rarely suitable for cultivation in the sense the French envisioned. These were instead planted with forests for fuelwood, timber and additionally for hunting grounds.

When advancements in the chemical industry made it possible to make fertilizer from industry waste, reclamation started to take off. The most important was the invention of the Gilchrist-Thomas process in 1877, which made phosphorus fertilizers readily available (van der Woude et al., 1992). Larger scale reclamation projects were initiated, and thousands of hectares heathland were introduced to cultivation. In the period of 1930 – 1960, the north and middle region lost about 80% of heathland and the southern region lost about 50% (although the total area of heathlands was already significantly lower).

Current farming structure

The current agricultural sector can be characterized by modern large-scale operations alongside remnants of traditional landscapes. The current structure was also researched by the local province, Provincie Limburg (2016). As can be concluded from the historical paragraphs, the south has known the longest time of anthropogenic land use. The north has developed rapidly in the last century, with many agricultural fields being only brought into cultivation only 70-90 years ago. The scale of agricultural operations is usually bigger in the northern region. Agricultural companies in the northern region earn about double the national average per company, and the southern region earn one-third of the national average. About half of the agricultural companies in Limburg have secondary income from a different activity than primary production(Provincie Limburg, 2016). Traditional crops for the region are fruits (like apples, pear, and cherry), arable crops (like cereals and maize) and asparagus. The southern region contains slight slopes which are very suitable for fruit cultivation. Fruit cultivation is also centred in the southern region due to the proximity of Maastricht as the biggest regional consumer market. Below, the most common crops in the separate regions are shown, taken from (CBS, 2022).

Table 4. Characterization of regions of Limburg

Region	Primary agricultural focus	Secondary focus
North	Horticultural crops (ornamental plants, tomatoes, bell pepper, asparagus, cut flowers)	Industry, food processing, chemical processing
Middle	Closed livestock systems, dairy farming, agricultural crops (e.g., maize, wheat, onions, and potatoes)	Industry
South	Dairy farming, fruits (apples, pears, cherries), vegetable crops (carrots, peas, celery, cabbages)	Tourism

2.6.3. Population and socio-economic conditions

Population development

Before the 1750's, the region was home to few. Estimates by Ekamper & Nederlands Interdisciplinair Demografisch Instituut., (2003) estimate there were about 215,000 people that used to live tin the region prior to the 1800's. Additionally, they describe the second half of the 19^{th} century, where populations across Europe started to change in a development called 'the demographic transition'. This transition describes the change from eras with high mortality, high fertility, and low degree of marriages to a new era with low mortality, low fertility, and high degree of marriages. The transition period between is characterized by population boom. In the Dutch context, this period lasted from 1870-1970.

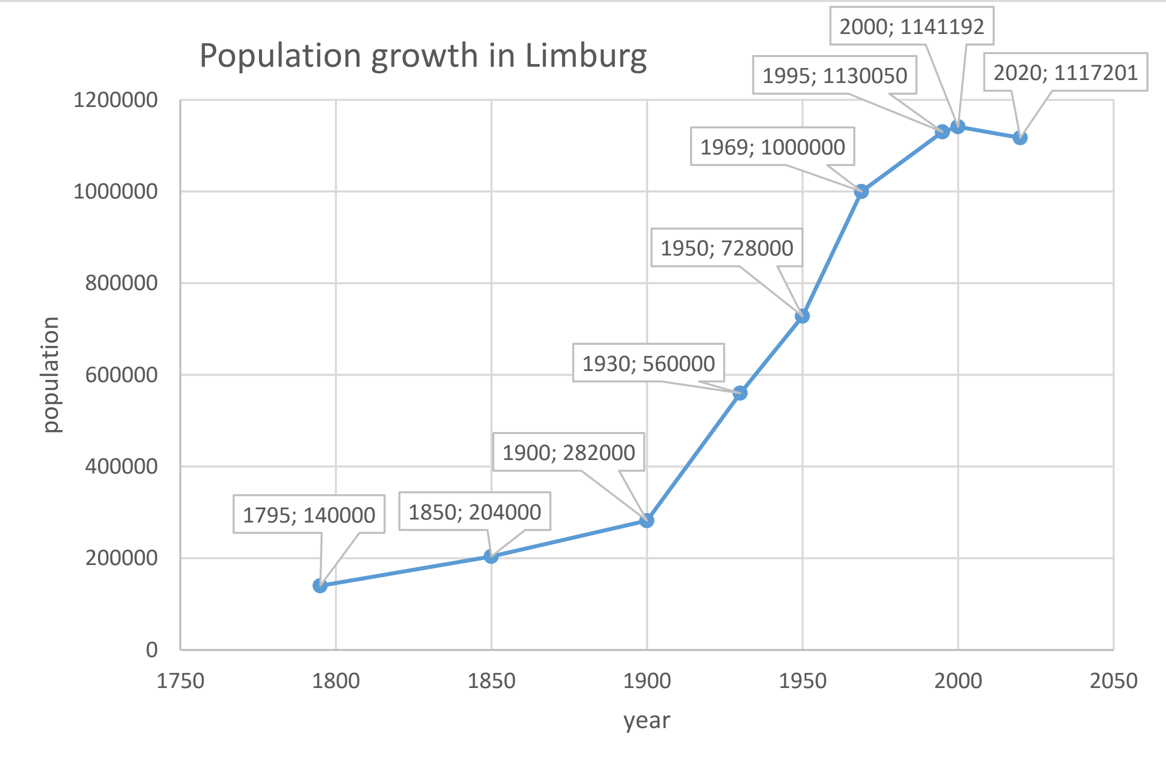

Figure 12. Development of population of Limburg, compiled from data taken from Ekamper & Nederlands Interdisciplinair Demografisch Instituut. (2003), Karel et al. (2006) and Provincie Limburg (2021)

Exponential growth of mining operations in the 20th century required many workers and caused exponential population growth. These workers were initially locals from farming families, but the lack thereof also required local governments to attract workers from further away. The population growth in the province is unprecedented for the Netherlands, as was researched by Ekamper et al. (2003). In 1899, the province was home to 280.000 people. In 1930, the total population amounted to 560.000: a doubling in thirty years. Also, after 1930, population growth remained higher than average for the Netherlands. New settlers were attracted from the provinces of South-Holland and North-Holland, but also from Germany, Poland, and Slovenia, as was discussed in van der Woude et al. (1992).

The population of Limburg was extensively researched by Karel et al. (2006). The current regional population structure is split into north, mid and south: the southern region is home to 60% of the population, the north to 25% and the middle region to 15%. Furthermore, as was found in the research, the population dynamics of Limburg do not seem to follow Dutch average: the population of the whole country grew with 5.2% in the period of 1996-2005, whereas the Limburg region only saw a 0.2% increase, significantly lower. The research identified an aging population, low birth rates and migration as main causes. Aging population is a problem across the whole country. The growing group of pensioners puts pressure on the pensions system, which is sometimes called ‘grey pressure.’ The prognosis for 2030 is that 28% of the population of Limburg will be 65+, whereas the national prognosis is 21.7%. The birth rate in Limburg has been below national average for two decades and this is also reflected in the decrease of population group 0-14, where there is a regional decrease of -4.3% and nationally there is an increase of 2.1%. Furthermore, the population is showing obvious signs of stagnation. In the period of 2000 to 2020, the population declined from 1.14 million to 1.12 (-2.11%) (Karel et al., 2006).

2.6.4 Agriculture and land-use

Land-use in the Netherlands is monitored by the central bureau for statistics and Agrimatie (associated with Wageningen University and Research). The datasets from CBS (2022) and Agrimatie (2022) form the basis for the analysis of land use and agricultural sector.

Land-use in the Netherlands is divided between agriculture (54%), build spaces (13%), water bodies and forests (34%) (Agrimatie, 2022). Forests, heathlands, beaches, and other natural areas cover 12% of the land mass. On a regional level, Limburg has allocated 59% of land for agriculture, 22% of build spaces and 19% for water bodies and forests. The relative share of forests in the last category is 16%, which is slightly higher than the national 12%. On a national level, in the period of 1996 to 2015, we can clearly see a trend with decreasing percentage of agricultural land and increased percentage of build spaces. In Limburg, the trend is less distinct, where only 3.6% of the total agricultural land was lost in the period of 1996-2015 (Agrimatie, 2022).

The agricultural land in Limburg is primarily used for arable agriculture and grass pasture. In 2020, 34% of agricultural area was used for grasslands. Arable agriculture accounted for 39% of the total. Production of feed for livestock contributed to 13%. The horticultural sector (open cultivation) accounted for 13% and horticultural production in greenhouses accounted for 1%. If we further zoom into the types of crops grown, we clearly see a higher amount of cereals grown in Limburg. Cereals amount for 15% of total agricultural area, whereas the national figure is 10% (CBS, 2022). The second biggest percentage accounts for potatoes, which are grown on 8% of total agricultural area (CBS, 2022). Open-cultivation horticultural crops are grown on 13% of the agricultural area (CBS, 2022).

The average farm size in Limburg is 26 ha, which is less than the national average 33 ha per company (CBS, 2022). Dutch acreage per farm is low compared to Czechia, with an average farm size of 102 ha (Jelínek, 2018) and Germany with an average of 60 ha. (Appunn, 2018). Because of the late development boom in Limburg, a higher than national average number of farms still maintain a tradition of mixed farming (Agrimatie, 2022).

2.6.5 Traditional applications of agroforestry in Limburg

Various forms of traditional agroforestry used to be widespread in Europe, many of which are rooted in practical considerations. For example, the agroforestry practice now recognized as slash and burn was 'developed' from the farmers required migration patterns due to limited natural fertility. Another example is found in high-stem orchards: grafted fruit trees always grew into large trees, from which the opportunity arises to use the underlying grassland/arable land for secondary production to use the land more efficiently. Most traditional agroforestry and agroforestry field boundaries were lost since 1950 due to upscaling of farms (Oosterbaan & Kuiters, 2008). However, new interest has been sparked with many local research and experimental sites being developed, as discussed by Borremans et al. (2018); Janssen et al. (2020); Oosterbaan & Kuiters (2008); Prins (2021). The following agroforestry practices are known to be practiced in Limburg traditionally: slash and burn, forest grazing, high stem orcharding, poplar with husbandry, wetland agriculture, erosion control hedgerows and mixed farming.

Slash and Burn

The first accounts of traditional agroforestry in many regions is slash and burn. Also, in the province of Limburg, there are accounts of the practice on heathlands, as described in (Berendsen, 2011). Small farmers would burn small patches of heathlands and plant these with crops for two seasons, after which they abandon the plot. This specific practice is known as 'buckwheat-burning-culture' (boekweitbrandcultuur) or heath-burning-culture (veenbrandcultuur). The first name also refers to the crop for which it was most practiced: buckwheat. The practice was abandoned around 1900 after agricultural innovations and the need for heathlands for turf mining (Arts et al., 2007). However, by that time the practice was only apparent in remote regions of the province.

Forest grazing

The practice of forest grazing was common up until 1938, when a law was passed that prohibited the practice to protect forests. Due to historical pressure on forests by pasturing, the forest cover is still exceptionally low compared to other European nations (7%) (Oosterbaan & Kuiters, 2008). However, research has also shown the open forests were high in specific biodiversity that is now increasingly under pressure due to increasingly closed canopy-forests and the lack of trees on farmland (Oosterbaan & Kuiters, 2008).

Due to historical grazing pressure, management and typical soil characteristics, Limburg has large areas of heathland. Due to natural succession, these heathlands grow into pine forests if not managed. Recently, initiatives started using highland cattle restore traditional heathlands with scattered trees, which can be considered a novel application of forest grazing.

Figure 13. Example of traditional silvopastoral system: heathland grazing (source: author)

High value fruit trees – grazed or intercropped orchards

Another form of traditional agroforestry in the region is the combination of high-value fruit trees with a secondary crop or pasture. In research by Westeringh (1975), the origin of the practice is estimated to be around the 15th century. It also discusses the historical significance of the practice. Farmers mentioned erosion control, dual-purpose land use and income reliability (if the prices for fruits were bad, livestock prices would still bring in income) as main benefits. Additionally, the history of farming practices in the southern region was researched by van der Woude et al. (1992). In the research, it estimated that in 1904, 5.380 hectares of land were planted with fruit, about 10% of the total agricultural land area. Cherry trees were most common, but also apples, pears and plums were planted. The number of high-stem fruit orchard has been drastically decreased since 1880.

Figure 14. Example of traditional high-stem orchards with cattle (Source: author)

When subsidies for improving agricultural efficiency were introduced in 1968 – 1973 about 70% of the grazed and intercropped orchards were lost. In (Oosterbaan & Kuiters, 2008b) it is estimated in 1984, 5000 hectare of the orchards was in production. Estimates for the current acreage from various sources vary from four hundred according to CBS (2017) to 550 hectares, according to Blezer (2022), severely less than 1984.

Poplar cultivation and cattle husbandry

A different type of traditional agroforestry in the region is a combination of poplar (*Populus ssp.)* in combination with animal husbandry. This practice was specifically practiced in the bordering province in Brabant, but also in the northern region of Limburg where similar conditions exist. In this system, the fast-growing poplars are grown for industrial purposes in rows between or bordering pastures. The pastures were used for hay production or pastured by cattle. The poplars were planted in densities of 100 – 200 trees per hectare. This system is rare today but used to be practiced on about 3000 hectares in Brabant, according to research done by Oosterbaan & Kuiters (2008).

Figure 15. Example of traditional poplar-agroforestry, taken from Boeckel Bosbouw (2020)

Wetland farming

A similar system as with the poplars was traditionally planted with alder (*Alnus glutinosa* L.) at the borders of wetlands in the northern provinces. The rows were planted in a similar density, which would allow for harvesting hay, pasturing, or cropping in between the rows. They would be harvested in a 25-year rotation period for timber but may also have been pruned on shorter rotations for firewood (Oosterbaan & Kuiters, 2008).

Figure 16 Example of traditional alder-agroforestry, taken from Landschap Overijssel (2020)

The practice is still practiced and an inventory from 2011 done by Oosterbaan & Raap (2011) estimated that there is still about 216 km of alder-strips in the Netherlands as a whole.

Hedgerows for erosion control along rivers

This specific traditional practice involves hedgerows planted perpendicular along the Maas River. These landscape elements form the oldest cultural landscape of the Netherlands. They are exclusively known from the Maas River. Commonly used were common hawthorn (*Crataegus sp*.) and sloe (*Prunus spinosa* L.), which are routinely braided into an impenetrable edge. During the event of floods, the hedgerows would slow down the velocity of the water and trap the fertile silt the river carried behind the hedges.

Figure 17. Example of erosion control hedgerows taken from Bogman (2021)

2.6.6. Novel and recent applications of agroforestry in the region of Limburg

Agriculture in the region is currently under pressure. Polarization has taken place and the agricultural sector is often seen as disconnected from landscape and consumers, as discussed in Verhue et al., (2011). Animal agriculture has shifted to closed systems for maximum productivity, but these industrial production facilities have fallen out of favour from the public as they cause high emissions. Agroforestry has received increasingly more attention as a solution as it answers social, environmental, and economic challenges. Currently, Limburg is facing the following challenges, taken from Corsten (2022).

- There is an increasing pressure on land use and available land for agriculture is decreasing. This results in higher pressure on soils and decreasing quality of soil parameters due to intensity of use.
- The traditional model of decreasing price of production by upscaling is no longer sustainable because it does not account for externalities that are increasingly becoming apparent. Novel business approaches require different qualities from entrepreneurs.
- The is increasing pressure from society and legislation to produce sustainably. Consumers are more critical for what happens with their surroundings and require producers to produce using fewer chemical inputs. Furthermore, they consume higher-quality foods in relation to nutritional values, certifications, product experience. The government enforces novel legislations to limit the negative externalities from production.
- The consequences of societal challenges, such as aging populations, internal migration and population decline create a challenging labour market. Furthermore, young professionals usually sheer away from agriculture as it is known to be physical and paid less than other jobs. Temporary labour forces are hard to come by.

In recent times there has been a renewed interest in agroforestry as provides answers to a wide range of these challenges. It has shown to provide number of ecosystem services and could aid to diversify farm income, as several researchers have suggested (Prins 2021; Rosa Mosquera-Losada et al. 2018). Furthermore, in experimental settings it has shown more climate resilience than monocrop cultivations and provide a range of ecosystem services (Gosme & Meziere 2016; Panozzo et al. 2022).

Secondly, there are indications it may lead to a better business model which can make help to make the sector more attractive for young professionals. The first initiatives started in the

2000’s when several experiments were initiated under the intergovernmental program ‘Sustainable technological development‘. This program aimed to find novel sustainable methods for food production. In total, 8 farmers were involved which planted a total of 10 hectare multipurpose orchards. The spacing among rows was 10 to 20 meters and the space between the trees was used as pasture or production of silage/fodder (silvopastoral). During the course of the project, several other farmers also planted similar setups and the total area of novel agroforestry was 48 hectare, as concluded from Oosterbaan & Kuiters (2008). These projects were almost exclusively silvopastoral, although there were also 3 farms with a total arrea of 3 hectare where a silvoarable system was developed for hyacint bulb production, potatoe cultivaiton and different horticultural species.

Based on the Paris agreement and national agreements for nature and forests, the ministery of Agrigulturem, Nature and Food qualtiy (LNV) set the goal for 25,000 hectare of agroforestry by 2030 (Bouwmeester, 2023b). The most recent inventory of active agroforestry farms and acerage was done by Louis Bolk institute and Prins et al. (2021). It was estimated that about 200 farmers in the Netherlands either have planted an agroforestry system or are in an advanced stage of planning one. Furthermore, in the research done my Prins et al. (2021), the total acreage of agroforestry in the Netherlands was estimated to be around 500 hectares. The same research found four active farmers in Limburg, with a total acreage of 7 hectares of agroforestry and about 15 hectares in the process of development. It also estimated the total acreage of traditional orchards to be 500 hectares, but did not include that in the total acreage due to the lack of information on these.

Applications of agroforestry in the province of Limburg are limited and for examples, we will have to look at different provinces. In the following paragraphs, we will describe agroforestry systems that are currently being experimented with.

Silvopastures for poultry

There is about 2,700 hectares of pastures intended for poultry pens in the Netherlands (Agrimatie 2022). The pastures are usually open landscapes without trees. In 2015, a project was initiated by Probos, Louis Bolk Institute and Face the Future to create examples of silvopasture with poultry and show how these would perform economically, regarding carbon capture and for animal welfare (Bestman & Bloksma 2015). Chickens are known to avoid open areas and planting the pastures with trees reduces stress levels and allows them to explore the whole pasture. Furthermore, it limits the number of geese that use the pasture as grazing area as these generally like open pastures. Research by Bracke et al. 2020 also showed geese are often vector for diseases and less goose faeces on the pasture will have a positive effect on the chickens.

Figure 18. Example of silvopastoral system with poultry taken from Bracke (2020)

Different combinations that were evaluated in this project planting the coup with fruits, nuts, and biomass trees. The different experiment plots are 7.8 hectare in total. In an earlier project from 2014, where the production of biomass in chicken coups was researched, 2.75 hectare of chicken coups was planted. The total of planted chicken coups is larger than the sum (10.55 ha) as in both projects there was a group of farmers interested and most were likely to also plant their own pasture. Key challenges for upscaling identified in both projects were the lack of practical examples, the high investment for trees and the uncertainty in regulation for planting the coups.

On regional level, this type of agroforestry shows promise as the northern and middle region of Limburg are known to be the egg-production centres of the country. Nearly 26% of all laying hens (more than 12 million in total) are kept in Limburg on a total of 135 farms (Agrimatie, 2022). Around 130 thousand hens are kept on organic farms (Agrimatie, 2022). There is regulation that states the amount of pasture that must be available per chicken to ensure animal welfare. A rough estimate for the total size of chicken pastures in Limburg would put the potential at 3,000 hectares (Bestman & Bloksma, 2015).

Silvopastoral systems with cattle and nut production

Another combination that is seeing increasing applications in recent years is nut/cattle pasturing combinations. More specifically, walnut (*Juglans regia*) combinations are increasingly being planted. Commonly mentioned advantages are the ease of implementation (it usually does not require the farmer to adjust their practices) and the relative reliability of walnut production and high value of its' wood. Trials for these systems have effectively shown the agrotechnical possibilities and economic viability (Oosterbaan & Kuiters 2008). Furthermore, there is also increasing attention for walnut cultivation in Flanders and larger-scale research projects initiated (Reubens & van Colen 2019; van Colen & Reubens 2021), which also supplies practical examples for Dutch farmers. The first research done on the topic by Oosterbaan & Kuiters (2008) included twenty-five hectares of walnut pastures, none of which was in Limburg. The current research includes at least eight hectares of walnut agroforestry in Limburg (Rombouts, personal communication). The potential for this type of agroforestry is large; the total area of pastures in Limburg is 30.617 hectare (CBS 2017), about one third of the total land cover.

Hedgerows for forage

A third example of novel applications of agroforestry in the region is hedgerows planted for forage in cattle pastures. The practice combines traditional landscape elements in a novel context: many farmers used to have hedgerows bordering their pastures traditionally but removed these to increase pasture area. The novel hedgerows are planted with species of woody plants that have nutritional value for the cattle. A widely planted species is willow (*Salix sp.)* which contains salicin, a compound that has pain relieving effects. Other species include alder (*Alnus sp*.), ash (*Fraxinus excelsior*), oaks (*Quercus sp*.) and maples (*Acer pseudoplatanus*). Commonly found compounds in these are tannins (aids in digestion of proteins) and flavonoids (disinfectant). Cattle is allowed to browse the hedgerows. Researchers from the Louis Bolk institute (Luske et al. 2017) are currently creating a database of species suited for the purpose of forage and their nutritional content. Research on the current scale of the practice is limited. Oosterbaan (2011) suggests the total length of hedgerows in the whole Netherlands to be 169 km. The practice is said to grow exponentially in Flanders and Netherlands in coming seasons as it is relatively easy to implement and is increasingly gaining attention from farmers, as was shown by van Colen & Valckx, (2021) & Vandenabeele (2021).

3. Aims of the thesis

The main objective of this research is to gather information about current applications of agroforestry in Limburg and the perspective of farmers to agroforestry. Firstly, a review was made for current extend of agroforestry practices in the region. After getting a sense of state of agroforestry in the region, informants and farmers were surveyed for their perspective of agroforestry on their farms and what different advantages they expect and concerns they have. With this input we will be able to describe the perspective of agroforestry in Limburg.
Specific research objectives are:

- To review current extend of AF practices in the Limburg province using LUCAS. Using LUCAS, the total extend of agroforestry in the Netherlands was estimated to be 27,800 hectare (den Herder et al. 2017). The scale of AF practices in Limburg is currently unknown. Knowing the area of agroforestry will be used to assess the state of agroforestry, novel adoption and traditional agroforestry practices, for Limburg specifically.

- To understand the farmers' perspective of AF in Limburg province. Previous research in the Czechia (Lojka et al. 2022) showed farmers are generally (64%) willing to establish agroforestry, but also identified several concerns. The concerns mentioned (labor demand, pest pressure) are expected to be generally shared by farmers in NL, however, there are specific conditions in Limburg that are rooted in the local culture, traditions and agricultural landscape. This research will determine the farmers' perspective on agroforestry in Limburg.

Currently, several regional agroforestry networks have been initiated in various provinces in NL. These networks differ in nature in each province and are variable due to the differences and specialization in the agricultural sector in each of the provinces. Results of this research will contribute to determining a strategy for establishing a regional network for agroforestry in Limburg.

4. Methodology

4.1. Data collection

Data collection can be separated into two parts for the two respective objectives. To review the current extend of AF in Limburg, secondary data was used from the LUCAS database. For the farmer survey, primary data was used.

4.1.1. Inventory of current extend of AF in Limburg province

The current extend of AF practices in the province on Limburg was estimated using LUCAS and the data provided by Agroforestry network NL. The preliminary estimation using LUCAS follows a similar methodology as used by den Herder et al. (2017).

LUCAS stands for Land Use/Cover Area frame Survey. It provides harmonized data for analysis and statistics on land use and land use change. It spans across the whole European Union territory. The data collection is done using direct observation by surveyors on the ground. LUCAS was initially intended for crop estimates. The first survey was held in 2001. In the following years, the tool has grown to become a key tool for policy makers and statisticians. The sampling methodology was changed in 2006 to include, next to agricultural land use, also land cover. From 2006 onwards, the survey was executed on a 3-year interval.

The dataset contains a grid of frames of 2x2 km, where surveyers identified land use and land cover. The survey is performed by the EU statistical office (Eurostat 2022). The land cover classes (9) are arable land, grassland, wooded areas, shrubland, bare land, artificial land, inland water areas and transitional water. For land use, these land cover classes are subdivided into twenty-nine classes and seventy-six subclasses. This either done by in-situ observation by surveyors or by photointerpretation. In the case of in-situ observation, the surveyors will also take a soil sample to be analysed for carbon content. The most recent published survey is from 2018.

Secondary land cover classification in LUCAS is sometimes used de describe specific landscapes; for example complex heterogenous areas. Using specific filters, it may also indicate agroforestry. In the method used by den Herder et al. (2017), this attribute was exploited for an estimate of the extend of agroforestry in the EU. In the research, agroforestry was devided into three categories: arable agroforestry (silvoarable) where crops are integrated with trees, agroforestry where livestock production is combined with trees (silvopastoral) and high value tree agroforestry where permanent woody crops take the prime role. All three are based on the assumbtion that agroforestry is present whenever the primary land classification or secondary land classification includes wooded pastures or trees.

The analysis was done by downloading the dataset from the EUROSTAT website and importing this into an excel file. Initial compressing of the dataset was be done by filtering the data based on the NUTS (Nomenclature of Territorial Units for Statistics) columns; NUTS0, NUTS1 and NUTS2 on respectively NL – NL4 (southern Netherlands) and NL42 (Limburg province). The following filter settings were used to identify agroforestry plots:

Table 5. Parameters and filters for identifying agroforestry systems in the LUCAS database

Agroforestry system	Parameters	Filter settings
Arable agroforestry	LC1	Permanent crops (B71 to B84), woodlands (C10 to C33), Shrublands with tree cover (D10)
	LC2	Crop cover (B11 to B54)
Livestock agroforestry	LC1	Permanent crops (B71 to B84), woodlands (C10 to C33), shrublands with sparse tree cover (D10) and grasslands with sparse tree cover (E10)
	Land management	Signs of grazing (1)
High-value tree agroforestry	LC1	Permanent crops (B71 to B84)
	LC2	Crops (B11 to B54), shrublands with sparse tree cover (D10) and grasslands with sparse tree cover (E10) and shrublands without tree cover (E20)
	Land management	Signs of grazing (1), signs of crop residue (1) or U111 (agricultural use)

To identify silvoarable agroforestry systems, combinations of LC1 and LC2 that potentially indicate intercropped permanent crops, woodlands or shrublands. More specifically, in the first layer ‘woodland‘, ‘shrubland with sparse tree cover‘ and ‘permanent crops‘ were considered. For secondary land cover, ‘crops‘ was selected, indicating any crop grown under cover of LC1.

For silvopastoral agroforestry, any area with woody vegetation which shows signs of grazing is selected. The primary land cover selected was ‘permanent crops‘,‘woodland‘, ‘woodland‘, ‘shrubland with sparse tree cover‘ and ,‘grasslands with sparse tree cover‘. From the condensed set, only datapoints that show signs of grazing (Land management column,‘signs of grazing‘) were considered.

High-value tree agroforestry is defined as trees which are able to provide a product either annually or biannually. The primary land cover selected should indicate high value trees. In the database, apple, pear, cherry, nut and other fruit trees can be selected for. For a next step, the selection is filterd on secondary land cover of crops (B11 to B54) for intercropped high-value trees, for secondary land cover based on pastures (E10 and E20) or on the land management column for signs of grazing.

All points that fit the set criteria were combined in an excel file. Coordinates were searched for on aerial maps to uncover location adress. All points were visited as a check for the actual situation on the field. Photo documentation was added to the appendices (appendix III).

4.1.2. Farmer survey

For the second part of the research, the data were collected during January and March 2023. The methodology for collecting data on farmers‘ perspectives is similar to Lojka et al. (2022) and Rois-Díaz et al. (2018). Two different methods of data collection were used: key informant interviews, for a wide understanding of the topic, and online farmer survey for quantitative validation of results from key informant interviews.

Qualitative data was obtained from eight key informants interviews (Table 8) that are representative for a group of farmers, early adopters or experts on a specific topic. In the interviews, a semi-strucutured scribt was used. The interview script was created based on Rois-Díaz et al., (2018), where the reasoning of farmers to uptake agroforestry was researched. In the interviews, thematic narrative was encouraged to increase the information basis for analysis. The scribt can be found in appendix I. The scribt was adopted for each informant. In the questionnaire, the informants were asked about a specific theme related to agroforestry and their perpective on agroforestry. They were asked about observations about agroforestry in the

Netherlands, the current scale, expected benefits, concerns and specific examples of agroforestry in Limburg.

Table 6. Overview of key informants used in this study

Interviewee	Organization
Jade Koop	JadeReforestry, organization promoting the adoption of agroforestry in the neighboring province of Brabant
Petra Schmitz	Schmitz Agroforestry Advies, regional consultant for farmers wanting to inplement nature-inclusive farming
Henk Venner	De Smaak van Leudal, farmer and representative for a study group for cattle farmers.
Michael den Herder	Researcher in the field of agroforestry, scale of agroforestry, associated with EURAF.
Evert Prins	Researcher in the field of agroforestry on NL-national level, Louis Bolk Institute associate.
Marco Bijl	Forestry Service Group, consultant for farmers wanting to implement agroforestry, active in neighboring provinces
Frans Blezer	NatuurrijkLimburg, farmer organisation that promotes nature-inclusive farming with subsidies
Daan de Ridder	Herenboeren land van Weert, farmer, early adopter

Findings of the key informant interviews provided the basis for the farmer survey. After qualitative analysis of the informant interviews, a structured questionaire was created and distributed online among farmers in the province of Limburg. The questionnaire was hosted online through the Qualtronics platform. Additionally, printed questionnaire was distributed to increase the number of participants. A total of 79 participants participated in the survey, from which 66 entries were used in the analysis (13 entries were not fully completed). A full overview of the questionnaire is found in appendix II.

For the questionnaire, participants were asked to respond to a set of statements on a 5-point Likert scale ranging from strong agreement to strong disagreement. The questions were mainly focussed on their current attitude towards trees and woody plants on their farms, after which it elaborately explained the concept of agroforestry and showed some examples. After the explanation, they were asked if they would be interested to experiment with the concept on their own farms. They were then asked to respond to statements related to expected benefits trees and shrubs can introduce and what concerns they have against planting them.

4.2. Data analysis

All data from LUCAS was collected in excel spreadsheets where a database was created for datapoints in Limburg that fit the definition of agroforestry. In a similar method as in den Herder et al. (2017), the ratio of datapoints that fit the definition of agroforestry were multiplied by the total land area of Limburg. A total of 309 datapoints were available for Limburg, representing a total land mass of 220,951 hectare. The result was rounded to one decimal. The result was also expressed as a percentage of the Utilized Agricultural Area (UUA). The total area of UUA in Limburg was 94,465 hectare (Agrimatie 2017).

All key informant interviews were transcribed. Thematic content analysis based on Fereday & Muir-Cochrane (2006) and Rois-Díaz et al. (2018) was applied. Thematic content analysis is a method to facilitate a broader understanding of data collected. A multi-layered coding structure was applied in a method similar to Fereday & Muir-Cochrane (2006) and Rois-Díaz et al. (2018). All interview transcripts were inserted into Atlas.TI software for first-stage coding, which summarizes the data into quotations. They were coded based on 5 categories: a characterization of the current agroforestry sector in the Netherlands, current applications and scope by qualitative descriptors, expected benefits, concerns and opportunities for Agroforestry in Limburg. The quotations were exported into Microsoft excel where the quotations were summarized and scanned for identifying initial themes by grouping in stage two coding. Following the second stage, themes were grouped, noted, and described.

The structured farmer survey was evaluated quantitively using Jamovi software and excel. The data was explored by primary descriptors. Additionally, it was explored for significant relations in willingness to establish agroforestry or woody boundary features based on groupings in the farm' descriptors. For the perception of trees on farmland, expected benefits and concerns, mean and distribution were described.

Table 7. Summary of the research process and used methods

Methods	**Objectives**	**Data yield**	**Data analysis**
Land use survey	current extend of AF practices in the Limburg province	4 datapoints	Data filtering in LUCAS, in-field validation
Key informant interviews	Current state of agroforestry in the region, understanding the farmer perspective	8 informants	Qualitative thematic analysis in Atlas.TI
Farmer survey	Understanding the farmer perspective	79 participants	Quantitative analysis in Jamovi

5. Results

5.1. Current extent of Agroforestry in Limburg

LUCAS Analysis

The filter for arable agroforestry yielded no datapoints.

The filter for livestock agroforestry yielded four datapoints. From these datapoints, two datapoints were grasslands with sparse tree/shrub cover, one was shrubland with sparse tree cover and one was cherry orchard combined with grasslands.

The filter for high-value tree agroforestry yielded four datapoints. One datapoint consisted of a cherry orchard, with signs of grazing. This datapoint was also found to be the same in the category of livestock agroforestry. Additionally, two of the datapoints were wide-spaced cherry orchards with pasturing and one was a wide-spaced apple orchard with pasturing.

The different parcels that were found were validated evaluated by tracking the coordinates in the LUCAS database and visiting the location. Photo documentation of the locations is included in appendix III. The observations were summarized in the table on the next page (Table 8).

Table 8. overview of identified datapoints in LUCAS database indicating agroforestry

Point ID	Primary land cover	Secondary land cover	Agroforestry system	Date of check	Observed land use
40183082	Grassland with sparse tree/shrub cover	permanent pastures, regular grazing, alpages, meadows	Livestock agroforestry	2-4-2023	Pastural system with scattered mixed (fruit) trees
40383190	Shrubland with sparse tree/shrub cover	regular grazing	Livestock agroforestry	24-3-2023	Heathland grazing with scattered trees (highland cattle)
40183084	Grassland with sparse tree/shrub cover	permanent pastures, regular grazing, alpages, meadows	Livestock agroforestry	2-4-2023	Pastural system with livestock and scattered trees
40203084	Cherries	grassland without shrub cover	Livestock agroforestry & High value trees	24-3-2023	Traditional high-stem cherry orcharding with signs of horse pasturing
40363090	Apples	grassland without shrub cover	High value trees	2-4-2023	Mixed orchard, no signs of grazing
40243088	Cherries	grassland without shrub cover	High value trees	2-4-2023	Traditional high-stem cherry orchard with horse pasturing
40323082	Cherries	grassland without shrub cover	High value trees	2-4-2023	Traditional high-stem cherry orchard with horse pasturing

From the datapoints, three were located in the region of Eijsden (south), one in Epen (south), one in Cadier en Keer (south), one in Ubachsberg (south) and one in Mook (north). Figure 20 below shows the distribution of these locations on the map.

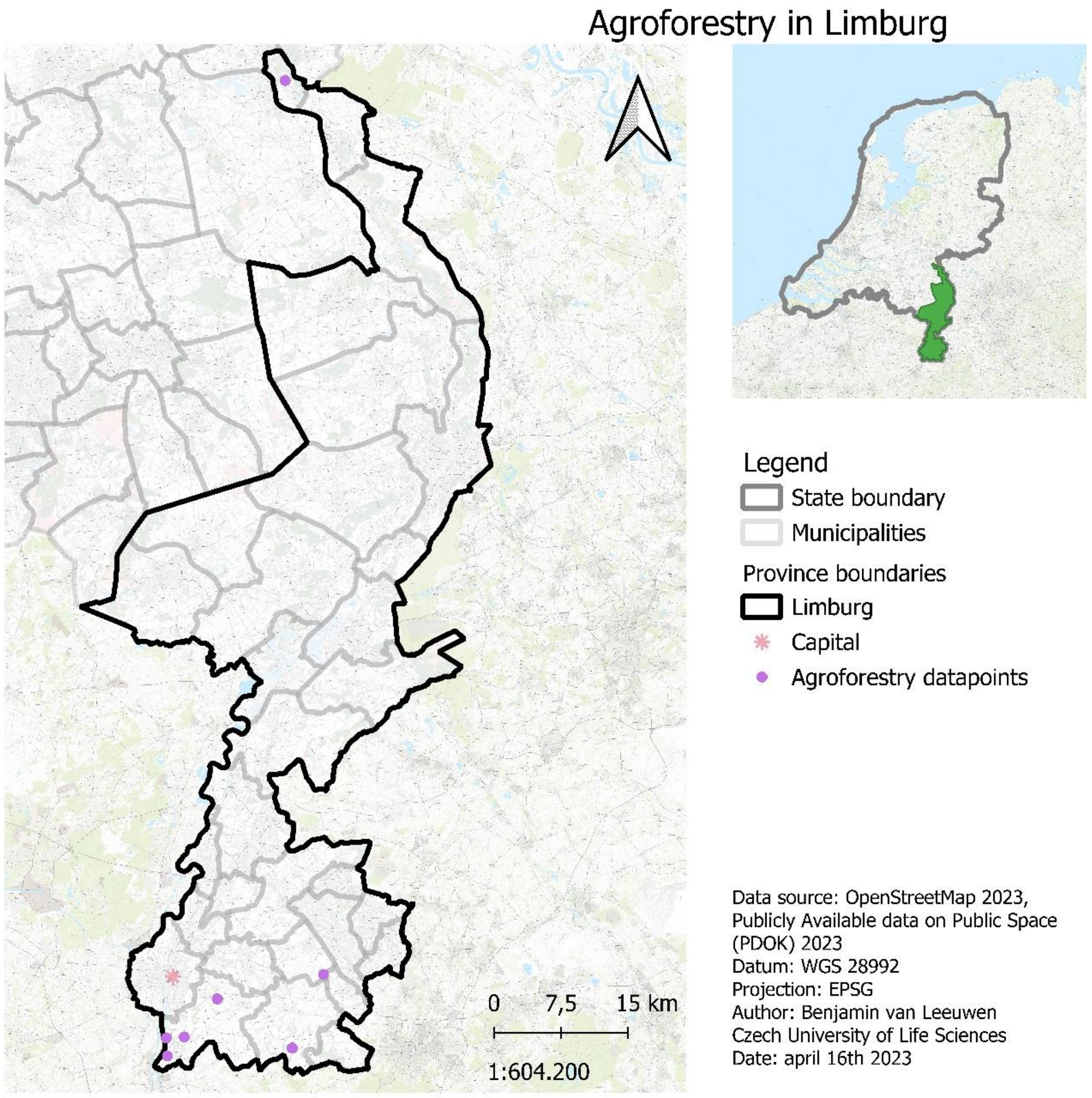

Figure 19. Locations of agroforestry in Limburg as found in LUCAS database

All datapoints were validated to be agroforestry systems. The ratio of 7 datapoints in a total sample of 309 suggests 2.26% of the total area of Limburg province is planted with agroforestry systems. The total extend was calculated to be 5004 hectare. The percentage of UUA was calculated to be 3.2%.

5.2. Farmers' survey

5.2.1. Key informant interviews

Characterization

For the characterization, 21 quotations were used. Key informants describe the current scale of projects as small and experimental. Farmers are increasingly experimenting with different agroforestry systems and crop/livestock combinations. They might use a small area or unproductive land for this and are hesistant to plant larger areas or fully convert areas to agroforestry. Pioneers are usually farmers that are already producing organic, bio-dynamic or have a direct relation with their consumers. One respondent specifically mentioned:

"You have to be creative, for now it's mainly for pioneers and entrepreneurs with a heart for nature and they will have to set good examples. As a result, there will soon be a larger group that thinks, hey, that might worth it.'' (Petra Schmitz, 2023, translated)

Cattle farmers generally have more land available and the yield of grass is generally low. This allows them to experiment more with their lands. Also, the effect of changing the setup of the field, e.g., planting tree lines, doesn't neccesarily have yield-limiting effects on the grass: the trees are small in the first years after planting. Product yield interactions in more mature systems is unclear, but the effects are not neccerarily negative. Furthermore, arable farmers seem hesitant to experiment with agroforestry. The interest in agroforestry has grown rapidly in the past years and one interviewee mentioned we are on the verge of a breakthrough. The area of agroforestry is not rapidly increasing as of yet, but the number of farmers in the an advanced phase of planning an agroforestry system is high. However, many farmers are still hesitant to implement agroforestry as subsidies for planting trees have not yet come into effect. There is limited funding for long-term research projects into agroforestry.

Regional applications of agroforestry

Twenty-five qoutations were used from the key informants to describe current applications. Agroforestry is not well known in the area, but planting trees and shrubs is a well-known practice. Traditional landscapes are commonly small-scale agricultural activity where trees are incorporated for biomass and additional production. On the topic of trees on farms, one respondent stated:

‘’Unfortunately, on the topic of trees of farms, no research was done hundred years ago. It was not necessary, it was working anyway. Now we have to prove that it works, which is difficult if there is nothing’’ (Evert Prins, 2023, translated)

Novel applications of agroforestry are limited but there are some examples of traditional farms which use trees and shrubs for the same purpose as in agroforestry. Traditional agroforestry systems are high-value tree orchards intercropped, high-value tree orchards combined with pasturing, *maasheggen* (erosion control using hedgerows) and landscaping elements such as hedgerows between fields, solitary trees, tree lines and partially forested arable land. Many farmers still have remnants of these on their farms, but many were lost in the last 50 years with the purpose of upscaling farms. Novel applications of agroforestry consists of alley cropping, high value tree orchards with berry production, fodder hedgerows, fodder trees, walnut orcharding combined with pasturing, willow-biomass production and ‘food forests’ (agroforestry where a high number of crops, fruits and trees are intercropped). Farm application of these systems is limited to few farms.

Benefits

A total of 36 unique expected benefits were identified from 106 individual quotations. These were summarized into eight groups, namely, potentially better earnings, costs savings, biodiversity improvement, soil improvement, agrotechnical benefits, improved animal welfare, risk management and social factors. The table below on the next page (table 13) shows an overview of all benefits mentioned.

All respondents mentioned benefits related to the business model. They identified several opportunities related to the business model where agroforestry can potentially has a positive effect. Secondary income was mentioned as a possibility and examples were given for opening a farm shop, -subsidies for providing habitat for wildlife, recreation and additional production from trees.

Table 9. Expected benefits of agroforestry mentioned by key informants, grouped

Grouping	Number of associated keywords	Specific keywords
Business model – earnings	10	Higher percentage of protein in dairy, increased property value, potentially improved income, opportunities for secondary income, timber and biomass production, wider product range to offer, opportunities for a farm shop, valorization of ecosystem services, recreational opportunities, earnings from carbon sequestration
Biodiversity improvement	6	more wildlife, more birds and insects, creation of diverse habitats, improvement of biodiversity, potential food supply for biodiversity, leaf litter supply
Soil improvement	5	Soil improvement, soil fertility, nutrient cycling ability, improved water retention, better drought resistance
Social factors	4	landscape embellishment, social integration (into the surrounding area), social interaction, harboring cultural heritage
Improved animal welfare	3	Animal welfare improvement, functional elements in fodder, shade and shelter
Less resources required	3	Lower usage of water, lower inputs needed, less diesel for irrigation
Better risk management	3	Pest management, erosion control, spreading harvest (loss) risks
Agrotechnical benefits	2	Potential positive crop interactions, wind protection (favorable microclimates)

Ecosystem service valorization was mentioned in the context of carbon (sales of carbon credits) and biodiversity (subsidies for providing habitat). One respondent with practical experience on a farm mentioned the combination of cost saving (lower diesel usage for irrigation) and maintained production is the biggest advantage. In the context of biodiversity, six respondents mentioned biodiversity improvement. Three also noted that the expected benefits are highly specific and differ per case. Two respondents stated the benefits for biodiversity have yet to be proven.

Soil improvement was mentioned by five respondents, in relation to soil organic matter, water holding capacity and fertility. Two respondents mentioned the lower water requirement to be beneficial as droughts are increasingly severe and irrigation as it is going now will possibly no longer be allowed (volume limitations will be introduced). One respondent specifically mentioned:

> *"I think the importance of controlling climate risk is finally taking hold. It is very limited now, farmers turn on their pump and are able to irrigate everything and still have yield. This is currently still allowed but I wonder if that is the case in ten years."* (Henk Venner, 2023, translated)

Social factors that are expected to be benificial were mentioned by four respondents. Landscape embellishment, conservation of cultural heritage and social interaction/integration were mentioned. One respondent mentioned the additional employment opportunities to be beneficial.

Agrotechnical benefits were mentioned by five respondents, in the context of nutrient cycling and -use and in the context of microclimates. Improved animal welfare was mentioned in three interviews. More specifically, reducing heat stress and self-medication using trees were mentioned. Risk management was mentioned by three respondents, where less risk of crop failure and climate resilience specifically were mentioned.

Concerns

A total of 93 quotations included concerns. From these, 44 unique concerns were identified. These were summarized into 9 groups, namely, lower production from the primary crop (or lack of research dismissing this), unprofitable business model, lack of assistance, bureaucracy, need for specialized machinery of lack thereof, the long planning horizon, higher labor demand, social exclusion and property value (loss). The table on the next page (table 14) shows an overview of all concerns mentioned.

Table 10. Concerns for agroforestry mentioned by key informants, grouped

Theme	number of keywords	Specific keywords
the lack of agrotechnical research	11	Lower volume of production, competition for resources, lower dry matter in grass, lower quality grass, competition for light, agrotechnical limitations, assumed bad conditions for woody plant growth, lack of experimental agrotechical examples, lack of research on pruning techniques, lack of substantiated research on production volumes, the current interest is a trend
unprofitable business model	8	worse business model, unsure profitability, unsure about continuity, different strategy associated with higher costs, higher general costs, high investment costs, logistic challenges, no added value
lack of assistance	5	lack of knowledge about trees and shrubs, knowledge difficult to spread, no examples, no standards for design and running, lack of knowledge on agrforestry
Bureaucracy	5	formal land use change, loss of manure-allowance loss of subsidies, regulation for tree protection, requirement for statements for tree conservation, replanting requirement
need for specialized machinery of lack thereof	5	maneuverability, agrotechnical limitations, physical soil limitations, trees in the way, weed pressure
long planning horizon	4	long time for trees to become productive, long term fixed land use, requires additional attention for long term, long time to become profitable
Social exclusion	3	social exclusion, social life, messy appearance
property value (loss)	2	lower value of land due to tree cover, lower value of real estate
higher labor demand	1	labor requirement

All respondents mentioned concerns related to lower production of the primary crop or lack of research dismissing this. They specifically mentioned competition for resources as limiting factor. Four respondents mentioned that shade to be negative for crop production. Two resondents mentioned the tree growth on sandy soils might be insufficient. Two respondents mentioned agrforestry is a trend and there is not yet established examples of how it would work in practice. Two respondents mentioned planting distances for trees as a concern.

All respondents mentioned concerns related to the business model. Six respondents mentioned the high investment costs. Five respondents also mentioned logistics and finding your customer as a concern. Three mentioned concerns for how farmers can find a customer that is willing to pay a premium price for agrforestry crops. Two respondent mentioned breaking from the most common cost-reduction strategy is very difficult.

Bureacratic concerns were mentioned by six respondents. Specific concerns mentioned were replanting obligations, conservation obligations, loss of subsidies and change of allowed land use. In the context of specialized machinery, four respondents metioned concerns related to maneuverability, fysical limitations related to landscape and weed pressure.

Other concerns mentioned were concerning the long planning horizon, as the farmers will need to give up flexibility in the cultivation planning for the trees and shrubs, the higher labor demand, social exclusion (mainly from other farmers) and property value loss.

Opportunities for agroforestry in Limburg

A total of 18 quotations included some remark about specific opportunities for agroforestry in context of Limburg. There are several local challenges that positively relate to agroforestry. Firstly, water management will become a central topic for agricultural companies in coming years and agroforestry is a method to deal with expected limitations on water extraction and increased droughts. In coming years, farmers will have less access to water in order to maintain drinking water quality and agroforestry as a strategy for water conservation might become more mainstream. There is also a regional initiative that aims to plant one million trees where the regional government has been involved with. This initiative will include subsidies for the planting of trees and might be a method for agroforestry to attract funding. Furthermore, there are also subsidies for the re-invigorating of landscaping elements and agroforestry might also be elegible for funding from the standpoint as it also uses trees and shrubs in a similar way. Agroforestry, specifically high value trees in combination with pasturing or crops, is a method to revive these traditional high-stem orchards.

Secondly, Agroforestry also shows potential for Limburg as it is relatively easy to implement on pastures, and a large area of agricultural land in Limburg province is used as pastures. Cattle farmers are usually open to implement projects if they have a positive effect on the welfare of the cattle. In this specific combination, this is very apparent: cattle is known to have a low tolerance for heat and the shade will help mitigate this. Furthermore, initial research also shows limited effect on the grass production. Another part of the regional agricultural sector is poultry. Due to increasing animal welfare regulations and a number of farmers converting to organic, farmers are required to have a growing area of pasture per animal available. Poultry is known to avoid open spaces and converting these pastures to agroforestry silvopasture will result in the poultry exploring further othe pasture, managing disease and improving animal welfare.

Thirdly, agroforestry shows potential in the region as there is a potential consumer base that is willing to pay a higher price for regional farm produce. Agroforestry is a method to create additional value in a product or as unique selling point, and tourists are a group of consumers that are particularly interested in regional higher-value products. One participant mentioned specifically:

*" I do think that opportunities in relation to recreation, if set up properly, if you are able to add that to your current business, things like small-scale farm accommodation and self-picking initiatives in areas near cities, could work very well " (*Petra Schmitz, 2023, translated)

5.2.2. Results of structured farmer survey

A total of 79 participants participated in the online survey. A total of 66 respondents completed the survey. The first topic in the survey were questions related to scoping. Anova based on Kruskal – Wallis was performed in Jamovi for diffent groupings. Two dependent factors were considered: the average willingness to establish AF on parcels and the average willingness to establish AF boundary features. Both these questions were answered on a Likerd scale (1-5), where 1 indicated no interest in AF and 5 indicated the farmer will most likely implement AF. The table on the next page, table 8 summarizes the data that was found.

Table 11. Participants in the farmer survey' average willingness to establish agroforestry inside parcels and agroforestry boundary features, based on N=66

Describtor	Factor	n	%	Average willingness to establish AF inside parcels		Average willingness to establish AF boundary features	
Primary activity	Primarily livestock	33	50%	3.11		3.59	
	Arable farm	15	23%	2.60		3.33	
	mixed farming	13	20%	2.23		4.23	
	Primary tree crops	5	8%	3.25		4.75	
Size of farmland	up to 25 ha	13	20%	2.25		4.17	a
	25 - 50 ha	23	35%	3.00		4.00	a,b
	50 - 100 ha	21	32%	2.68		3.53	a,b
	over 100 ha	8	12%	3.38		2.88	b
legal structure of farm	Sole proprietorship	6	9%	3.17		3.50	
	(general) Partnership	54	83%	2.76		3.80	
	LLC	5	8%	2.80		3.40	
Management	Conventional	40	62%	2.47	a	3.58	
	Additional certification (Milieumeetlat, MPS, direct supply)	18	28%	3.44	b	3.76	
	Certified organic (SKAL)	7	11%	3.17	a,b	4.67	
Share of pastures in total farm area	0%	19	31%	2.53		3.47	
	Up to 25%	5	9%	2.80		4.00	
	25 – 50%	8	12%	2.50		4.13	
	50 – 75%	6	9%	2.67		3.67	
	75 – 99%	16	28%	2.88		3.59	
	100%	6	11%	4.00		4.33	

** The averages of willingness to establish AF inside parcels of AF boundary features is based on an average on the Likerd scale, from 1 (not at all interested) to 5 (will likely implement agroforestry). Different letters indicate significant difference (p < 0,05) in the willingness to establish AF inside parcels or willingness to establish AF boundary features*

A total of 33 livestock farmers, 15 arable farmers, 13 mixed farming and 5 tree farmers participated in the study (table 15). A majority, 55, of these farmers are (general) partnerships, 6 run a sole proprietorship and 5 run a business oriented farm

There were no observed statistical differences between groupings of primary activity. There was a significant relation identified where farms up to 25 hectare were more likely to establish agroforestry boundary featerus than farms over 100 hectare. There was also a significant difference for farm management and willingness to establish agroforestry on fields, where conventional farmers with additional certification (Planet Proof, Milieumaatlat) were more willing to establish in-field agroforestry than conventional farmers.

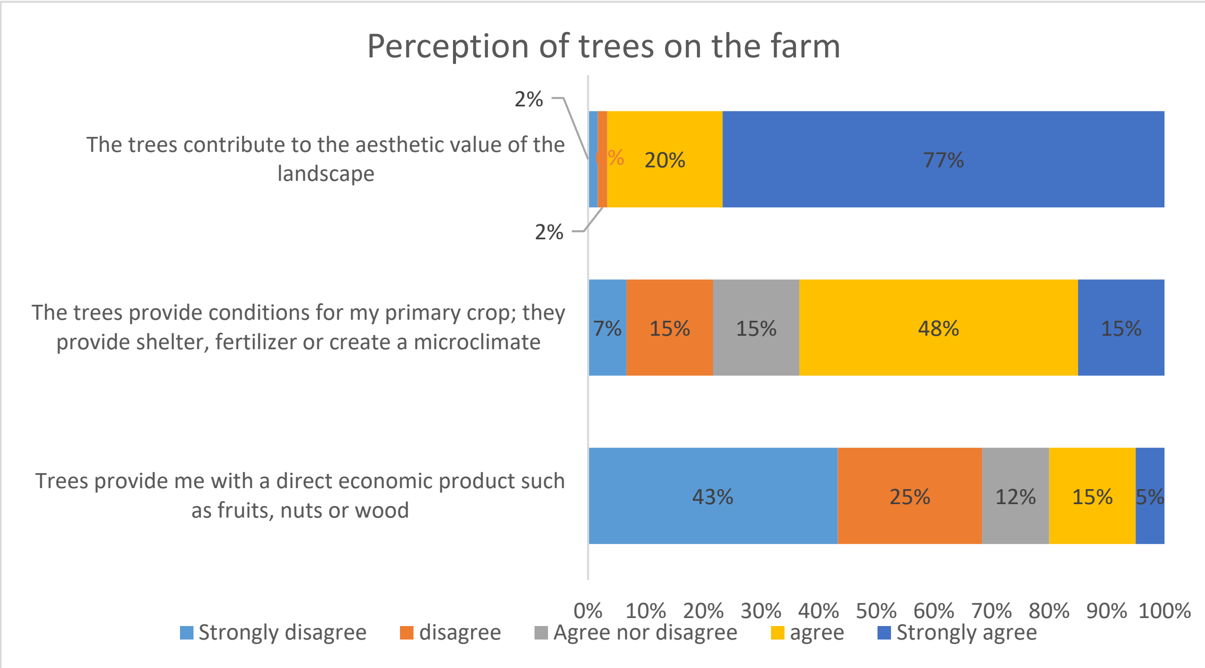

Figure 20. Farmers' perception of trees and shrubs on the farm. Numbers indicate the percentage of participants of the total number of participants (n = 66)

About 76% of participants completely agrees with the statement that the trees and shrubs on their farm provide landscape embellishment (figure 21). About 48 percent slightly agrees the trees have a functional role on their farm: they provide shelter, fertilizer or create a favourable microclimate. The majority of participants, 43 percent, strongly disagree with the statement that the trees and shrubs on their farm provide a direct economic product.

For where the trees are, many participants mentioned they are located around the farmhouse. They generally have them around the farmhouse and few in the fields. Some mention they have trees planted on hedgerows and tree lines. Some also mention they have a small forest where they have numerous trees.

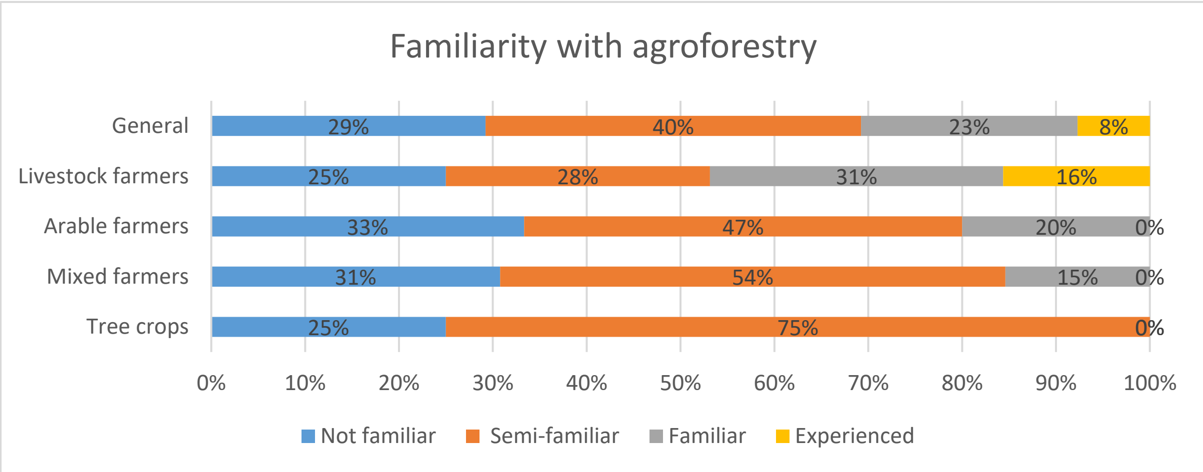

Figure 21. Familiarity of participants with agroforestry. Numbers indicate the percentage of participants of the total number of participants (n = 66)

The majority of farmers, 69%, were not familiar with agroforestry (Figure 22). 19 participants stated they were not familiar at all and 26 participants mentioned they heard the term before but are not familiar with the concept. A minority of 8% were fully familiar with agroforestry and concepts. All respondents (5) that were completely familiar with agroforestry were livestock farmers.

After learning about agroforestry and seeing the demonstrations, the participants were asked if they would be willing to implement an agroforestry system on their own farm, for which they were slightly positive. When asked if they would be interested to plant agrforestry systems within fields, the general mean among participants was 2.79, on a scale from 1 (not interested) to 5 (interested). When asked if they would be interested to establish woody plants as border features they were slightly more interested, where the mean was 3.74. Some participants also mentioned boundary features already in the scoping questions.

The participants generally agree with the key informants about benefits (Figure 23). They are strongly motivated by the trees improving the aesthetic value of the landscape. Some of the farmers aleady have trees and shrubs on their farms and receive a subsidy for it, but it is generally difficult for farmers that don’t currently have subsidies to find these. The participants strongly disagree with the notion the key informants identified that agrforestry can help to diversify income. On that topic, one farmer mentioned it is much easier to stick to a business model based on quantity, where there already is an established marketplace, than to develop this on your own. Tree-products are not farmed on larger scale: they will most likely have to develop their own production chain and this is something they are wary of.

The participants generally agree with trees and shrubs being able to reduce nutrient leaching. They neither agree nor disagree with the statements that trees and shrubs might reduce pest pressure and improve water availability. They generally agree with trees and shrubs having a positive effect on soil and improving biodiversity.

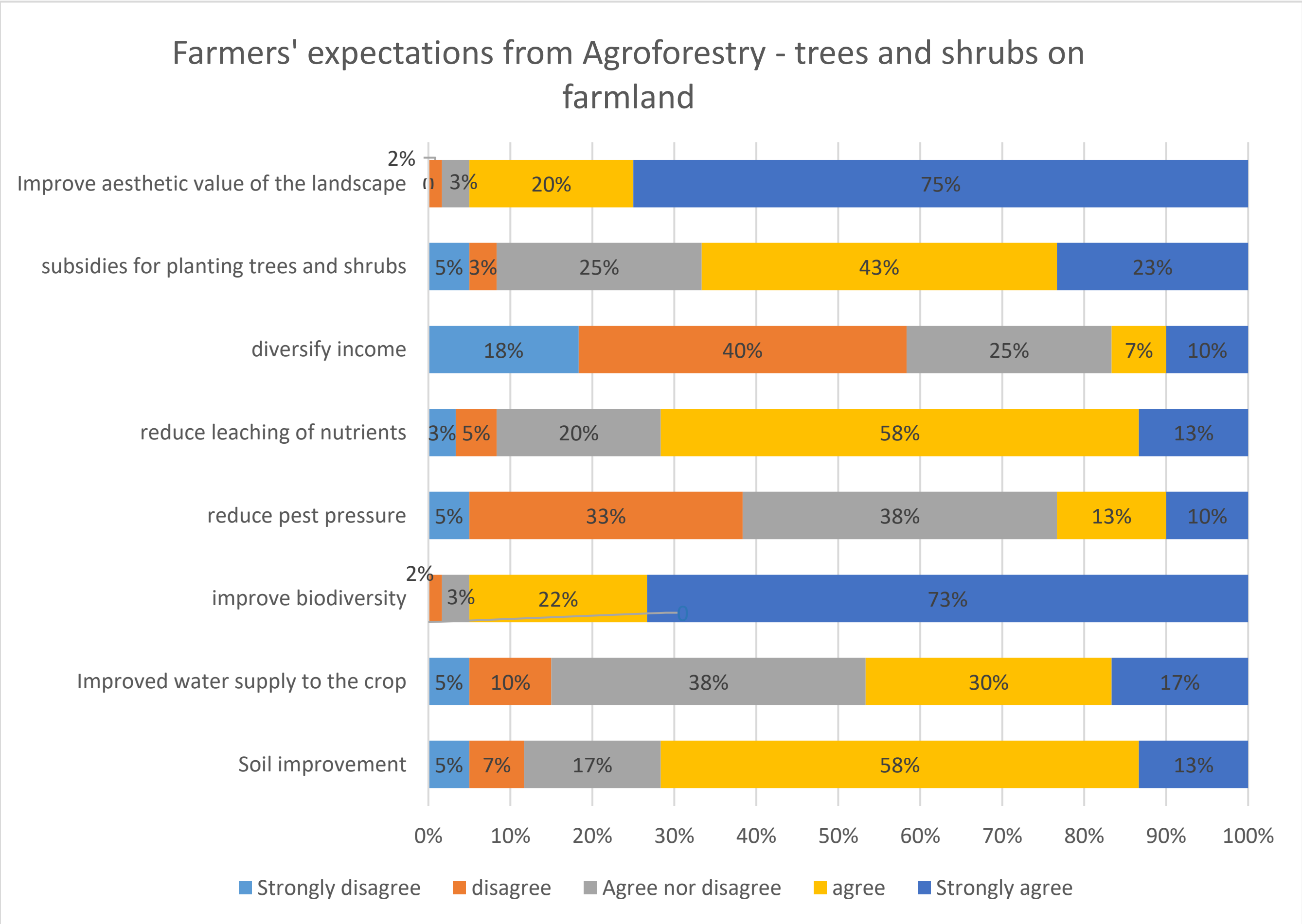

Figure 22. Respondents' expectations from agroforestry and trees on farmland. Numbers indicate the percentage of participants of the total number of participants (n = 66)

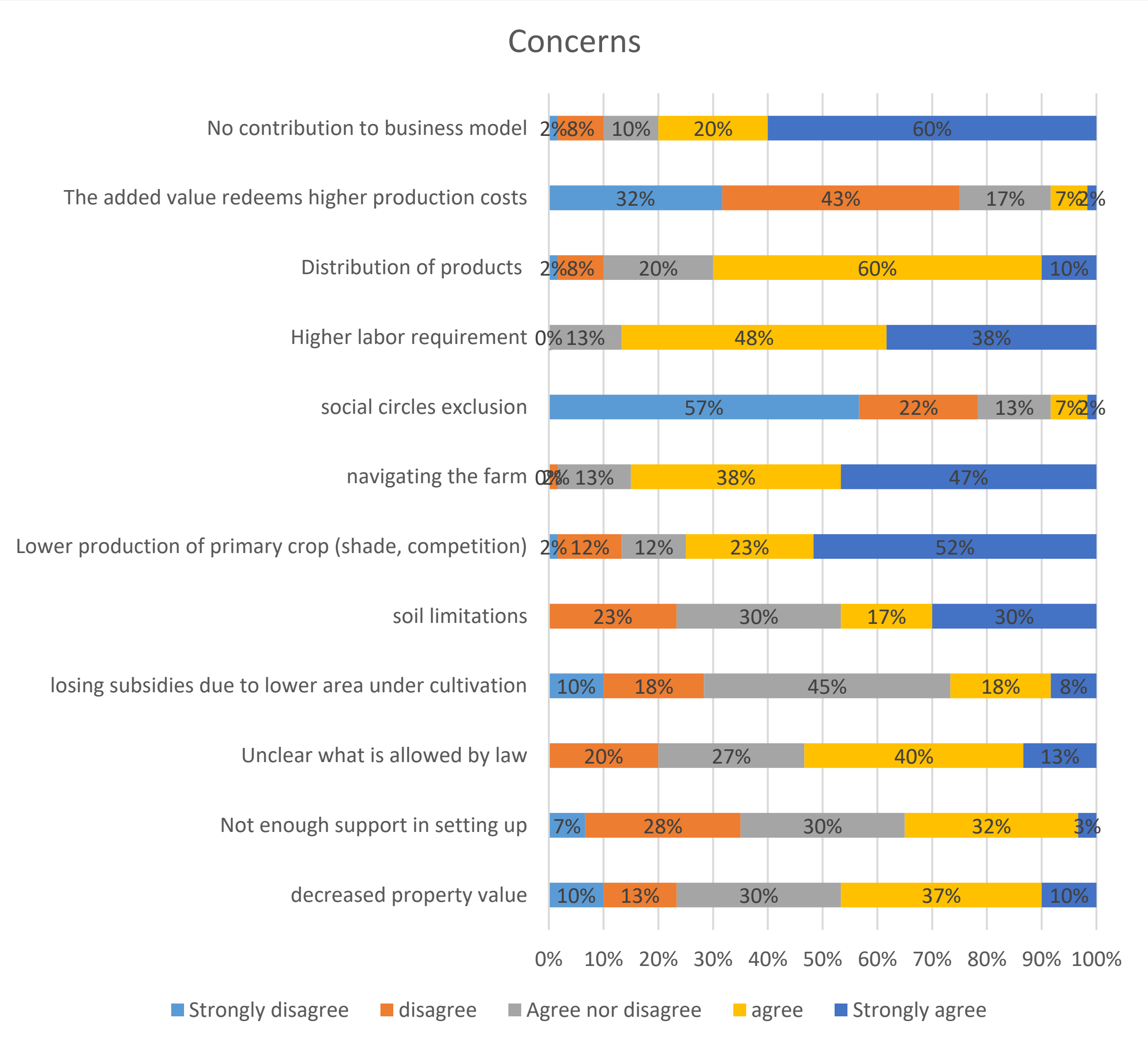

Figure 23. Respondents' concerns for implementing agroforestry. Numbers indicate the percentage of participants of the total number of participants (n = 66)

After expectations, the participants were asked to respond to statements related to concerns the key informants identified. For the most part, the particpants agree with the key informants (Figure 24). The key informants identified concerns related to the business model and generally stated these are central to the farmers‘ decision making. Similarly, the participants feel strongly about the business model and 60 percent of participants fear the trees and shrubs will not contribute to the business model. They generally have a business model based on bulk production (dairy, meat, vegetables) and have little experience with higher-value smaller quantity products. They feel the added value they create by producing in an agroforestry setting won't yield them a better price for their products. Altogether, 75 percent of participants feels the added value created by producing in an agroforestry system will not lead to better prices paid for their product. On that topic, one participant noted it is not only higher production costs that he is wary about, but also the development of a marketplace for higher-value products. The actual distibution of the product, but also organizing the processing chain for the product: sorting, packaging and getting it to a vendor. Altogether,70 percent of participants also agree on the notion that marketing and sales for the novel product is difficult.

The aspect of labor was underexposed by the key informants, but mentioned several times while approaching farmers to contribute to the survey. Altogether, 86 percent of participants agree planting trees and shrubs in agroforestry settings will require more labor. A recurring notion was that they already work overtime and are not interested in any production system that requires more labor. The farmers that focus on mass production generally organise their company in a way that they are the only employee, they can manage the whole company by themselves. Introducing a new production system where labor is attracted from somewhere else sounds foreign to them. Furthermore, they argued that‘‘no one wants to work on manual jobs on farms anymore‘‘, which is reflected in the decreasing number of farmers.

The key informants mentioned exclusion from social circles as a possible concern for farmers. They mentioned farmers commonly have professional and personal networks interwoven, and divergence from the group, especially in large-scale agricultural areas where predominantly conservative farmers live, can be looked down upon. A majority of participants, 57 percent, strongly disagrees with this concern. A majority of participants, 85 percent, agrees trees and shrubs will make it more difficult to maneuver with essential machinery their farm. Altogether, 75 percent of participants mentioned lower production of primary crop and 47 percent soil limitations.

It is still unclear to farmers what the effect of the new CAP will be on their subsidies and also what new reforms to local policy will bring. 45% agrees nor disagrees with the statement that implementing agroforestry will have a negative effect on the amount of subsidies they receive. A similar spread in the concern of it not being clear what is allowed to plant (and remove) under legistlation. The are worried implementing agroforestry will result in their own liberties our subsidies being limited. Furthermore, they are concerned with the property value decreasing as planting agroforestry limits a succesor in their options. Altogether, 47 percent of participants agrees or strongly agrees with the property value being decreased by implementing agroforestry.

The questionnaire was concluded with a question about what form of support the farmers desire for implementing agroforestry. The majority, 40 participants, stated they would want excursions to farms to demonstrate possibilities on farm level. This will further help them to understand crop/livestock and tree/shrub interactions. Key informants also stated the lack of examples to be a main limitation for upscaling, as farmers generally like to see demonstrations in the field rather than on paper and models. Additionally, handbooks and workshops were mentioned for supporting the farmers. Both of these were mentioned by 16 participants. Project support was mentioned 13 times.

6. Discussion

6.1. Using LUCAS for identifying agroforestry

The total area of agroforestry in Limburg waas estimated to be 5,004 hectare. If we consider the research done by den Herder et al. (2017), where 27,800 hectare of agroforestry was found for the whole country, these results suggest a concentration of agroforestry in Limburg. Limburg accounts for 5.8% of the total agricultural area of the Netherlands, 5.8% of 27,800 would be about 1,612 hectare of agroforestry in Limburg. Our estimate is considerably higher than expected. In previous inventories, for example Prins et al (2021), the inventory is based on primary data, e.g., lists of prior projects and contacts. This inventory found 6.6 hectares of agroforestry in Limburg and five hundred hectares in total in the Netherlands. The use of secondary data is more accurate as it analyses actual land use independent of individual farmers and also includes traditional silvopastoral systems.

Furthermore, if we compare the relative share of agroforestry to den Herder et al., (2017), our method found the share of UUA in Limburg to be 3 percent, double the figure found by den Herder et al. (2017). The higher figure can possibly be explained by a relatively higher share of traditional landscapes in Limburg and pastures with some degree of tree cover, as was suggested by key informants. Additionaly, den Herder et al. (2017) used the LUCAS dataset of 2015 and this research is based on LUCAS data from 2018. Some changes in land-use change might have occured. There are also other examples of agroforestry parcels that were not identified by LUCAS due to the year of data collection. There is a group of 10 farmers that participated in a pilot project for the development of agroforestry systems in Limburg in 2021-2022, from which several already started planting. All participants will eventually plant silvopastoral systems. The total area is estimated to be eleven hectares, ranging from 0.5 to 2 hectare per company, but it is also possible a larger group of farmers is already starting that was inspired by the pilot but not related to the research group (Rombouts, 2022).

The methodology used introduced several limitations. Regarding LUCAS, the square grid (2 x 2 km) LUCAS is large and sampling density roughly 30%. All points outside sampling are assigned a land cover class based on satellite image, orthophotos and CORINE land cover survey. This approach makes it difficult to yield reliable results on smaller datasets. Another aspect is landscape heterogeneity. Agroforestry is the intentional combination of elements and because the grid in LUCAS is large, there might also be coincidental secondary land cover present, in the form of small agricultural operations next to each other. Additionally, this method is only appliccable for indentifying trees on parcels. For agroforestry boundary features, such as tree lines, riparian buffer strips and hegderows, these are not identified using LUCAS, as the parameters in LUCAS do not allow for identifying linear features.

Due to these factors, it is possible the estimate is not accurate. However, it is the first study to approach the scale of agroforestry in the region using secondary data. The current research effectively shows where within-field agroforestry is present, including farm systems that are not directly recognized as agroforestry (e.g., traditional silvopastoral systems) or located on farms that are not associated with stakeholders or prior projects.

6.2. Farmers' perspective of agroforestry in Limburg

Agroforestry in Limburg is only practiced on experimental scale. Traditional applications of trees in the agricultural landscape provide examples of how these can be integrated in novel agroforestry settings on a larger scale. In this research, it was found farmers generally do not retain or grow trees and shrubs on their farms for economic purposes. The productive function of trees and shrubs is usually subordinate to an aesthetic function or cultural function. Furthermore, a majority of farmers in the province of Limburg is unaware of agroforestry. However, in the research it was found farmers are slightly positive (2.79 on Likerd scale) to establish novel agroforestry on fields and positive (3,74 on Likerd scale) about establishing agroforestry in boundary features.

An overall obseration from the responses from participants is their general risk-avoidance. Pioneers in this stage are commonly livestock farmers which are interested in agroforestry from the point of animal welfare as primary driver. Also the relatively limited effect on the farming system plays a part: impact on grass yields is assumed to be limited. Furthermore, they are already observing heat stress on their cattle and providing shade is a method to mitigate this. For arable farmers, the impact of implementing agroforestry is assumed to be more impactfull as the effect of competition on the crop yield is more direct. Also the price they pay for their land is also higher, making them more risk-averse.

In this stage farmers are generally not interested in economic benefits, or they assume it has a negative impact, and are motivated by non-financial benefits. This was also the case 20 years ago in research into organic farming, as was found in De Lauwere et al. (2003). Many of the concerns are were not factual, but rather boil down to (financial) uncertainty: there is a lack of examples that show profitability. This occurence was described by De Lauwere (2005)) as financial conservatism. It describes any innovation needs to reach a certain size for institutional research to take place and standardized approaches to be developed, and before that has happened, many farmers will be hesistant to implement the innovation. For livestock farmers, it should also be noted that there is a lot of discussion about their part in climate affairs, which the farmers feel is politicized. This results in social stigma when implementing or developing new ideas, as was found by Ambrosius et al. (2015), even though the farmers in our study generally disagreed social stigma plays a part in their decision making.

As was also concluded from Lojka et al. (2021) in Czech republic, the farmers seem locked into a production paradigm. However, the production paradigm and associated cost-price reduction strategy is the most common farming strategy in the Netherlands and is therefore also the most risk-free. For example, value chains for conventionally produced livestock meat are based on large volumes and prices are generally stable. Farmers argue that value-added products and business opportinities, specifically ecosystem service valorization, are currently still small-scale value chains and are more risky.

Furthermore, in our research farmers mentioned they are worried about changing conditions for farming. They mention droughts, climate extremes and legislative barriers will limit their allowed use of water resources. They see agroforestry as a way to manage this risk and are generally aware planting trees and shrubs will make their farming system more robust to climate extremes. This concern was not mentioned in previous research, such similar research into organic farming and farmers‘ persective (De Lauwere et al. 2003). Applied research into drought resistance of farm systems seems to be increasing (Witte et al. 2020) where agroforestry is also increasingly receiving attention.

The two main concerns found in this research were the assumed lower production of the primary crop and unprofitable production. The farmers are concerned the competition for resources (sunlight and water) will limit crop yield. They worry the added value they create by producing in an agroforestry setting will not be paid for. There were also concerns related to local conditions and tree crops not being able to grow or yield sufficiently. There is a clear need for practical examples of crop combinations and economically feasible farming systems.

A concern that was not found in other regions in AGROFORWARD research into agrforestry was that planting agroforestry systems will result in decrease of property value. A possible explanation is the shrinking agricultural sector. The total acreage, but also the number of farms has been steadily decreasing over the last 50 years. There is a growing number of farmers closing their operations, among other, due to lack of sucessors and regulatory limitations. There is a group of farmers that worries that planting trees and shrubs on their farmland will already determine the farm layout for any successor, which limits possibilities for development, which assumingly decreases its‘ value.

7. Conclusion

This study has reviewed the perspective of Agroforestry in Limburg using literature, land use analysis and farmer perspective analysis. The total extend of agroforestry in the Limburg province was estimated to be 5,004 hectares, based on seven datapoints coding for agroforestry in LUCAS. Estimating the total extend of agroforestry proved difficult due to the limiting definition of agroforestry adopted for the purpose of analysis in LUCAS. Agroforestry was mainly found in the southern region of the province. The farmer perspective on agroforestry was assessed using nine key informants and sixty-six participants in farmers survey. The sector can be characterized by experimental, with livestock farmers being most involved. Farmers are generally interested into establishing agroforestry but are concerned about profitability and the negative influence of trees on crop yields.

Agroforestry shows potential for further implementation in Limburg. It positively relates to regional challenges, such as drought and loss of traditional landscapes. Water conservation is a growing factor in farmers‘ decision making and agroforestry can be a strategy to deal with this. The large areas of pastures that characterize the current landscape can be transformed into silvopastoral systems relatively easily and some already contain woody field boundaries. The farmers in this research are also generally positive to establish boundary features of agroforestry. Furthermore, the regional government has announced subsidies for planting trees and this will further encourage farmers to establish agroforestry. One of the motivations for implementing agroforestry is also socio-cultural: traditional landscaping elements are applied traditionally in Limburg and restoring these is encouraged with subsidies for cultural heritage. The region also attracts tourism, which can serve as a consumer base for added-value products.

Lastly, we recommend further research should focus on further defining agroforestry in the regional context of Limburg. Applied research on regional demonstration farms with region-specific crops will further help to spread the awareness of agroforestry.

8. References

Aarts, N. 2021. de levende natuur en het succes van de maasheggen. De Levende Natuur.

Agforward. 2017. Agroforestry in Europe. Cranfield University

Agrimatie. 2022. Dataset: Limburg. In dataset . Wageningen Economic Research head office.

Albers, W. J., Wouters, H. H. E., Remigius Dieteren, O. F. M., Philips, J. F. R., Grauwel, J., Janssen de Limpens, K. J. Th., Jansen, J. C. G. M., & Panhuysen, G. W. A. (1974). Geschiedenis van de beide Limburgen tot 1632. Maaslandse Monografieen.

Alberts, J. W., Janssen de Limpens, K. J., Panhuysen, G. W. A., van Rooy, Ch. J. M. A., van Houtte, J. A., Petri, F., & Spiertz, M. G. (1964). Maaslandse monografieen.

Alterra. 2006. Soil types in the Netherlands. Alterra research

Ambrosius, F. H. W., Hofstede, G. J., Bock, B. B., Bokkers, E. A. M., & Beulens, A. J. M. 2015. Modelling farmer decision-making: the case of the Dutch pork sector. British Food Journal, 117(10), 2582–2597. https://doi.org/10.1108/BFJ-01-2015-0037

Appunn, K. 2018. 709602. CLW.

Arts, N., Huijbers, A., Leenders, K., Schotten, J., Stoepker, H., Theuws, F., & Verhoeven, A. 2007. De middeleeuwen en vroegmoderne tijd in zuid-nederland. https://dare.uva.nl

Augere-granier, M. L. 2020. Agroforestry in the European Union.

Berendsen, H. J. A. 2011. De vorming van het land, Inleiding in de geologie en geomorfologie.

Bestman, M., & Bloksma, J. 2015. Bomen voor buitenkippen. Ekoland.

Blezer, F. 2022. Hoogstamboomgaarden in Limburg. https://www.Natuurrijklimburg.Nl/Project/Hoogstamboomgaarden/. (accessed 13-2-2023)

Borek R., G. M. 2018. Identifying bottlenecks and gateways for Agroforestry Development in Poland.

Borremans, L., Marchand, F., Visser, M., & Wauters, E. 2018. Nurturing agroforestry systems in Flanders: Analysis from an agricultural innovation systems perspective. Agricultural Systems, 162, 205–219. https://doi.org/10.1016/J.AGSY.2018.01.004

Bouwmeester, R. 2023, February 17th). Kabinet neemt opschaling agroforestry mee in gebiedsaanpak (Parliament includes agroforestry in regional development planning). Nieuwe Oogst.

Bracke, J., de Haas, E., Van Vooren, L., Pardon, P., Nelissen, V., Decroos, T., van Grembergen, D., Tuytens, F., & Reubens, B. 2020. Leg combinatie ILVO Mededeling. Departement Landbouw En Visserij.

Castro, M. 2008. Silvopastoral Systems in Portugal: Current Status and Future Prospects. In Agroforestry in Europe (pp. 111–126). Springer Netherlands. https://doi.org/10.1007/978-1-4020-8272-6_6

CBS. 2017. Database verdeling areaal fruitteelt Limburg. In Centraal bureau voor statistiek.

CBS. 2022a. Dataset: landbouwtelling . In Centraal bureau voor statistiek. CBS.

CBS. 2022b. Bevolkingsontwikkeling Nederland. Population Count.

Corsten, H. 2022. Agrifood Productie Proeftuin. Economisch Actieprogramma Agrifood (EEA).

De Lauwere, C. C. 2005. The role of agricultural entrepreneurship in Dutch agriculture of today. Agricultural Economics, 33(2), 229–238. https://doi.org/10.1111/j.1574-0862.2005.00373.x

De Lauwere, C. C., Drost, H., De Buck, A. J., Smit, A. B., Balk-Theuws, L. W., Buurma, J. S., & Prins, H. 2003. To change or not to change? Farmers' motives to convert to integrated or organic farming (or not).

Den Herder, M., Burgess, P., Mosquera-Losada, R., Herzog, F., Hartel, T., Upson, M., Viholainen, I., Contributors, A. R., Corroyer, N., Hermansen, J. E., Mirck, J., Palma, J., Pantera, A., Papanastasis, V., Plieninger, T., Vityi, A., Quickenstein, A., & Watté, J. 2016. Preliminary stratification and quantification of agroforestry in Europe. www.agforward.eu

Den Herder, M., Moreno, G., Mosquera-Losada, R. M., Palma, J. H. N., Sidiropoulou, A., Santiago Freijanes, J. J., Crous-Duran, J., Paulo, J. A., Tomé, M., Pantera, A., Papanastasis, V. P., Mantzanas, K., Pachana, P., Papadopoulos, A., Plieninger, T., & Burgess, P. J. 2017. Current extent and stratification of agroforestry in the European Union. Agriculture, Ecosystems and Environment, 241, 121–132. https://doi.org/10.1016/j.agee.2017.03.005

Dupraz, C., Lawson, G. J., Lamersdorf, N., Papanastasis, V. P., Rosati, A., & Ruiz-Mirazo, J. 2018. Temperate agroforestry: the European way. Temperate agroforestry systems (pp. 98–152). https://doi.org/10.1079/9781780644851.0098

Ekamper, Peter., & Nederlands Interdisciplinair Demografisch Instituut. 2003. Bevolkingsatlas van Nederland : demografische ontwikkelingen van 1850 tot heden. Elmar.

FAO. 2022. Agroforestry. www.fao.nl/agroforestry (acessed 15-3-2023)

Fereday, J., & Muir-Cochrane, E. 2006. Demonstrating Rigor using thematic analysis: a hybrid approach of inductive and deductive coding and theme development. In International Journal of Qualitative Methods (Vol. 5, Issue 1). http://www.ualberta.ca/~iiqm/backissues/5_1/pdf/fereday.pdf

Gosme, M., & Meziere, D. 2016. System Report: Durum Wheat Production in Agroforestry Systems in France. www.agforward.eu (acessed 2-2-2023)

Harris, I., Osborn, T. J., Jones, P., & Lister, D. 2020. Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Scientific Data, 7(1). https://doi.org/10.1038/s41597-020-0453-3

Hermansen, J. E., Bestman, M., Westaway, S., Kongsted, A. G., Bondesan, V., Losada, R. M., Luske, B., Novak, S., & Smith, J. 2017. Guidelines for improved agroforestry systems for livestock production Work-package 5: Agroforestry for Livestock Systems Milestone Deliverable 5.15 (5.3) Guidelines for improved agroforestry systems for livestock production Date of report. www.agforward.eu (acessed 2-2-2023)

Hilberink, D. 2023. College Boer met Mark Venner: Melkkoeien maken plaats voor voedselbos. Nieuwe Oogst.

Janssen, J., Patrick, V., & ten Thije, S. 2020. Waarom de landbouw van toen dé toekomst heef. www.hetpon.nl acessed 1-12-2022

Jelínek, L. , M. T. , F. I. , H. J. , B. S. 2018. social and Economic Consequences of Direct Payments Capping and Redistribution on the Czech Large-scale Farms. 162nd EAAE Seminar The Evaluation of New CAP Instruments: Lessons Learned and the Road Ahead.

Karel, D., Maastricht, T., Sittard, Reverda, N., & Zuyd, H. 2006. Demografische data Zuid-Limburg vergeleken met Limburg, Euregio Maas-Rijn en Nederland. http://www.hszuyd.nl (acessed 2-3-2023)

Lainka, R. 2018. Quantification of agroforestry systems in the Czech Republic [MSc.]. Prague: Czech University of Life Sciences.

Lojka, B., Teutscherová, N., Chládová, A., Kala, L., Szabó, P., Martiník, A., Weger, J., Houška, J., Červenka, J., Kotrba, R., Jobbiková, J., Doležalová, H., Snášelová, M., Krčmářová, J., Vávrová, K., Králík, T., Zavadil, T., & Lawson, G. 2022. Agroforestry in the Czech Republic: What Hampers the Comeback of a Once Traditional Land Use System? Agronomy, 12(1). https://doi.org/10.3390/agronomy12010069

Mantazanas, K., Papnastasis, V., Pantera, A., & Papadopoulos, A. 2017. Lessons learnt: Silvoarable agroforestry in Greece. www.agforward.eu

McAdam, J. H., Burgess, P. J., Graves, A. R., Rigueiro-Rodríguez, A., & Mosquera-Losada, M. R. 2008. Classifications and Functions of Agroforestry Systems in Europe. In Agroforestry in Europe (pp. 21–41). Springer Netherlands. https://doi.org/10.1007/978-1-4020-8272-6_2

Mirck, J., Kanzler, M., & Quinkenstein, A. 2015. Alley Cropping in Germany Work-package 4: Agroforestry for Arable Farmers Specific group Alley Cropping Systems in Germany. www.agforward.eu

Mosquera-Losada, M. R., Santiago-Freijanes, J. J., Pisanelli, A., Rois-Díaz, M., Smith, J., den Herder, M., Moreno, G., Ferreiro-Domínguez, N., Malignier, N., Lamersdorf, N., Balaguer, F., Pantera, A., Rigueiro-Rodríguez, A., Aldrey, J. A., González-Hernández, M. P., Fernández-Lorenzo, J. L., Romero-Franco, R., & Burgess, P. J. 2018. Agroforestry in the European common agricultural policy. Agroforestry Systems, 92(4), 1117–1127. https://doi.org/10.1007/s10457-018-0251-5

Mukhlis, I., Syamsu Rizaludin, M., & Hidayah, I. 2022. Understanding Socio-Economic and Environmental Impacts of Agroforestry on Rural Communities. Forests, 13(4). https://doi.org/10.3390/f13040556

Nair, P. K. R. 1993. An introduction to Agroforestry (2012th ed.). Springer.

Norgrove, L., & Beck, J. 2016. Biodiversity Function and Resilience in Tropical Agroforestry Systems Including Shifting Cultivation. In Current Forestry Reports (Vol. 2, Issue 1, pp. 62–80). Springer International Publishing. https://doi.org/10.1007/s40725-016-0032-1

Oosterbaan, A. 2011. De toestand van 42000 landschapselementen. Nieuwe natuurblad https://www.researchgate.net/publication/254846595

Oosterbaan, A., & Kuiters, A. T. 2008. Agroforestry in the Netherlands. In Agroforestry in Europe (pp. 331–341). Springer Netherlands. https://doi.org/10.1007/978-1-4020-8272-6_16

Oosterbaan, A., & Raap, E. 2011. De toestand van 42000 landschapselementen. https://www.researchgate.net/publication/254846595

Panozzo, A., Huang, H.-Y., Bernazeau, B., Meunier, F., Turc, O., Duponnois, R., Prin, Y., Vamerali, T., & Desclaux, D. 2022. Impact of Olive Trees on the Microclimatic and Edaphic Environment of the Understorey Durum Wheat in an Alley Orchard of the Mediterranean Area. Agronomy 2022, 527. https://doi.org/10.3390/agron

Paris, P., Lauteri, M., & Ciolfi, M. 2016. System Report: Trees for Timber with Arable Crops in Italy. www.agforward.eu

Pointereau, P. 2015. Concevoir son pré-verger et valoriser ses fruits.

Prins E.. 2021. Advies Community of Practice Agroforestry. www.louisbolk.nl/publicaties

Prins, E., van Leeuwen, S., Vijn, M., Thijssen, E., & Kruit, J. 2023. Onderzoek naar Agroforestry in Nederland. www.louisbolk.nl/publicaties

Provincie Limburg. 2016. Koers naar de toekomst. www.limburg.nl

Provincie Limburg Hoofdgroep ROV. (1967). Gebiedsbeschrijving Limburgs peelgebied

Reubens, B., & van Colen, W. 2019. Factsheet walnoten. https://www.agroforestryvlaanderen.be/NL/Kennisloket/Boomsp (acessed 2-2-2023)

Rois-Díaz, M., Lovric, N., Lovric, M., Ferreiro-Domínguez, N., Mosquera-Losada, M. R., den Herder, M., Graves, A., Palma, J. H. N., Paulo, J. A., Pisanelli, A., Smith, J., Moreno, G., García, S., Varga, A., Pantera, A., Mirck, J., & Burgess, P. 2018. Farmers' reasoning behind the uptake of agroforestry practices: evidence from multiple case-studies across Europe. Agroforestry Systems, 92(4), 811–828. https://doi.org/10.1007/s10457-017-0139-9

Rombouts, P. 2022. Results Agroforestry pilot Limburg.

Rosa Mosquera-Losada, M., Javier Santiago-Freijanes, J., & Moreno, G. (2018). Agroforestry in Europe: a land management policy tool to combat climate change. https://www.researchgate.net/publication/327057437

Russo, R. O. 1996. Agrosilvopastoral Systems: A Practical Approach Toward Sustainable Agriculture. Journal of Sustainable Agriculture, 7(4), 5–16. https://doi.org/10.1300/J064v07n04_03

Taylor, J. R., & Lovell, S. T. 2021. Designing multifunctional urban agroforestry with people in mind. In Urban Agriculture and Regional Food Systems (Vol. 6, Issue 1). John Wiley and Sons Inc. https://doi.org/10.1002/uar2.20016

Tichelman, G. 2013. Romeinse tijd in Limburg.

van Colen, W., & Reubens, B. 2021. Opstartende proef laat uitlopende walnoot in agroforestry. Agroforestry Vlaanderen.

van Colen, W., & Valckx, W. 2021. Voederbomen voor bio-herkauwers: lessen uit Nederland.
van der Woude, A. M., Renigius Dieteren, O. F. M., van der Eyken, A. F., Smets, L., Ubachs, P. J. H., van Uyten, R., & Vandevelde, S. 1992. Geschiedenis van de landbouw in Limburg in de twintigste eeuw.
van Gent, T. 2019. Sustainable Business and Innovation: food forest business models in the Netherlands – challenges and opportunities [Msc]. Utrecht University
Vandenabeele, V. 2021. Voederhagen en -struiken voor vee. https://www.agroforestryvlaanderen.be,
Verhue, D., Vieira, V., Koenen, B., & van Kalmthout, R. 2011. opvattingen_over_megastallen_een_onderzoek_naar_h-groen_kennisnet_168111. Veldkamp Onderzoek.
Vienna. 1815. Final Act of the Congress of Vienna/General Treaty. http://www.dipublico.com.ar/english
Vityi, A., Marosvolgyi, B., & Schettrer, P. 2015. WP4_HU_system_description. AGFORWARD.
Westeringh, W. 1975. Hoogstamboomgaarden in Zuid-Limburg. Wageningen Landbouwhogeschool Publicatie, 91–100.
Wigboldus, S., van Leeuwen, S., Schoutsen, M., Vijn, M., & Kruit, J. 2022. Agroforestry kansrijk(er) maken in Nederland : hoe rekenen, waarmee rekening houden, en waaraan werken? https://doi.org/10.18174/585185
Witte, J.-P., De Louw, P., Van Ek, R., Bartholomeus, R., Van Den Eertwegh, G., Gilissen, H. K., Van Rijswick, M., Beugelink, G., Ruijtenberg, R., & Van Der Kooij, W. (2020). AANPAK DROOGTE VRAAGT TRANSFORMATIE WATERBEHEER.
Wouda, T. 2023. Melkveehouders planten 20.000 bomen. Nieuwe Oogst.

9. Appendices

I. Key informant interview protocol

Introduction	What is your expertise? What organization do you work for? Are you familiar with agroforestry? In what way? How much experience do you have with agroforestry?
Characterization	How would you describe agroforestry? What delineates agroforestry? How would you describe agroforestry in NL (Limburg)? What can you say about agroforestry pioneers?
Expected benefits	Do you run into any problems where agroforestry can be a solution to? What benefits do you expect to see after implementing agroforestry? What benefits can you describe?
Concerns	What concerns do you have for agroforestry? What is holding people back from planting trees and shrubs on farmland? What factors of land, machines and labour do people keep in mind?
Specific opportunities	What can agroforestry mean for Limburg specifically? What characterizes the regional agricultural sector? What crops or livestock is most easily incorporated into agroforestry and is there some overlap with locally grown crops/livestock systems?
Closing	Do you want to share any remaining thoughts?

II. Farmer survey

Farmer survey questions
General introductory questions

1 Type of farm Primarily crop production/livestock/ perennial crops (orchards)/mixed farming
2 Total size of farmland in ha
3 Share of privately owned land in the total farmland in %
4 Legal form family farm/company/cooperative
5 Management regime organic/conventional/not specified
6 Share of arable land in the total farmland in %
7 share of pastures in the total farmland in %
8 What geographical region of Limburg are you? North/middle/south
9 Are you familiar with the term 'Agroforestry'? Yes, partly yes, partly no, no

Trees on farmland – current application

10 Are there trees and woody plants present around the farm and where are they located mainly?
11 What is the number of existing of woody plants on your farmland?
12 What is the number of existing hedgerows and liniear tree features on the farmland?
Statements:
13 I use woody plants economically, I have directly benefit from wood or fruits
14 I need the trees for setting the scene for my primary crop, they provide me shelter, litter, pest control or create a microclimate
15 I use the trees for a different tool: they probide a raw material I use somewhere else on the farm
16 The trees are form the aesthetics of the landscape
17 I must endure them because of nature conservation and environmental protection.
18 I receive a subsidy for planting and maintaining woody plants.

Agroforestry
(Interlude: explanation about agroforestry and different applications, different explanation based on answers scoping questions)

Establishment of AFS

19 Would you be interested in establishing AFS as trees between parcels.
20 Would you be interested in establishing AFS inside parcels.
21 Number of hectares to establish AFS in ha.

Expectations (ecologic, economic, social) – statements on Likerd scale

22 By planting trees or shrubs I can improve the soil
23 By planting trees or shrubs I can better control water supply
24 By planting trees or shrubs I can imcrease biodiversity
25 By planting trees or shrubs I can reduce pest pressure
26 By planting trees or shrubs I can make better use of nutrients and reduce leaching
27 By planting trees or shrubs I can better adapt to climate extremes
28 By planting trees or shrubs I can diversify my income (fruits, nuts, tourism)
29 By planting trees or shrubs I can reduce the importance of my primary income source

30 By planting trees or shrubs I can receive compensation in the form of subsidies

Concerns ((ecologic, economic, social)

31 Planting trees or shrubs will not improve my business model
32 I can receive a better price for agroforestry crops
33 Logistics of these crops is challenging
34 There is not sufficient assistance in developing these systems
35 The surrounding area will react bad to me planting trees and shrubs
36 The schade created will have a negative effect on my primary crop
37 By planting trees I will have a harder time navigating machines
38 Planting trees or shrubs will not grow adequately on my soil
39 Planting trees or shrubs will require more labor
40 There is unclarity about the regulations regarding trees on farmland
41 I can lose subsidies for acreage if I plant areas with trees
42 By planting trees or shrubs my land will lose value

Assistance needed
43 What form of assistance would you welcome in setting up AFS?
Printed handbook, online courses, courses and workshops, expert analysis and project support, excursions and practical demonstrations, advisory service, other

III. Photo documentation LUCAS datapoints

Point ID	**Land** cover	Land use	Date of check	Photo
40183082	E10	U111	14-3-2023	

40383190	D10	U111	24-3-2023	
40183084	E10	U111		
40203084	B73 / E20	U111	24-3-2023	

40363090	B71 / E20	U111	2-4-2023	
40243088	B73 / E20	U111	2-4-2023	

40323082	B73 / E20	U111	2-4-2023