Green fertilization for soil sustainability and biodiversity.

Assessing the sustainability potential of an innovation in cultivated arable farming practices.

Master thesis Sustainable Business and Innovation (45 ECTS)

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Abstract

The Dutch cultivated arable farming sector is known internationally for its efficiency and high production, but the farming practices used to achieve this are deemed unsustainable. Many of the sustainability issues in this sector are related to soil. As a result, agricultural soil sustainability management has become an important avenue in the search for sustainability in agriculture. Green fertilization, the practice of growing certain crops to plow through the soil for their sustainability and biodiversity enhancing qualities can help solve these issues arising from intensively used agricultural land. This technique has a long history and has demonstrated its usefulness in combatting modern day agricultural soil sustainability issues. The research identifies four functions by which green fertilization crops does so.

It furthermore evaluates the effectiveness of current practices of green fertilization implementation through agricultural innovation system analysis. This analysis creates an overview of the cultivated arable farming sector, the actors and networks embedded therein as well as laws and regulations pertaining to green fertilization. Although uptake of green fertilization is nearly ubiquitous in the sector, its contribution to sustainability and biodiversity improvement is found to be lacking. The reasons for this are shown to be a misalignment between the legislative requirements of the law responsible for this increase, and the intended goal of the legislation. Incentives embedded in the laws surrounding green fertilization do not contribute to the implementation of sustainable forms of green fertilization.

The research then assesses the factors that drive and inhibit uptake of more environmentally sustainable forms of green fertilization and provides 4 policy recommendations on how to encourage future uptake of these forms.

1. Incorporate a broader set of farm-level evaluative indicators to assess sustainability and biodiversity effects of GF through the four functions in future legislation.
2. Stimulate fundamental research into GF ‘white spots’, aggregate research initiatives’ results and make the available information usable for farmers.
3. Incentivize GF implementation that promotes biodiversity and sustainability using the broadened set of evaluative indicators. Reward farmers that disproportionally contribute.
4. Create legislative stability by enshrining agricultural sustainability goals in long term legislation.

This research provides an in-depth overview of green fertilization practices using the most recent available insights on the subject and shows how green fertilization as an agricultural tool for sustainability can be used in the future of Dutch agriculture.

Keywords: ‘Green fertilization’, ‘agricultural soil’, ‘Agricultural Innovation System’ (AIS), ‘sustainable agriculture’.

Inhoudsopgave

1. Introduction

1.1 Introduction

The Netherlands has an uncommonly large agricultural sector compared to the small size of the country. In fact, the Netherlands is the second-largest exporter of agricultural products in the world after the United States of America (Gomes, 2020; Poppe, 2020). In 2019, it exported € 94.5 billion in agricultural produce, semi-finished products and machines; growing 4.6% compared to 2018 (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020). The Dutch agri-food complex is aimed at importing bulk products, like cereals and soya beans, and exporting products with a high value as well as processed products, such as flowers, vegetables and products from the livestock industry (Mulder & Kupper, 2006; Lesschen et al., 2020).

This research focusses on the open ground cultivated arable farming sector in the Netherlands. This is the agricultural sub-sector concerned with producing agricultural produce on open soil farms. The historical high intensity of agricultural activity in this sub-sector has not been without ramifications. Producing large amounts of crops on a relatively small area of land has resulted in a sophisticated system of high input-high output farming methods (Bos et al., 2013; Gomes, 2020). These farming methods cause a variety of persistent sustainability issues.

Manuring regimes, using either synthetic manure or animal manure, used to keep the soil productive cause increased emission of nitrogen and phosphate into the air and bodies of water (Velthof et al., 2017). This process causes nitrogen deposition and subsequent eutrophication throughout the Netherlands, especially damaging natural areas under preservation efforts (Velthof et al., 2017). Furthermore, due to the pressure applied by livestock and heavy machinery, agricultural soil is often compacted (Bos et al., 2013; Post et al., 2020). This process cements lower soil layers, preventing water infiltration, further increasing the runoff of nutrients from agricultural land.

Additionally, agricultural land is a significant source of greenhouse gasses like methane and CO_2 due to metabolic processes in the plowed soil (Post et al., 2020; Gomes, 2020). The intensive use of agricultural land decreases soil quality, resulting in decreased nutritional value for agricultural produce, which has an adverse effect on public health (Roberts & Mattoo, 2018). As a result of all the issues mentioned above, agricultural soil management is an essential factor in agricultural sustainability efforts.

In order to promote sustainability in agriculture, the European Union embedded sustainability clauses in the Common Agricultural Policy (CAP), incentivizing its member states and the farmers therein to adhere to its requirements through cross-compliance and so-called ‘green direct payments’ that promote sustainable interventions (European Commission, 2020).

The environmental performance of the Common Agricultural Policy over 2017-2020 has been low on European levels, with subsidy misalignment and a lack of support for environmental action and climate-friendly practices being cited as the leading causes (Scown et al., 2020). Implementation of legislation to promote agricultural sustainability has failed in reaching its intended sustainability goals.

One of the measures employed to promote soil sustainability and biodiversity in agriculture is the implementation of so-called 'green fertilizers'. 'Green fertilization' (GF), alternatively called 'green manuring' is the practice of plowing undecomposed green plant tissue into the soil (Warman, 1980; Hoek & Korthals, 2007). The aim of applying this technique is to improve the physical or chemical properties of the soil in order to benefit the main cash crop (Timmer et al., 2003; Postma et al., 2020). GF crops can be grown for their known specific soil altering properties and subsequently plowed through the soil to decompose before sowing the main crop (Warman, 1980; Haagsma et al., 2019). European farmers have used this technique for over 2000 years (Pieters, 1927).

Figure 1: *Rapeseed grown as GF crop (LG Seeds, 2021)*

The term 'green fertilization' implies that the purpose of growing a GF crop is to use it as a substitute for manuring or other forms of fertilization, which is often not the case. Although it can be a suitable substitute for a manuring regime in some settings, this is generally not its main purpose (van der Burgt & Timmermans, 2020). Instead, GF is more commonly used to reuptake excess nitrogen to be added to the soil as organic matter once it is plowed into the soil. This principle of transformation of nitrogen as a soil fertilizer into organic matter and subsequent sequestration is found in the obligation for Dutch silage maize farmers to sow a so-called 'catch crop' to reduce runoff of excess manure after the harvest through uptake. This catch crop re-releases nutrients in the soil in a biodegradable form after plowing the plant material (Fageria, 2007; Haagsma et al., 2019).

How the turned-in crop affects the soil properties is dependent on the botanical characteristics of the crop used, the time it has to grow, under what circumstances it grows, how it is processed, and the way it decomposes in the soil (van Schooten et al., 2006; Fageria, 2007; Abera & Gerkabo, 2021). Therefore, it is essential to look at the needs or shortcomings of the soil when choosing a crop for green manuring (Haagsma et al., 2019; IRS, 2020). Ideally, GF crops can be used in this way to alleviate specific soil sustainability issues.

There are four overarching functions of growing green fertilizers: addition of soil organic matter, improvement of soil structure, improvement of crop health, and improvement of aboveground and belowground biodiversity. Most GF crops are used to fulfill multiple functions, and some fulfill more functions than others (Haagsma et al., 2019).

GF as a practice is broad, and many agricultural practices operate by the same natural mechanisms. Because this wide variety exists, a narrow definition of GF to be used in this research is formulated:

Green fertilization is the purposeful growing of a crop with no, or very limited direct cash value, which is subsequently ploughed through the soil to promote one or more aspects of soil quality through the four functions proposed by Haagsma et al. (2019).

Currently, GF application within line with this definition is being widely applied in cultivated arable farming practices. In the Netherlands, 96% of all open ground farmers implement GF within their crop rotation (Bouma et al., 2019). However, not all agricultural land undergoes a rotation of GF each year. Internally published figures on amounts of GF seed sold obtained from Plantum, a branche-organization for plant breeders, revealed that a maximum of 10-25% of cultivated arable acreage could be sown in with GF crops, or mixtures of GF crops yearly (Sales representative seed company, personal communications, 2021).

Literature reveals that GF has the theoretical potential to make an excellent contribution to soil sustainability and biodiversity while providing yield increase for the farmer (Haagsma & Schröder, 2003; Haagsma et al., 2019; van der Burgt & Timmermans, 2020). However, when evaluating government sustainability goals in legislation throughout 2017-2020, the contribution of GF to those goals was found to be small. It did not contribute to the living space for flora and fauna and had little effect on biodiversity in agriculture (Elbersen & Lazebnik, 2020).

So while the adoption of GF practices among open ground farmers is nearly ubiquitous, and there exist demonstrable benefits for sustainability, biodiversity and farmer profitability in applying GF, these benefits are not being fully exploited.

This leads to the main research question:

Main research question
How can current green fertilization practices in the Dutch cultivated arable farming sector be steered by policy to contribute more to sustainability goals while safeguarding profitability for farmers?

In order to answer this question, first, an assessment had to be made of the reasons why current GF implementation is not contributing to sustainability goals. This was done in the context of current agricultural policy, as the evaluation of this policy yielded the described negative results.

Sub-question 1
What are the policy-related causes for green fertilization to not contribute within its theoretical potential to soil sustainability and biodiversity enhancement in the Dutch cultivated arable farming sector?

Secondly, the dynamics behind adoption of GF in agriculture need to be examined within the context of the wider cultivated arable farming sector as it is crucial to understand the underlying motives of stakeholder behavior from a broader perspective. Combining stakeholder motivations and other systemic factors like laws and the influence of market dynamics will be needed to uncover the reasons for implementation.

Sub-question 2
How is green fertilization currently embedded in the cultivated arable farming sector?

Insight in farmers' motivation to implement GF are to be enhanced in order to steer the implementation towards a more sustainable and efficient form. The barriers to implementation are to be examined to determine their influence on adoption and to devise ways to alleviate them. The second and third sub-questions become:

Sub-question 3
What are the drivers and barriers to more sustainable green fertilization implementation within the Dutch cultivated arable farming sector?

Sub-question 4
How can these drivers be enhanced and barriers be alleviated by adaptation of policy for green fertilization to contribute more to sustainability and biodiversity while safeguarding profitability for farmers?

By answering the fourth sub-question the main research question will be answered.

1.2 Research contribution

This research adds to the existing body of knowledge of the agricultural sustainability potential of GF as an agricultural innovation, and elaborates on its current and future role in agricultural sustainability efforts in the Netherlands. It uses a framework constructed of different innovation transition frameworks to fit the analysis of an innovation in a specific national agricultural sub-sector and tests the efficacy of this framework. It does so by critically assessing the findings produced by the framework, their relevance and implications in light of literature related innovation system analysis.

It provides a detailed overview of the sustainability potential of GF in the cultivated arable farming sector as well as the status quo around GF as an agricultural technique for sustainability and biodiversity within the context of this sector. It uncovers the reasons why this potential is not reached while accumulating the most recent available literature and data around GF implementation to form this assessment.

This assessment is then placed it in the context of a sub-sector systemic analysis that documents the drivers for, and barriers to implementation of GF as a sustainability innovation. Furthermore, it provides insight in farmers motivations to engage in sustainability efforts in their operations while testing the efficacy of current agricultural legislation surrounding GF as an agricultural innovation and provides recommendations for improvement.

As the current debate on sustainability in agriculture is one of the higher priorities of the Dutch Ministry of Agriculture, Nature and Food-quality towards the new Common Agricultural Policy to be implemented in 2023, it is the right time to look at sustainability techniques like GF that can used to alleviate agricultural sustainability issues and evaluate their potential contribution to the goals therein.

2. Theoretical framework

2.1 Overview

In order to answer the research questions, first a theoretical framework was constructed that clarifies in detail what GF practices in the Netherlands entail and what their potential contribution to sustainability in agriculture is. This clarification can then be used in the assessment of why it, in fact, is not contributing to this theoretical potential.

Furthermore, relevant frameworks for analysis that give insight into what drives farmers to implement sustainability interventions in their operations will be discussed and the framework used in this research will be presented. The choice for the elements, and the construction of the framework used in this research will furthermore be addressed.

2.2 The sustainability potential of green fertilization

As mentioned before, there are four functions that GF can fulfil in a rotation plan. These functions are tied to the sustainability potential GF techniques have. The functions and the sub-functions by which they operate are depicted in *table 1*. The agricultural problems mentioned in the introduction that can be alleviated by GF according to literature are included.

Table 1: *Overview of the possible benefits of GF in a rotation plan, using the 4 main functions. (Tabularised from Haagsma et al. (2019), chapter 3.) Articles that support the findings are depicted in the middle-right column and the soil sustainability issues that can be alleviated according to this literature are added on the right hand side.*

Function	Sub-function	Supported by	Alleviates
Addition of organic matter	Addition of usable nutrients to the soil	Haagsma & Schröder, 2003; Hoek, 2007; Garg et al., 2009; van der Burgt & Bus, 2012; van der Scheer, 2014; Bernard et al., 2014; Hoek, 2017; Wood et al., 2018; Šarauskis et al., 2019;	Nitrogen and phosphates emissions Nutritional deficits in produce
	Influences the other 3 functions	Timmer et al., 2003; Šarauskis et al., 2019	Soil quality degradation
Improvement of soil structure	Protection from soil compaction and erosion	Warman 1980; Haagsma & Schröder, 2003; Timmer et al., 2003; van Schooten et al., 2006; Hoek, 2017	Soil structure degradation & compaction
	Improvement of water infiltration	Warman 1980; Timmer et al., 2003; van Schooten et al., 2006	Nitrogen and phosphate runoff
	Weed suppression	Boydston & Hang, 1995; Hoek & Korthals, 2007; Drenth, 2018	Additional labor for farmer/use of herbicides

Improvement of main crop health	Plant parasitic eel suppression	Mojtahedi et al., 1991; Mojtahedi et al., 1993; Haagsma & Schröder, 2003; Hoek & Korthals, 2007; Drenth, 2018	Loss of harvest/harvest quality
	Mold and virus suppression	Haagsma & Schröder, 2003; Bernard et al., 2014	Loss of harvest/harvest quality
Improvement of biodiversity	Promotes presence of bees and bumblebees	van der Scheer, 2014; Underwood &Tucker, 2016; Baddeley et al., 2017 van der Haas, 2019; van den Berg et al., 2021	Reduction of farmland resillience; loss of harvest
	Provides refuge for animals	Fageria, 2007; Underwood &Tucker, 2016	
	Improvement of soil biodiversity (microbiota)	Mancini et al., 2004; Javaid et al., 2010; Baddeley et al., 2017; Longa et al., 2017; Kahn et al., 2020	Decrease in farmland biodiversity/soil quality degradation

The fulfillment of these functions have tangible benefits for sustainability and for farmer profitability. The extent to which they are fulfilled after a rotation determines these benefits and gives insight in the sustainability potential of GF as an agricultural technique.

The are no guaranteed sustainability or profitability benefits to implementing GF. As mentioned, these depend in large part on the circumstances under which the crop grows, the botanical characteristics of the crop used, how it is processed, and the way it decomposes in the soil (van Schooten et al., 2006; Fageria, 2007; Haagsma et al., 2019). Therefore, they are subject to circumstance, the intended goal of using GF and the ability and willingness of the farmer implementing the technique. There is no 'miracle' GF crop that fulfills all functions best, therefore a choice must be made as to which function has priority for the farmer (Haagsma et al., 2019). A crop that fulfills that function can then be identified and grown.

Here, an attempt is made to show the current maximum documented potential of GF in Dutch agriculture using case studies found in literature. Where possible the crop used to achieve the result is mentioned. The presented results are a showcase of the best documented outcomes in field tests and other domestic research. An elaboration on how the functions in *table 1* are related to these results is added. The overview is what will be regarded as the sustainability potential of GF in Dutch agriculture to be used as a reference throughout the research.

2.2.1 Addition of organic matter

The Louis Bolk institute, a prominent agricultural research institute focused on Dutch agricultural research, has an ongoing research project called PlantyOrganic since 2011 in the Wadden area of the Netherlands. The aim of this project was to design and operate an agricultural area without the use of fertilizers and to run the farm with 100% own-supply nitrogen in combination with non-inversion soil tillage (van der Burgt & Bus, 2012). The results over the years show that a consistent nutrient supply can be achieved using solely GF legume crops, accompanied by good production levels of the main cash crops (van der Burgt & Bus, 2012; van der Burg & Timmermans, 2020). In this case, GF makes the use of a traditional manuring regime superfluous.

2.2.2 Improvement of soil structure

Timmer et al. (2003) outlined that compaction of soil can be entirely abated by growing a GF crop that makes strong, thin and densely packed root canals like some species of grass. These crops not only aerate the soil to alleviate mild, existing compaction, they also prevent compaction through the remaining decomposing root structures that benefit aeration over a longer period of time. Soils that have these complex root structures are less at-risk of waterlogging after heavy rainfall while eroding significantly less under weather influences when compared to land left fallow between crop rotations (Timmer et al., 2003).

2.2.3 Improvement of main crop health

The University of Wageningen conducted experiments over four years to assess the role of GF in suppressing weeds (Kruidhof et al., 2005). Subsequently, a book was published on the role of GF cover crops on weed management (Kruidhof, 2008). The research published therein shows that GF crops, especially those that quickly produce aboveground mass, that grown in the period between two cash crops have potential to spearhead ecological weed management strategies, foregoing the need for herbicides. In late summer and autumn the cover crop can suppress growth and seed production of weeds, whereas the incorporation of GF residues in spring reduces and slows weed emergence when applied properly (Kruidhof, 2008).

Domestic research on the influences of GF practices on soil pests and microbial communities is lacking (Haagsma et al., 2019). However, Larkin & Griffin (2007) show that soilborne diseases can be controlled using rapeseed as a GF crop between potato harvests. Tests by the University of Maine on disease suppression by rapeseed confirmed the insight that it can be effective at reducing disease and increasing yield under both conventional and organic production practices (Bernard et al., 2014).

2.2.4 Improvement of biodiversity

Relatively little domestic elementary research on the direct effects of GF on biodiversity in agriculture could be found. This is mirrored in the review performed by Haagsma et al., 2019 as one of the areas of further inquiry for GF research. Organic Dutch farms incorporating GF are more biodiverse than non-organic farms, however these results cannot be directly attributed to solely implementation of GF in the rotation plan (Meijers, 2019). While researching pest control van den Berg et al. (2021) found that flowering types of GF like white clover provide refuge for the natural enemies of *Thrips tabaci,* a common pest in cultivated arable farming. This increase in agricultural biodiversity negatively influenced the presence of this pest, although other factors like mechanical obstruction and soil organic content proved more important in combatting *Thrips*. The research concluded that the clover was not present long enough on the field to elicit a significant and measurable effect.

The absence of domestic literature on the effects of GF on biodiversity is offset by the abundance of foreign literature on these same effects on soil biodiversity (Mancini et al., 2004; Javaid et al., 2010; Baddeley et al., 2017; Longa et al., 2017; Kahn et al., 2020). These studies report an overall positive effect on belowground biodiversity due to the increase in soil organic content. This increase in belowground biodiversity is linked to positive agronomic effects like the increased availability of nutrients for the main cash crop (Mancini et al., 2004; Longa et al., 2017).

Furthermore, using mixtures of GF seeds causes an inherent increase in biodiversity in agriculture as moving away from a monoculture on the field is considered an increase in biodiversity. More complex mixtures of GF crops, incorporating different species, add more biodiversity to the agricultural landscape. Having green cover instead of fallow land in winter also increases agricultural biodiversity and could provide cover for farmland birds and other critters (Fageria, 2007; Underwood &Tucker, 2016).

2.3 Analyzing green fertilization as an innovation in agriculture

Now the theoretical contribution of GF to agricultural sustainability and biodiversity is outlined, the reasons for the absence of these effects becomes the focus of this research. In order to discover these reasons and to answer the research questions, GF was analyzed as an innovation in agriculture, adhering to innovation transition dynamics.

The adoption, development and innovation of agricultural sustainability innovations like GF does not happen in isolation, but rather in a network of actors from the sciences, business, civil society, and government that co-produce the technological, social, and institutional changes that co-shape a transitional landscape (Lamprinopoulou et al., 2014; El Bilali, 2020). This innovative landscape, its actors, their connections and the dynamics between them is called an '*Innovation System'* (IS). The practice of applying GF, how it develops as a technique and which factors influence adoption can be better explained when put within the context of this innovation system.

For analysis of GF within this innovation system, a fitting framework of analysis must be used. Several frameworks, explaining the trajectory of innovation within their respective innovation systems exist within the field of innovation sciences (Lamprinopoulou et al., 2014; El Bilali, 2020; Klerkx & Begemann, 2020). They analyze the system by defining and visualizing the relevant actors, exploring and explaining connections between these actors and using this information to give insight in system dynamics (Hekkert et al., 2011; Weber & Rohracher, 2012).

When the implementation of GF is viewed through the lens of one of these frameworks, a better understanding of the drivers, barriers and trajectory of the innovation is the result.

The Multi Level Perspective analysis (MLP) is the most common framework used to explain the dynamics behind innovation processes in agro-food sustainability research (El Bilali, 2020). It states that that innovation transition comes about through interaction processes within and between three analytical levels: niches (micro level), socio technical regimes (meso level) and the exogenous socio-technical landscape (macro level) (Geels, 2019). In Multi Level Perspective analysis, transitions are defined as shifts from one regime to another caused by interaction on these three levels. Innovations build up momentum in their niche; changes at the landscape level create destabilizing pressure on the regime, and regime destabilization creates windows of opportunity for radical niche innovations to gather momentum to take center stage within the system (El Biliali, 2020). As GF is not a radical innovation and is already embedded in the socio-technical regime of the cultivated arable farming sub-sector, this approach is less suited as a lens to explain the dynamics governing GF as an innovation at this stage.

Another example of an often used transitional framework are the 7 functions that explain the speed and direction of technological change in an innovation system as proposed by Hekkert et al. (2007). Insight in these 7 functions and their connecting dynamics can explain the adoption and diffusion of new technologies within an innovation system. When these functions are fulfilled to their utmost extent, the innovation system functions optimally. This causes innovations entering the innovation system to be developed, adopted and adapted seamlessly.

A framework that incorporates these 7 functions is the Technological Innovation System (TIS) analysis. A Technological Innovation System can be defined as the set of actors and rules that influence the speed and direction of technological change in a specific technological area. The purpose of analyzing this Technological Innovation System is to analyze and evaluate the development of a particular technological field in terms of the structures and processes that support or hamper individual innovations within it (Hekkert et al., 2011). In Technological Innovation System analysis, first the structure of the system is analyzed. This is done by mapping actors and the rules that make up the system. Then, the 7 functions are used to evaluate system functioning. When all 7 functions are fulfilled optimally, innovations develop and diffuse optimally in the system, which is often not the case. Functions that hamper system functioning can be determined, and the reasons for dysfunctionality determined. These are the barriers we here attempt to assess.

While Technological Innovation System analysis could give insight in the dynamics behind the development of GF techniques and their adoption in the cultivated arable farming sector, the analysis is designed to explain change in technology-oriented sectors. GF is not a technique that requires a lot of technological sophistication. The Technological Innovation System framework, as is, could therefore be considered to not be a good fit for analyzing GF as an innovation in agriculture.

An example of a framework suited for analyzing GF as an agricultural innovation is a form of Technological Innovation System analysis that is adapted to explain agricultural system dynamics. This type of analysis is aptly called an 'Agricultural Innovation System analysis' (AIS-analysis) as applied by Lamprinopoulou et al. (2014). This framework is based in Technological Innovation System analysis and utilizes building blocks from several transitional studies including the 7 functions proposed by Hekkert et al. (2007). Lamprinopoulou et al. (2014) expands upon these 7 functions by splitting the function of 'resource mobilization' into 'funding' and 'non-monetary resource mobilization' allowing for higher detail of analysis. 'The 'resource mobilization' function will focus on non-monetary resources like physical infrastructure and human resources, and 'funding' will focus on monetary structures and dynamics around GF implementation. The 8 resulting functions used in this research are shown in *table 2*.

***Table 2**: System functions and function indicators. Tabularized from Lamprinopoulou et al. (2014) and made specific for GF.*

Function	Function name	Indicators
1	Entrepreneurial activity and experimentation	Farmers experimenting with GF, farmers that have made GF an integral part of operations
2	Knowledge Development	Amount of research concerning GF published
3	Knowledge diffusion/exchange	Presence and quality of knowledge sharing networks
4	Funding	Government subsidies, business investment in GF, financing structures
5	Non-monetary resource mobilization	Physical resources mobilization (infrastructure, material) Human resources (skilled labor)
6	Market formation	Commercialization of products like GF seeds and products related to GF
7	Guidance of the search	Identifying problems, recognition of the potential for change and showing the direction of search for new GF technologies
8	Creation of legitimacy	Counteracting resistance to change and legitimization technologies related to GF

This function level perspective (assessing to which extent these functions are fulfilled by the system) will be combined with a structure level perspective (what actors and rules are responsible for function fulfillment) as suggested by Wieczorek & Hekkert (2012), clearly outlining the relationships between the functions and system structures as structures make functions meaningful. For example alteration of a structural element is always necessary for policies to enable or strengthen functions (Lamprinopoulou et al., 2014).

This type of framework is suited for the analysis of GF since it is designed to find system failures that are the barriers under research. While this type of analysis is designed to find failing elements in an IS, its results also highlights elements that are functioning well (Klerkx et al., 2010; Weber & Rohracher, 2012). These system merits will be outlined alongside its failures as the drivers for the innovation system of GF.

Using this AIS analysis as a methodological framework will provide insight in the drivers and barriers for GF implementation in the Dutch cultivated arable farming sector. From these insights, recommendations can be postulated to enhance its sustainability and biodiversity potential.

3. Methodological framework

3.1 Overview

The methodological framework for this research consists of 4 parts. First, the research scope will be elaborated on, explaining why the cultivated arable farming sector was chosen for this research and how this sub-sector is structured in relation to the wider Dutch agricultural complex. Secondly, the data collection process is elaborated on. Third, the research setup, incorporating the AIS analysis is outlined in a step-by-step approach. Last, the data analysis process in relation to AIS research is elaborated on.

3.2 Research scope delineation

This research focusses on soil sustainability in the Dutch cultivated arable farming sector. Here, an outline is made of the place of this sub-sector in the Dutch agricultural complex.

The Dutch agricultural complex can be divided up in 4 sub-sectors. These sectors encompass all activities that are related to growing crops, be it produce for human consumption or animal feed. The 4 sectors, according to CBS (2021):

1. **Grassland and animal feed crops**: growing crops as fresh feed for livestock or maintaining grassland.
2. **Cultivated arable farming land**: growing (annual) crops on open ground, mostly for processing and direct human consumption.
3. **Horticulture on open ground**: growing (perennial) crops on open ground, mostly for direct human consumption.
4. **Horticulture under glass**: horticultural practices that take place in greenhouses or tunnels, under cover of plastics or glass.

All 181.516.027 acres of Dutch cultivated land in 2020 can be divided into these sub-sectors. The largest sub-sector is grassland and animal feed crops, covering 118.445.836 acres (~65.3%), followed by cultivated arable farming land (52.689.519/~29.0%), horticulture on open ground (9.336.150/~5.1%) and horticulture under glass (1.044.522/~0,6%).

In theory, forms of GF can be applied in all of these sectors, but the main reason the research scope is defined to cultivated arable farming is that GF practice in line with the research definition demands rotation of crops with intercrops of GF. It is furthermore the second largest sub-sector, enhancing result implications.

The cultivated arable farming sub-sector is concerned with production of arable crops in open agricultural soil for direct human consumption as well as processing. The most common crops grown according to CBS (2020b) are:

1. **Potatoes** (direct consumption) - 12.3 million acres (~23,3%)
2. **Wheat** (processing) - 12.1 million acres (~23,0%)
3. **Sugar beets** (processing) - 7.9 million acres (15,0%)
4. **Starch potatoes** (processing) - 4.5 million acres (~8,5%)
5. **Unions** (direct consumption) - 2.9 million acres (~5,5%)

Together these five practices account for more than 75% of all sector activity by surface area, the other 25% is made up of a wide variety of vegetables, grains, beans, fruits and seeds (CBS, 2020b)

An important note when looking at this sub-sector is that due to its variety in crops, practices and techniques, all kinds of GF can technically be applied. That is to say that the farmer specifically makes room in his rotation plan.

3.3 Data collection

All research questions are answered using a combination of interviewing and literature review. Literature was used to put the interview data into perspective, to follow up on insights resulting from the interviews and to test statements made against available knowledge on the subject.

3.3.1 Literature review

For the first sub-question, the sustainability goals of current agricultural policy were assessed using government publications and data. These findings were then compared to the sustainability potential of GF as posed in 2.2. This comparison was subsequently incorporated in the structural analysis in the first step of the AIS analysis and used to guide the recommendations made in the final step of the AIS analysis.

For answering the remaining sub-questions, an initial scientific literature review was performed using a concept-centric approach as proposed by Levy & Ellis (2006). General search terms like ‘green manuring’ and ‘green fertilization’ in combination with ‘innovation system’ and ‘drivers’ and ‘barriers’ were used. The literature found was examined for further areas of inquiry. New insights were incorporated in new combined search terms. Additionally, forward reference searches from essential review literature like Haagsma et al. (2019) were used. This helped to shape the first contours of the AIS and identified the first relevant interviewees in their respective AIS domains.

The databases for peer-reviewed literature consulted included Google Scholar, Scopus and PubMed. The research repository of Wageningen University & Research as well as the Dutch

Central Bureau for Statistics (CBS) databank (StatLine) proved good sources of domestic agricultural literature and data. From the literature found, further forward reference- and author searches were performed to find additional relevant literature.

Grey literature was consulted when necessary or when peer-reviewed literature was absent. All relevant literature found was organized in a Zotero library and categorized by subject for easy access and re-readability.

After the initial literature review an interview guide was composed with the purpose of filling the gaps in literature pertaining to the system structure, the analysis of the 8 functions and their structural component influences.

3.3.2 Interviewing

Expert or key stakeholder interviews were an integral part of the research. Interviewing was done using a semi-structured approach. Semi-structured interviewing is done by asking open ended questions that give room for the interviewee to articulate his/her opinion and leaving room for follow-up questioning when interesting insights emerge (Woods, 2011).

Key stakeholders are those actors in the AIS that have experience with the use of GF, have researched GF or have a vested interest in GF methods or products. Suitable candidates for interviewing were identified by adapting criteria proposed by Lamprinopoulou et al. (2014) to the innovation system of GF. These criteria were relevant for identifying the right interviewees who are knowledgeable about GF and its position in the cultivated arable sub-sector. They allowed the researcher to select the right candidates that could provide data-dense interviews. This was essential as time and resources were limited. The relevant criteria identified were:

- Interviewee knowledge/insight in the Dutch AIS landscape and the place of GF therein;
- Interviewee influence/power within their organization and in the wider AIS landscape;
- The position of the interviewees organization in the AIS as recognized by other interviewees.

In order to fulfill the last criterium the first interviews participants were asked if they knew of potential other interviewees with specific knowledge on the subject in other domains. Furthermore, during the interviews, other possible participants were identified when an interviewee referred to them when addressing their own shortcoming in knowledge of a particular subject. In this way, potential participants were identified and contacted subsequently.

In order to form a more holistic view of AIS functioning at least one interviewee per AIS structural domain was interviewed except for the ‘funding’ domain. No interviewee specifically tied to this domain could be found using the three criteria as described above. In total 14 experts were interviewed over 13 interviews, the overview of participants and their domain of expertise is included in appendix A.

5 open ground farmers that implement GF in their crop rotation were interviewed. These farmers were selected on the fact that they had mixed operation with a rotation of crops that was similar to the description of cultivated arable farming provided in 3.2. All but one farmer cultivated

potatoes, sugar beets and grain crops in rotation over a larger acreage containing multiple plots with different crops annually.

All three researchers interviewed were recognized by interviewees form other domains as integral to the research efforts of the innovation system of GF as they had major influence on the research direction of GF in Dutch agriculture. All have multiple publications on either AIS analysis in the Dutch agricultural context or GF in the Dutch agricultural context.

All other interviewees were identified in the first interviews by their organizations importance in the AIS of GF, and their knowledge of GF as a practice.

As not all interviewees had a system wide overview, the line of questioning was adapted to the interviewee's area of expertise in the AIS. Additionally, in this manner data gaps could be purposefully filled by interviewing additional experts in the corresponding domain when insights required further elaboration. This was done on two occasions.

All interviews were conducted in Dutch as this was native language of the interviewees, allowing them to more readily express their opinion without occurrence of a language barrier. The transcription was also performed in Dutch as, upon review, transcript translation to English caused loss of nuance in statements. Therefore the translation step was made by the researcher when assessing the content of the data to avoid issues related to double translation when presenting results.

3.3.3 Informed consent and privacy

At the time this research was conducted, the COVID19 pandemic was ongoing. Due to the resulting restrictions in the Netherlands the interviews took place in a digital environment (MS Teams, Zoom, telephone). This allowed for recordings to be made of the interview, to be transcribed afterwards. All participants were asked for permission for the recording. All participants agreed. Participants' details have been anonymized, which allowed them to speak freely with the assurance that their statements would never be connected to them personally. For the use of direct quotes from the interview transcript additional consent was obtained at a later stage in the research. This resulted in the content of one of the quotes being adjusted as requested by the interviewee to ensure its representative accuracy for the context of the research. This was indicated in the result section by marking it as '(edited)'.

3.4 Agricultural Innovation System analysis

The complete AIS analysis performed consisted of four parts as depicted in *figure 2*. As mentioned before, the general structure of the analysis follows Lamprinopoulou et al. (2014). Lamprinopoulou et al. (2014) uses the structural framework as proposed by Ostrom (2009), which characterizes system actors in four broad categories: the research-, enterprise-, intermediary- and demand domains to make a structural overview of the AIS. The analysis performed here will incorporate the more detailed structural framework by Hekkert et al. (2011), which incorporates 8 domains for a more detailed structural overview of the AIS. This is necessary as the analysis performed here is on a sub-sectoral level, not on an inter-national level, requiring a higher resolution that incorporates individual businesses and organizations.

The functional analysis incorporated the functional-structural analysis as performed by Lamprinopoulou et al. (2014). To avoid repetition of overlapping results between the functional and functional-structural analysis, only the complete functional-structural analysis is presented in the results. In this analysis the eight functions of the AIS were assessed and the extent to which they are fulfilled was examined. These functions were then coupled to the actors responsible for their fulfillment or absence thereof. This coupled analysis shows an overview of the AIS and its performance or system drivers and barriers. Based on these drivers and barriers recommendations were given to alleviate system failure on a policy level.

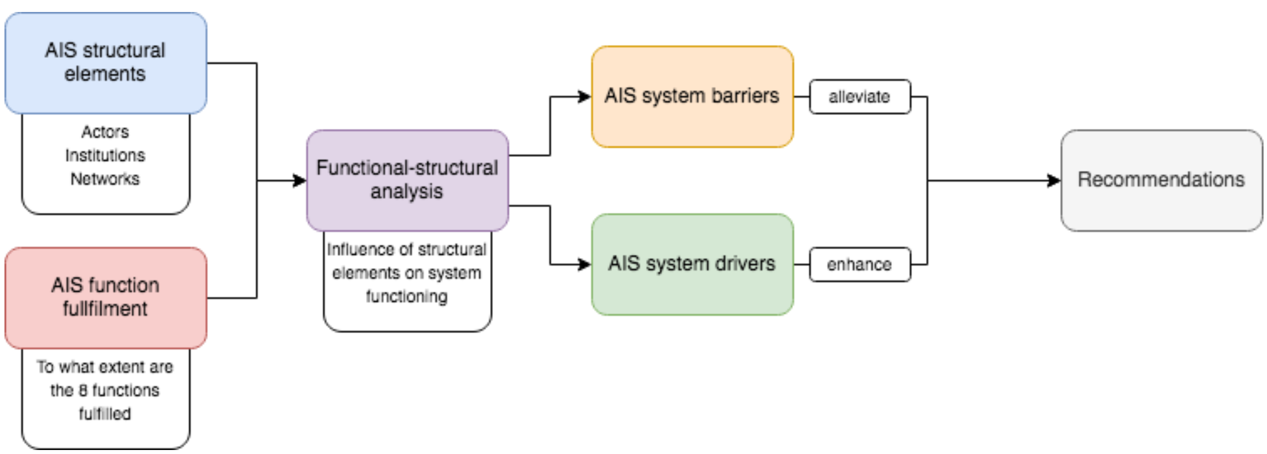

Figure 2: *Research overview. The result section will present the structural analysis, the functional-structural analysis and the resulting drivers and barriers. Resulting recommendations for alleviation of the barriers and enhancement of the drivers to improve system functioning will be given subsequently.*

3.4.1 Structural analysis

The general structure of the innovation system relative to the innovation was drawn, and an overview of the relevant factors pertaining to green fertilizers within the Dutch agricultural system in accordance with Hekkert et al. (2011) was created. This structural overview is made up of 3 building blocks. Actors are the first building block and influence the AIS through choices and actions. They generate, diffuse and utilize technologies. Examples of relevant actors are knowledge institutes, educational organizations, industry, market actors, government bodies and supportive organizations.

The second building block are institutions. The institutional structure can be defined as the humanly devised constraints that shape human interaction (Hekkert et al., 2011). These institutions come in two forms: hard and soft institutions. Hard institutions are the set laws and regulations, soft institutions are the so-called 'unspoken rules' that system actors adhere to. Assessing the hard institutions in the structural analysis yielded the answer to sub-question 1: *What are the policy related causes for green fertilization to not contribute within its theoretical potential to soil sustainability and biodiversity enhancement in the Dutch cultivated arable farming sector?*

The third building block is the central idea of the innovation system framework, namely; networks. An example of networks is the connections organizations and businesses make with each other in research projects. The last building block consists of technological factors. These are structures that consist of artifacts and the technological infrastructures in which they are integrated, either driving or constraining the activities of actors in the innovation system (Hekkert et al., 2011).

When the structure containing all three building blocks was constructed, sub-question 2 could be answered. *How is green fertilization currently embedded in the cultivated arable farming sector?*

The overview of the system structure was furthermore used to identify the experts to be consulted for the evaluation of system functions in the functional analysis. When analyzing and describing the system structure and its connections the overview served as a guide.

3.4.2 Functional analysis

The evaluation of the eight functions as depicted in *table 2* was done by asking analytical questions in semi structured interviews with stakeholders. Some of the functions can be quantitatively assessed to an extent, citing absolute amounts (ex. funding, number of research papers), some functions are more descriptive and require a qualitative evaluation to show how the system is performing. This analysis cannot be performed using solely quantitative data as quantification of some functions hasn't been performed yet or data is not readily available.

After analyzing the eight functions the outcome yields functions that are not functioning optimally, forming an obstacle to the adoption, development and diffusion of GF. These obstacles are analyzed and their causes disseminated.

3.4.3 Functional-structural analysis

The functional-structural analysis connects the functional performance of the system to the structural components responsible in accordance with the analysis of Lamprinopoulou et al. (2014). This is done by looking at the AIS structure and determining how each individual actor contributes to the eight system functions in *table 2* by asking:

Occurrence: Is the actor involved in this function? Is there an absence of an essential actor normally fulfilling this function?

Necessity: Is their involvement in the function necessary? To what extent?

Quality: how well does this actor fulfill the function?

Some of the indicators flowing from this coupled analysis can be quantitative and extracted from data and literature. Assessing whether an actor is involved in fulfilling a function can often be determined by looking at data around their contribution. Determining the necessity and quality of their contribution was done by assessing the opinion of the experts in relation to relevant literature. The three types of questions as outlined above were incorporated in interviews when data on the relationships between functional and structural elements was scarce, absent or required further elaboration.

The broader system functioning relates to how well coordinated, aligned and harmonized the functions and structural elements of the system are. This overview askes the essential questions: Does the system allow for transformational change to happen? And what are the largest drivers and barriers to GF within this system? The functional-structural analysis thereby answer sub-question 3: *What are the drivers and barriers to more sustainable green fertilization implementation within the Dutch cultivated arable farming sector?*

3.4.5 Recommendations

After finding the drivers and barriers to GF in the form of system failures and functioning and assessing total system functionality, an analysis was performed of the implication of these results. Policy recommendations were subsequently drawn, aimed at alleviating the interconnecting barriers. This will be done by first giving an overview of the interconnecting barriers that inhibit GF in reaching its sustainability potential in a problem nexus. This problem nexus visualizes the barriers and how they are causally connected. Policy-oriented recommendations were formulated whereby these problem nexuses can be solved using the drivers for GF implementation found in the functional-structural analysis.

This answers research question 4: *How can these drivers be enhanced and barriers be alleviated for green fertilization to contribute more to sustainability and biodiversity while safeguarding profitability for farmers?*

3.5 Qualitative data analysis

After the interviewing was concluded and interview transcription completed, emerging insights from individual interviews were coded using Nvivo 12 for qualitative data extraction. An emerging insight is a statement made by an interviewee that provides insight in system functioning or system structure. In qualitative data analysis, these insights are coded by assessing the content of the statement and assigning a label or code to the corresponding section of text (Akinyode & Khan, 2018).

The coding sequence performed was structured according to the AIS functional-structural analysis, connecting structural components to their functional context. For example, when talking about a certain actors occurrence, or lack thereof, the context could be connected to the structural component. This method of data collection allowed for quick overview of codes discussed across interviews on three different levels: function wide, functional-structural and structural-component.

To acquire an easy overview of the metadata, a tabularization of codes across interviews made as shown in *table 3.*

Table 3: *Tabularization of emerging insights. The x-axis represents the structural domains (see figure 2). The y-axis shows the 8 functions (see table 2).*

Actor domain/Function	F1: Entrepeneurial activity	F2: Knowledge development	F3: Knowledge diffusion	F3: Funding	F5: Non-monetary resource mobilisation	F6: Market formation	F7: Guidance of the search	F8: Creation of legitemacy
	Occurence?	Occurence?	Occurence?	...	...	...	...	...
Politics, policy and institutions	Necessity?	Necessity?	Necessity?	...	...	...	...	...
	Quality?	Quality?	Quality?	...	...	...	...	...
	Occurence?	Occurence?	...	...	...	...	...	...
Research	Necessity?	Necessity?	...	...	...	...	...	...
	Quality?	Quality?	...	...	...	...	...	...
	Occurence?	...	...	...	...	...	...	...
Education	Necessity?	...	...	...	...	...	...	...
	Quality?	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...
Supply	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...
Demand	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...
Investment	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...
Support organizations	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...

These codes were reviewed after aggregation within the data structure, as described below, to form themes. A theme is a series of codes that are identical or similar in content. An example of a theme is a shared opinion or view across interviews. When multiple interviewees agree on a certain theme, this strengthens the basis of the theme. Themes discussed across interviews were assessed for content and put into context using available literature to form a more comprehensive view of system functioning.

Novel, emerging insights into system dynamics as well as networks proposed by the interviewees that were discussed and were not categorizable under the three main components were separately coded in an 'Outside data structure' section in Nvivo. The final data structure is shown in *figure 3.*

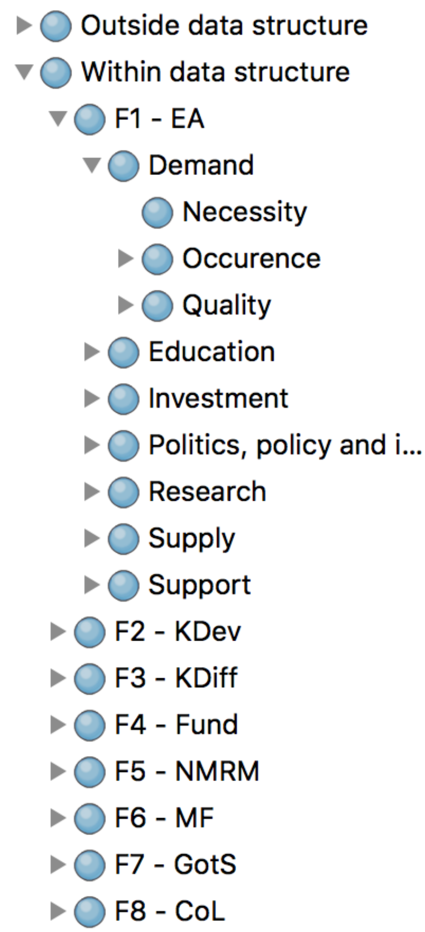

Figure 3: *Data structure of nodes in Nvivo 12 for Mac OS. The first indentation in the data structure shows an overview of the functions (F1 to F8). The second indentation denotes the structural elements of the actors present in fulfilling the function. The third indentation denotes the three indicators of occurrence, necessity and quality. The 'outside data structure' node encompassed information about interviewees background, involvement in the AIS and elements like market volume quantification that could not be incorporated in the data structure.*

4. Results

4.1 Structural analysis

4.1.1 Overview

The structure of the AIS, emerging from interview insights and literature review is depicted in *figure 4*. The actors and their networks as well as institutions are discussed below per structural domain. This overview of the structure of the AIS details how GF is embedded in the cultivated arable farming sector answering research question 2: *How is green fertilization currently embedded in the cultivated arable farming sector?*

The overview of the institutional domain of the AIS answers the first research question: *What are the policy related causes for green fertilization to not contribute within its theoretical potential to soil sustainability and biodiversity enhancement in the Dutch cultivated arable farming sector?*

Direct quotes from the interviews are provided where relevant. They are highlighted in brackets.

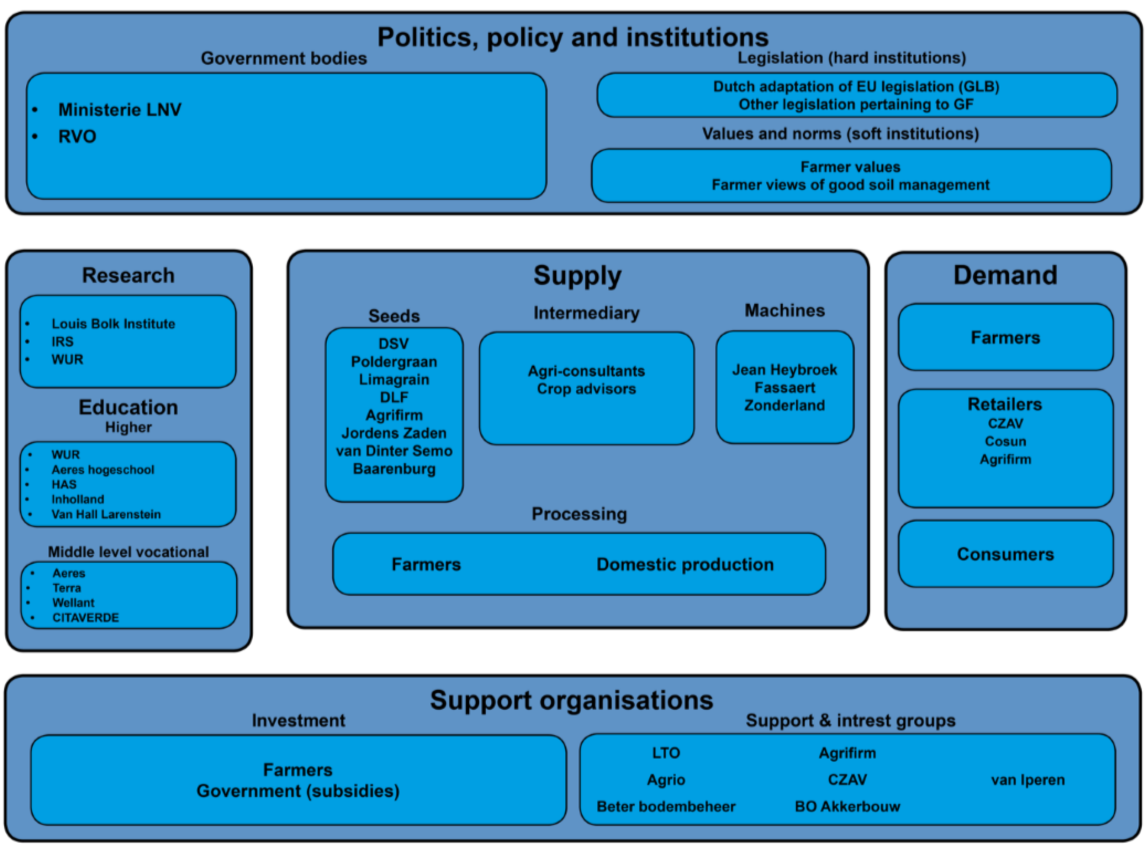

Figure 4: *visual overview of AIS actors and institutions.*

4.1.2 Politics, policy and institutions

The government body responsible for agricultural legislation in the Netherlands is the ministry of Agriculture, Nature and Food-quality. The ministry adapts the European Common Agricultural Policy into the Dutch Common Agricultural Policy. Currently the policy follows the direction set out in 2013, has undergone multiple review processes and is steered towards a new direction, to be implemented in phases towards 2023 (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2021).

The RVO is the Dutch National Service for Entrepreneurs. Farmers can contact them with questions in the field of sustainable, agricultural, innovative and international entrepreneurship. The RVO's main purpose is to implement regulations and to ensure that laws and regulations are complied with (RVO, 2021).

There are three pieces of legislation that currently pertain to GF implementation in the Netherlands. They are outlined below.

Direct payments from the Common Agricultural Policy

The Common Agricultural Policy contributes to farmers operations by giving direct payments coming from the European Common Agricultural Policy. Compliance with the mandatory requirements is nearly ubiquitous as farmers depend on these direct payments for viability of their operations (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020). Sector-wide, farmers rely on these payments for 28% of total farm income. Mixed operations with multiple cash crops, exemplary to the cultivated arable farming sector, rely for an average of 50% on direct payments (Berkhout et al., 2019). Here, we outline the current system of direct payments as they are important to the innovation system of GF.

The current architecture of sustainability requirements for farmers in order to receive the direct payments are outlined in *figure 5*.

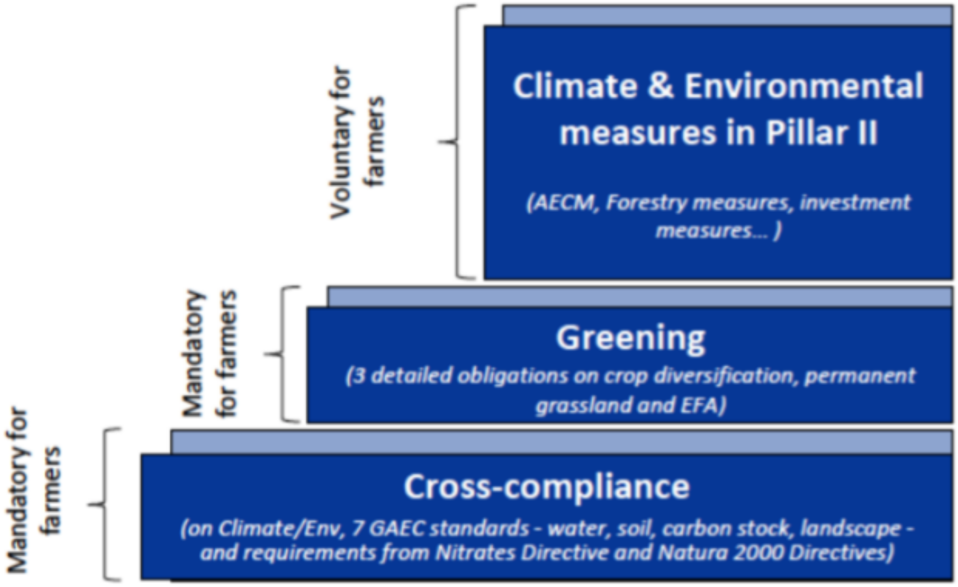

Figure 5: *The current Common Agricultural Policy architecture on sustainability measures. (Erisman & van Doorn, 2018, p. 9)*

Under the current legislative architecture farmers receive a compensation in the form of a base direct payment of €260,- per hectare and an additional €115,- if the farmer adheres to the cross-compliance and greening requirements (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020). The farmer must adhere to the greening requirements in order to receive both direct payments, failing the greening requirements upon inspection can be penalized by losing both direct payments. The Dutch National Service for Entrepreneurs monitors what is grown on each holding, and cross-references this with the crop rotation plan which farmers submit yearly (RVO, 2020a). The part of these greening requirements that is most relevant to the innovation system of GF is the requirement for an 'Ecological Focus area' for farmers with more than 15 hectares of land under management (RVO, 2020b), which is formulated in European regulations as such:

Ecological focus areas 'should be established, in particular, in order to safeguard and improve biodiversity on farms. The Ecological Focus area should therefore consist of areas directly affecting biodiversity such as land lying fallow, landscape features, terraces, buffer strips, afforested areas and agro-forestry areas, or indirectly affecting biodiversity through a reduced use of inputs on the farm, such as areas covered by catch crops and winter green cover' (Regulation 1307/2013, EC, 2013).

Farmers have to implement this Ecological Focus Area on 5% of their total acreage annually. For fulfilling the Ecological Focus area requirement farmers are allowed to use GF catch crops (RVO, 2020b). There are 3 categories of approved GF catch crops for implementation in an Ecological Focus area:

1. Cat 1: general catch crop
2. Cat 2: catch crop for abatement of plant parasitic eel infection
3. Cat 3: catch crop of grass or legume sown under main crop

All three categories have embedded rules for application that dictate the ultimate sowing date, sowing density, mix of species to be used and minimum growing time of the catch crop (RVO, 2020a; Haagsma et al., 2019). All catch crops categories have the same weighing factor of 0.3, indicating that 1 hectare of GF catch crops counts for 0,3 hectares of Ecological Focus Area fulfillment (Haagsma et al., 2019). This means that a farmer that has 15 acres of land in total, must sow 2.5 acres of GF catch crops annually to meet the greening requirements if he chooses the GF option.

Cat 1 and 2 catch crops need to be sown as an approved mixture of different crops in order to promote biodiversity. A related legislative issue pointed out by two of the 'research' domain interviewees is that, while this is done to increase biodiversity efficacy of the rotation. The legislation states that a mixture must contain at least 3% of each chosen crop species from the approved list (Haagsma et al., 2019). While the intended goal of this clause is that it gives farmers the freedom to implement complex mixtures that help increase biodiversity in the agricultural landscape and enhance the benefits through the four functions (see 2.2), it more often results in mixtures of 97% of a single crop, with the remaining 3% being another. The effects of a complex GF mixture on soil, productivity and biodiversity are harder to research or experience for a farmer than those of a more straightforward two-component mixture. The list of variables that could be the cause for improvement or failure grows larger with each added component, reducing the overview and control the farmer has over the result. It is therefore not surprising that two-component mixtures are popular (CropSolutions, 2019). This legislative requirement has therefore failed in reaching its intended goal.

The costs associated with the implementation of GF was perceived as low among the interviewed farmers, this is in line with findings in domestic literature (Erisman & van Doorn, 2018; Bouma et al., 2019) The fact that GF implementation fits in the current agricultural infrastructure was also given as the main reason by the interviewees from the 'politics, policy and institutions' domain for why farmers overwhelmingly choose GF over other ways of fulfilling Ecological Focus area requirements.

> *'And because it (GF) fits in well with current agricultural practices, as mentioned before, most - by far the most farmers opt for it. All other measures from which you can choose within the Ecological Focus Area do not come into consideration at all.'* - Team coordinator ministry of Agriculture, Nature and Food-quality 1

Elbersen & Lazebnik (2020) evaluated the efficacy of Ecological Focus areas in the Netherlands in reaching the goal of improving biodiversity on farms as per the goal set out in Regulation 1307/2013 described above. They specifically commented on the wide adoption and subsequent effect on the contribution of GF in reaching biodiversity goals set by legislation:

The Ecological Focus acreage can potentially make a good contribution to nature and biodiversity by increasing the semi-natural acreage on agricultural land. This was also the original intention of the measure. Most of the farmers in the Netherlands have chosen to fill in Ecological Focus areas with production-related elements such as catch crops and nitrogen-fixing crops. As a result, they cover an average of 99% of the Ecological Focus acreage over the investigated period from 2015 to 2019. These crops can make a positive contribution to the soil, although it remains to be investigated whether this contribution is optimal, given the short time that are on the land; however, they contribute almost nothing to the improvement of nature and biodiversity. (Elbersen & Lazebink, 2020, p. 29-30)

The indicators used to come to this conclusion are based on the evaluative framework posed by van Doorn (2015), of which the only biodiversity related indicator was the development of farmland bird populations. Since 2000 the amount of breeding birds in the Dutch agricultural landscape has declined with 35%. Since 2013 the decline has been less rapid but there are not yet signs of an upward trend (Berkhout et al., 2019).

Potatoes and maize on sand or löss soils

The second important piece of legislation tied to the use of GF is related to growing maize for animal fodder (called silage maize) and potatoes on sand or löss soils. From 2018 forward farmers that are growing silage maize or potatoes on these types of soil are obligated to use a GF catch crop (RVO, 2020a). The growing of both silage maize and potatoes is done using an excess of fertilization, a lot of which remains in the soil after harvest when compared to other cash crops (Haagsma et al., 2019). If the land is left fallow after harvest, much of this fertilizer is run-off in bodies of water after rain due to the porous nature of the soil. This legislation was added to the nitrate-measure action program to abate this runoff (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020).

GF crops planted to fulfill the silage maize and potato catch crop obligation do not count towards the fulfillment of the Ecological Focus area (RVO, 2020a).

GF to create additional nitrogen space

The third piece of legislation is also related to use of fertilizer. Open ground farmers in the Netherlands must adhere to strict legislation on maximum allowable manuring and fertilizing. These obligations stem from the Nitrate-Measure Action Program (Actieprogramma Nitraatrichtlijn) which is the result of the European commitment to keep surface water nitrate concentrations below 50 mg/l, and is specifically focused on the abatement of nitrogen runoff (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020).

The program and the subsequent legislation determine the maximum allowable nitrogen gift for each type of crop on different types of soil (RVO, 2021b). A farmer therefore has a maximum allowable fertilization capacity, called the ‘nitrogen space’. As a result of this legislation farmers have to calculate how much they can fertilize and when. Adding fertilization in excess of this nitrogen space would however still increase the yield of the farmers cash crops, therefore farmers are looking for ways to either increase their nitrogen space, or to utilize the space they have to its maximum efficiency.

GF crops, when sown immediately after the main crop and left on the field for a minimum of 10 weeks create an additional fertilization opportunity for the farmer as they are allowed to be fertilized outside of the main nitrogen space (RVO, 2021b). Sowing a GF crop therefore has the added benefit of increasing the total fertilization capacity of the farmers soil, with the added benefits of the GF crop's four functions fulfillment as described in 2.2. This dynamic makes implementation of GF crops even more attractive to farmers.

Conclusion sub-question 1

As the legislative structure around GF is complex and interconnecting, an overview is provided here. This overview will answer the first research question: *What are the policy related causes for green fertilization to not contribute within its theoretical potential to soil sustainability and biodiversity enhancement in the Dutch cultivated arable farming sector?*

Farmers are heavily dependent on payments coming from the European Common Agricultural Policy, and will therefore adhere to the legislation bound to the requirements for these payments. There are three interconnection pieces of legislation that are important to the innovation system of GF. The most important legislation is the greening requirement of the Ecological Focus Area.

The Ecological Focus Area legislation was instated to promote biodiversity in the agricultural landscape as well as improve soil sustainability (Regulation 1307/2013, EC, 2013; Elbersen & Lazebink, 2020). GF in one of the ways farmers can adhere to the requirements for the Ecological Focus Area and most opt in for this option as it fits well within their operational structure, is considered cheap to implement and adds to the farmers nitrogen space (Erisman & van Doorn, 2018; Bouma et al., 2019). This dynamic has caused massive uptake of GF within the cultivated arable farming sector. Currently, 96% of all open ground farmers implement GF within their crop rotation (Bouma et al., 2019). However, due to the way the legislation is structured, the GF crops contribute very little to biodiversity increase and soil sustainability (Elbersen & Lazebink, 2020). Furthermore, the legislation stipulates that only 5% (excluding weighing factor) of the farmers total acreage has to undergo a rotation of GF each year in order to adhere to the legislation. Outside of the obligations tied to Ecological Focus Areas and the production of silage maize and potatoes there is room for broader implementation GF. In practice, farmers that fall under one, or both requirements do not practice other forms of GF (Elbersen & Lazebnik, 2020). There are no government incentives for broader application.

There are plenty of legislative stimulants for implementing GF in the sub-sector, but none are currently tied to sustainability performance of the GF rotation performed, but rather circumstantial factors like time on the field, mandatory species to be used and ultimate sowing date. The added regulation around the use of mixtures, which is aimed at improving agricultural biodiversity, fails at reaching its intended goal. Furthermore, the sole indicator used to evaluate the contribution of GF to biodiversity (development of farmland bird populations) can be deemed insufficient as it does not describe the full complexity of biodiversity in the agricultural landscape. It does not account for the effects GF implementation has on belowground biodiversity as described in 2.2.

In short, the answer to sub-question 1 as mentioned above is:

Contribution to biodiversity and sustainability through the four functions detailed in 2.2 is currently not incentivized by the legislation most important to the uptake of GF. A combination of the use of insufficient evaluative indicators, poor structuring of the legislation, and a misalignment of the requirements for fulfillment embedded in the legislation when compared with its intended goals are the causes of current GF practices to not contribute within their theoretical potential to soil sustainability and biodiversity in the Dutch cultivated arable farming sector.

4.1.3 Research and education

The Netherlands has several Universities researching GF as well as several research institutes that are conducting research pertaining to the development of GF. Wageningen University is recognized by all interviewees upon inquiry as the main source of agricultural research in the Netherlands. They have published a wide variety of research pertaining to GF and is actively participating in several studies and cooperations on the subject. Wageningen University is also the main institute evaluating the efficacy agricultural legislation (Berkhout et al., 2021)

The IRS, the Dutch institute related to research pertaining to the growing of sugar beets has conducted research into GF host plant suitability and composed an overview of which GF crop to use for which pest problem in the open ground cultivation of sugar beets (IRS, 2020).

The Louis Bolk Institute has several publications on the role of GF in making agriculture more sustainable, and its role in carbon sequestration and soil management as mentioned above (van der Burgt & Bus, 2012; van der Burg & Timmermans, 2020). The Louis Bolk institute is also involved in the evaluation of agricultural legislation and takes part in several multidisciplinary research initiatives related to sustainability in agriculture.

According to Mulder & Kupper (2006) the structure of agricultural education in the Netherlands consists of two levels, vocational education and academic education. Vocational education is split in middle level vocational education and higher-level vocational education, while the academic education is provided in universities. Both vocational education levels focus more on practical education in the agricultural sector in comparison to universities and are attended by future practicing professionals like farmers and agri-consultants. Academic agricultural education is more geared towards agricultural research. There are furthermore, so-called course educations available which are short courses for adult education provided by private training bodies related to state-financed agricultural education institutions.

The agricultural educational organizations that have been identified are presented in *figure 4*.

4.1.4 Supply and demand

The ‘demand’ domain of the AIS consists of the farmers implementing GF. They are the consumers of GF seeds, knowledge and machinery.

The ‘supply’ domain of the AIS consists of agricultural businesses and cooperations selling supplies needed for the implementation of GF in agricultural practice. Most of these organizations are selling seeds, breeding varieties of GF crops or both. The interviewee from the ‘supply’ domain pointed to Limagrain and DLF as being market leaders in the sale of GF seeds, DSV was identified as market leader in GF mixtures and 4th in market capacity.

The total known market volume, according to internally published figures shared by the interviewee from the ‘demand’ domain was 4.8 million kilograms of GF seeds in 2019. The total acreage that can be covered by this amount is hard to determine since different crops require different sowing densities. Typical sowing densities vary between 35-70 kilograms per hectare, which would mean that the total market volume represents approximately 65.000 to 135.000 hectares of GF crops. Japanese oats were the largest crop with 950.000 kg, followed by Italian ryegrass with 933.000 kg and English ryegrass with 535.000 kg. Yellow mustard and fodder radish together covered 967.000 kg and the total amount of mixtures amounted to 555.000 kg. Not all suppliers are represented in these statistics, but the majority are.

This would imply that less than 10% of Dutch agricultural land undergoes a rotation with GF each year, given that the total amount of agricultural land in the Netherlands as described in 3.2 is 1.8 million hectares. If all GF implementation took place in the cultivated arable farming sub-sector, this would be a maximum of ~25% of the sub-sector, but no data could be found on the proportional spread of implementation across sub-sectors. As regulation around GF is mostly aimed at open ground sectors an assumption can be made that proportionally more GF implementation takes place in the cultivated arable farming sector than in for instance horticultural practice. Using this assumption, based on these figures, a maximum of 10% to 25% of the open ground cultivation sub-sector will be covered with a rotation of GF each year.

The ‘supply’ and ‘demand’ side of the AIS are connected by a network of intermediaries that are often linked to companies operating in the ‘supply domain’, called crop advisors (teeltadviseurs). Farmers rely on these advisors for information about things like agricultural techniques, innovations, machinery and regulation applicable to their operation. According to the interview data, these advisors exist in different capacities and have different specialties. Those important to the AIS of GF are mainly related to the companies that farmers buy their seeds from. They help farmers navigate GF legislation and give advice on which GF crop or mix of crops could be suited for the farmers operation. One of the interviewed farmers relied solely on the advice given by such an advisor when selecting his GF crops, the others combined the advice with their own research and experience. Only one farmer selected his own GF crops without intervention of an advisor.

4.1.5 Investment and support

The 'investment' domain around GF is virtually nonexistent. All farmers interviewed paid for the necessities to facilitate growing GF themselves. Only one farmer mentioned applying for, an receiving a POP3 subsidy years ago in order to purchase the sowing machine he used for sowing GF seeds as well as his winter grain. None of the farmers have a financing structure specifically for GF implementation, the cost is added to the cost of operation. The absence of GF investment options or organizations could be explained by the fact that this cost seems to be perceived as low, and GF can be performed using conventional machines owned by most open ground farmers. Sowing a GF crop seems to not incur costs that are high enough to warrant a complex financing structure.

'A green manure crop is also just a crop, which does not require much extra special mechanization. You can just use something that is already in the shed.' - Open ground farmer 4

As of now, the financial structures bound to GF are focused around the direct payments coupled to the greening requirements in the Common Agricultural Policy as discussed in 4.1.2.

There are several support organizations that influence the AIS of GF, the largest support organization is BO Akkerbouw. This is the branche organization for cultivated arable farming in the Netherlands. Their goals is to serve as the central platform and knowledge center for the sub-sector and help solve collective issues for farmers. They are the larger umbrella under which other AIS support actors (Agrifirm, LTO, CZAV, Cosun, van Iperen and Plantum) operate. BO Akkerbouw serves as a roundtable and coordination network for these organizations in cultivated arable farming (BO Akkerbouw, 2021).

LTO is the advocacy organization for Dutch agricultural entrepreneurs in all four sectors outlined in 3.2. They represent the interests of farmers in the cultivated arable sub-sector in policy establishment (LTO Nederland, 2019).

Agrio and van Iperen are commercial organizations that serve as knowledge sharing hubs which provide mainly consultancy and farmer commercial support. They are advisory organizations that help farmers produce better and more crops and help navigate changing legislation and other issues (van Iperen, 2021; Agrio, 2021). Agrifirm, CZAV and Cosun are cooperations that have a hybrid function. They buy produce from farmers to retail on the market and provide services like knowledge distribution and consultancy like Agrio and van Iperen (de Jong & Griffioen, 2021).

Beter Bodembeheer is an organization that coordinates research initiatives on agricultural soil. They bundle and publish knowledge and have an active research cooperation on the effects of GF on soil microbe status (Beter Bodembeheer, 2021).

4.1.6 Cross-domain and intermediaries

There are several types of intermediaries active in the system. The first type, as described before connects the 'supply' and 'demand' side of the AIS.

Another cross-domain cooperation that is often mentioned is the public-private cooperation (publiek-private samenwerking) (PPS). This cooperation is part of a state program to incentivize practical research in, among others, the agricultural sector (RVO, 2021d). It combines public and private funds to conduct research that is expensive or complicated in its execution and requires a stable financing structure for its duration. The government wants to incentivize research that helps sector economic growth, the businesses get the opportunity to co-finance scientific research that benefits them, and the farmers can be part of the forefront of solutions for agricultural problems.

The PPS that is currently researching GF (PPS groenbemesters) is led by a team of researchers from Wageningen University and research and part of TopSector research Agri and Food, aiming to improve the international competitive position of the Dutch agricultural sector (TopSector Agrifood, 2020). The PPS is subdivided in two PPS projects, coded AF 18085 & TU18150. Its combined goal is researching the potential of GF in influencing the composition of soil microbial communities and disease suppression in open ground cultivation. The PPS was started in 2019 and has recently been extended to 2023. In its current form it consists of 4 seed companies (DSV, Jordens Zaden, van Dinter Semo and Baarenburg), three agricultural cooperation's (BO akkerbouw, van Iperen and TCO), researchers from Wageningen University and research and participating farmers.

The cost of the PPS is split between the participating companies and the government through subsidies. The contribution from the companies is split into two segments, half (a quarter of total funding) consists of research done by the company itself and the other half is direct funding to research in the PPS. For its own research the companies use their own funds and facilities.

4.1.7 Conclusions structural analysis

The structural analysis yielded the answer to sub-question 1 as described in 4.1.2. It furthermore showed how GF implementation is embedded in the cultivated arable farming sector answering sub-question 2: *How is green fertilization currently embedded in the cultivated arable farming sector?*

The main findings suggest that GF as an agricultural practice is firmly embedded in the sub-sector. The legislation around GF caused massive uptake of the practice but is found lacking in reaching its intended goals of contributing to biodiversity- and soil sustainability increase due to a misalignment of the requirements and the result these requirements elicit on the chosen evaluative indicators. The Netherlands has an established agricultural knowledge network in which GF is researched by different research institutes and universities. It has several levels of agricultural education that could facilitate GF knowledge diffusion. The market structure around GF is found to be relatively straightforward, with the farmers comprising the extent of the demand for GF seeds and supplies, and a combination of agricultural businesses and cooperations selling these seeds and supplies comprising the supply-side. There is no investment domain focused specifically on GF, this is explained by the cost for implementation being low and being paid out-of-pocket by the farmer. There are several support organizations identified to the innovation system of GF that advocate for- and consult farmers, aid knowledge diffusion and incentivize and bundle research.

These findings will be used in the functional-structural analysis to assess the drivers and barriers to system functioning when put into context with the 8 functions from table 2.
They will furthermore act as an established overview of the AIS of GF for further reference.

4.2 Functional-structural analysis

4.2.1 Overview

The structure of the AIS as presented above is combined here with the functional analysis using data from the interviews. The functional analysis evaluates to what extent the 8 functions from *table 2* are fulfilled. These functions, when fulfilled optimally cause the AIS to function optimally. As this is not the case, their analysis yielded the barriers we wished to assess; aspects of functions that did function well yielded the drivers we wished to assess. The analysis of the links between the structural elements and the found drivers and barriers were then put into context using available literature.

This overview will answer sub-question 3: *What are the drivers and barriers to more sustainable green fertilization implementation within the Dutch cultivated arable farming sector?*

The data matrix giving an overview of the metadata of emerging insights per functional-structural element of the analysis is enclosed in appendix B and will be referenced throughout the results. For each part of the functional-structural analysis, first an overview of the metadata is given to show which connections between functional and structural elements were most prominently discussed in the interviews. Direct quotes are provided throughout the results where relevant. They are highlighted in brackets. After each section, a short summary of the findings is provided.

4.2.2 Function 1: Entrepreneurial activity and experimentation

The data matrix in appendix B shows that there is a high concentration of themes discussed around two domains: 'demand' and 'politics, policy and institutions'. The concentration around the 'demand' domain is the result of farmers own initiatives in implementing and experimenting with GF in their operation. The concentration around 'politics, policy and institutions' consists largely of legislation that interviewees mentioned and their effects on entrepreneurial activity and experimentation.

The total amount of entrepreneurial activity and experimentation with GF is perceived differently by the interviewees. Three farmers viewed the implementation of GF crops in a rotation as commonplace; one thought it was gaining traction only recently. The interviewee from the demand domain divulged that in some places it is more commonplace than others.

Interviewed farmers who had started implementing GF in their operation experimented with different forms in order to see what fits best for their particular situation. All but one farmer interviewed has experimented with different forms, although most seem to eventually settle, for the most part, on a certain form that works for their operation after a while, reducing the amount of experimentation. Additionally, three farmers indicated that experimenting with GF crops should not be too costly for them and that the benefits should mirror those costs.

‘*To put it bluntly in a very simple farmer's-practical way: such an experiment should simply not cost too much, and I have to see a certain benefit or do it out of a personal interest.’* - Open ground farmer 3

These findings are supported by literature (Westerink et al., 2018; Erisman & Verhoeven, 2019; Bouma, 2020). Farmers are viewed as having a hard-working mindset and they maximize the utilization of available infrastructural elements in their operations for meeting (sustainability) requirements posed in legislation (Karel, 2020). However, most open ground farmers (~65%) do not go beyond what is required by law to meet requirements (Erisman & Verhoeven, 2019). They are prone to experiment with different tools and techniques as long as they are reasonably readily available and fit within their existing operational structure (Westerink et al., 2018; Karel, 2020).

All but one of the farmers interviewed owned the large majority of their land, some rented a small percentage in order to increase room for a wider rotation of crops or for extra revenue. The LTO board member interviewed pointed out that farmers who own their land are more inclined to take greater care of soil quality, as there are invested in the long-term potential of this soil to produce cash crops. Landowners are more likely to implement techniques like GF as they see it as a long-term investment in their soil.

‘Yes and then you are on leased land. I don't know how you handle a rented house, or an average person handles a rented house compared to a home they own. And farmers, they are also just people, they do the same with the soil.’ - LTO board member

These claims are supported by Middendorp (2017), who found that farmers who own their land, either through inheritance or other forms of acquisition, are more likely to implement sustainability interventions that yield benefits over the longer term. Owning land was not, however, a requisite. Some farmers who exclusively rented land over a longer period were also interested in sustainability interventions. In the cultivated arable sub-sector, the last complete dataset on land ownership stems from 2017. It details that 25.021.400 acres out of the then total of 50.915.000 acres was owned and used by farmers (CBS, 2017; CBS, 2021). At the time there was a slight upward trend in farmer land ownership nationwide. Knowing that the mobility (relation between sale and purchase of land) of agricultural soil has not significantly changed in the period 2012-2021 we can assume that still approximately 50% of agricultural land in the sub-sector is owned by farmers (Silvis, 2021). At the moment, the average prices for agricultural land are at an all-time high (€67.400/hectare), further increasing the added value of productivity maintenance (Cotteleer et al., 2007; Silvis, 2021). The actual value of agricultural land is heavily intertwined with the quality of the soil and its subsequent capacity to produce healthy and abundant crops (Cotteleer et al., 2007). This entire dynamic is considered a driver for AIS functioning and a driver for farmers to implement more sustainable forms of GF in their operations.

In conclusion, overall good farmer entrepreneurial capacities, in combination with the finding that GF as a sustainability innovation can be implemented well within current cultivated arable farming practices can be viewed as a strong driver for AIS functioning. Farmers who own land or rent it over a longer period of time are more likely to invest in the sustainability of their soil, possibly further enhancing this driving effect. As approximately 50% of sub-sector land is under ownership and the price for agricultural land is at an all-time high we presume that this effect is significant. As analysis of function 1 revealed no clear barriers but yielded several drivers or potential drivers, its fulfillment is considered here to be an overall driver of AIS functioning.

4.2.3 Function 2: Knowledge development

The experts from the research domain who were interviewed all pointed out that the Netherlands has large, established networks around agricultural knowledge development. GF is researched in these same networks. The government acts as a coordinator of these networks. These networks combine private sector and government funding in order to research relevant agricultural gaps in knowledge, the PPS being the most prominent example of such a network found.

One of these interviewees pointed out that as a result of this the research of GF has always been splintered as it is dependent, in part, on funding from the private sector and since GF crops do not produce direct profit, motivation could be lacking to invest in research. Several farmers who implement GF acknowledge this notion and mention it, however, as a driver for experimentation with GF in their own business.

> *You can experiment well with it (GF) because if you have a cash crop and it is not going so well, it immediately goes at the expense of your income. But with a GF crop it ... does not have to yield anything.* - Open ground farmer 1

> *‘I can remember something being wrong with a (GF) mix because a certain part did not grow, but that wasn’t such a disaster. No, I have had two (similar) instances with the emergence of one of the regular crops. That is purely about the hard euros in the end, of course*.’ - Open ground farmer 3

This could indicate that fundamental scientific experimentation with GF, which is costly, could suffer from this research fragmentation, but farm-level experimentation could benefit from the fact that the farmer does not expect GF to return immediate profit. Farmers could be more inclined to take risks and experiment with several types of GF because it will not directly financially affect them if there is a cultivation problem. They view it as a bonus if it yields benefits instead.

Farm level experimentation is important for the integration of innovations in an agricultural system as farmers themselves use the available knowledge and implement it in the best possible way for their specific situation regarding farm circumstances like soil and climate (Kummer et al., 2017; Šūmane et al., 2018). This advances innovations, improves the resilience of farmers operations in changing circumstances and can even lead to new innovations within the same system, functioning as a driver to AIS functioning (Kummer et al., 2017) However, the importance of fundamental research for system functioning cannot be understated. It provides the bases for the information farmers use for the farm level experimentation in upstream media like the trade magazines and improves knowledge development system wide (Kummer et al., 2017; Fears & Canales, 2021).

The ‘research’ domain contributes to the development of GF through research and collaboration with public and private parties like the seed suppliers. Throughout the interviews the University of Wageningen was identified as a prominent source of knowledge production about GF. A team at Wageningen University and research has produced a practical guide book on GF implementation, gathering all the available knowledge on GF in the Dutch setting (Haagsma et al., 2019).

Two of the ‘research’ domain interviewees noted the problem of individual research initiatives connectivity. As part of cooperation's and government initiatives, research is performed for a set period of time into a certain subject. When the project ends, the government or cooperative funding stops and focus is shifted to the next subject. Aggregating the results from these initiatives, maintaining databases and making results accessible for those who could benefit from them is not always incorporated in these projects or initiatives.

‘Every project has a database, the EU, they absolutely love databases of databases and overviews of overviews. From their EIP, European Innovation center, you have a project called Liason and it tries for the hundredth time to bring all those experiences together. ... So I don't see them all as very functional. Wat matters is being able to find them.’ - Researcher WUR 2

This dynamic could explain the notion two of the farmers had that very little information was available about GF crops and their effects on the soil. This highlights the importance of accessible review initiatives like the publication of the GF handbook in Haagsma et al., 2019.

Conducting fundamental research into the harder-to-quantify aspects (white spots) of GF implementation, like alleviation of soil borne pathogens and nematodes as well as the effect on microbial communities in the soil is difficult and requires high control of a wide variety of variables.

"Whether you can fight pathogens with it is much more complicated to investigate, because you need field tests that contain relevant pathogens. This concerns pathogenic fungi and plant-parasitic nematodes. This is complex because such pathogens are often not homogeneously distributed in a field. Or they are so strong that the crop becomes sick and you cannot determine yield differences. Or they are present in low quantities and then it is difficult to measure them. So you have to think carefully beforehand about how you want to conduct such tests.'' - Coordinator GF research group (edited)

This type of research is however, essential to discovering the full potential of GF implementation in agriculture.

The main theme emerging from the data around the ‘demand’ domain is that farmers often develop knowledge around the implementation of GF themselves, through experimentation and experience, and in some cases is passed on along generations of farmers.

‘The real innovation really lies with the farmer. Not with the arbitrator (intermediary) and not with the civil servant. So talk to people and go and see why others do things differently’ - LTO board member

The ‘supply’ domain mainly contributes to GF knowledge development by breeding specific strains of GF crops, researching the properties and applicability of their commercial GF mixtures, by joining in these cooperations and by setting up field tests with farmers.

In conclusion, the Netherlands has a large, network around agricultural knowledge development in which GF is researched. GF research and the databases containing data on the subject are however splintered and lack central coordination. As GF does not return immediate profit, financial incentives for fundamental research are often lacking. This notion is however a driver for farm level experimentation; farmers often develop knowledge on GF implementation by themselves. Research cooperatives, combining public and private funds make room for more difficult research into the harder-to-research ‘white spots’ of GF implementation. Overall, the analysis of function 2 yielded more barriers than drivers. As a result, the fulfillment of the function is considered to have an inhibiting effect on wider system functioning. The main reasons for this are that fundamental research is lacking, fragmented and does not reach the farmer. This significantly hampers function fulfillment.

4.2.4 Function 3: Knowledge diffusion/exchange

The ‘diffusion of knowledge’ shows similarities with the ‘knowledge creation’ function when looking at the spread of discussed themes in appendix B. Diffusion of knowledge shows overlap in central roles for system domain actors, with a higher concentration of themes around the ‘education’ and ‘demand’ domain.

A central role in the fulfillment of this function is centered around the farmers themselves. In 7 of the 12 interviews the importance of inter-farmer knowledge exchange is discussed. The findings suggest that farmers learn about GF and other techniques first and foremost by learning from other farmers in their geographical neighborhood or from farmers with similar main cash crops. This knowledge exchange can take place in the form of farmers visiting each other and exchanging information, to a more coordinated form of study groups of farmers with a specific goal. In some cases these study groups are guided by a crop advisor or research intermediary.

'If the neighbor suddenly has a completely new GF crop then you are talking about it, we are curious in that way among ourselves. And if he gets very good results from that, then I want to know.' - Open ground farmer 3

These findings are supported by domestic as well as foreign literature (Franz et al., 2010; Dijkshoorn-Dekker & Kortstee, 2020; Marinus et al., 2021) Farmers indicate they prefer to learn from first-hand experiences, like peer teaching and are motivated by saving time and money. They like learning about cutting edge research that could help them do that (Franz et al., 2010).

Research indicates furthermore that this peer learning is the most effective way of knowledge diffusion for farmers. They tend to pick up agricultural practices fastest if shown by peers (Franz et al., 2010; Dijkshoorn-Dekker & Kortstee, 2020) However, they progressively depend less on these geographically close networks, as 60-80% of farmers indicated their main source of knowledge to be shifting toward trade magazines, internet and crop advisors (Dijkshoorn-Dekker & Kortstee, 2020). This is reflected in the data as it revealed that a central role for the diffusion of knowledge lies with the seed suppliers. They provide farmers with options for GF implementation and knowledge about GF crop properties. They are quoted by the farmers as a primary source of information about possible GF crops that are suited to their situation. Most farmers interviewed have a crop advisor attached to the cooperation they buy their cash crop seeds from.

Farmers do not read scientific publications (Westerink et al., 2018), and the data indicates they perceive a lack of other more digestible forms of information available to them. Additionally, they indicated leaving their farm less often for learning activities (Dijkshoorn-Dekker & Kortstee, 2020).

This shift away from peer learning can be viewed as a barrier for system functioning; it was attributed by the interviewed LTO board member to the farmers' heavy workload. As a result, they do not always have sufficient time to look at innovations other farmers have implemented, which would make the farmer more dependent on the agri-consultants and arbitrators for knowledge. These system actors are not impartial as they have financial incentives from the companies they work for.

Cuperus et al. (2019) provides an exhaustive list of the most utilized ways for farmers to obtain knowledge and mirrors the abovementioned networks found in the data. It ads 'government' as a source of knowledge to the list which is not mentioned explicitly in the interviews.

Two interviewees from the 'research' domain emphasized that GF implementation, and more broadly, sustainable agricultural practices are currently subjects being taught in higher agricultural education as well as middle-level vocational education. Conversely, upon inquiry, the interviewee from the 'education' domain explained that GF is not a subject being explicitly taught in higher agricultural education. The farmers interviewed confirmed this, with all but one interviewee affirming that it had never been part of their education in any form, whether it was higher, middle level vocational or both. One farmer could not remember whether it had been part of his education, adding that his knowledge on the subject was largely from experience with implementation.

Upon review, no data was found on any AIS educational organization incorporating GF implementation practice in the main courses. However, several bachelor theses were found on the subject, published between 2018 and 2020 indicating that some students do research the subject as part of their education (HBO Kennisbank, 2021). Additionally, the handbook for GF (Haagsma et al., 2019) was originally published as part of a request from agricultural education institutions to guide students in this broad subject (Greenport, 2019). This could indicate that GF practices have been gaining attention in agricultural education in recent years. This current lack of knowledge diffusion in the 'education' domain of the AIS can be seen as a barrier to the functioning of the AIS.

In conclusion, peer learning among farmers is the most effective way of knowledge diffusion driving AIS functioning. However, the data and literature show that farmers depend progressively less on these peer networks, with a current shift towards other channels like trade magazines and crop advisors. Currently implementation of GF is not explicitly part of agricultural education, which forms a barrier to function fulfillment. Overall, function 3 is viewed here as inhibiting to wider system functioning. The analysis yielded more barriers than drivers and the barrier of GF not being part of agricultural education weighs heavily on the total fulfillment of the function. As farmers must find their own sources of information regarding GF and the effective method of peer learning becomes less utilized in favor of a shift towards less effective sources of information distribution, the influence of the function on wider AIS functionality is deemed inhibiting as a result.

4.2.5 Function 4: Funding

As mentioned before, funding related to GF is largely government mediated and bound to the direct payments in the Common Agricultural Policy. The data shows a concentration of themes around 'politics policy and institutions' partly for that reason, as well as a concentration around the 'demand' domain.

The theme most prominently emerging from the 'demand' domain is the result of the fact that, upon inquiry, all farmers and 3 other interviewees agreed that a GF crop pays for itself through the added benefits for the soil. The increase of follow crop yield, the workability (aeration) and increased infiltration of the soil were quoted as the main reasons for this conviction. This can be viewed as a strong drivers for adoption, as well as an explanation of why farmers opt in for GF for fulfillment of Ecological Focus area requirements. The themes embedded in the 'politics policy and institution' domain are more scattered. An interesting insight is that 5 interviewees mentioned the role the government had in 'true pricing', or the incorporation of

Both the coordinator GF research group and the sales manager GF of seed retailer that were interviewed emphasized the importance of the split funding in the PPS. The independence of the researchers and the involvement of government and private parties in equal measure creates legitimacy for projects like these.

In conclusion, the fulfillment of function 4 lies with the farmer who pays for the necessities to implement GF. He does so because in return he receives compensation in the form of direct payments from the Common Agricultural Policy budget. These payments are at the foundation of operational profitability for the farmer. Among interviewees there is wide agreement that a rotation of GF pays for itself, which is a driver for AIS functioning. Overall, the fulfillment of function 4 cannot be said to have a conclusive driving or inhibiting effect on AIS functioning. The financial aspect of GF implementation has a minor role in current practices as it is considered cheap and provides a perceived return on investment.

4.2.6 Function 5: Non-monetary resource mobilization

The metadata (appendix B) shows a concentration of themes discussed around the ‘demand’ domain and the ‘education’ domain.

The concentration around the ‘education’ domain concerns the education of the ‘demand’ domain and the knowledge the farmers take from their education into practice. As discussed in 4.2.4, according to the data, GF seems to not be specifically taught in agricultural educations. The interviewee from the ‘education’ domain stated that it was not part of the curriculum, but that he has made an attempt to give GF a more prominent role in the students’ projects.

> *‘Here at school, I thought it was a snowed-in item, so I picked it up again ... one of the highlights was a group of students who turned it into an item in a fourth-year assignment and visited all the companies.’* - Lecturer HAS

He stated that he recognized the added value of the subject, but that there are too many important subjects in the curriculum and not enough time to fully embed it.

The infrastructural demands for the implementation of GF seem to be low, and the infrastructure necessary is in most cases already present in an open ground cultivation farm. As sowing, mowing, plowing and similar soil and crop operations are standard for farmers, GF implementation can use the existing infrastructure. Two farmers reported investments in machinery made for the implementation of GF, but these seem to be mostly multifunctional in their purpose. None of the farmers interviewed related the acquisition of these resources fully to the implementation of GF.

> *‘Yes, over the years we have bought a flail mower of three meters, which is now almost the most used piece of machinery, after the sprayer.’* - Open ground farmer 4

When a farmer buys a more precise sowing machine, for example, he uses it for all his sowing operations. The extent to which machine manufacturers are involved in the AIS seems to be limited to delivering multi-purpose machines that can be used for implementation of GF, but have a primary purpose in facilitating run-of-the-mill agricultural operations like mowing and ploughing. No examples have been found of machines specialized for GF implementation throughout the data or in literature. Van der Boom (2011) discusses the process of sowing GF crops in detail, only referencing regular and extant agricultural machines.

While no domestic research specifically detailing further physical infrastructural demands of GF was found, research in integration of GF in combined livestock and cropping systems in Canada concludes that the additional infrastructure required to implement a GF system was low in every case under research (Martens & Entz, 2011). This is in line with the findings in the structural analysis. The potential for nearly seamless integration in current agricultural practices, without being costly can be viewed as a strong driver for GF as a soil sustainability measure. However, because of this wide implementation, the uptake of more permanent landscape elements that potentially have a higher contribution to biodiversity is lower. This contributes to the legislation surrounding the Ecological Focus area as being deemed inefficient in reaching its intended goals (Bouma & Oosterhuis, 2019).

In conclusion, as GF implementation is not explicitly part of agricultural education farmers have to educate themselves on the subject. This low influx of skilled human resources can be viewed as a barrier for AIS functioning. Furthermore, the cost and infrastructural demands of GF are found to be low. GF practices can integrate in common agricultural practice nearly seamlessly. This is considered a strong driver for AIS functioning. Overall, the total fulfillment of function 5 is considered to have a minor driving effect on wider system functioning as the lack of influx of knowledgeable labor in the system is partly offset by the fact that GF excels in using the existing infrastructure. However, adoption GF of practices in agricultural education could vastly improve this driving effect.

4.2.7 Function 6: Market formation

Fulfillment of function 6 almost exclusively lies with the ‘supply’ domain of the AIS according to the data. The market for GF seems to be quite straightforward in terms of the customers (the farmers) and the suppliers (the seed companies). The dynamics among, and between these two system actor domains seems to encompass the current fulfilment of the function.

The data suggests that there is an established market for GF supplies. None of the farmers interviewed reported any problems with acquiring the necessities for GF implementation upon inquiry. Open ground farmer 1 illustrates this by responding to the question of whether he had to do a lot of effort to acquire GF seeds or other supplies:

> *‘No, if I order it (seeds; supplies) now it will be delivered at the end of the afternoon.’* - Open ground farmer 1

The companies that sell seeds reach the farmers by several means. They send farmers promotional material in the form of flyers and brochures, by farm visits and other forms of in-person promotion. The data yielded no specific insights in dynamics between suppliers or suppliers and agricultural cooperations that promote or distribute GF supplies.

While there seems to be an established market for GF supplies, this market is more aimed at enabling farmers to adhere to legislative requirements by offering GF seeds and mixtures that are compliant with legislation rather than fulfilling the four functions by which GF adds to soil sustainability. While the benefits a GF can bring are outlined by the seed suppliers and different options are certainly available, the promoted mixtures are disproportionally aimed at ease-of-use and legislative compatibility (see 4.1.2). This could give an insight in the priorities farmers currently have where compliance is more important than actual contribution to soil sustainability.

In conclusion, there is a rather matured market for GF supplies. The supply side of the AIS reaches the farmers trough conventional promotional channels. Farmers have easy access to everything they need to comply with legislation around GF. However, there seems to be a focus on GF mixtures and seeds that fulfill legislative requirements rather than benefit soil sustainability or biodiversity. Therefore, the total fulfillment of function 6 is viewed here as inhibiting to wider system functioning as the current market structure does not promote the adoption of more sustainable GF practices but rather enables current practices.

4.2.8 Function 7: Guidance of the search

The data on function 7 shows an aggregation on themes around the ‘politics, policy and institutions’, ‘supply’ and ‘demand’ domain.

The concentration around the ‘politics, policy and institutions’ domain is largely due to the fact that the vision and subsequent institutions formed by government have a large impact on the direction GF as an innovation. The cluster of themes discussed is formed, in large part, by the effects the current Common Agricultural Policy has on the fulfillment of the function. Another theme that is often discussed is the distorted relation between farmers and the government as a whole.

The first reason for this distorted relation found in the data, and emerging theme in six interviews, is the perceived lack of long-term vision by the government. Especially the farmers perceive legislation as changing too quickly. Two farmers viewed this as an obstacle to making practical adjustments and invest in the right kind of technologies and practices. The interviewees from the ‘politics, policy and institutions’ domain recognized this problem.

> *‘Yes, surveys are regularly conducted on this, and the impression is that confidence in government, certainly due to the nitrogen crisis, has plummeted.’* - Team coordinator ministry of LNV 2

Farmers’ ability to adapt to changing legislation is influenced by the low margins on products, investments in sustainability, specialization and upscaling, and the debt these changes incur (Vink & Boezeman, 2018). Market and government incentives, past and present, have caused farmers to upscale their operations to stay profitable as larger farms tended to show better economic results in terms of lower cost prices and higher incomes (Vink et al., 2020). This upscaling has incurred large debt for a lot of farmers. Loosening of set price agreements by government has subsequently caused economic uncertainty and this exacerbates the perception of consequences for legislative instability (Smit et al., 2020). The current systematic changes in regulations due to changes in social needs like sustainability and climate change action make plotting a strategic course with associated multi-year investments virtually impossible for farmers (Nederlandse Vereniging van Banken, 2020). The revenue model for farmers is under pressure while margins are already thin, which causes legislation promoting sustainability goals that incur extra costs to be perceived as putting unnecessary additional pressure on farmers livelihoods (Vink & Boezeman, 2018). As a result, farmers seem skeptical of any change in legislation, with deteriorating consequences for their relationship with the government. This can be detrimental for the willingness of farmers to invest in more sustainable forms of GF and other forms of sustainability measures in their operations. It can therefore be considered a barrier to the innovation system of GF.

'Often things are forced on you (the farmer)... metaphorically: if you have a house and you have just installed a nice kitchen with a gas stove in it, and then the government says: 'yes, we are going to get rid of the gas'. 'You won't get gas tomorrow.' But you have already invested € 3/4,000,- in it... What are you going to do then?' - Board member LTO

The second reason is that the legislation surrounding GF is perceived as impractical, the main reason for this seems to be the time the crop needs to be on the field in order to fulfill the requirements for EA. These 8 weeks force farmers to hastily sow the GF crop after the main cash crop. When conditions are sub-optimal in the late harvest season, they are still forced to sow the GF crop in order to reach the mandatory ultimate sowing date and time on the field. This can compound problems like soil compaction when a farmer has to use his heavy machinery on wet soil after rainfall.

'...especially if you have to harvest your crop late due to weather conditions. If you then still have an obligation to grow a GF crop that has to be on the land for 10 weeks, that means that you have to plow in December. Yeah, that's like swearing in church to me. I absolutely disagree.' - Open ground farmer 3

The farmers view the crop as not having enough time to develop before it is worked under, reducing the benefits it has for the soil and eroding the effectiveness of the legislation. An interviewee from the ministry of Agriculture, Nature and Food-quality confirmed this insight.

'I recognize some practical problems for farmers. Especially after maize, especially if the ministry demands (sowing) dates, that everything must be done very quickly, and the maize is not finished yet, and you have to under-sow the GF and things like that, that sometimes leads to misunderstanding and questions like 'is that effective'?' - Team coordinator ministry of Agriculture, Nature and Food-quality 2

On the other hand, the implementation of legislation around Ecological Focus areas seems to have caused a rapid uptake of GF as a practice. One of the farmers, who started implementing GF after the legislation took effect, viewed it not as a problem and tried to make the most of it. He informed himself about the effects GF has on the soil, experimented with cultivars of a crop that suited his situation and is now implementing GF more broadly than demanded by regulation.

'...and that (the regulation) is no issue, but you have to try and get the most out of it. You can just simply sow a GF crop, but it should also be of some use.' - Open ground farmer 2

Another emerging insight is the misalignment between national and regional implementation of legislation. Individual provinces have a lot of freedom in shaping legislation around destination plans for parts of the landscape. The effects of this dynamic on the innovation system of GF could not be determined.

'You've got the national government where policies are set, and then the local government comes along and listens to some civilian party and says: 'we are not going to issue an agricultural permit'. That is where things go wrong.' - Open ground farmer 2

The data cluster around the 'supply' domain consists of themes emerging from the data related to the seed company advisors solving problems with the implementation of GF. Four of the farmers identified these advisors as the first person they would contact in case of a problem with a rotation of GF, adding that in some cases they are not able to help solve the problem at hand.

In conclusion, the found institutions have great influence on the adoption of GF. The legislation around the Ecological Focus Area has caused massive uptake of GF in cultivated arable farming. However, the rules on mixture implementation do not reach their intended effect of promoting the use of complex mixtures that possibly enhance biodiversity. The legislation is furthermore perceived by farmers as impractical mainly due to the required sowing dates and the minimum of eight weeks they need to be on the field. This can cause farmers to have to work their land under sub-optimal conditions that could potentially exacerbate sustainability issues like soil compaction. Furthermore, farmers view legislation as unstable and have little trust in government, which they find lacking in long-term vision. This is compounded by the slim profit margins farmers in the sub-sector generally operate on. As a result, they struggle in plotting multi-year courses and investments for their operations while maintaining a high degree of financial uncertainty. As all these findings are considered barriers to AIS functioning, and the legislative structure behind GF implementation is found to be imperative to that functioning, the overall fulfillment of function 7 is viewed here as having a strong inhibiting effect on wider system functionality. The uptake of more sustainable forms of GF is strongly inhibited by function 7.

4.2.9 Function 8: Creation of legitimacy

Function 8 mainly shows aggregations of themes around 'politics, policy and institutions' domain and the 'demand' domain.

The themes around the 'demand' domain are mainly concerned with the way farmers view GF, and how the media and immediate surroundings of the farmers view them as agricultural practitioners. Upon inquiry, all but one farmer said they didn't feel like a better farmer or more connected to their profession or products as a result of using GF. Three farmers, however, did mention they thought they were doing good things for the environment by implementing GF and other nature inclusive elements in their operation. All of the farmers interviewed acknowledged the benefits GF as a technique had for their business and the perceived sustainability of their operation.

Another theme discussed is the mindfulness of farmers of the public's perception of their operation. One farmer mentioned that one of his main motivations for choosing a GF mixture is that it looks nice for passers-by when grown, another divulged that he implemented flowers in his field borders with the motivation that the people who lived nearby loved it. Both these farmers mentioned these influences as part of their 'license to produce'.

> *'...people have more time to walk and have more time to enjoy the countryside. And then you also have to make the countryside look attractive and nice. That is also one of the reasons I sow those flower borders.'* - Open ground farmer 2

Bouma (2020) affirms this intrinsic motivation resulting from public perception as one of the driving factors for farmers to incorporate sustainability in their operations, even without direct compensation. Three of the interviewees discussed the negative image that surrounds farmers in the media. The perception is that, on the international stage, the Netherlands is proud of the efficiency, innovation and output of its agricultural sector, but in domestic media the farmer is portrayed as a polluter and animal bully. The effects this has on the adoption of more sustainable forms of GF is hard to quantify and is not described in literature. It can either be a driver due to the farmer wanting to change that image or a barrier when he distances himself from public opinion while persisting in his known practices.

In conclusion, farmers are aware of the sustainability benefits GF can have for their operation, and regard this as something positive. They are mindful of the public perception of the way they operate and acknowledge the contribution GF as a sustainability intervention has on this perception. These factors are viewed as drivers for AIS functioning. However, farmers seem to have a negative view of how the media portrays them in the overall public discourse, the effect of this dynamic was not successfully related to AIS functioning. Overall, the current fulfillment of function 8 seems to promote the use of more sustainable GF practices and is therefore considered a driver to wider system functioning.

4.2.9 Conclusions functional-structural analysis

The overview of function conclusions is shown in *table 4.* This table provides an exhaustive overview of the found drivers and barriers and the resulting impact on overall system functioning. Along with the extended analysis performed above, it provides the answers to the third sub-question: *What are the drivers and barriers to more sustainable green fertilization implementation within the Dutch cultivated arable farming sector?*

Table 4: *Overview of research findings. Left columns portrays the eight functions under analysis. The middle column shows whether the function is considered driving or inhibiting to overall AIS functioning. The right-most column provides an overview of the identified drivers (green text) and barriers (pink text).*

	Function	Effect on AIS functioning	Main causes (drivers & barriers)
1	Entrepreneurial activity	Driving	- Farmers entrepreneurial capacities & experimentation preparedness - Land ownership & subsequent care incentive
2	Knowledge development	Inhibiting	- Research initiatives are splintered - Fundamental research into GF is complex & expensive - Database maintenance is lacking - Farm level experimentation with GF is cheap - Extant research collaborations between actors (PPS)
3	Knowledge diffusion	Inhibiting	- GF not part of agricultural education - Shift to less effective forms of farmer learning - Lack of digestible information about GF for farmers - Peer learning is often used and effective
4	Funding	Neutral/inconclusive	- No funding infrastructure for GF - GF is cheap - GF pays for itself
5	Non-monetary resource mobilization	Minor driving	- Low influx of skilled human resources in AIS - GF fits in current agricultural practices
6	Market formation	Inhibiting	- Market focus on compliance with legislation, not improvement of the four functions (2.2) - Easy access to GF seeds and supplies for farmers
7	Guidance of the search	Strong inhibiting	- Legislative instability causes uncertainty for farmers - GF legislation is ineffective in reaching its intended goals

			- Legislation is perceived as impractical by farmers - Potential adverse effects of legislation on compaction of soil - Farmers have little trust in government - Legislation caused massive uptake of GF practices
8	Creation of legitimacy	Driving	- Farmers regard perceived sustainability benefits of GF as positive - Farmers view GF as beneficial for public perception of their operation

Based on these findings the conclusion is postulated that overall AIS functioning does not promote the uptake of more sustainable forms of GF within the cultivated arable farming sector. Although there are incentives and resulting drivers that have a beneficial effect, they are disproportionally offset by the barriers found. Especially the legislative structure around GF that is at the base of system functioning is found to prevent more sustainable forms to be developed and diffused in the system.

4.3 Analysis of results

The analysis here focusses on how the abovementioned identified system barriers could potentially be alleviated and how the drivers can be enhanced to do so in order to stimulate functioning of the described AIS towards implementation of more sustainable forms of GF. This will answer research question 3: *How can these drivers be enhanced and barriers be alleviated for green fertilization to contribute more to sustainability and biodiversity while safeguarding profitability for farmers?*

The policy recommendations flowing from the analysis do not alleviate every individual systemic barrier identified but instead focus on important interconnecting system barriers form across the functional-structural analysis. These 'problem nexuses' are first visualized, described in detail and the recommendations made are analyzed for their implications. Not all problem nexuses could be solved here.

4.3.1 Analysis of AIS knowledge system

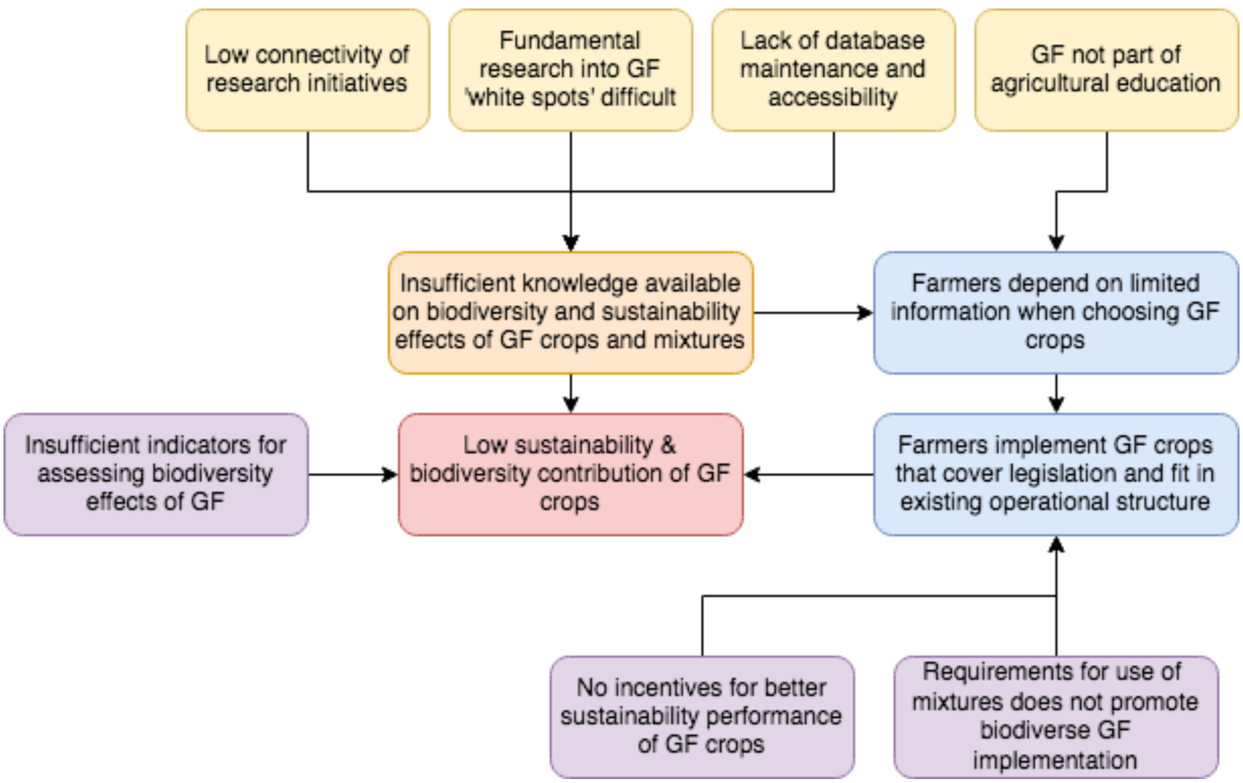

Figure 6: *Problem nexus for GF and knowledge diffusion/exchange. Arrows represent causal relations. Yellow boxes represent knowledge creation and diffusion factors, and purple boxes represent legislative factors. Blue boxes represent demand/supply interactions.*

The structural analysis in 4.1.2 revealed that the contribution of GF to biodiversity in its current form is minimal when looking at the indicators used in the evaluation of legislation. However, the indicator for biodiversity used (development of breeding bird populations) can be deemed insufficient in describing the full complexity of biodiversity dynamics related to GF implementation. The research in 2.2 showed a positive effect of GF on belowground biodiversity, resulting in better nutrient availability.

By incorporating a broader set of farm-level indicators in evaluation, the effect on biodiversity and the other 3 functions described in 2.2 could be better assessed and quantified. This would provide new and better insight in the extent to which GF and other sustainability techniques can contribute to agricultural sustainability and biodiversity.

Recommendation 1
Incorporate a broader set of farm-level evaluative indicators to assess sustainability and biodiversity effects of GF through the four functions in future legislation.

However, incorporating a broader set of farm-level evaluative indicators in legislation brings about two distinct problems. First, indicators like belowground biodiversity are very local and can differ even between adjacent acreages (Mancini et al., 2004). As a result, these indicators will yield a far larger dataset than the currently used broad scale indicators for legislation sustainability evaluation used, as posed by van Doorn (2015). The data will need to be gathered trough more intensive methods than in the current set of indicators as they have higher resolution and are therefore more data-intensive (de Olde et al., 2017). And secondly, this data needs to be stored and made accessible for review. This makes evaluation of their meaning more complex, costly and time consuming. There are, however, extant networks that gather financial data on a farm-level being used in the European Union. A review by Kelly et al. (2018) showed that these same networks, with relative few alterations, can be used to gather high detail sustainability data on a farm level and make this information accessible for policy evaluation. This does however not abate the costs and additional efforts that come with such an undertaking.

As a result of the abovementioned, the indicators used in the evaluation of agricultural sustainability are a continuous scientific point of discussion. There seems to be little consensus on which indicators should be unilaterally used and which indicators are most important to measure and consider for policy evaluation (de Olde et al., 2017). Additionally, not all indicators can be considered due to constraints in resources and time. Therefore, a multidisciplinary approach in the co-creation of the relevant indicators is needed (de Olde et al., 2017). The indicators that could assess the sustainability effects of GF need to be part of a more comprehensive package of evaluative indicators that facilitate analysis of other sustainability innovations in agriculture. Further research is required to determine the content of this indicator package.

The possible benefits of GF for soil sustainability are present, well documented and experienced by farmers that implement GF. However, finding access to the information related to what GF crop or mixture can bring the most benefit to their operation and sustainability efforts proves difficult for farmers as described in 4.2.4. This is caused by the information either not existing, by absence of fundamental research, or by lack of access to data in a digestible form. GF practices are not explicitly part of agricultural education, exacerbating the problem.

Recommendation 2
Stimulate fundamental research into GF 'white spots', aggregate research initiatives' results and make the available information usable for farmers.

Research projects like the PPS, described in 4.1.6, that stimulate participation from across the AIS have shown to be an effective way to generate and diffuse agricultural knowledge across domains. However, as most farmers are not part of this cooperation, they have to find usable information about GF themselves. It is imperative for improvement of system functioning that it is made accessible to them via the channels that they use most often and in a way they can digestas outlined in 4.2.4. The research identifies study groups, crop advisors and trade magazines as the main channels by which information reaches the farmer.

There are furthermore no legislative incentives for sustainability performance of GF crops, only regulations mandating practical aspects like ultimate sowing date, species to be used and minimum time on the field as stipulated in 3.1.2. The legislation around the mandatory use of mixtures does not reach its intended goal as it fails to promote complex mixtures of GF crops that could improve biodiversity in the agricultural landscape. As a result, farmers eventually settle on a certain form of GF that fits in their operational structure and covers legislative requirements, eroding the contribution to sustainability of GF implementation.

Recommendation 3
Incentivize GF implementation that promotes biodiversity and sustainability using the broadened set of evaluative indicators. Reward farmers that disproportionally contribute.

Recent research among Dutch farmers showed that financial incentives based on level of contribution ranked highest among the preferred methods of compensation for changing agronomic management in cultivated arable farming (Janssen, 2020). This resonates with the research finding in 4.2.2 that farmers have good entrepreneurial capacities and are hard-working. This dynamic can be enhanced in the use of financial incentives given the proper tools to measure farmer contribution.

In order to be able to incentivize sustainable implementation of GF, the indicators stipulated in recommendation 1 have to first be measured as part of sustainability legislation evaluation. When these indicators can be assessed, incentives can be coupled to legislation promoting these aspects of sustainability in agricultural operations through the four functions in 2.2. Farmers can receive compensation based on the extent of their contribution. This approach fits well in the plans for the current restructuring of the Common Agricultural Policy towards 2023 which emphasize flexibility for the farmer and focus on contribution-based incentives in several tiers (Erisman & van Doorn, 2018). The Dutch government has done tests with contribution based-payments in 7 pilots Nationwide in the past year (RVO, 2021c). The findings of these pilots have, as of the moment of writing, not all been reported on. However, the first two pilots report a support base among participants for broadening of the application of these performance-based payments (Geling et al., 2021; de Wit et al., 2021). However, the contribution in these pilot reports is not related to the farm-level performance indicators described in recommendation 1, but rather the wider sustainability indicators currently used on a European level (van Doorn, 2015; Erisman & van Doorn, 2018). As of the time of writing, a comprehensive model of how to incorporate rewards for sustainability contribution on a farm level in the current Dutch agricultural complex is lacking (Jongeneel & Baltussen, 2019).

4.3.2 Analysis on GF and farmer profitability

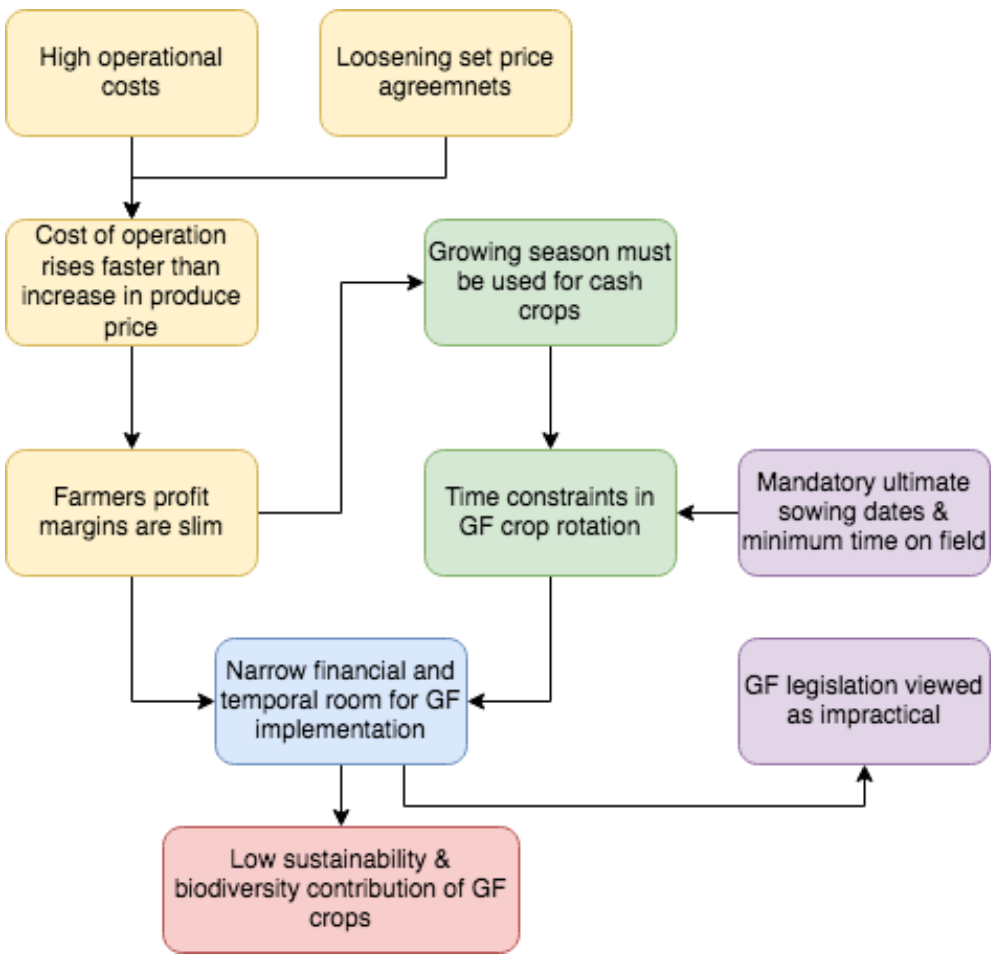

Figure 7: *Problem nexus for financial and temporal factors on low biodiversity contribution of GF crops. Arrows represent causal relations. Yellow elements are financially related, green elements are related to crop rotation.*

Farmers must deal with time constraints and profitability constraints when implementing GF. A rotation of GF can, in most cases, not take place during the productive season as the farmer needs to grow his main cash crops at that time. The functional-structural analysis on 'guidance of the search' in 4.2.8 showed that the cost of operation for farmers rises faster than product price, partly because of loosening of set price agreements. This results in slim profit margins for farmers. This, in turn, means that crop rotations must be efficient in order to ensure financial viability for farmers. As a result, they are temporally tight overall. GF implementation is therefore usually done in the off-season from late autumn to winter, decreasing the biodiversity promoting efficacy of the practice as the crop grows under sub-optimal conditions and for example, pollinators that benefit from the rotation are not present. A rotation of GF that is in line with legislative requirements has a mandatory sowing date and minimum time on the field as outlined in 4.1.2, as a result little financial and temporal room remains for GF implementation.

Growing a GF crop during the productive season, providing a resting period for the agricultural soil could improve sustainability and biodiversity contribution of the GF rotation (van der Burgt & Timmermans, 2020). The rotation of GF would be treated as a full cash crop rotation. However, not using agricultural land over the growing season diminishes farmers profitability. More room for GF implementation outside of the productive growing season would need to be created to achieve that, which is costly for the farmer.

Solving this problem nexus could in theory be done by strengthening of the financial position of the farmers, which would provide room for broader implementation of GF in the productive season. However, there is no guarantee that farmers will use this room to implement sustainability measures in the productive season. It is more likely they will use it to expand operations to include more cash crops (Vink et al., 2020). Furthermore, strengthening the position of farmers in the value chain is a complex process involving market dynamics, government and the farmers themselves and has been under debate and research for a long time (Kleijn, 2018; Karel, 2020). The complexity of this debate cannot be portrayed here in its entirety.

Another option would be incentivizing farmers in a different way to steer them towards the use of soil sustainability enhancement trough GF implementation. Subsidization of a rotation of GF during the productive season to offset the lost revenue could be a more straightforward solution to create financial space while achieving greater contribution to sustainability and biodiversity. Leendertse et al., 2021 outlined that such government subsidies for the implementation of certain specific GF crops in the productive season already exist in France and Belgium. However, the wider legislative implications of implementing such a subsidy in the Netherlands are vast, and justify in-depth research of their own. The problem nexus as described above will not be solved here. Its content will serve as an overview for avenues for future research and provide insight in this complex paradox.

4.3.3 Analysis of GF and legislative pressure

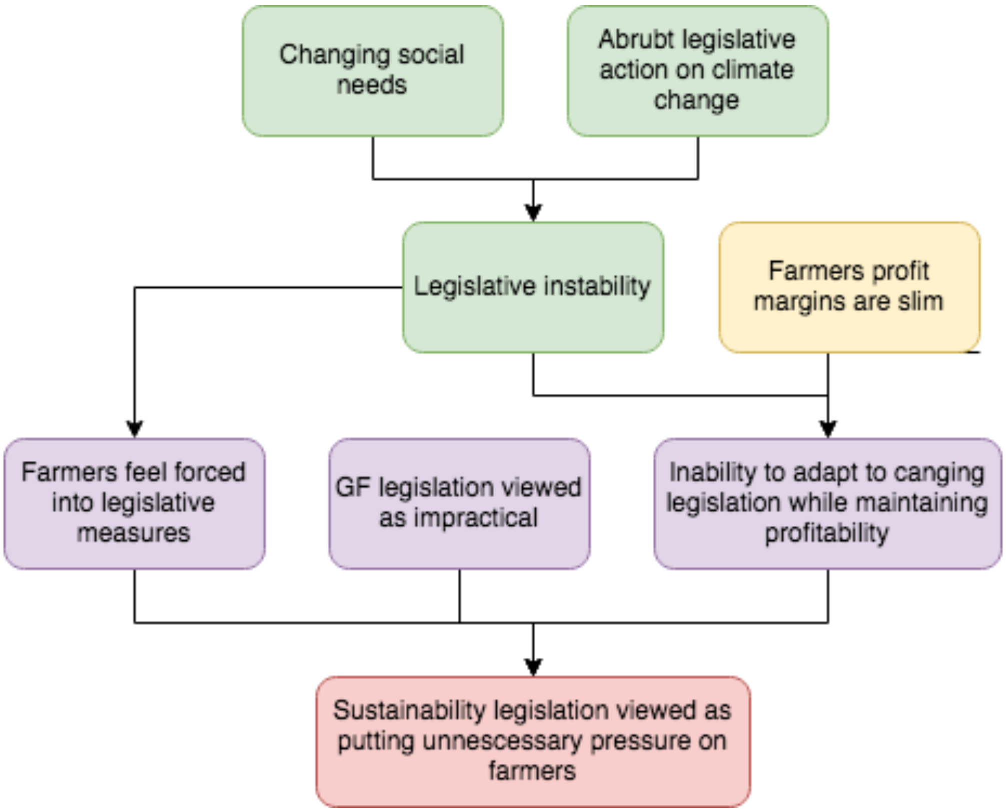

Figure 8: *Problem nexus for GF and legislation. Arrows represent causal relations. Yellow boxes represent financial factors and purple boxes represent results of legislation. Green boxes represent drivers of legislative process.*

The problem nexus shown here shows connectivity with *figure 7*. The combination of legislative instability due to changing social needs, abrupt action on climate change issues and slim profit margins influence the ability of farmers to adapt to legislation while maintaining profitability. They furthermore see the current legislation surrounding GF as impractical, further influencing their negative view as outlined in 4.2.8. As a result they feel forced into new legislation that puts unnecessary pressure on their profitability.

Recommendation 4
Create legislative stability by enshrining agricultural sustainability goals in long term legislation.

By creating legislative stability, farmers are able to plan operational approaches and associated investments without the risk of such investments becoming a liability due to suddenly changing legislation. This can, over time, restore some of the trust farmers have in government and make them more perceptible to participation in the sustainability transition currently taking place in agriculture. In combination with the results from the other two recommendations it could steer them to implementation of more sustainable forms of GF.

Legislative stability pertaining to sustainability in agriculture has a prominent role in the debate around the current transition in Dutch agriculture. The dynamics described in this research, where farmers lack trust in government vision and policy as a result of rapidly changing legislation has been under review for implementation of the new Common Agricultural Policy as shown in 4.2.8. There is broad agreement that stability is a requisite for making agricultural legislation a success (van der Schans & van Beek, 2018).

5. Discussion

5.1 Overview

The discussion will contain three parts. First, the research process and data quality will be reflected on. Secondly, the constructed framework used for analysis will be evaluated. Thirdly, the implications of the results will be discussed as well as their wider applicability.

5.2 Research process and data quality

In qualitative data analysis two factors are important when assessing data quality. The first is thematic saturation. Full thematic saturation would imply that all themes regarding the subject of research have been found and discussed. To reach thematic saturation, additional interviewing and research would have to consistently reveal no new themes (Green & Thorogood, 2004). The second factor is theoretical saturation which occurs when additional data cannot further develop the qualitative theory derived from the data (Lowe et al., 2018). Additional interviews would in that case yield no more insights in previously discussed themes

The data acquired for this research was extracted from relatively few interviews when compared to the scope of the research (national and sectoral). Giving comprehensive insight in large system dynamics requires a lot of data, as such, the amount of data points gathered for this research could be considered to be misaligned with research scope (Green & Thorogood, 2004). Gathering more data points using the similar lines of inquiry as used in the research approach would have solidified the thematic saturation presented in the results and could have possibly discerned more insights in system functioning. We can assume that thematic saturation around the functioning of the AIS of GF has not been reached in this research (Lowe et al., 2018).

The data quality per interview varied, as some yielded a relatively high number of varied themes across functional-structural elements, and others were more in depth in a certain specific element. This caused the spread of themes to not be evenly distributed across functional-structural elements. Some of these elements were not discussed in their entirety, this could have pointed to the absence of an actor/structural element in the AIS, though confirming this using literature was not always possible. Some relevant connections may have been overlooked in favor of discussing the established functional-structural elements in more depth with multiple interviewees. We can assume that theoretical saturation has not been reached in this research.

The themes emerging from interview data caused the following interviews to be steered and adapted in direction in addition to the interview preparation to the interviewee's expertise or the part of the AIS they were most knowledgeable in. Some of the questions posed in the first interviews were found to be irrelevant to AIS functioning or based on assumptions made beforehand that proved to be incorrect. The line of questioning in subsequent interviews was adapted to these advancing insights. This could have furthered the influence the spread of discussed functional structural elements and explain why some elements as presented in the metadata table in appendix B did not come under discussion at all.

As a result of the above-mentioned, very little discussed themes found broad agreement among interviewees. All of the themes found did not exceed the rule of thumb that a thematic grouping is saturated if it is replicated in more than 70 percent of the interviews as a result (Maher et al., 2018). We therefore consider these themes and the resulting drivers and barriers to system functioning as indicative, not conclusive. As the themes discussed are mostly qualitative in nature, quantification of the effects of and barriers on system functioning proved troublesome.

The data gathered and its qualitative interpretation are subject to the individual interpretation of the researcher, the effects this has had on research quality is hard to quantify.

Another interesting discussion point is the fact that upon review, all interviewed farmers had their operations on clay soil, or partial clay soil. As the choice for GF crop is dependent on the specific situation of each farm, and farmers tend to choose for a crop that fits well in their operation, this could have influenced the general opinion about the efficacy of GF crops. Resulting biases were as best as possible abated by putting normative statements in context with available literature that included GF implementation on soils with other soil types.

In conclusion, due to the amount of interviews conducted and varying data quality there was no broad agreement among interviewees on emerging themes. The found themes were strengthened by putting them in context with available literature, but they still cannot be regarded as conclusive. This is to be taken into account when using the research findings for future research efforts into the subject.

5.3 Evaluation of the research framework

The framework used in this research was constructed by using several parts of individual frameworks that are related to Technological Innovation System analysis but is mostly in line with the analysis performed by Lamprinopoulou et al. (2014). Throughout the research process adjustments have been made to the framework as a result of advancing insights in system functioning and data saturation concerns.

Overall, the framework used performed well. It yielded insights in the drivers and barriers that were sought out in the research setup and it had good applicability in the software used for quantitative data analysis (Nvivo 12). The data structure used as presented in *figure 3* allowed for easy overview of the data and facilitated finding and matching themes across interviews. A few deliberations, however, are necessary.

Discovering the connectivity between themes to assess wider system functioning in-depth proved challenging. This was the result of lack in data saturation around AIS functionality themes (Akinyode & Khan, 2018; Maher et al., 2018). The reasons for lack of thematic and theoretical saturation this are disclosed above in 5.3.2. The amount of identified interconnected cause-and-effect relationships between themes and wider system functioning has suffered as a result. Lamprinopoulou et al. (2014) incorporates a 'systemic failure analysis' to connect barriers found in the functional-structural analysis to the wider available literature on system functioning. This analysis uses identified tiers of systemic failure types and test whether they are applicable to the system under analysis. Higer tiers of systemic failure types are connected to wider system functioning. Examples are the extent to which policy creation is coordinated between system actors and the extent to which the AIS allows for self-reflection on identified issues. When an AIS performs well on these aspects, they are indicative of good system functioning. Description of these failures or merits requires a more comprehensive overview of AIS functioning and discerns macro-scale themes using insights discussed lower tier thematic analysis (Lamprinpopolou et al., 2014). Lack of macro-scale insights can be caused by lower data saturation on lower scale themes, which was the case in this research (Maher et al., 2018). For that reason, the broader system failure analysis was not included in the results as the data obtained in the interviews did not provide sufficient insights in their dynamics.

Furthermore, because of how the framework was embedded in qualitative analysis, it did not allow for thorough quantification of total function fulfillment in 4.2.9. Instead, it was subject to the researcher's interpretation of the relative effects of the drivers and barriers when creating the overview. This resulted in the categories of 'minor driving', 'driving', 'neutral/inconclusive', 'inhibiting' and 'strong inhibiting'. The reasons for why each category was assigned are outlined in detail in the conclusions of the functional-structural analysis in 4.2 to form an adequate overview of system functioning. However, future use of this framework or a similar framework would benefit from incorporating a form of quantification of these functions. This quantification can be added by asking interviewees to rate function performance in the interviews as proposed by Hekkert et al. (2011). This allows the function performance analysis to be based off several interpretations done by experts rather than the interpretation of the researcher alone. This strengthens the bases on which the assessment is made and its conclusions are drawn.

In conclusion, the research framework used in this research performed well. It however did not provide insight in the more in-depth aspects of system functioning; this was however not caused by how the framework was constructed but by a lack of thematic and theoretical saturation. Furthermore, the research could have benefitted from quantification of system functionality to strengthen the bases of the findings. Future, similar research on this sectoral scale should incorporate more interviews to more closely approach data saturation and allow for quantification of system functionality as suggested above.

5.4 Implications and result applicability

The research presented here gives a current overview of GF as an agricultural innovation in the Dutch cultivated arable farming sector. It evaluates its position in agricultural practices, the extent to which it contributes to sustainability goals in legislation and how it can be made to contribute more.

Applicability of the majority of the results in other agricultural sub-sectors is considered limited. The farmers interviewed were all typical cultivated arable farmers, the content of their statements cannot be directly connected to other agricultural sub-sectors as described in 3.2. Furthermore, the agricultural practices of all sectors except horticulture on open ground are vastly different, with different laws and regulations governing them. Application of GF in these sectors will have a different form to fit within sector practices. For example, arborists increasingly grow GF crops before they plant their seedling trees (Groen Kennisnet, 2017). They dedicate a full growing season to growing a GF crop that maximizes soil organic content before doing so. As described in 4.3.2 cultivated arable farmers do not have the capacity to do so. Arborists are convinced the added benefits for tree growth and health over the long term outweigh the cost associated with the GF rotation. This example demonstrates that dynamics governing GF implementation in other sectors are governed by different considerations.

Some of the themes emerging from the data are however related to the wider agricultural complex in the Netherlands. This is unsurprising as the cultivated arable farming sector cannot be seen as separate from the wider agricultural complex. Sector wide, the profitability of farmers is under pressure by the same dynamics as presented in 4.3.2, albeit to a different extent per sector (Nederlandse Vereniging van Banken, 2020). Farmers in all sectors have little trust in government vision and policy as demonstrated by the ongoing farmer protests (Grashuis, 2021).

Many of the findings presented in this research are not novel. The current debate about the ongoing agricultural sustainability transformation has yielded a lot of scientific publications detailing possible pathways forward and assessing the role of certain agricultural sustainability efforts. The research therefore finds high connectivity in discussed themes with this research on the ongoing transformation. As agricultural problems resulting from this transformation are inherently complex, multidimensional and multilevel, this research will likely not have covered this full complexity for GF implementation in open ground cultivation (Schut et al., 2015).

6. Conclusion

The research presented here aimed to map the role of green fertilization practices in the Dutch cultivated arable farming sector, as this agricultural technique has great theoretical potential in alleviating modern day agricultural sustainability issues in this sector. This potential, however, was not perceived when evaluating sustainability and biodiversity effects agricultural legislation. This lead to the main research question:

How can current green fertilization practices in the Dutch cultivated arable farming sector be steered by policy to contribute more to sustainability goals while safeguarding profitability for farmers?

To answer this question, first, the baseline theoretical potential of green fertilization practices for sustainability and biodiversity in the cultivated arable farming sector was determined and outlined. Green fertilization was found to attribute to four distinct, interconnected functions related to agricultural sustainability and biodiversity. A showcase was presented of the best results found in domestic literature pertaining to fulfillment of these four functions.

Subsequently, a review was performed of the legislative causes for lack of sustainability and biodiversity improvement contribution by current green fertilization practices. This analysis revealed that the legislation currently most important to the uptake of green fertilization as an agricultural practice did not incentivize the fulfillment of the four functions found. Furthermore, a combination of the use of insufficient evaluative indicators, poor structuring of the legislation, and a misalignment of the requirements for fulfillment embedded within the legislation when compared to its intended goals were determined to be the causes of current green fertilization practices to not contribute within their theoretical potential to soil sustainability and biodiversity in the Dutch cultivated arable farming sector.

Using this assessment, the Agricultural Innovation System drivers and barriers to the implementation of more sustainable forms of green fertilization were researched. This analysis revealed that the current barriers to total Agricultural Innovation System functioning inhibited adoption of more sustainable forms of green fertilization. To postulate recommendations aimed at improving system functioning, the interconnecting barriers found across the AIS analysis were visualized and outlined in three problem nexuses. These problem nexuses gave a broader perspective of system functioning and facilitated analysis of the complex issues embedded therein. They resulted in four recommendations for policy to improve the performance of the Agricultural Innovation System which is necessary to facilitate the adoption of green fertilization practices that have a greater contribution to sustainability and biodiversity:

1. Incorporate a broader set of farm-level evaluative indicators to assess sustainability and biodiversity effects of green fertilization through the four functions in future legislation.
2. Stimulate fundamental research into green fertilization 'white spots', aggregate research initiatives' results and make the available information usable for farmers.

3. Incentivize green fertilization implementation that promotes biodiversity and sustainability using the broadened set of evaluative indicators. Reward farmers that disproportionally contribute.
4. Create legislative stability by enshrining agricultural sustainability goals in long term legislation.

Green fertilization has the capacity to yield real sustainability benefits in modern agricultural practices while adding to farm resilience and profitability. It is a tool in the complex, multifaceted process of reaching sustainability in agriculture and should be implemented as part of a comprehensive program to achieve this goal. The research presented here has provided footholds in the form of recommendations to be used for future legislation to improve the result this technique has on the desired sustainability outcomes. It has furthermore provided an up-to-date overview of the current knowledge around the subject and provided further avenues for research.

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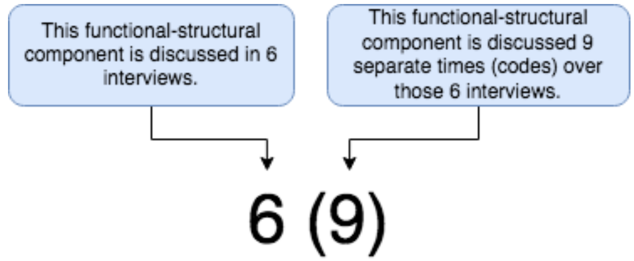
8. Appendix

Appendix A – Interviewee overview

	Description	Domain	Details
1.	Open ground farmer 1	Demand	Mixed open ground cultivation – clay soil
2.	Open ground farmer 2	Demand	Mixed open ground cultivation – clay soil
3.	Open ground farmer 3	Demand	Mixed open ground cultivation – clay and sand soil
4.	Open ground farmer 4	Demand	Mixed open ground cultivation – clay soil
5.	Open ground farmer 5	Demand	Mixed open ground cultivation – clay soil
6.	Sales manager GF seed retailer	Supply	Market leading company in GF seed mixes
7.	Researcher WUR	Research	Has researched and published about GF
8.	Researcher WUR	Research	Has researched the Dutch AIS
9.	Team coordinator ministry of Agriculture, Nature and Food-quality 1	Policy	Influences legislation around GF implementation
10.	Team coordinator ministry of Agriculture, Nature and Food-quality 2	Policy	Influences legislation around GF implementation
11.	Lecturer HAS	Education	-
12.	Board member LTO (LLTB)	Support/cross-domain	Biological open ground cultivation farmer as well as soil quality expert at LTO
13.	Board member KnowHouse	Support/Cross-domain	Intermediary/support and farmer advocacy organization
14.	Coordinator GF research group	Research	Public-private cooperation on GF research (PPS)

Appendix B – Metadata overview

The metadata overview, incorporating discussed emerging insights from the interviews. The first number is the amount of interviews in which a certain functional-structural component was discussed. The second number in brackets represents the total amount of codes for that functional structural aspect. Higher numbers mean that there are multiple codes in multiple interviews discussing that aspect.



	F1: Entrepreneurial activity	F2: Knowledge development	F3: Knowledge diffusion	F3: Funding	F5: Non-monetary resource mobilization	F6: Market formation	F7: Guidance of the search	F8: Creation of legitimacy
Politics, policy and institutions	6 (9)	1 (3)	2 (3)	10 (19)	1 (1)	0 (0)	11 (58)	5 (9)
Research	0 (0)	6 (18)	2 (3)	0 (0)	0 (0)	0 (0)	4 (8)	1 (1)
Education	0 (0)	1 (2)	9 (17)	0 (0)	10 (17)	0 (0)	1 (1)	0 (0)
Supply	2 (2)	4 (10)	8 (14)	1 (2)	1 (1)	5 (11)	9 (19)	3 (3)
Demand	12 (48)	5 (14)	13 (26)	11 (33)	8 (15)	4 (4)	7(14)	9 (22)
Investment	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
Support organizations	0 (0)	2(3)	3 (4)	3 (3)	0 (0)	0 (0)	3 (5)	2 (3)
Cross-domain	0 (0)	4 (7)	3 (3)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)