Everyone off the Treadmill

Mitigating Soil Greenhouse Gases from Dutch Agriculture

Anna Gomes

Master Thesis Series in Environmental Studies and Sustainability Science,
No 2020:011

A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science (30hp/credits)

LUCSUS
Lund University Centre for Sustainability Studies

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Submitted May 12, 2020

Supervisor: Sara Brogaard, LUCSUS, Lund University

Abstract:

Working to increase the sustainability of agriculture is a complex challenge of balancing food production and economic profitability with environmental and climatic impact. As the second largest exporter of agricultural products worldwide, the Netherlands is a global production hub, a leading example of high yields per hectare. However, with this high productivity comes intensive farming practices, placing a significant risk on the climate through increased emissions of greenhouse gases N_2O and CO_2 from soil. This problem can be illustrated by the Agricultural Treadmill theory, representing a causal relationship between on-farm economics, farm size, and technology adoption, in turn leading to increasingly intensive farming systems with higher soil emissions. A large focus of current agricultural research and policy is focused on mitigating methane emissions from livestock production; however, similar attention should be extended to direct soil greenhouse gas emissions. To meet global climate change efforts, the Netherlands must reduce its climatic impact, including soil emissions, but the main challenge lies in shifting the adoption towards specific farming practices. As farmers work toward this shift they face social, economic, political, and environmental barriers, which hinder their progress and shrink their motivation.

This research aims to identify these challenges and explore the implications. The main research question is: What are the barriers and opportunities for Dutch arable farmers to transition to farming practices which mitigate greenhouse gas emissions from agricultural soils? Beginning with a literature review and informant interviews, this is followed by conducting semi-structured interviews with farmers, policy-makers, and boundary organizations. The findings include (1) a lack of awareness by Dutch farmers of their soil greenhouse gas production, (2) six barriers and five opportunities for farmer adoption of mitigation practices, and (3) the placement of these barriers and opportunities into different steps of adoption, with implications for the surrounding political and economic systems. Critical barriers include economic challenges, personal mindset, on-farm complications, and the need to reconcile different stakeholders' rates of adoption. However, exciting opportunities lie with farmers becoming interested and able to quantify soil health, positively framing farmers in the media, and policies or economic mechanisms to financially compensate farmers. Finally, key leverage points which tackle barriers and enhance opportunities are identified to motivate the adoption of greenhouse gas mitigation practices on Dutch soils. If the Netherlands can transition to a farming system with reduced greenhouse gas emissions from arable soils, the opportunities for the global food system could be significant.

Keywords: agricultural production, soil management, climate change, farmer adoption,
the Netherlands, sustainability science

Word count: 11,998

Note to the Reader:

I love soil science, farming, and agriculture. With this passion comes great concern for sustaining the climate and environment, while feeding society. Farmers are the behind-the-scenes heroes to keeping our global society in motion, as we rely on them to grow our food, fuel, and fiber. But how can we have farms without damage to the surrounding landscapes? How can we instead have an agricultural landscape which consists of healthy soils, buzzing biodiversity both above and below ground, and nutrient cycles which feed the plants and not the water or atmosphere? How can we have farms which provide quality jobs for sustaining rural communities?

Growing up in a rural California town of dairy farmers, as well as working with a local vegetable farmer in high school, starting my own small plant business, and teaching tractor driving during my bachelor's degree, I understand the hard work and dedication farmers put into their livelihood. Whether it's a holiday or a sunny summer day, they are awake at sunrise to feed their animals and care for their crops. How can we produce food without contributing to climate change and make agriculture exciting to attract people in my generation to want to join in on this adventure? Sustainability scientists are trained in working to unfold complex social-environmental systems. Pile on the economics, politics, and tradition embedded in an industry with a deep-rooted history of traditional livelihoods within rural communities, and you have a challenge worth exploring.

Throughout the thesis process I would often take a writing break and go out for a brainstorming jog. One sunny Swedish day, I ran alongside a farmer at work in his tractor preparing the field for planting. This led me to pondering, how can I bridge the gap between the 50 page pdf I was writing and the real changes in the daily life of a farmer? Continue reading to shovel into this complex soil profile and find out what soil-lutions are found.

Acknowledgements

To begin, I would like to acknowledge and thank my wonderful supervisors Sara Brogaard and Pytrik Reidsma for your generous guidance and advice, and the three fantastic individuals who helped me to jump start this research adventure, Murray Scown, Laura Maja Stenbæk Fløytrup, and Juliana Dias Bernardes Gil. Further, I would like to recognize the numerous researchers who serve as inspiring informants to this research project, those from Wageningen University: Jan Willem van Groenigen, Gerard Velthof, Saskia Visser, Bert Rijk, Oene Oenema, Judith Westerink, Jan Verhagen, Bridgette Kroonen, and Daan Verstand, in addition those from Utrecht University: Giuseppe Feola, Hens Runhaar, and René Verburg, and Thierry Stokkermans from Zip Drill, a start-up developing farm machinery for conservation agriculture.

Thank you to the Plant Production Systems graduate students at Wageningen University who invited me along to your field work and greenhouse tasks. To Paul Ravensbergen, it was a pleasure traversing through potato fields with you in the heat of the summer and thank you for being an enthusiastic translator. To Inge Vandewiel, thank you for the always great conversation and the many lessons you taught me about Dutch agriculture. Also a big appreciation to the farming families who opened up their farms and their homes to me, thank you for the lunches, it was a pleasure getting to know you and your work. To the Dutch LUMESians, thank you for making the Netherlands feel a bit more like home, for the city tours and extra love, just when I needed it most.

Finally, thank you to my LUMES classmates for everything, for the critical discussions and learning moments, for the laughs and endless good memories, for teaching me what sustainable living truly looks like, and for making Lund feel like home. You are all extraordinary people giving me optimism for a brighter future. Thank you to my LUMES thesis group for your support, feedback, weekly calls, and for listening to my farming monologues. And last but not least, thank you to the amazing Stephanie Lew, Alyssa DeVincentes, and Jess Chiartas for your feedback, support, and overall passion towards creating impactful work. And of course to my mom, as my forever editor-in-chief, what would I do without you.

Thank you all for sharing your time and expertise in support of this thesis completion, what an exciting and challenging year of learning how to be a sustainability science researcher.

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Abbreviations

AES/AECMs: Agri-Environmental Schemes/ Agri-Environment Climate Measures

BO: Boundary Organization

CAN: Calcium Ammonium Nitrate

CAP: Common Agricultural Policy

CLD: Causal Loop Diagram

CO_2: Carbon Dioxide

EU: European Union

FM: Farmer

GHGs: Greenhouse Gases

II: Informant Interview

IPCC: Intergovernmental Panel on Climate Change

MPs: Greenhouse Gas Mitigation Practices

N_2O: Nitrous Oxide

ND: Nitrate Directive

NH_3: Ammonia

NO_3: Nitrate

PM: Policy-Maker

SOC: Soil Organic Carbon

SOM: Soil Organic Matter

1 Introduction

Globally, food production is contributing to anthropogenic climate change. As the population is expected to surpass nine billion by 2050, food security requires increased production of food; however, intensifying agricultural production can have severe consequences for the climate (Tilman et al., 2011). Agricultural landscapes are multifunctional and must balance the need to produce food while providing regulation of water and greenhouse gases (GHGs) (Todman et al., 2019).

1.1 Climate Change & Agriculture

Working to increase agricultural sustainability is a complex challenge, as it requires considering food security, environmental impact, economic profitability, and social equality, with immediate needs and long-term tradeoffs (Foley et al., 2005). A bi-directional relationship, agricultural production contributes to climate change by producing GHG emissions, and climate change affects agricultural production with shifting temperature and precipitation patterns (Kang et al., 2009; Smith & Olesen, 2010). Globally, food systems produce 19-29% of anthropogenic GHGs with agricultural production comprising the majority at 80-86%, including indirect emissions from land cover change (Vermeulen et al., 2012). Agriculture is seen as the major driver of fully transgressing, or placing the Earth system at high risk, for the boundary of 'biogeochemical flows', the biogeochemical cycling of nitrogen and phosphorus (Campbell et al., 2017).

1.2 Dutch Farming & Soil GHGs

Since the Second World War, the Netherlands has been producing food for the world (Hoogervorst, 1993), as the second largest exporter of agricultural products with over 50,000 farmers (Gowling, 2014). This production has come with environmental consequences. As of 2012, agriculture contributes to 8.3% of total GHGs in the Netherlands (UNFCCC, 2012). In 2017, 'agricultural soils' contributed almost 30% of GHGs from the agricultural sector (Ruyssenaars et al., 2019). From 2005-2013, the Netherlands had the highest intensity of agricultural soil management and the highest GHG emissions per hectare in the European Union (EU) (Dace & Blumberga, 2016). Additionally, the Netherlands has the highest nitrogen load per hectare within the EU, leading to several environmental challenges with nitrogen (Van der Hoek et al., 2007). Up to two-thirds of the nitrogen applied to the field is applied in excess of crop demand, leaving it susceptible to leaching or volatilization (Bowles et al., 2018). Nitrogen in the form of nitrate (NO_3) is linked to leaching, groundwater contamination, and eutrophication, or the creation of dead zones in bodies of surface water (Carpenter et al., 1998). Nitrogen as ammonia (NH_3) can lead to nitrogen deposition in nature reserves (Hoogervorst, 1993). However, this thesis will focus on nitrogen challenges in the form of nitrous oxide or N_2O, a potent GHG.

Dutch arable farmers can take several soil management approaches to minimize the GHGs, CO_2 and N_2O, emitted from their soils. In the existing literature regarding the link between farming practices and soil GHGs, it is clear that this can be a complex relationship with many interacting factors. Intensive physical soil management plus high nutrient inputs, whether organic or synthetic, are the two main drivers for GHGs production. For the purposes of this research, certain farming practices will be considered the key GHG mitigation practices (MPs), based on informant recommendations and literature review findings (Table 1). For a detailed description of the production of soil GHGs see Technical Appendix A.

Table 1. Greenhouse Gas Mitigation Practices and their Soil GHG impacts (Oertel et al., 2016)

GHG Mitigation Practice	***GHG***	***Soil GHG Impact***
Grow cover/catch crops	N_2O CO_2	Takes in plant available nitrogen in the soil which could turn into N_2O & adds carbon inputs
Increase nitrogen use efficiency	N_2O	Matches applied fertilizer quantity and plant demands, aiming to reduce nitrogen inputs
Apply slow release fertilizers or nitrification inhibitors	N_2O	Avoids excess nitrogen application which could turn into N_2O
Implement reduced/no tillage systems	CO_2	Reduces carbon losses
Add surface residue	CO_2	Adds carbon inputs

Farmers are uniquely positioned to implement change in the system, as they determine whether MP are executed for arable crop production. Technological and procedural methods are often ready, but fail to be broadly adopted, as behavioral change and policy compliance is limited by complex barriers. Overcoming these barriers, while enhancing existing opportunities, is key to widespread implementation. This thesis explores how to create the behavioral change necessary amongst arable farmers in the Netherlands.

According to Van Dijk et al. (2018), social, political, and economic challenges are leaving farmers struggling to keep up and feeling left without options for adopting a different system. In order to frame this research study, the Agricultural Treadmill theory is utilized, connecting the economic market situation to the intensity of crop production, and hence the production of soil GHGs. A range of studies exist analyzing Dutch farmer adoption of innovation (Long et al., 2016), Agri-environment schemes (Kleijn et al., 2001), and nature inclusive farming (Runhaar, 2017); however, none which focus specifically on adoption of practices which mitigate soil emissions. This existing research gap may be due to the political prioritization of other climatic impacts of the agricultural sector, including methane emissions from livestock and carbon emissions from the oxidation of organic soils. Arable soils, however, are critical to include in Dutch climate change mitigation efforts, as they represent the highest share of land use at 30% (CIA, 2011), and GHG emissions from agricultural soils are the second largest percentage of sectoral emissions (UNFCCC, 2012). To achieve the magnitude of changes needed for GHG mitigation from soils, the system needs to change to support full adoption of MPs across the 1.01 million hectares (CIA, 2011) of arable land.

1.3 Research Aim

My research aims to increase knowledge and understanding of the adoption of farming practices which reduce GHG emissions from arable soils. To address this issue, this thesis discusses the following main question: What are the barriers and opportunities that Dutch arable farmers experience in transitioning to farming practices which mitigate GHGs from agricultural soils? The sub-questions that aim to supplement the main question are: (i) How do farmers connect their practices to GHG emissions from their soils?, (ii) What do farmers see as the barriers and opportunities of adopting practices which mitigate soil GHGs?, (iii) How do the existing barriers and opportunities align with different steps of adoption?

1.4 Navigating this Thesis

Beginning with a contextualization of the research questions, Chapter 2 portrays the natural, social, economic and political landscape of the Dutch farming sector. Chapter 3 introduces the analytical framework and theory. Chapter 4 outlines the research design, data collection and analysis process. Chapter 5 illustrates the outcomes of the data analysis and places the data into the main framework. Chapter 6 contextualizes the findings within existing literature, in addition to placing the research questions into the broader story of Dutch agriculture. Finally, the thesis will conclude with suggestions for further developing this topic and research reflections.

2 Adoption in the Dutch Agricultural Landscape

Agricultural production is interconnected within several 'landscapes', and requires systems thinking to develop sustainable management. Readers will gain insight into the broader background of unique challenges farmers face pertaining to the context-specific soils, culture, and political-economic situation in the Netherlands.

2.1 Natural Landscape

With over half of the Dutch landscape covered with agricultural land (CBS et al., 2015), the physical terrain of the country serves as a critical starting point. The mineral soil type is dominated by old clay marine soils in the north and central regions, with sandy soils covering the south (Figure 1; Brus et al., 2009).

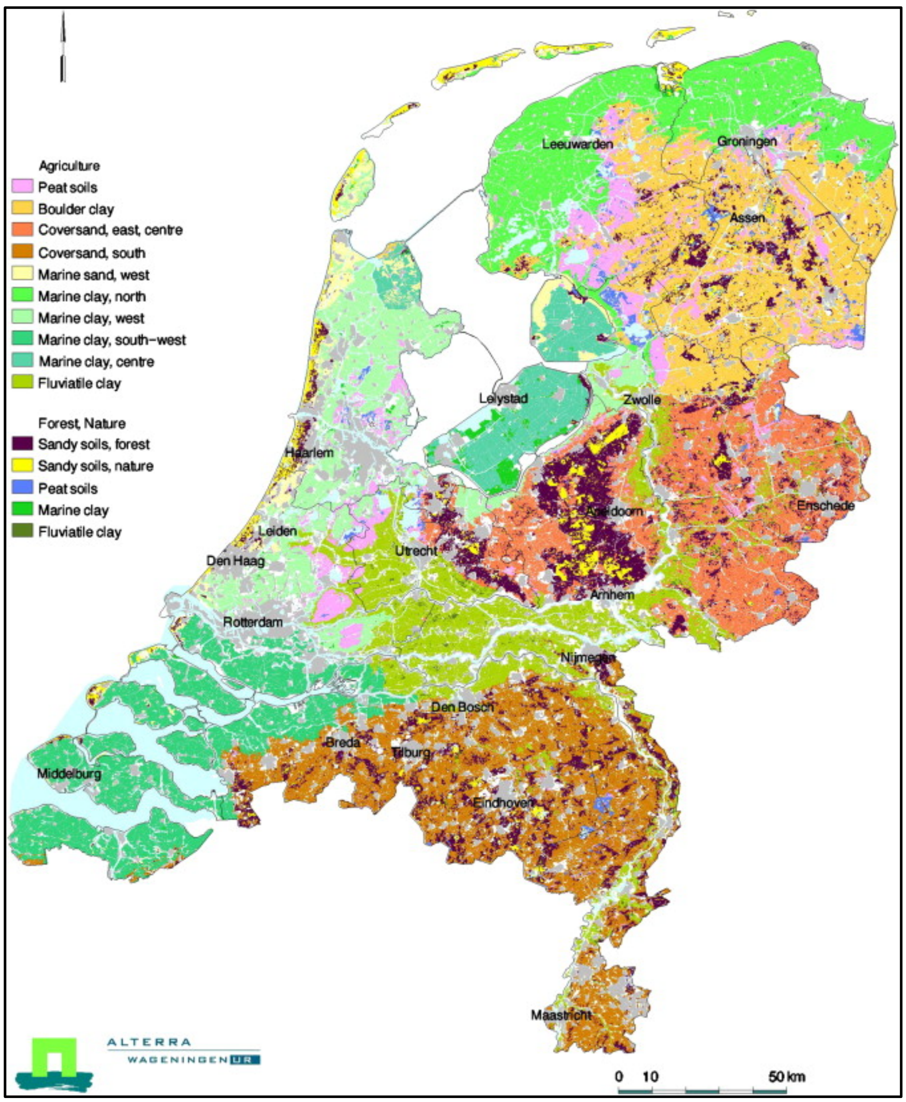

Figure 1. Soil Map of the Netherlands, See "Agriculture" categories (Brus et al., 2009)

The land is characterized as sitting at or near sea level, having fertile soils and large livestock quantities, surrounded by a dense human population (Hoes et al., 2019). The main crops include potatoes, cereals, vegetables (arable), and sugar beets (CBS, 2020). The variation in climatic and edaphic factors across the Netherlands leads to variations in GHGs from agricultural soils. These include soil type, soil water content, soil temperature, nutrient availability, soil pH value, and land cover (Figure 2; Oertel et al., 2016), further explained in Appendix A.

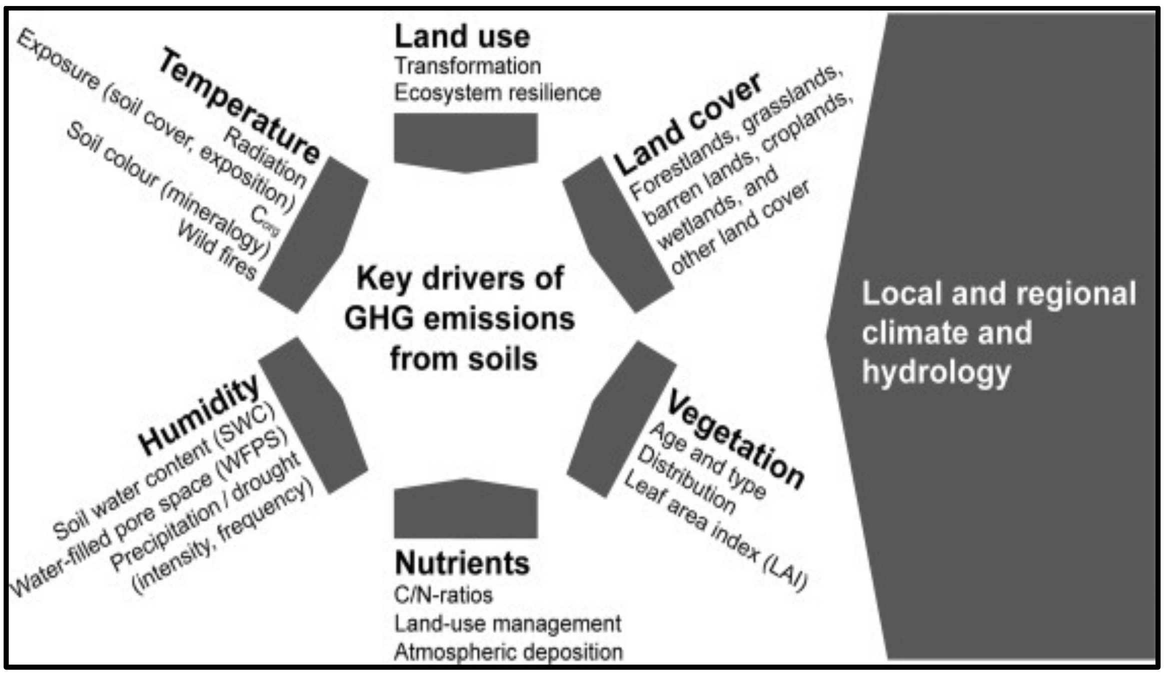

Figure 2. Key Drivers of GHG Emissions from Soils (Oertel et al., 2016)

2.2 Social Landscape

The natural landscape also shapes the historical and cultural context of Dutch agriculture. Due to the optimal soil conditions found for crop production, agriculture naturally grew and ultimately, intensified. Over time, through modernization, farms moved from being a synergy between farming communities and local ecological conditions, to extractive factories teeming with artificial inputs and actors guided by conflicting goals (Renting & Van Der Ploeg, 2001). Following the Second World War, with the need to feed many hungry civilians and the availability of war chemicals for use in producing fertilizers, an increasing focus was placed on scaling up the production of agricultural crops; boosting yields exponentially (Hoogervorst, 1993).

2.3 Political & Economic Landscape

By 1985, nitrogen flow policies along with the extensification of Dutch farmland was proposed to simultaneously address existing environmental problems and reduce the driver for increased production. However, in 1992, the creation of a single EU market guaranteed farmers stable prices and a place to sell their goods, further incentivizing intensive production (Hoogervorst, 1993).

Today, as Dutch farmers work to produce food for global export, the tension between profits and the push for environmental policies is rising. The high price of land and labor, continuous low prices at the farm gate, and increasing costs for inputs and infrastructure demands intensification of operations (Bos et al., 2014). Many farmers are unable to compete, lose their land, and thus consolidation of farmland has become characteristic of the Dutch rural landscape (Hoogervorst, 1993).

The current economic landscape demands support from the political landscape to make adoption possible. The EU Common Agricultural Policy (CAP) determines the funding farmers receive, both as direct payments or pillar 1 and as additional funds, or pillar 2. The CAP aims to establish a free exchange of goods and fair market competition within the EU. Started in 1992, Agri-environmental schemes (AESs) are 5-7 year funding schemes within pillar 2 of CAP to encourage the adoption of sustainable practices, compulsory for all EU countries within their rural development programs. Although the Netherlands must offer AESs, it remains optional for the farmers to participate and includes measures related to farm biodiversity conservation, permanent pastures, and grasslands ("The common", 2020). AESs have been heavily criticized for lack of effectiveness to implement the intended beneficial environmental impacts (Kleijn et al., 2001; Breeuwer et al., 2009; Runhaar, 2017). In 2016, as an effort to increase ambition, the Netherlands adopted a cooperative approach, creating 40 agri-environmental cooperatives which will carry out farmland biodiversity measures (Terwan et al., 2016). Several attempts for adoption of pro-environmental practices have been made in the form of short-term contracted projects carried out by environmental cooperatives or farmer cooperatives (Van Dijk et al., 2016; Westerink et al., 2017).

In order to receive EU farm subsidies, cross compliance mandates that one meets several directives which aim to protect the natural water bodies, air quality and biodiversity ("The common", 2020). The Nitrate Directive (ND), created in 1991, is especially relevant, as it determines the current levels of nitrogen arable farmers are allowed to apply to their soils, and hence the amount of fertilizer (Van Grinsven et al., 2016), which directly impacts soil GHG emissions. The ND is a means-oriented regulation with crop type-soil type specificities given on a hectare basis, but checked at the farm level. In practice, farmers can decide which hectares receive more or less fertilizer, as long as the farm level limits are not exceeded (B. Rijk, personal communication, April 15, 2020). With limits on nutrient application becoming stricter each year from 2006-2015, in order to reach these EU directives, total nitrogen fertilizer consumption has decreased by 50% since 1990. However, research has found that nutrient losses from agricultural production systems have overall not decreased (Van Grinsven et al., 2016). Critical loads in the majority of ecosystems have been exceeded, and surplus manure remains a problem. In 2000, the Water Framework Directive was established as a goal-oriented regulation aimed at reaching good ecological status of waters through NO_3 management, and in 2001, the National Emissions Ceiling Directive was passed to reduce NH_3 emissions (Van Grinsven et al., 2016).

Currently, the EU CAP is under reform, providing an opportunity to identify more specific objectives for the agricultural sector, as well as implement measurable targets to meet these objectives (Pe'er et al., 2019). The Dutch strategic plan will include specific measures, including how much funding farmers can receive for various environmentally sustainable practices. Reform proposals include additional AESs, renamed as Agri-Environment Climate Measures (AECMs). Those relevant to MPs include: the compulsory use of a new Farm Sustainability Tool for Nutrients, maintenance of soil organic matter (SOM) through a ban on burning stubble, as well as demanding each member state make a Farm Advisory System available ("The environmental", 2019).

At the national level, aiming to keep nutrients and waste within a cycle as local as possible, Circular Agriculture has become the main political framework ("Vision Ministry", n.d.). Additionally, the Netherlands has adopted the Dutch Climate Agreement, targeting a national, cross-sectoral 49% reduction in GHGs compared to 1990 levels by 2030, 95% by 2050. The agricultural sector is tasked with reducing six megatons of emissions by 2030 and expected to mitigate emissions from agricultural soils through "Pilots, knowledge dissemination, technological innovation, (and) training of advisers" (Climate Agreement, 2019, pg. 125).

2.4 Dutch Farmer Characteristics

Furthermore, it is important to reflect on lessons from existing literature concerning the adoption of pro-environmental farming practices by Dutch farmers. Uncertainty of market conditions, environmental policy, and perceived production risks have been illustrated as barriers to adoption. One example of adoption literature is concerning the pro-environmental practice of Integrated Arable Farming Systems (IAFS), or "multifunctional crop rotation that supports crop protection and nutrient management strategies, sub of chemicals with mechanical methods and balanced nutrient inputs and outputs" (De Buck et al., 2008, pg. 153). The combined need for reduced input costs and inner transformation of farmers through an intensive learning process, was critical for adoption success. The researchers conclude with the need to consider IAFS as a series of adoptions of separate practices, each with their own variables (De Buck et al., 2008).

Bartkowski & Bartke (2018) highlight the need to consider the 'objective' characteristics of farmer gender, age, level of education, as well as farm characteristics of size and technical conditions. These 'objective' variables influence environmental attitude and past experiences, key factors of decision making at the individual land manager level. Runhaar et al. (2016) also discuss the importance of extrinsic characteristics, including the need to receive demand and legitimation from other actors. Dutch farmer adoption of self-initiated nature conservation practices is also positively correlated with the absence of external constraints, the existence of organic agriculture certification, farm size, and the quality of the surrounding area (Runhaar et al., 2018).

Throughout the greater literature, data regarding the number of farmers which have adopted nature inclusive farming, IAFS, or GHG mitigation practices is sparse or overall non-conclusive. One study analyzing the existing governance models of nature-inclusive farming found a relatively small portion of Dutch farmers involved, each arrangement with 5-10% of all farmers (livestock and arable) and covering, at maximum, 20-25% of all farmland (Runhaar, 2017).

3 Theory & Analytical Framework

3.1 Theoretical Approach

For this thesis, the Agricultural Treadmill is adopted through a systems-thinking lens (Meadows, 2008) to frame the challenge of reducing soil GHGs on arable farms in the Netherlands.

Described as an economic model, the Agricultural Treadmill can be illustrated through a causal loop diagram (CLD), with decisions made by individual farmers which impact the greater whole in the long term (Levy et al., 2018). Theoretically, as efficiency increases, the cost per unit decreases and thus farmer income should rise. However, this is not the case in agriculture, as illustrated by the Agricultural Treadmill theory. Created by William Cochrane in 1958 and shared to the world through his book *Farm Prices: Myth and Reality,* the Agricultural Treadmill describes a self-reinforcing cycle, increasing the efficiency of agricultural inputs and machinery while suppressing farmer income and food prices. This in turn forces farmers to become even more efficient and inevitably leads to consolidation of farmland across a landscape. Some argue technological innovation is powering the treadmill's motor (Crews et al., 2018), while others debate a simple cost benefit ratio destruction, with farm costs increasing while income remains stable or even declines (De Buck et al., 2008). Dutch farmers feel stuck in the system, with constant pressure to scale up and further intensify (Van Dijk et al., 2018), as illustrated by the Dutch Arable Farming Treadmill (Figure 3).

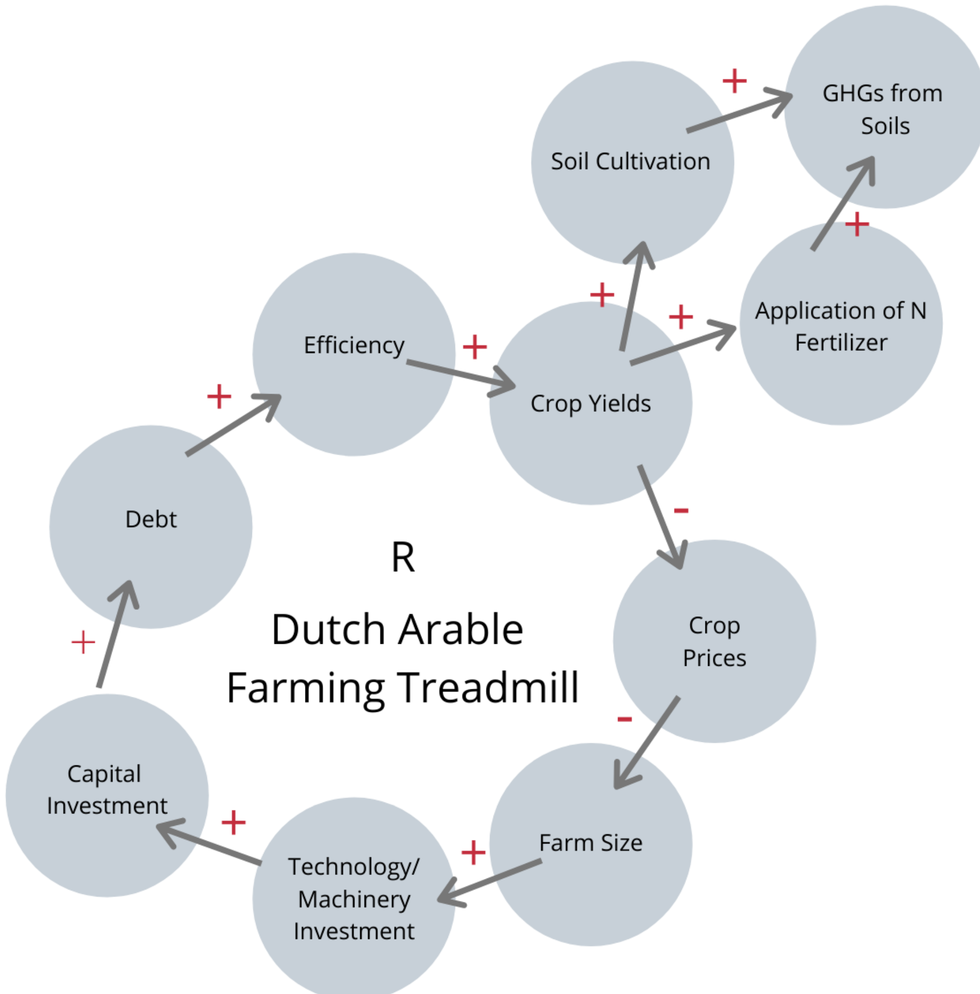

Figure 3. Causal Loop Diagram (CLD), Based on Agricultural Treadmill introduced by William Cochrane (Cochrane, 1958). Illustrated as a reinforcing feedback loop R, the CLD has both (+) positive and (-) negative interactions. When the variables exhibit similar directional behavior, this is a + interaction, for example when one increases, so does the other. In this CLD, technological change and machinery investment cause the farmer to make significant capital investments with large bank loans. In debt, farmers increase their farm efficiency, targeting higher crop yields, often leading to heavier or more intensive physical work of the soil with higher quantities of fertilizer. Soil cultivation and application of nitrogen (N) fertilizer are both positively related to GHGs from soils, CO_2 and N_2O, respectively.
Own Illustration

Transitioning from the theoretical approach to the analytical framework, this research zooms in on the causal arrows between crop yields and GHGs from soils. This relationship is critically linked to on-farm management decisions by Dutch farmers, and hence motivates the need to explore the influence of this behavior through the chosen framework.

3.2 Analytical Framework

Originally inspired by an adoption curve image found in a company report from ALM Intelligence Consulting (Greene, 2018), I created the AD Adoption Curve Framework (Figure 4) to use in this research study. Constructing the framework consisted of combining a literature review, informant interviews, in addition to my own ideas and concepts populated with empirical findings.

In several studies researchers have analyzed the rate of farm practice adoption behavior, ranging from incremental adoption to sudden or immediate transformation. In an analysis conducted within one Dutch arable farming system, farmers revealed feelings of anxiety regarding transformation, as the assumed pace of change is too fast (Meuwissen et al., 2019). Bartkowski & Bartke (2018) also showed that EU farmers prefer incremental changes over longer periods of time rather than large, 'uncertain' transformations over shorter periods of time. The work conducted by De Buck et al. (2008), further confirms this point, as they found partial adoption of Integrated Arable Farming Systems more successful over changing the entire farming paradigm. Based on aforementioned literature, the step design was deemed best fit for modeling farmer adoption over time.

The original image was created to model the adoption of artificial intelligence, and consisted of simply the main upward black arrow with the five stages, from 'Nothing' to 'Advanced Adoption'. I evaluated that these stages would be useful to structure my data, but redefined them in terms of farmer adoption of MPs (Table 2). Additionally, I added an x-axis (time), y-axis (number of farmers adopting MPs) and letters (A, B, C, and D) to represent the steps between each adoption stage. Due to the framework representing the process farmers undergo in moving along the curve, from step A to step D, I called the framework the AD Adoption Curve. This framework will be utilized to map out results from the qualitative analysis and to inform discussion pertaining to the main research aim.

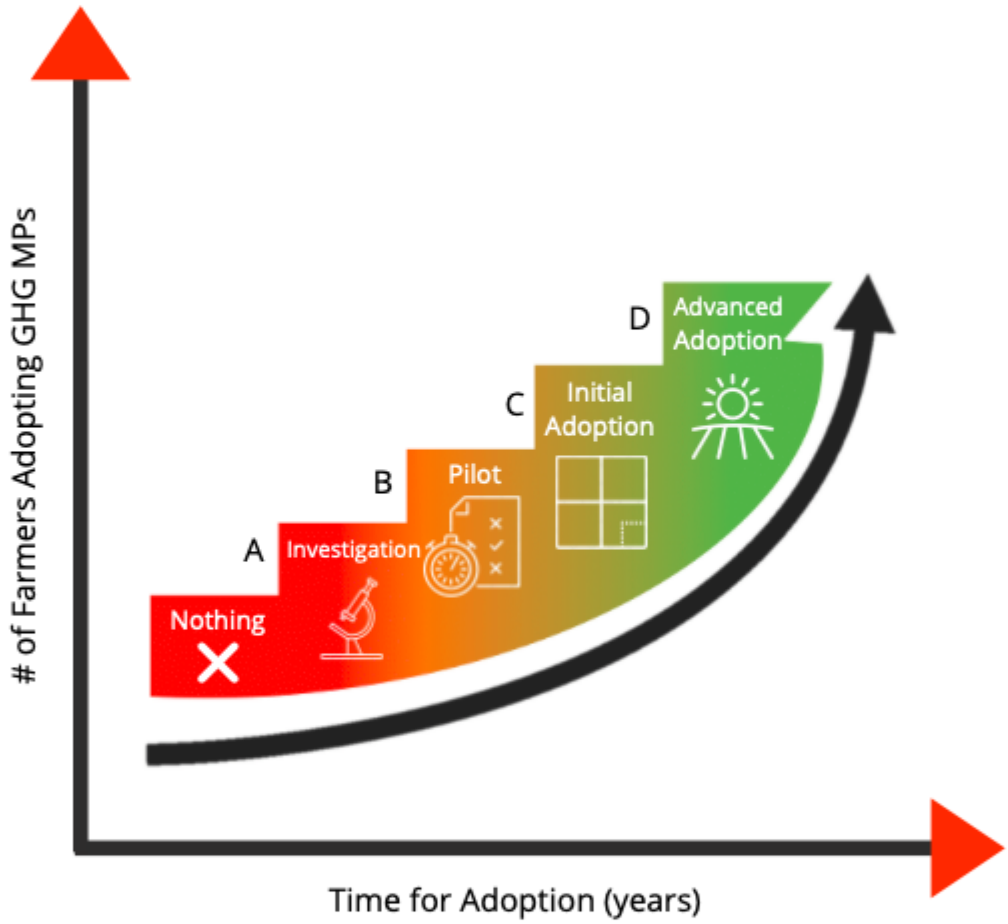

Figure 4. Analytical Framework, Farmer Adoption of GHG Mitigating Soil Management Practices. The considered stages are Nothing, Investigation, Pilot, Initial Adoption, and Advanced Adoption, and the steps as A, B, C, & D.
Own Illustration

Table 2. Descriptions for each stage in the AD Adoption Curve Framework, Author defined.

Framework Term	***Description***
Nothing	Farmer has no interest in the practices; 'not for me' response
Investigation	Farmer becomes interested in the practice and begins to look for more information
Pilot	Farmer tries the practice on the farm, typically through a pilot project coordinated through (environmental) cooperatives or farmer organizations
Initial Adoption	Farmer implements the practice on a relatively small portion of farm
Advanced Adoption	Farmer executes full scale adoption of the practice on most, if not all, of the land in production

4 Research Design & Methods

4.1 Research Design

The research design (Figure 5) includes combining a narrative literature review, informant interviews, semi-structured stakeholder interviews, a thematic content analysis, and finally an analysis within the main framework. The system boundary consists of the agricultural production system in the Netherlands, specifically the arable farming sector.

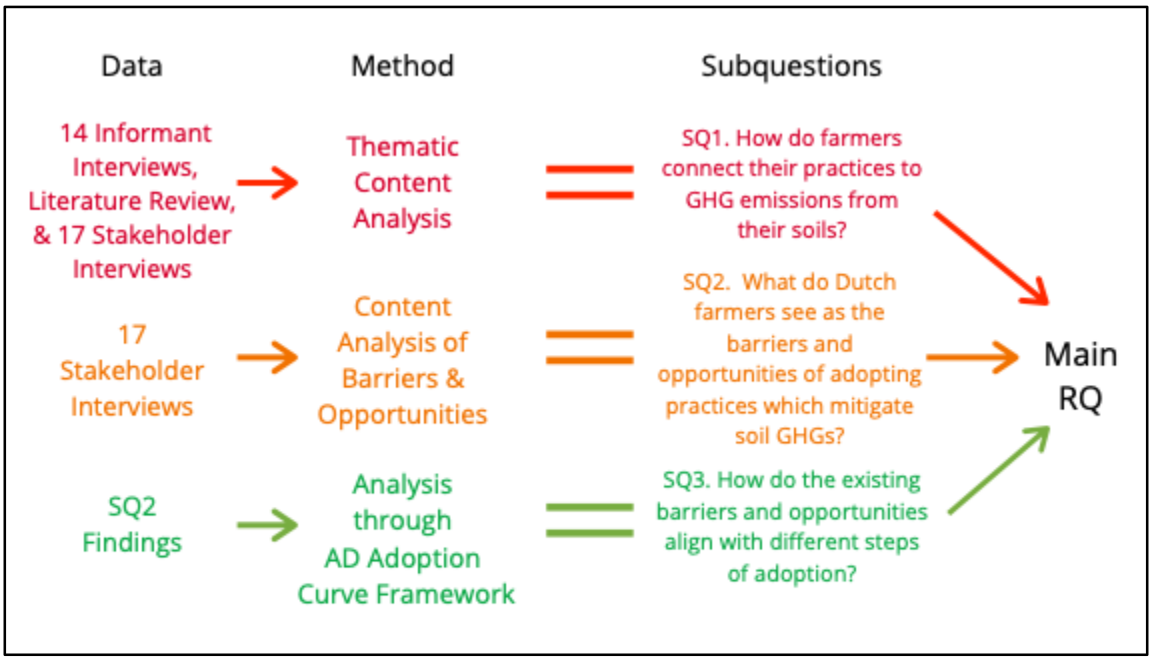

Figure 5. Visual Depiction of Research Design, Each sub-question (SQ) is answered with a specific data-method combination. Main Research Question (RQ): What are the barriers and opportunities that Dutch arable farmers experience in transitioning to farming practices which mitigate GHGs from agricultural soils?
Own Illustration

In order to grasp a full picture of the system, this work narrows in on three stakeholder groups, farmers [FM], policy-makers [PM], and boundary organizations [BO]. Boundary organizations are those which aim to institutionally form a bridge between science and policy to communicate, translate, and mediate between actor groups on either side (Cash et al., 2002). Cash (2016) researched the critical role of boundary work in agricultural systems, noting that decision making in agriculture is complex, as it is subject to shifting technological information and scientific advancements and is inextricably linked to dynamic economic and natural systems.

4.2 Data Collection

Due to the highly contextual nature of challenges in sustainability science, it is critical to work with local experts who have experience within the system. Field work consisted of residing in Wageningen from June 15th until July 26th, 2019. See Figure 8 in Appendix B for the field work calendar. Based on recommendations by my supervisor at Wageningen University, a top agricultural research institution globally, initial stakeholders were identified. Interviews with the informants also provided additional potential stakeholder contacts. When inquiring over email for an interview, informants were asked if they could recommend other experts in this field whom to also contact. Farmers were identified through current Wageningen University students who have family farms, a Google search, and a conference tour hosted at Wageningen University in June 2019. Boundary organizations were also identified through a Google search. The snowball method was implemented to find the remainder of informants and stakeholders to interview (Goodman, 1961).

Figure 6. Field Work Map, Map of the Netherlands with
10 Farm Locations (blue) plus Wageningen University & Research Fields (red),
Google MyMaps, *Own Illustration*

Data collection included conducting 31 interviews, consisting of 14 informants, five policy-makers, two boundary organizations, and 10 farmers. I traveled to seven of the 10 farms (Figure 6). The informants were chosen due to their stated academic expertise, as relevant to the research topic. The informants include academic researchers, an agricultural extensionist, and an agri-business owner located in the Netherlands. The policy-makers work at the national level of Dutch government. The two boundary organizations represent 35,000 agricultural entrepreneurs and employers, and 9,000 Dutch farmers, respectively.

For the farmer group, a mix of conventional and organic farmers (market typology) was used with the aim of identifying shared barriers and opportunities across all Dutch arable farmers. The diversity of farms interviewed (Table 3), ranging from 3.5 to 250 hectares in size, with various crops grown on different soil types, brings a diversity of unique perspectives to the primary data set. The field work map (Figure 6) can be compared with the soil map (Figure 1) to illustrate the spatial and soil diversity of farmers interviewed. As the farmers are not the same 'type' (Table 3) as classified according to Therond et al. (2017) and Buck et al. (2008), I wanted a broad range of farmers to avoid any biases that certain types of farmers might have. Although it can be acknowledged that farm and farmer characteristics could influence the time to move along the AD Adoption Curve, I choose not to focus on the farms individually and instead explore shared characteristics impacting MP adoption. Compared to the 25-30,000 Dutch arable farmers in the Netherlands, I interviewed a typical farmer, with the average farm size of 26 ha (Eurostat, 2013), and growing the main crops (CBS, 2020).

Interviews with farmers, policy-makers, and boundary organizations were arranged, with contact details and communication recorded in a detailed spreadsheet. Supported by suggestions from the informants [II] and a literature review, semi-structured interview questions were created (Table 5 & 6). Interview questions varied slightly between the three stakeholder groups interviewed. For full interview guides reference Appendix C. Each interview began with a series of opening questions to collect information regarding, for example, education, personal background, farm size, or crops grown (Table 3). Written notes were taken throughout each interview as a method of capturing key terms and statements for transcription clarification due to the heavy Dutch accents. These notes serve as the field observations and preliminary results. Interviews were recorded with the aim of transcription, coding, and thematic content analysis.

Table 3. Farmer Characteristics. From 10 farmers interviewed, these seven farmers were chosen and the interviews transcribed. Farmer 2, 7, & 9 were not included as the remaining farmer interviews fully represent the presented opinions. Reference Appendix D for farmer classification details (UK: unknown, ha: hectare).

	Farmer						
Characteristic	1	3	4	5	6	8	10
Size (ha)	4	3.5	50	60	250	120	70-80
Market Typology	Organic	Organic	Conventional	Organic	Conventional	Conventional	Conventional
Farm Typology (De Buck et al., 2008)	Organic Arable Farming	Organic Arable Farming	Conventional	IAFS	Conventional	Conventional	Conventional
Farm Typology, (Therond et al., 2017)	Bio-input-based farming system & Alternative food system	Biodiversity-based farming system & Alternative food system	Chemical input-based food system & Globalized commodity-based food system	Bio-input-based farming system & Globalized commodity-based food system	Chemical input-based food system & Globalized commodity-based food system	Chemical input-based food system & Globalized commodity-based food system	Chemical input-based food system & Globalized commodity-based food system
Farming Generation	First	First	Several, Family Farm	Several, Family Farm	Several, Family Farm	Several, Family Farm	Several, Family Farm
Crops	Mixed Vegetables	beans, soy, high protein grains, and wheat	sugar beets, potatoes, onions, winter wheat, beets and barley	wheat, clover, potato, onion, spinach, pumpkin, maize, parsley	bulbs, cabbage, and potatoes	wheat, sugar beets, canola	potatoes, onions, sugar beets
% SOM	3%	3.4%	3%	4%	UK	2-2.5%	5%
Soil Type	Sandy	Sandy clay	Sea clay	Sea clay	Light sea clay	Heavy sea clay	Clay

4.3 Data Processing

Starting in November 2019, a subset of the interviews were transcribed word-for-word including all policy-makers, all boundary organizations, and seven farmers who represent the full saturation of farmers interviewed. Interviews were transcribed utilizing *HappyScribe* software, cleaned for spelling errors, and uploaded to *Atlas.ti* software. Due to the focus on the perspective of the farmer, the farmer interviews and the two boundary organization interviews (which claim to represent Dutch farmers) were first searched for knowledge of and connection to soil GHGs (SQ1), then coded for the barriers for adoption and opportunities for adoption. Interviews were coded with an iterative process, see Appendix D for detailed analysis steps. The resulting barriers and opportunities are thematically categorized into six main barriers and five main opportunities, listed in no particular order (SQ2). This method is inspired by Long et al. (2016). Due to identifying the temporal aspect as a main barrier, it became an additional component of the framework analysis to be coded in *Atlas.ti.* The opportunities and barriers motivating adoption were placed into the analytical framework (SQ3). In placing the analysis into the framework, the method combines primary (stakeholder interviews) and secondary (literature review) data to justify the placement of the barriers and the opportunities into the AD Adoption Curve.

5 Results

This chapter presents several findings structured according to the three research sub-questions.

5.1 Connecting Farm Management to Soil GHG Emissions

Subquestion 1. *How do farmers connect their practices to GHG emissions from their soils?*
The production of GHGs from arable soils is dependent on several complex variables. For every interview, farmers were asked which practices they do on their farms to reduce GHG production from their soils. I categorized the responses to this question as follows:

a. Several farmers asked for clarification or responded with a confused facial expression until I followed up with "for example, cover/catch crops, reduced/no tillage, etc." listing the previously defined MPs from literature. One farmer stated: "*It's all of course indirect but what I do differently is improve soil quality and therefore incorporate carbon in the soil, I guess. I hope...I'm not measuring it actually you know... the results should be high organic matter content*" [F1]. This farmer is referring to his use of cover/catch crops and reduced/no tillage as an attempt to incorporate carbon in the soil, indirectly reducing CO_2 emissions.
b. Several farmers responded by discussing practices they use to reduce NH_3 gas production, for example injecting their pig manure instead of applying it to the surface. NH_3 is not considered a GHG. N_2O is the nitrogenous gas I am inquiring about.
c. The remaining farmers mentioned reducing their use of farm machinery as their effort to lower combustion emissions. Operating their farm machinery less often, for example, if they adopt no/reduced tillage, would reduce the CO_2 emissions from the internal combustion engine in the tractor, considered indirect GHG mitigation.

None of the farmers specifically mentioned efforts to reduce direct CO_2 or N_2O emissions from their soils. When asked if the Dutch agricultural sector has a role in reducing national GHGs, they reference livestock emissions, seemingly unaware of the potential for reducing GHGs from their arable land. When asking the BOs the role of farmers in reducing GHGs from soils, one informant expressed concern that the farmers need to understand why they need to change, in addition to how their actions impact the rest of the environment, and essentially, their neighbors [II]. They also mentioned a lack of farm advisors with experience with soil health management, and even fewer with knowledge of GHGs from soils in connection to specific farming practices. Farm advisors are an important avenue of information dissemination to farmers.

Overall, most farmers are not aware that their practices relate to GHG emissions from soils. They experience confusion with the concept and associate GHGs from Dutch agriculture with livestock emissions alone.

5.2 Barriers & Opportunities for Adoption of GHG Mitigation Practices

Sub-question 2. *What do Dutch farmers see as the barriers and opportunities of adopting practices which mitigate soil GHG emissions?*

The main results include six barriers and five opportunities farmers experience in adopting MPs. Found in no particular order, each is more or less relevant depending on the step of adoption, which will be explored in the following section. The barrier categories include: personal mindset, nutrient limits with manure challenges, balancing demands, temporal dilemma, practical on-farm challenges, and economic challenges. The opportunity categories include social incentive, new focus on soil health, mitigation as climate adaptation, framing farmers as a solution, and quantification of soil quality.

5.2.1 Barriers for Adoption of Mitigation Practices

Barrier 1. Personal Mindset

Personal mindset refers to some farmers' hesitation to change their behavior. Many farmers express that they themselves or their farmer friends want to continue to operate their farming system as they originally learned and have always done. One farmer talked about stepping out of one's comfort zone, *"You have to be interested yourself first, you have to be motivated differently and you have to step out of your comfort zone and do something new. That's the biggest challenge"* [FM5]. This is linked to their comfort level with how they operate the farm and the perceived risk with changing. Farmers feel they are already doing what they can for sustainability. According to a farmer interviewee: *"I think as arable farmers, for sustainability, we are often far on it I think….We do a lot for sustainability. I don't know if we can do more. But maybe farmers act depending on the price we are paid for it"* [FM4]. Farmers discussed their sustainability efforts to include using organic manure on their farms and their work to become more efficient.

Barrier 2. Nutrient Limits with Manure Challenges

Farmers are conflicted between wanting to increase their livestock manure application (pig slurry, straw mix, cow manure) in order to build their SOM, and the on-farm nitrogen and phosphorous application limits set by policy. One can consider these limits a finite budget, as set nitrogen and phosphorus levels. Several farmers mentioned that they would like more space, a larger budget, for applying manure as it's beneficial for the soil. One farmer states: *"So it's very very difficult, so we hope in the new policy in (the) national government that we… have more space for using manure. Because it's very good for our soil"* [FM4]. None of the interviewees mentioned the distinction of N_2O emissions between the synthetic and organic fertilizers, but most of them stated their assumption that organic fertilizers are better for the environment. A few farmers linked increasing their organic manure application to soil carbon sequestration for the climate, pointing out this co-benefit.

Barrier 3. Balancing Demands

Farmers are struggling to know how to balance and prioritize the environmental demands placed on them. Several mentioned the need to worry about monitoring biodiversity, planting nature strips or field borders, and reducing their farm nutrient runoff and pesticide drift. They feel weighed down with an extensive list of policies to comply with in order to keep their CAP subsidies. When asked about MPs, communicated how they are already doing these other practices for the environment and trying to pay more attention to their soil. According to a farmer interviewee, *"it's difficult, very difficult to monitor everything. Yeah or maybe not difficult, but it's expensive or time consuming"* [FM6]. Monitoring nutrient fate can include expensive technical equipment and requires a long duration of measurements, as the soil structure changes slowly. Trying to focus on yields and pest control, some farmers feel burdened to divert time and resources to pro-environmental efforts, especially when there can be trade offs of various practices. One boundary organization emphasized this point stating, *"And then the farmer says, Yeah what is more important to reduce the amount of methane or is it more important to reduce the amount of nitrogen loss from the land or towards the soil or watch the groundwater or surface water and then it's really difficult for the farmers when they say I'm doing one thing right. But then the legacy of the policy or the society says you're doing two things wrong"* [BO]. Farmers are left without direction as to what pro-environmental endeavor to prioritize and are feeling criticized regardless of their efforts.

Barrier 4. Temporal Dilemma

Every farmer interviewed unexpectedly mentioned the concept of time in some form at some point in the interview. “Time” is referred to as the time needed to change their practices, and in some cases time to witness the results. They expressed a feeling of being expected to change their farming practices too fast, with various time-related pressures. One farmer states, *“But I think… what politicians maybe want or would like is that the process go faster. We go faster to do it”* [FM5]. One farmer interviewee mentioned the need to have time to try out farming practice changes and to fit it in with their farm management. Furthermore, soil is slow to change, as one farmer expresses, *“Lot of positive effects. But it's not that if you start with minimum tillage now that the next year you will have soil full of worms. It takes time”* [FM8].

Several farmers mentioned that they are unsure if policies will change and what chemicals they will be allowed to use on their farm, making long-term planning extra difficult. According to one farmer interviewee, *“I already made the investment you know and that's with a lot of things it's if you can't look five at least five years ahead of you then it's difficult to make a real good plan on what you want to do”* [FM8]. This uncertainty makes changing one’s farming practices seem risky, both socially and financially. For example, several farmers mentioned that they are concerned that the EU will ban the use of glyphosate in the future. This chemical is often used for clearing weeds in a reduced/no tillage system, or used to clear the cover/catch crops before planting cash crops. However, adopting reduced/no tillage and cover/catch crops are two key MPs. Connecting the temporal dilemma to the first barrier of personal mindset, shifting practices from one’s own motivation might take longer, but the adoption will be more permanent. One academic informant confirmed the temporal concern by farmers, explaining that farmers need time to learn about and how to adopt new practices [II].

Based on primary data from the stakeholder interviews, several temporal factors influencing Dutch farmer adoption of MPs are identified. Two distinct adoption timelines (Table 4) were developed moving farmers from ‘Nothing’ to ‘Advanced Adoption’ on the AD Adoption Curve framework. Farmers (a) perceive the adoption curve over multiple scales from two years to four decades, compared to policy-makers (b) which are clearly focused at one scale, essentially an election cycle. Farmers are operating on a scale which is two to three times slower than policy-makers.

Table 4. Adoption Timelines. Years from “Nothing” to “Advanced Adoption” on the AD Adoption Curve framework. These approximations are based on the combination of several average time estimates, in years.

a. Farmers’ perspective timeline: 10-15 years

Duration (Years)	***Temporal Factor***	***Interview Data***
20	Period of use for new farm machinery	[FM3]
6	Period of time between when adopt practice and when see reduced inputs, for instance nitrogen	[FM5]
2	Period of reduced yields with initial adoption	[FM8]
4-5	Period between official soil tests	[FM1/FM6]
10-20	Opportunity for a change of management, younger generation taking over the farm	[BO/PM]
30-40	Period of farm under one’s management	[BO]
15	Period of time it takes to achieve a 1% SOM increase	[BO]

b. Policy- Makers perspective timeline: 4-7 years

Duration (Years)	***Temporal Factor***	***Interview Data***
4	Dutch Ministry of Agriculture changes leadership and hence policies	[FM3]
5-7	Project funding length, Agri-environmental schemes (AECMs)	[PM]
10	Dutch Climate Agreement to meet the targets of climate-friendly land use with ‘carbon storage in soil and vegetation’	[PM]
3	Project funding length, farmer cooperative projects	[BO]

Barrier 5. Practical On-Farm Challenges

Almost every farmer interviewee mentioned some form of practical challenge to shifting their practices to MPs. They mentioned these challenges as obstacles between wanting to adopt a new practice and this practice not working on their soil, or with their crops or available machinery. One farmer states, *"It's difficult to do to the seeding if you had the minimum tillage. But I'm talking about my soils it could be very different in other soils"* [FM8]. Farmers believed that only certain crops are ready for the implementation of reduced/no tillage systems [FM4]. Farmers also expressed challenges with fertilization and weed management. One farmer discussed the internal debate between organic and synthetic fertilizers and the need to balance the speed at which the nutrients are released with the soil moisture while avoiding soil compaction from machinery [FM5]. Several farmers mentioned weed management as the main barrier, specifically in reduced/no tillage systems. Linked to the previous barrier, the temporal dilemma, many farmers expressed their frustration over the EU and national policies, mentioning that policy-makers design policies and expect farmers to develop the solutions without adequate resources and support in unrealistic time frames [FM10].

Farmers expressed their frustration with the evolving agricultural policies, one farmer states: *"And farming is getting harder and sometimes rules are made up that we don't understand… We have a guest of the politics in the building and we explain something and they're like flabbergasted"* [F10]. This farmer refers to the surprise policy-makers experience when farmers explain how their farming operation works, revealing the lack of practical farm knowledge many decision makers have. For an example of this disconnect, although not directly related to GHGs from agricultural soils, farmers expressed their confusion over the recent political decision to ban chemical coated seeds. They shared that now without the coated seeds, their pesticide application rate is vastly larger and is not as effective.

Barrier 6. Economic Challenges

Almost every farmer mentioned the lack of compensation for investing in the environment. Some mentioned that despite this point they still consider MPs important and try to adopt them, but monetary payments or compensation would increase the scale and degree to which they adopt MPs. A few interviewees communicated feelings of inequity in that they pay the costs while society receives the benefits. One farmer interviewee states, *"So in fact you take risks but you don't see added value in the products you produce. That's the difficult part. If you would have added value, direct added value and you would get, for example, to sell your product for a higher price or you get carbon credits because you don't* *plow, something like that"* [FM5]. Currently, farmers only receive added value if they completely transition to biological or organic farming, with no compensation for anything in between [FM10]. One informant emphasized this point outlining that if farmers don't benefit by increased yields or reduced costs, they need to be economically compensated to adopt MPs [II]. This compensation would better ensure the ability of farmers to have a profitable livelihood. Farmers already endure such hard work for such low profit margins, that attracting the next generation of farmers is a difficult task. Several family farmers jokingly asked if I was interested in taking over their farm, as their own children were not interested. They explained that there are so many rules farmers have to follow these days, and it's a tough job without the biggest paycheck. One young educated farmer stated, *"So if you can indeed, if we can crack the code and you know, develop a way of farming where it's fun again and still economically viable"* [FM3].

5.2.2 Opportunities for Adoption of Mitigation Practices

Opportunity 1. Social Incentive

Several farmers mentioned they became interested in MPs by seeing neighbors testing them, by visiting a practice farm nearby, or attending a field day. Another, relatively new platform to spread social incentive throughout the farming community is social media and online magazines or newspapers. One farmer states, *"I got interested by reading articles"* [FM4]. Farmer magazines are increasingly talking about sustainability. During a farmer interview in which we were discussing this topic, a farmer said, "Let's do an experiment." The farmer opened the news application on his iPhone, with the Dutch agricultural news marked, and counted how many articles discussed environmental sustainability in some form. He counted almost half of the articles as sustainability related [FM3].

Opportunity 2. New Focus on Soil Health

Almost every farmer mentioned that soil quality and health is increasingly common as a discussion topic within farmer communities, one farmer stating, "*I will tell you, the last few years we are, you know, getting aware*" [FM6], when discussing his attention paid to SOM. One interviewee mentioned that the biological movement has led even conventional farmers to get interested in soil health [FM10]. This is encouraging, as it means awareness of soil health is being experienced by farmers in a diversity of categories (Table 3), and that MPs may have an opportunity to extend beyond biological farmers. This awareness might be connected to the relatively recent inclusion of sustainable soil management beyond soil's importance for maximizing yields, in vocational training education at the HBO and MBO levels [BO]. During the interviews, soil health was also discussed in the context of preparing one's farm for the future and protecting one's inheritance, *"I think I'm more aware of the soil...in the beginning you try to maximize yields, but that's not always the good way to go for the future. Because your next children far far away, they have also use the soil in a good way"* [FM4]. This farmer is referring to the importance of maintaining soil quality so that the land can feed and provide for the next generation. While the initial inclination may be to think short-term about maximizing crop yields, many farmers also consider the long-term impact of this productivity on soil health.

Opportunity 3. Mitigation as Climate Adaptation

Without any direct inquiry, several farmers mentioned their shift to adopt MPs as a way to better prepare their farms for unexpected weather patterns; on-farm climate adaptation. MPs that build SOM and/or preserve soil structure provide many co-benefits for adapting to climate change. One example of this synergy is the adoption of reduced/no tillage. One farmer states, *"One of the reasons we stopped plowing was to build a robust system and what I experienced is that we have a very heavy rain shower...There's a fear of the fields to flood. But then within hours all the water is gone. So it's working. … the climate changes every year. We have to be ready for that. I think it is, might be getting more extreme"* [FM5]. With reduced/no tillage, a practice that conserves soil structure and soil carbon, the soil can absorb standing surface water under a heavy rainfall, reducing crop damage and the time it takes to get in the field for planting. Another farmer mentioned a realization that beyond problems with *"get(ting) the water off your fields"*, he also noticed that *"When there is no rain, then you see you've got more problems with the drought"* [FM8]. Farmers who communicated changing their farming management system because of intense weather patterns (heavy rain events, and drought need to irrigate) passionately discussed their adoption without realizing they adopted MPs for climate adaptation. Finally, one interviewee commented that reduced/no tillage, although not the best practice for maximizing his yields, was helpful in buffering the flux of yields in especially wet or dry weather.

Opportunity 4. Framing Farmers as a Solution

There exists an opportunity to frame farmers as a solution to climate change mitigation efforts, as opposed to the problem. Several of the farmers mentioned their hesitation to turn on the national news channel due to what the media might be saying about farmers polluting the environment. One farmer shared a story of attending a child's birthday party and being reserved about sharing that he is a farmer due to the concern that people may see him in a negative light. This reveals the powerful role of the media to influence the feelings and behaviors of the farmers. This power could be utilized instead for positive media attention and recognition, focusing on what farmers do to feed society and their efforts to mitigate soil GHGs. One farmer states a *“Need to focus on the front-runners”* [FM5] who are working hard to reduce their environmental and climate impact, with a boundary organization saying, *“But in our way we say farmers have the future, farmers have the solution to a lot of problems. For example climate adaptation, mitigation...”* [BO], referring to the ability for arable farmers to store carbon in their soils.

Opportunity 5. Quantification of Soil Quality

One of the reasons that soil quality is rarely found to be measured and translated into financial benefits is the difficulty to quantify beyond a soil lab test conducted only every four years. Stemming from one of the organizations and one young farmer interviewed, they excitedly discussed the novel developments for monitoring and measuring soil quality on-farm. This opportunity could serve as a direct means to receive financial payment. One example is the Soil Passport tool, *“I think the solution is to give insight in what you're doing at the moment and to quantify it. And that's why I preach towards the soil passport because a lot of farmers actually are working in goods soil management”* [BO]. This development of quantification may translate soil health into a language in which Dutch farmers resonate with. During an informant interview with a company selling no-tillage farming machinery to Dutch farmers, the interviewee relayed his experience in working with Dutch farmers compared to other EU farmers. He explained that Dutch farmers are very quantitative and need to see the evidence in the data before committing.

5.3 Applying the Framework

Sub-question 3. *How can the existing barriers and opportunities be mapped onto the AD Adoption Curve Framework?*

The following section presents the AD Adoption Curve Framework (Figure 7), including justifications for the placement of barriers and opportunities within specific steps. Most adoption factors fit at certain steps along the curve (as based on stakeholder interviews), with one barrier standing out as fundamental to the entire curve.

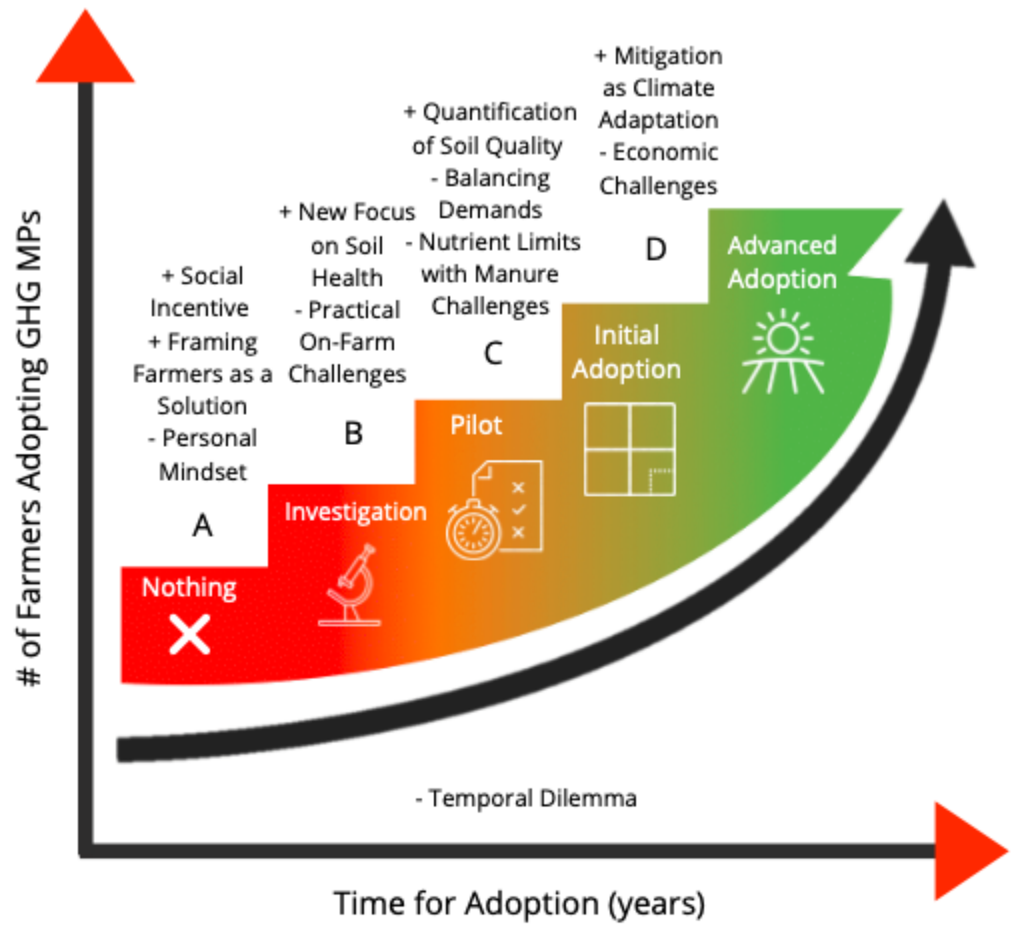

Figure 7. AD Adoption Curve Framework with Results. The six barriers and five opportunities for MP adoption, identified in SQ2, are placed at a specific step (A, B, C, D) along the curve, with one barrier applicable to all steps and can be found underneath the curve. The plus signs (+) refer to opportunities and the minus signs (-) refer to barriers. *Own Illustration*

Step A: From Nothing to Investigation

Getting farmers originally interested in MPs requires heavy weight on social drivers. Farmers need to have a mindset open to exploring new options for their own farming operation, *"and some (farmers) are saying well it's very nice that you do it, but it works for you. But I'm pretty sure it wouldn't work for me"* [FM8] (Personal Mindset Barrier). However, opportunities to get farmers engaged in exploring MPs can be found amongst the farmer community (Social Incentive Opportunity) as well as within the broader news and media outlets (Framing Farmers as a Solution Opportunity).

Step B: From Investigation to Pilot

Bridging the gap between initial interest in MPs and trialing practices on one's farm requires a combination of awareness and understanding (New Focus on Soil Health Opportunity), in addition to the tools to push beyond the practical challenges with weeding, planting, fertilizing, and harvesting, which can come with on-farm implementation (Practical On-Farm Challenges Barrier).

Step C: From Pilot to Initial Adoption

If farmers had the ability to measure and see that their soil quality improves while piloting, they could be more likely to continue the MP past the test period (Quantification of Soil Quality Opportunity). However, it becomes challenging for farmers to prioritize MPs over other pro-environmental practices (Balancing Demands Barrier). This is in addition to the nutrient budgets they face potentially being overdrawn if they expand this pilot scale to an initial adoption level area on their farm (Nutrient Limits with Manure Challenges Barrier).

Step D: From Initial to Advanced Adoption

In the final step of full farm adoption, the entire farming system is under revision. Farmers must consider the costs associated with scaling (Economic Challenges Barrier). One farmer states: *"And every year we are doing a little bit more. Because in the first two years you have, some reduced yields"* [FM8]. One incentive which could justify the advanced adoption is the need to build a resilient farm with high climate adaptation capacity, in order to maintain yields under heavy rain showers or fear of flooding (Mitigation as Climate Adaptation Opportunity).

From A to D:

Fundamental to transitioning along the entire curve is the speed of transition that the farmers are comfortable with compared to the expected or desired speed by other stakeholders (Temporal Dilemma Barrier).

5.4 Summarizing Main Findings

Main Research Question. *What are the barriers and opportunities that Dutch arable farmers experience in transitioning to farming practices which mitigate GHGs from agricultural soils?*

This research found a missing link between farmer practices and GHGs from their soils, due to a lack of awareness and knowledge. From the Dutch farmer perspective, I categorize and identify six main barriers and five main opportunities to adopting MPs. Most of these themes fit at certain steps within the AD Adoption Curve Framework, with one overriding theme extending throughout the entire curve (Figure 7). In combination, the analysis provides several leverage points, or key changes to the system for large scale impacts resonating throughout the entire Adoption Curve (Meadows, 2008), with optimism for moving all arable farmers from 'Nothing' to 'Advanced Adoption' of MPs.

6 Discussion

The main research findings are contextualized within the existing literature and the implications of the six barriers and five opportunities are discussed. This is followed with a solution-focused conclusion, stating leverage points for systemic change. Finally, the study limitations and future research concepts are outlined.

6.1 Within the Dutch Landscape

The evident complexities experienced by arable farmers in the Netherlands challenge their ability to adopt MPs. At the policy level, policy-makers must prioritize. They must put factors contributing to agricultural climate mitigation in black and white boxes, with one policy maker mentioning the difficulty of translating science into policies. In practice, the Dutch Circular Agriculture Initiative, supported by the Climate Agreement, could play a central role in motivating MPs. In targeting circular nutrient cycling, it is expected that a greater share of organic fertilizer, over synthetic, would be encouraged. As illustrated by Velthof et al. (2002), synthetic fertilizer is shown to have higher N_2O emissions than organic. Organic fertilizer, although now mainly coming from livestock manure, could come instead from food waste or green composting. Or, as mentioned by both a conventional family farmer and a first-generation farmer with a master's degree, the use of human manure for turning the linear chain into a circular system. This would capture the nitrogen at the 'end' of the chain, process it, and return it back to the farm as fertilizer.

Currently, policies which explicitly address GHG mitigation from agricultural soils are non-existent. Neither the Nitrate Directive, Water Framework Directive, nor other EU directives contain specific soil GHG mitigation advice or policies for arable farms. There has been a political focus on nitrogen in the form of nitrate (NO_3), a water-soluble compound polluting groundwater and surface water (EU Water Framework Directive) or nitrogen in the form of ammonia (NH_3), a gas classified as air pollution (National Emissions Ceiling Directive). However, policies aiming to address nitrogen in the form of N_2O, a powerful GHG, are lacking.

Giving more power to the member states, the CAP revisions currently underway could provide the Dutch government with increased agency in financially compensating farmers for adopting MPs, with potential funding for managing nutrients and building SOM, in addition to the renewed development of a Farm Advisory System. The time period between the EU approval of the 2020 CAP reform and when farmers could see changes to their individual farms is expected to be 2022 or 2023 (M. Debernardini, personal communication, March 19, 2020), which would provide farmers with more time for adoption transition. This reform could dramatically enhance the discussion around motivating Dutch farmers to adopt farming practices which mitigate GHGs from their soils.

Complimentary to farm management, including soil cultivation and nutrient application, the natural factors of soil pore water content and temperature, determine emissions (Oertel et al., 2016). Emissions will also be different between the two dominant soil types, sand and clay (Jarecki et al., 2008). Furthermore, the shifting groundwater levels and hence soil water content, due to impacts from sea level rise, may complicate the connection between farmer practice and GHG emissions (Bowles et al., 2018). This emphasizes the urgent need to create localized plans to help farmers shift their practices, with co-benefits for GHG mitigation and adaptation, centered on building resilient farming systems. Confirming previous findings by (Runhaar et al., 2016), Dutch farmers are feeling stuck within the existing system. Regardless of their internal motivation to shift their practices (Bartkowski & Bartke, 2018) or personal mindset, there is a lack of farm advising for soil GHGs, leaving farmers without assistance. Despite current societal awareness of climate change, my research reaffirms past work by Oenema et al. (2001), finding that farmers are unaware of soil GHGs or measures to reduce them from their farms, requiring the tools, information, skills, and context-specific management assistance.

My research results parallel conclusions from other farmer pro-environmental adoption literature, with personal mindset towards behavior change (Runhaar et al., 2016) as a main barrier, and social incentive (Kuhfuss et al., 2016) as a promising opportunity. If farmers think that the majority of farmers are, for example, adopting MPs, they would be increasingly motivated, known as the 'nudging effect' (Kuhfuss et al., 2016). Meuwissen et al. (2019) also found Dutch arable farmers experience "frustration about lack of long-term and stable policies", "performance of public goods is relatively poor", and "challenges which cannot be influenced are perceived to be most important (media attention, impact of pesticides)". As De Buck et al. (2008) identified, the adoption of IAFS, another pro-environmental practice, is a spectrum of sustainable farming practices, difficult to put into one silo, since most farmers are at least doing one of the practices considered under IAFS. This characteristic remains true for the adoption of MPs, as there exists a menu of practices (Table 1).

In order to meet national GHG mitigation efforts, there exists a need to surpass low adoption rates found for AECMs (Van Dijk et al., 2016) and nature-inclusive farming (Runhaar, 2019). The agricultural sector needs large-scale behavioral changes, shifting all arable farmers along the AD Adoption Curve.

Although the temporal aspect of Dutch farmer adoption is largely missing from the literature, a global model was developed by Kuehne et al. (2017) which models farmer uptake of new agricultural practices and found actual 'time to peak adoption' to vary between 6-22 years, similar to my findings of 10-15 years. Additionally, researchers De Buck et al. (2008) have acknowledged a temporal delay between when farmers learn about an innovation and the time when they adopt it, an economic concept called Innovation Adoption Lag.

6.2 Implications of Findings

6.2.1 Analyzing the Curve

Motivating Dutch arable farmers from 'Nothing' to 'Advanced Adoption' consists of several steps, each requiring different tools from policy-makers, farmer organizations, and from within the farmer community itself. In the early portion of the adoption curve, farmers must gain social awareness of soil GHGs, how these farmers impact this emission production through their soil management, and finally how to overcome the existing challenges with changing their farming system: weeds, nutrient application, and seeding crops. In the latter half of the curve, political and economic challenges surface which require risk potentially without market-based payment.

As one can see from the framework, economic incentives or farm advisory services alone will not move all 25,000 Dutch farmers along the curve. These farmers will face various barriers at each step and this will ultimately slow or prohibit MP adoption. All barriers need to be tackled if farmer adoption is to be transitioned. It is not enough for most of the Dutch farmers to reside on the beginning of the adoption curve, as climate change mitigation requires a concerted effort reaching all 1.01 million hectares of arable land. If we know how existing Dutch arable farmers are distributed along the curve, we would know where to focus immediate efforts.

Attempting to link the farm typology identified in (Table 3), a pattern could not be generated by my data. The data cannot suggest that farms with certain typologies, for example conventional compared to biological, are more or less 'best' in adopting MPs. Each farm has the potential to shift towards practices to mitigate soil GHGs and become a more sustainable farming system.

Bartkowski & Bartke (2018) and Meuwissen et al. (2019) illustrate that farmers prefer incremental changes over longer periods of time rather than large, uncertain transformations; therefore the step-by-step framework is fitting, and the governance of this adoption shift should be flexible to allow for step-by-step adoption of practices. With an adaptive governance approach, it becomes possible to test policy ideas, remove those which deem ineffective, and move forward those which work, while continuing to ask the users for feedback, keeping arable farmers central to the conversation (Folke et al., 2005).

6.2.2 Tackling Barriers & Enhancing Opportunities

Four barriers which are especially relevant to **motivate movement along the MP adoption curve**:
(1) farmer unawareness of GHGs produced from their soils, (2) economic challenges, (3) practical on-farm challenges, and (4) reconciling time scales. Each is complimented with respective opportunities for addressing the barrier or continuing the discussion.

My research findings reveal a **lack of awareness by Dutch arable farmers of the connection between their farming practices and GHGs from their soils**. It is evident there exists a complexity of factors, both natural and farmer management, which combine to produce soil GHGs. Some farming practices have tradeoffs between CO_2 and N_2O mitigation, or pollution swapping between NH_3 and N_2O (Velthof et al., 2002). Farmers cannot visually see or measure the gases from their soils, and they are surrounded by media and political priority placed on mitigating livestock emissions. For farmers, prioritizing between several environmental concerns is difficult, especially with a knowledge gap of the entire carbon or nitrogen cycle, and the need to already place attention towards farm biodiversity and groundwater pollution, amongst other social capital. Furthermore, if farmers don't understand the reason behind the policies they are told, in example, if they are not communicated the reason for adopting cover/catch crops as a means to soak up excess nitrogen in the soil before it can volatilize, they are less likely to move towards 'Advanced Adoption' of the practice.

From the farmers' perspective, they struggle with the recurring theme of **needing to be economically compensated**. Since many arable farmers grow crops which are sold to factories to end up as sugar in your soft drink or fries with your favorite dip, it is difficult to gain added market value on growing crops with

MPs. The costs are faced by farmers, however, most benefits are felt by society. Existing funding 'pilot' programs for these practices are short term, farmer cooperative projects lasting three years and CAP AES projects lasting five to seven years. This funding ends once the project or program ends and the farmer is left without funding to offset additional costs or sacrificed income into the future. Some informants shared that if farmers can reach higher yields under these MPs then they wouldn't need additional payments, however the yield gap in the Netherlands is already very narrow for most crops [II]. CAP subsidies could pay for the environment, food production under MPs could have a price additive, or public goods could be incorporated into the market, for example with carbon credits tied to tillage practices.

Furthermore, combining the knowledge that many farmers think in quantitative terms with new methods to quantify soil quality, several economic incentive programs could become a possibility with opportunity for measuring and receiving appropriate payment. Performance indicators, stemming from the Circular Agriculture Initiative or connected to loan discounts from Rabobank, an initiative started with dairy farmers, could be linked to the ability to quantify soil health. With the CAP reform comes the greening of the CAP. In current political discussion, farmers who comply with enhanced conditionality will then be able to apply for pillar 1 funded eco-schemes ("The environmental", 2019). In practice, the Netherlands could establish an eco-scheme for cover/catch crops, a MP, in which Dutch arable farmers are paid by the number of hectares in which they adopt this practice for one year. Some farmer interviewees mentioned that despite the fact that they do not get paid for MP adoption, many still find them important to adopt, but would increase the scale and degree to which they adopt if receiving additional payments.

Farmers need the tools to **overcome practical on-farm challenges.** They need advising expertise for how to navigate the practical implications, or they require the platform to collaborate with neighboring farmers who share the same soils and climatic conditions. One tradeoff concerns the nutrient application limits and the addition of organic manure to soils for improving quality and sequestering carbon. Several informants and policy-makers made clear that the agricultural sector is one of the only sectors which can 'reverse' or 'slow' climate change by sequestering carbon in the soils [II/BO]. This manure tradeoff, amongst previously mentioned conflicts concerning weeds and fertilizer application, complicates farmers' ability to decide the best choice in regards to soil management for mitigating GHGs. As a way for farmers to escape the treadmill, to reduce the need to invest in their own machinery with large bank loans, they can hire contract work to plant cover/catch crops, use reduced/no tillage machinery, or to plant seeds through soil residue. One of the farmers interviewed discussed the increased demand for contract work to plant cover/catch crops [FM3]. Another option is to create a collective of farm machinery fit for executing MPs, which is shared and cared for amongst its members, lowering the financial burden and risk for each farmer.

As illustrated, Dutch farmers are showing increasing attention to their soil quality and health, however may not have access to advisors with the appropriate knowledge, or may not clearly understand the science behind their respective farming practices. One idea could be to develop a boundary organization of national Soil Health Extensionists, one for each province so that the advice can be soil and climate specific. The public program could consist of 12 boundary agents plus the development of a future farmer program with university students who could assist Dutch arable farmers with addressing practical farming challenges associated with MP adoption. Useful knowledge by boundary organizations must be credible, salient, and legitimate in order to effectively bridge scientific or technical knowledge to decision making (Cash et al., 2002), hence it will take time for these boundary agents to establish trust in the farmer community. Additionally, the newly established Dutch agri-environmental cooperatives could extend their definition of ‘farmland biodiversity’ to include soil biodiversity, linked to soil health.

Reconciling time scales between what farmers perceive as a comfortable time to slowly shift their practices and what policy-makers expect from farmers, is critical. There is a time lag between when farmers adopt cover/catch crops or reduced/no tillage and when they 'see' benefits, for example lower input costs or soil water infiltration during heavy rain events. It also becomes challenging if farmers are unsure of when certain policies will change in the future. Farmers need time to transition or they need the tools to speed up the process.

Farmers perceive movement across the adoption curve over multiple time scales, 10 to 15 years up to four decades, while policy-makers see farmer adoption happening at one clear scale from four to seven years, essentially an election cycle (Table 4). There exists a need to strike a sensitive balance between enhancing the speed of MP adoption for the benefit of climate change mitigation and the autonomy many Dutch farmers desire. This also requires a combination of self-motivation by farmers to be interested in adopting MPs and the economic and political systems which provide them the tools, while working to address adoption barriers that are slowing their movement through the AD Adoption Curve.

Opportunities exist with farmers experiencing a shifting discourse towards a renewed interest in soil quality and soil health. Taking this one step further, is the need to prepare their soils in the face of climate change. Increasing focus is placed on the need to build a resilient farming system, for example by adding manure or other organic matter to arable soils, in order to improve the soil water holding capacity (Smith & Olesen, 2010). Reduced/no tillage, a MP, maintains soil structure, while cover/catch crops, also a MP, encourages water infiltration, both practices having co-benefits for GHG mitigation and adaptation. Under heavy rain events, water can infiltrate quicker and minimize topsoil erosion, while in drought conditions, rather than having to irrigate with salt-contaminated water, water is more effectively held in the soil. This also relates back to the barrier found in the research analysis: manure application with nutrient limits. Further emphasizing the need for farmers to understand the inherent trade-offs in balancing farm productivity with mitigation and adaptation efforts, especially relevant to the increasingly uncertain weather conditions associated with climate change.

Other actors in the system can work to enhance adoption opportunities, highlighting the positive work Dutch arable farmers are executing to 'do their part' for climate change mitigation. Positive communication can reward those who are taking the extra risk and costs in order to reduce their farm's climatic impacts. Kuhfuss et al. (2016) found that farmers acknowledged for their contribution to the environment or a better quality of life are more likely to maintain practices without payment, in addition to the importance of communication framing, positive messages are more effective. In practice, this could materialize as media showcases of farmers working to protect the environment and reduce their GHG emissions, a tool of social recognition (Fraser, 2000) to show appreciation to those farmers and incentivizing the rest to become interested.

6.2.3 Relevance for Science & Practice

Key leverage points for enhancing the adoption of MPs:

1. Need to improve farmer knowledge of C and N cycles in connection with farming practices
2. Need to get an idea of where farmers are located along the AD Adoption Curve
3. Need to provide farmers with the tools: policies, economic incentives, farm advisors
4. Need to speed up farmer movement along the adoption curve timeline by removing existing barriers and focusing on exciting opportunities: media recognition and soil health education
5. Can use these findings as inputs for scenario analysis and policy development

6.3 Future Research

If the treadmill of Dutch arable farming continues business as usual, intensification could lead to drastic climatic and environmental consequences. Current political discussion is focused on peatlands and livestock, but eventually the agricultural sector as a whole will have to make a choice. Efficiency has a threshold and land is limited. Can the sector approach a form of sustainable intensification, or should extensification with shifting to knowledge over product export be an option? What is the relationship between intensity and efficiency? Some farmers claim they are already sustainable because they are efficient, but does efficiency imply sustainability?

Moving forward with this research, an interdisciplinary approach is needed, incorporating natural and social science questions. To begin is the need to confirm the trade-offs and synergies between N_2O and CO_2 soil emissions, and more specifically for the soil found in the Netherlands. Bridging these questions to the social science questions is how to translate technical knowledge of GHGs from agricultural soils to farmers, or how to move farmers from 'Nothing' to 'Investigation' on the adoption curve. Building on the identified barriers should be future research which explores each in depth, where do the barriers stem from and why do they exist in the current system? Within the framework analysis, further research should be conducted regarding moving along the AD Adoption Curve. By narrowing in on each step, A, B, C and D as separate research questions, the unique factors affecting each can be addressed.

Future work should aim to fill other knowledge gaps as identified by this research including the distribution of farmers along the Adoption Curve, how to reconcile temporal scales between stakeholder groups, namely farmers and policy-makers, what the role of the CAP reform will have on MP adoption in the Netherlands, and how to reconcile moving individual farmers along the curve with the larger discussion surrounding a system transition in the agricultural sector? Furthermore, research should be conducted on factors which could reverse the Adoption curve, leading farmers to go from D to A. This could include if certain chemicals are banned, or an economic downturn tightens profit margins, or as increasing impacts from climate change unfold.

Future changes to the social, political, economic, and natural landscapes will impact the ability of Dutch farmers to mitigate GHGs from their soils. Four factors in particular emerged and should be further explored. (1) Consolidation, if fewer Dutch farmers will individually manage more land, is this worse or better for MPs? (2) Technology, can specialized farm machinery improve nitrogen use efficiency and allow for weeding, seeding, and fertilization with less soil disturbance? (3) Future farmers, will more farms shift from family farms to company management, do first generation farmers come with new methods, educational backgrounds, and ideas for farming? (4) Market shifts, will the Netherlands see an emergence of local and regional markets or will arable farmers continue to produce mainly for the world market?

At the end of the story lies the intrinsic challenges of addressing global climate change. As our planet has one shared atmosphere, climate change is an accumulation of GHGs emitted from agricultural soils spanning the globe. Dutch agriculture is seen as an example of 'successful' production due to its high yields and sophisticated use of technology, as a developed country with an arguably strong influence on other countries, India for example. What role does Dutch agriculture play in global agriculture? If not produced in the Netherlands, will food be produced elsewhere with worse environmental impact?

6.4 Research Reflections

This research is the first qualitative study conducting semi-structured interviews to explore arable farmer adoption of practices aimed at soil GHG mitigation in the Netherlands. As an exploratory research study, key problems are identified and the solution conversation is opened. The chosen research approach, semi-structured interviews, is appropriate for understanding the opinions and perspectives of the stakeholder groups, however is limited in determining causal relationships and is impossible to scale these findings from 10 farmers to the 25-30,000 existing. Although there is a diverse variation of arable farmers interviewed (Table 3), this research is based on a limited sample and does not represent the perspective of every Dutch arable farmer. Furthermore, this research is unable to quantify the amount of Dutch farmers using MPs or where the 25,000 farmers lie on the AD Adoption Curve. This is a problem for setting indicator-based policies and the ability to monitor progress towards targets.

Possible bias includes only interviewing farmers who have basic English speaking proficiency, or those who feel comfortable being interviewed. Some interviewees struggled to find the English equivalent for a Dutch word, so there is a possibility of meaning lost in translation. For two of the farmer interviews, I had a Dutch university student along to translate any clarifications. Implicit bias is introduced with this research approach, as I am interviewing several people which already have a connection to a research institution. These farmers are potentially more clued in than an average farmer, or are more open to external input. Utilizing the perspective of the Dutch farmer, this shifted my bias towards focusing on their opinions, over those of other system actors. This prevented the research to take an agricultural sector viewpoint, as I chose one stakeholder to view the system through. Reflecting further, it would have been valuable to have interviewed BO-Akkerbouw, the arable farmer organization, and it would have been beneficial to have all farmer interviews on-farm, as three were conducted off-farm due to availability and travel distance.

7 Conclusion

This research sought to identify the barriers and opportunities experienced by Dutch arable farmers in the adoption of MPs which could inform evidence-based and policy-relevant change. Utilizing semi-structured interviews, this work aims to fill the scientific knowledge gap with a sustainability science approach. Main challenges of MP adoption include unawareness by farmers of if and how GHGs are produced from farm soils, overcoming personal mindset and practical on-farm barriers, navigating existing political and economic systems, and reconciling temporal frameworks amongst stakeholders. In order to motivate all 25-30,000 arable farmers towards advanced adoption of MPs for climate change mitigation efforts, these system actors need technical advising and economic tools. There exists momentum to support farmers through the power of media recognition and shifting discourse, technological tools to measure and track soil quality, climate change mitigation and adaptation synergies, as well as the future ability for the Dutch government to provide financial compensation through the revised CAP. Several leverage points exist and should be prioritized in order to motivate adoption of MP and overall systemically slow the Dutch agricultural treadmill. This research can improve the knowledge base on how to spark the ignition for climate change mitigation on agricultural soils and serve as a source of excitement for a farming system full of healthy soils and thriving rural livelihoods.

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9 Supplementary Material

9.1 Appendix A. Technical, GHG Production from Soils

How are GHG emissions produced from agricultural soils?

The central actor in turning carbon and nitrogen in the soil into GHGs is the complex world of soil life, microorganisms in the soil composed of bacteria, actinomycetes, fungi, algae, and protozoa. These microbes convert solid or aqueous forms of nitrogen and carbon into gaseous forms which escape into the atmosphere (Oertel et al., 2016).

How is nitrous oxide (N_2O) produced from soils?

- Most of the N_2O emissions from soils derive from the denitrification process under anaerobic conditions, with a water filled pore space (WFPS) greater than 50%. The remaining N_2O stems from the nitrification process under aerobic conditions (Oertel et al., 2016).
  - Denitrification: NO_3- to NO_2- to **N_2O** to N_2
  - Nitrification: NH_4+ to NO_2- **(to N_2O)** to NO_3-

How is carbon dioxide (CO_2) produced from soils?

- Soils become a CO_2 source when they reach a positive net ecosystem exchange threshold. This means that ecosystem respiration, or breaking down above and below ground organic matter, exceeds ecosystem photosynthesis, or taking in CO_2 to build organic compounds (Oertel et al., 2016).
  - Photosynthesis: **carbon dioxide** plus water plus energy from sunlight produces glucose (organic matter) and oxygen
  - Respiration: Glucose (organic matter) plus oxygen produces **carbon dioxide** and water

For determining N_2O emissions, this is based on type of fertilizer and method of application, type of crop residue and its application, the soil type, and the existing carbon to nitrogen ratio (C:N) of the soil. The quantity of nitrogen applied to the farming system is the major factor, despite uncertainties surrounding the exact N_2O emissions between different manure sources (Velthof et al., 2003). Another factor determining the N_2O emissions is based on the type of fertilizer. Two main categories of crop fertilizer are organic and inorganic. Organic fertilizers are derived from plant and animal sources and need to be converted to inorganic forms by soil life in order to be taken up by crops. Inorganic fertilizers are produced through a manufacturing process and contain fewer nutrients but in specific combinations to be directly consumed by the plants (Pokorny, 2015). In comparing the N_2O emissions between organic manure and inorganic synthetic fertilizer (NH4NO3 or CAN, calcium ammonium nitrate), a study at Wageningen University on sandy soils with low SOM, shows synthetic fertilizer to have almost double N_2O emissions compared to organic manures (Velthof et al., 2002). CAN is the highest consumed nitrogen fertilizer in the Netherlands, comprising 70% of all fertilizer use (Kramer et al., 1999). In mineral soils, 1-4% of nitrogen applied on the soil surface as CAN fertilizer is emitted as N_2O. This fertilizer is produced from ammonia (NH_3), which is derived from natural gas, a fossil fuel. Although my research excludes methane, it is important to mention that the production of CAN is an important source of methane, which is also a GHG (Kramer et al., 1999).

Furthermore, the type of application method also matters for emissions, as soil injected or incorporated fertilizers have higher emissions than those that are applied on the surface (Velthof et al., 2002). According to an informant interviewee, the longer crop residue is left on the surface, the more effective for avoiding soil emissions [II]. In addition, crop residues returned to the soil increase N_2O emissions, with emissions from residues on sandy soils being higher than on clay (Velthof et al., 2002). The N_2O emissions differ by type of crop residue which is characterized by a certain degree of easily mineralizable nitrogen or N and carbon or C, which depends on the crop, higher in fresh green residues than for straw, and strongly dependent on soil management. The C: N ratio of the organic material affects the rate of N mineralization, denitrification, and hence N_2O emissions (Velthof et al., 2002). The Netherlands has both sand and clay dominated soils. It is suggested by Jarecki et al. (2008) that due to the higher cation-exchange-capacity (CEC) and lower WFPS in clay soils, their N_2O emissions may be lower.

The nitrogenous focus of this research concerns the "direct N_2O emissions" from agricultural soils as classified by the IPCC, comprising 50-60% of total agricultural soil emissions, and intentionally excluding "indirect N_2O emissions" (Van der Hoek et al., 2007). "Direct N_2O emissions" is the direct application of inorganic or organic fertilizer, the urine or dung of grazing animals, addition of crop residues, or the cultivation of organic soils (Ruyssenaars et al., 2019). In the Netherlands, over the 1990-2003 period, nitrogen fertilizer consumption declined by almost 30%, with the proportion of animal manure application reducing and ammonium-based fertilizers increasing (Van der Hoek et al., 2007). Specifically for 'agricultural soils', between 1990-2017 total N_2O emissions decreased 40%, mainly due to a relatively large reduction in all forms of soil N inputs. However, this decline was partially offset by manure incorporation into the soil, again decreasing NH3, but with a rise in N_2O (Ruyssenaars et al., 2019). N_2O emissions 50-200 years ago could be largely attributed to grassland and forest conversion to cropland, while current emissions are largely attributed to agricultural intensification (Mosier et al., 1998). Cover/catch crops, one heavily emphasized MP, can both reduce N_2O by catching excess nitrogen in the soil and reduce CO_2 by covering the soil to serve as additional carbon inputs.

For determining CO_2 emissions, tillage is the most relevant MP. Tillage, or the mechanical breaking up of soil aggregates, exposes the organic matter inside these previously-closed aggregates and allows the microbes to feast (respire) the organic matter transforming it into CO_2. The aim for CO_2 mitigation is to avoid soil disturbance, as it initiates soil carbon losses (decomposition/erosion), and to have increased carbon inputs (crop residue which can become SOM) (Smith et al., 2008). However, these carbon inputs as surface residue can also affect N_2O emissions as mentioned above. Soil organic carbon (SOC) content, representing roughly half of SOM, differs by geographic region and mineral soil type. In a study examining change in SOC in the Netherlands from 1984 to 2004, researchers found that on average the top portion of soil profile SOC tended to slightly increase in most regions. This was mainly through the continued application of livestock manure (Reijneveld et al., 2009). This links the application of organic matter in the form of livestock manure to building soil carbon and hence reducing CO_2 emissions.

As far as the farming practices which cause an interaction between CO_2 and N_2O, these relationships are being researched. Reduced/no tillage, as a means to reduce CO_2 emissions, has mixed effects on N_2O emissions (Smith et al., 2008). The application of organic fertilizers aiming to increase soil carbon sequestration have substantial, but uncertain, carbon accumulation and nitrogen emissions tradeoffs, especially with slurry (pig or cattle) application (Bos et al., 2017).

The future potential for soil GHG mitigation by 2030 is highly dependent on the climatic region (Smith et al., 2008). With climate change, this will exacerbate several environmental variables impacting the production of GHGs from soils. For example, with warmer conditions and shifting precipitation patterns, more extreme wet to extreme dry, these conditions are optimal for increasing nitrogen gas emissions from global soils (Bowles et al., 2018).

9.2 Appendix B. Field Work Schedule

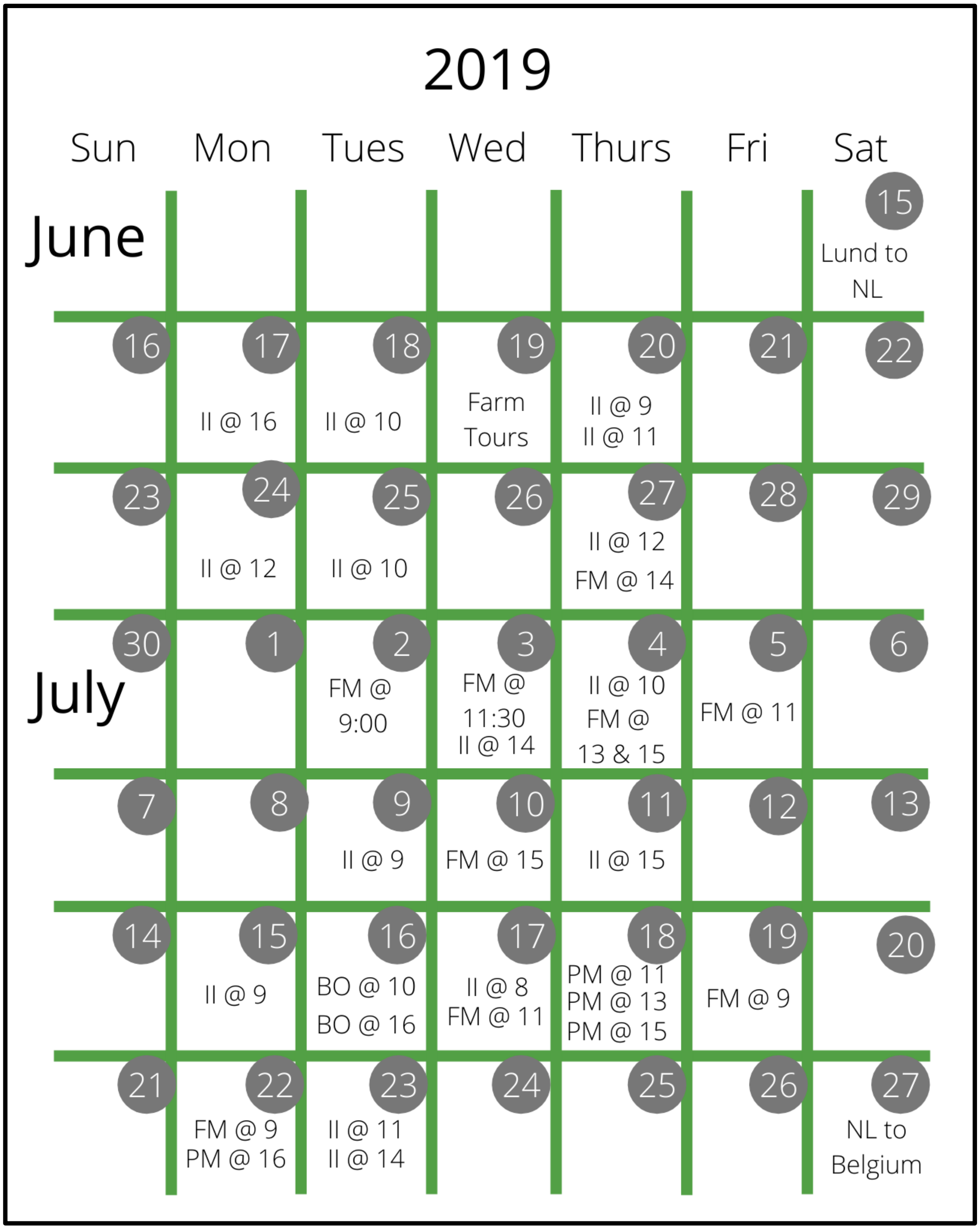

Figure 8. Field Work Calendar, Summer 2019,
II, Informant Interview; BO, Boundary Organization Interview; FM, Farmer Interview;
PM, Policy-Maker Interview, *Own Illustration*

9.3 Appendix C. Interview Guides

Table 5. Arable Crop Farmers Interview Guide

Purpose	Theme	Questions

To ease into the interview with some basic questions	**Open**	- Can you tell me a bit about your background as a farmer - how did you end up where you are now?
		    - How many years have you been here?
		    - What type of farm do you have?
		    - How big?
		    - What do you mainly grow?
		    - What type of mineral soil do you have?
		    - What is your background?
		    - How did you gain your skills/farming knowledge?

RQ 1. What is the state of the science on mitigating GHG emissions from agricultural soils and how is this knowledge currently transferred to farmers?	**Background**	- Has climate change affected your farm?
		    - If so, in what ways?
		    - Or, what ways do you expect to experience it in the future?

RQ 2a. What are the synergies and tradeoffs for mitigation of on-farm GHG emissions?
 	
RQ 2b. How do farmers view agricultural transformation and what are the barriers and incentives for the adoption of GHG mitigation farming practices?
	On- Farm Practice	- Do you currently use farming practices that reduce GHG emissions from your farm soils?
		    - (Provide examples if confused: cover/catch cropping, reduced/no tillage, crop rotation etc.)
		- What does adoption of on-farm GHG mitigation practices (insert examples) imply for productivity?
		    - What about farm income?
		- What was your motivation to transition your practices?
		- How do other farmers perceive you?
		- Have your farming practices changed since you started running the farm?
		    - How have your farming practices changed since you started the farm?
		    - Why did you become interested? Do a trial? Permanently incorporate the practice into the farming plan?
		- What are your priorities on the farm? How would you list them?
		- Do you have specific areas in environmental sustainability that you would like to work on?

RQ 3. What are the political and economic variables in place to shape	**Political & Economic Perspective**	- Do you experience incentives for transitioning to (even) more sustainable practices?

adoption of GHG mitigation practices and where are the potential leverage points?		- Do you gain economic benefits?
		- Do you feel political pressure or support?
		- Do your consumers or customers ask about the practices on your farm?
		- Do you face logistical challenges in changing your farming practices to become more sustainable?
		  - What is the largest logistical challenge you face in adopting farming practices which reduce your climate impact?
		  - What could be a solution to this problem?
		- Do you face other challenges?
		- Do you feel heard by policy-makers?
		- What would you suggest to policy-makers for how to make this transition possible?

RQ 4. What are the solutions to scaling up on-farm GHG mitigation practices in the Netherlands?	**Future**	- Do you think the Dutch agricultural sector should reduce GHG emissions? Is this possible?
		- Do you have a vision for an environmentally sustainable Dutch farming system?
		  - What is your vision?
		  - How should we get there?
		  - What is your role?
		- For the future of your farm, who will take over? Will this change the management?
		- Is a sustainable agricultural transition happening?
		  - Who is pushing the sustainable agricultural transition?
		  - Who should be pushing it?
		  - And how?

To round-up the interview and make sure that nothing is left out/ make sure to include relevant additional information from the interviewee	**Round-up**	Simply ask if the interviewee has anything to add

Table 6. Remaining Interviewees Sample Interview Guide. Includes a sample of Policy-Maker, Boundary Organization Stakeholders and Informant Interview Questions to give the reader an idea of the various interview guides utilized for this research study.

Purpose	**Theme**	**Questions**
To ease into the interview with some basic questions	**Open**	- What is your role in your organization/government department? - How long have you worked in Dutch agricultural policy? - What is your background?

RQ 1. What is the state of the science on mitigating GHG emissions from agricultural soils and how is this knowledge currently transferred to farmers?	**Background**	- Is the agricultural sector considered an important actor for reducing national emissions?
		    - What do you see as the role?
		    - What type of support from policymakers does the agricultural sector need in order to reduce emissions?
		- How does the Dutch agricultural sector fit into the NDCs under the Paris Climate Agreement?

RQ 2a. What are the synergies and tradeoffs for mitigation of on-farm GHG emissions? RQ 2b. How do farmers view agricultural transformation and what are the barriers and incentives for the adoption of GHG mitigation farming practices?	**On- Farm Practice**	- How many farmers, or what percentage are adopting the MP? - What are farmers' incentives to adopt these practices? - How are they exposed to MPs? - How are farmers' views/opinions involved in the decisions? - Are the policies promoting reduction of GHGs from agricultural soils focused more on top-down or bottom-up action?

RQ 3. What are the political and economic variables in place to shape the adoption of GHG mitigation practices and where are the potential leverage points?	**Political & Economic Perspective**	- Do current policies support the adoption of MPs?
		- What incentives are currently provided to farmers for changing their practices?
		    - Are the incentives, provided by the government or the market, adequate for farmer transition?
		    - How are these incentives communicated to farmers?
		- Would you describe the policies for farmers as following the carrot or stick approach?
		    - Do you think this is working?
		- Ministry of Ag's 'circular ag' initiative, how to get farmers a larger share of the profits?

		- Low hanging fruit already in place? Now what? - What is your opinion about the current nutrient caps for N & P?

RQ 4. What are the solutions to scaling up on-farm GHG mitigation practices in the Netherlands?	**Future**	- Is a sustainable transition happening in the agricultural sector?
		    - Who is pushing the sustainable agricultural transition?
		    - Who should be pushing it?
		    - And how?

To round-up the interview and make sure that nothing is left out/ make sure to include relevant additional information from the interviewee	**Round-up**	- Do you have any additional information you would like to add?

9.4 Appendix D. Extended Research Methods

Farmer Typology:

This paragraph aims to explain the categorization of the farmer interviewees according to Therond et al. (2017) and Buck et al. (2008), as found in Table 3. Following De Buck et al. (2008), Dutch arable farms can fit into three typologies: (1) conventional arable farming: very high external input system practiced since the 1960s, (2) organic (biological) arable farming: without chemical pesticides or fertilizers, and (3) integrated arable farming systems (IAFS). The second method is established by Therond et al. (2017) in an effort to include both the biotechnical function and the socio-economic context in categorizing farms globally. The three biotechnical functions include (1) chemical-input based farming system, (2) bio-input based farming system, and (3) biodiversity-based farming system, with the four socio-economic contexts: (1) globalized commodity-based food system, (2) Circular economy (3) Alternative food system and (4) integrated landscape approach.

Literature Review:

In order to provide context information and position this sustainability challenge as a relevant, urgent, and significant problem, the research design begins with informant interviews and a narrative literature review. The general narrative review style is a method of literature review to identify key concepts and knowledge gaps within the existing research (Onwuegbuzie & Frels, 2016). For the literature review, Papers for Mac reference software was used to search for key terms “climate change,” “the Netherlands,” “soil management,” “greenhouse gas emissions,” then followed articles from those first identified. Additionally, specific articles written by the academic informants interviewed during field work were sought.

Interview Analysis:

All 33 interviews are incorporated: 14 informants used to create stakeholder interviews and inform the background chapter, and the two boundary organizations, five policy-makers and 10 farmers used for SQ1, SQ2, and SQ3. The interview recordings were moved to HappyScribe transcription software. This program creates a ‘best’ transcription text document, highlighting uncertain words and statements. Following this, each interview was reviewed, correcting mistakes within the HappyScribe program. A Dutch colleague confirmed any clarifications needed on the transcriptions. The transcriptions were exported from HappyScribe as a Word Document and first cleaned for any spelling mistakes, and then inserted into Atlas.ti.

Due to the inductive exploratory nature of this research, the analysis approach allows the data to reveal the patterns. For (SQ1) a thematic content analysis was completed. Additionally, I conducted a literature review and talked with academic informants to connect GHGs to specific practices, so when I asked farmers about their adoption of MPs in the interviews, I could provide concrete examples.

For SQ2, a content analysis of the barriers and opportunities was completed. Extra emphasis was placed on barriers and opportunities which were mentioned by most, if not all, farmers and boundary organizations. The data was searched using Auto-coding in Atlas.ti for barriers and opportunities using the strings below.

- Barriers to adopt MPs: challenges*|barriers*|struggles|hard|difficult
- Opportunities to adopt MPs: opportunities*|positive|solutions*
- Temporal Dilemma: time*|year|years

For SQ3, the barriers and opportunities were placed into the AD Adoption Curve Framework based on specific comments mentioned in the interviews. This mapping of data was not based on how I perceive the barriers and opportunities to fit from a systems perspective, but rather in which context interviewees discussed these factors.