MSc Thesis, Plant Production Systems

Barriers and Incentives for Cover Crop and Non-Inversion Tillage Adoption in a Tumultuous Time for Dutch Arable Farmers

A 2023-2024 EDF Soil Carbon Sequestration Case Study

Bas du Mortier

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Name: Bas du Mortier
Student-ID: 1207164

Study: MSc Resilient Farming and Food Systems
Specialisation: Agroecology
Course code: PPS80436

Chair group: Plant Production Systems
Supervisors: Dr. Renske Hijbeek
MSc. Marti Vidal-Morant

Examiner: Dr. Marloes van Loon

Location: Wageningen University and Research,
Wageningen

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Abstract

In recent years, rising CO_2 emissions have accelerated global warming, causing soil degradation and heightened crop failure risks. Agricultural soil carbon sequestration practices like cover cropping and non-inversion tillage (NIT) are often cited as possible solutions to mitigate excessive emissions, however the agronomic potential is currently unknown. Farmers face multiple challenges such as soil type variations affecting carbon sequestration potential, and varying costs and benefits. Understanding these challenges is crucial for quantifying the potential adoption of soil carbon sequestration practices in the Netherlands. This study aims to uncover Dutch arable farmers' perceptions of agronomic and socio-economic constraints and incentives, and their impact on the adoption of cover cropping and NIT, while also exploring correlations with soil characteristics. This study was conducted using an online survey (N=47) and semi-structured qualitative interviews (N=12) to explore the correlation between adoption rates and soil characteristics, agronomic constraints, socio-economic factors, and government policies. Data obtained from the online survey were analyzed quantitatively, while data from the interviews were used to provide contextual analysis for the results obtained from the survey analysis.

Results show that 46 out of 47 respondents adopted cover cropping, and 42 out of 47 adopted non-inversion tillage. Results regarding the adoption of NIT show 16 respondents adopting NIT in all fields (full-adopters), and 26 respondents in some fields (half-adopters), leaving five respondents not adopting NIT in any fields (non-adopters). The most important constraints on adopting NIT were related to soil characteristics such as controlling the soil water balance and the topsoil layer being too dry for heavy soils or too wet for lighter soils to prepare an adequate seedbed. In the case of cover crops, adoption was quantified by both the percentage of total arable land used to grow cover crops and the percentage of land without a winter sown crop, referred to as the relative adoption gap. The mean adoption and mean relative adoption gap for cultivating cover crops were 48.8% (Min 19.4% and Max 100%) and 24.6% (Min 0% and Max 76.8%), respectively. There were little differences in adoption gaps between soil types; instead, agronomic factors emerged as more influential. The most important constraints identified by farmers were: higher incidence of weeds, nutrient competition, poor cover crop establishment and difficulties incorporating cover crops into the soil. Overall, socio-economic factors were not observed to be as important as agronomic factors. It is noticeable, however, that agronomic constraints are inherently linked with socio-economic factors, poor cover crop establishment and higher incidence of weeds are either wasted money or require extra labour.

Farmers expressed that the future is uncertain, but not all farmers take matters into their own hands. Some are pioneers willing to undertake risks, and others only abide by the rules, leading to differences in the adoption of alternative practices like NIT. Furthermore, the current policy to support farmers in making sustainable changes is deemed ineffective. Farmers point out that it needs to be unambiguous and goal-orientated, but above all, offer long-term stability. To address climate change adaptation and mitigate risks, there is a need for proactive measures as well as the importance of clear, goal-oriented and supportive government policies to incentivize sustainable agricultural practices. Suggested improvements of government policies include reducing government control, increasing multi-stakeholder collaboration, employing performance-based subsidies and region-specific regulation. Improvements like these are needed to develop widespread adoption and ensure the resilience of Dutch arable farms in the face of evolving environmental and economic pressures.

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List of abbreviations

CO_2	Carbon di-oxide
SOM	Soil organic matter
SOC	Soil organic carbon
NIT	Non-inversion tillage
EU	European Union
GHG	Greenhouse gas
CAP	Common agricultural policy
ANOVA	Analysis of variance

1 Introduction

In recent decades, increasing carbon dioxide (CO_2) emissions have accelerated global warming; leading to degradation of agricultural soils, due to desertification, and an increased risk of crop failures (Stocker et al., 2013; van Oort et al., 2023). Agriculture may offer promise as a partial solution to climate change by employing soil carbon sequestration techniques (Janzen, 2006; Dignac et al., 2017). The Dutch agricultural sector, being the world's second-largest exporter and predominantly composed of intensive arable farming systems, is particularly affected by climate change and sees potential in adopting soil carbon sequestration practices (Visser et al., 2019; Westerink et al., 2020). These practices are now a focal point of the European Union's Common Agricultural Policy, shaping the future management practices of arable farms across the Netherlands (Regulation (EU) 2021/2115). However, farmers face various challenges in implementing these practices due to factors such as soil type, crop rotations, and carbon sequestration potential, as well as varying costs and benefits associated with different soil types (Smit et al., 2019). Identifying these challenges and understanding the driving and constraining factors is essential for quantifying the potential adoption of soil carbon sequestration practices in the Netherlands.

1.1 Soil carbon sequestration

Soil carbon sequestration involves storing atmospheric CO_2 in agricultural soils by increasing soil organic matter (SOM) content through various practices (Castellano et al., 2015; Dignac et al., 2017). Soil organic matter content fluctuates due to organic matter input and decomposition processes (Amundson & Biardeau, 2018; Robertson et al., 2019). Effective management is required to ensure an annual increase in SOM and its transformation into stable soil organic carbon (SOC) (Eagle et al., 2022a, 2022b).

1.1.1 Increasing carbon inputs through cover cropping

Management strategies for maintaining or increasing SOC often focus on increasing the carbon influx, which can for example be achieved through cover cropping (Blanco-Canqui et al., 2011; Frelih-Larsen et al., 2016; Kathage et al., 2022). Unlike conventional periods with barren lands in-between crops and especially during autumn and winter, as is often seen in Dutch arable farming, cover cropping involves planting crops instead of leaving land barren to increase the input of organic matter into the soil (Abdalla et al., 2019; Bai et al., 2019; Smit et al., 2019; Buitenhuis et al., 2020). The rate of sequestration, however, can vary greatly from region to region; because of differences in sequestration potential, type of crop, and environmental factors (Quemada et al., 2020; Hughes et al., 2023). Recent research on soil carbon sequestration through cover cropping found an average carbon sequestration rate of 320 ± 8 kg C/ha/year for European arable land (Poeplau & Don, 2015; Kaye & Quemada, 2017).

1.1.2 Reducing carbon losses through non-inversion tillage

Besides increasing the influx of carbon into the soil, management practices can also focus on minimizing losses to effectively store SOC (Conant et al., 2011; Zhu et al., 2020). Non-inversion tillage, for instance, might reduce carbon losses by maintaining the sub-soil structure and minimizing exposure to oxygen (Alskaf et al. 2019; Meena et al., 2019; Krauss et al., 2022; Lessmann et al., 2022). Non-inversion tillage (NIT), as compared to conventional ploughing practices in the Netherlands, does not invert soil up to a depth of 20-25 cm, but loosens the soil up to a depth of 10-15 cm (Lebbink et al., 1994; Cooper et al., 2019). The potential for carbon loss reduction, however, can vary greatly due to the complex interplay of farming systems and the environment (Cooper et al., 2019; Lessmann et al., 2022). When these two tillage practices are compared to each other, a range of the mean difference in SOC stocks of 1000±2000 t C/ha after multiple decades (Cooper et al., 2019) and a reduction of CO_2 equivalent emissions between 40-50% has been found (Alskaf et al., 2021; Lessmann et al., 2022).

1.2 Arable farming in the Netherlands

From 1500 AD onwards, agriculture in the Netherlands transitioned gradually from a primitive system to one of the world's most productive by 2000 AD, driven by the adoption of artificial fertilizers and mechanization (Bieleman, 2010). As of 2020 AD, the Netherlands had approximately 540,000 hectares of arable land, with a slight increase observed over the past eight years (CBS, 2023a, 2023b). Cereals, potatoes, and sugar beets are the predominant arable crops cultivated (CBS, 2023b), with around 9000 arable farms averaging 60 hectares each (CBS, 2023a; Wageningen Economic Research, 2023).

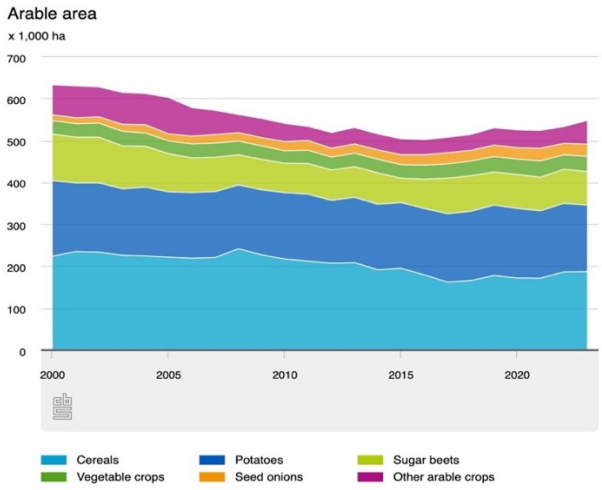

Figure 1: Graphical representation of cultivated arable area per crop type over the past decades since 2000 (CBS, 2023b).

Current Dutch arable farming focuses on intensification, which has raised environmental concerns stemming from the extensive adoption of environmentally harmful practices like mono-cropping, excessive fertilizer application, and mould-board ploughing (Buitenhuis et al., 2020). In typical Dutch arable farming systems, crops are grown in a rotation between fields to reduce the negative effects that mono-cropping has on the soil quality and crop productivity (Silva et al., 2017). The frequency and intensity of applying environmentally damaging practices differ from region to region because of regional-specific characteristics and farmers' preferences (Silva et al., 2017; Smit & Jager, 2018).

Variation of soil types

In the Netherlands agricultural regions are commonly classified based on soil type (Bokhorst, 2016). Due to the relatively small size of the Netherlands, there is generally a moderate maritime climate across the whole country, causing little differences in environmental effects across the country (Smit & Jager, 2018). The country's soils primarily consist of clayey, loamy, sandy and peat types, influencing farming practices and environmental considerations (*Figure 2*) (Bokhorst, 2016; Smit & Jager, 2018).

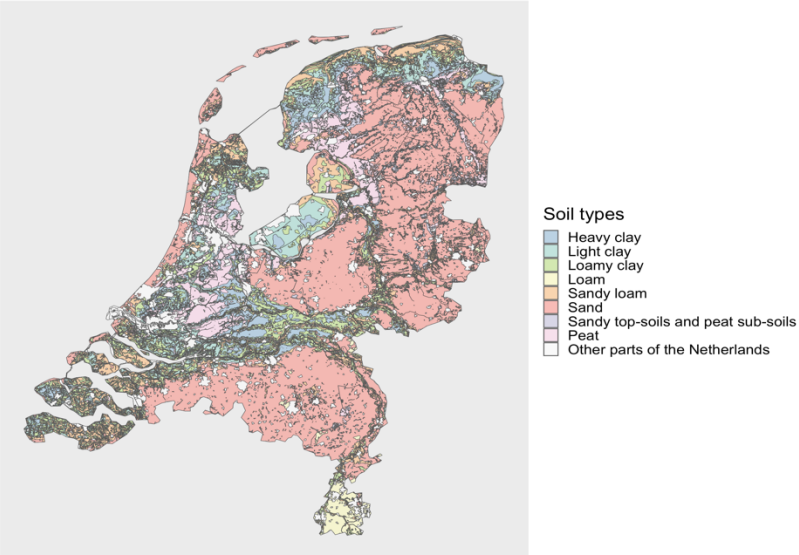

Figure 2: Variation of soil types that can be found across the Netherlands.

Table 1: Soil characteristics of the four common soil types in the Netherlands, adapted from Reijneveld et al. (2009), Verhagen et al. (2009), Rezanezhad et al. (2016), Rai et al. (2017), Leifeld et al. (2020), Knotters et al. (2022).

	Bulk density (g/cm^{-3})	SOC content (g/kg)
Sand	1.05±0.05	22±8
Loam	1.2±0.1	14±4
Clay	1.45±0.15	44.5±37.5
Peat	0.275±0.225	107.5±77.5

Soil characteristics vary across soil types, affecting carbon sequestration potential (Bai et al., 2019; Knotters et al., 2022). Due to their lower bulk density and mineral content sandy and loess soils cannot retain organic matter as well as clayey soils, which is further exacerbated by soil characteristics as high porosity and a relatively low water holding capacity (Bai et al., 2019). Due to these characteristics, sandy and loess soils require additional management to prevent environmental risks, such as nitrate leaching and soil erosion (Smit & Jager, 2018; Knotters et al., 2022). This is the basis for the differential financial support for farmers based on soil type and applied practices (RVO Nederland, 2022; Silva et al., 2017).

1.3 Agricultural policy

The Sustainable Development Goals (SDGs) aim for a climate-neutral world by 2050, with the European Union (EU) targeting a 55% reduction in emissions by 2030 compared to 1990 levels under the European Green Deal (United Nations, 2015; European Commission, 2019; Visser et al., 2019). European agriculture accounts for approximately 10% of total global agricultural emissions and 12% of Europe's net greenhouse gas emissions (GHG), highlighting the potential for climate change mitigation efforts (FAO, 2020; European Commission, 2022).

1.3.1 European policy

To address GHG emissions, the EU proposes sequestering CO_2 and offsetting annual emissions by utilizing 47% of the total 161 million hectares of EU agricultural land to incorporate practices like cover cropping and non-inversion tillage (Chabbi et al., 2017; Abdalla et al., 2019; Smit et al., 2019; European Commission, 2022). Despite efforts by the European Common Agricultural Policy (CAP) in recent years to encourage farmers to adopt sustainable farming practices through direct payments under 'Greening measures', practices such as monocropping, mouldboard ploughing, and excessive use of fertilizers and pesticides remain prevalent today (Matthews, 2018; Dijksma, 2013, 2014; Smit & Jager, 2018). The CAP 2023-27 has a different strategy, emphasising climate change mitigation and agricultural productivity improvement, with farmers at the forefront (Guyomard et al., 2020; European Commission, 2022). The EU provides member states with guidelines, tools, and funding to support and incentivize farmers to adopt innovative practices (Guyomard et al., 2020; European Commission, 2022). The EU facilitates farmers in taking up these practices using eco-schemes where farmers are paid according to the combination of their practices, making €14.7 billion available of the total €307 billion CAP 2023-27 budget (European Commission, 2022).

1.3.2 Dutch policy

The Netherlands aligns with EU goals through its strategic plan, emphasizing support for farmers by implementing eco-schemes, providing solution-based cooperation and rewarding of future resilience in an area-oriented approach (Ministerie van LNV, 2021a). Financial aid, including income support, eco-schemes and other subsidies, is crucial for farmer participation, given the sector's lower income compared to other Dutch industries (European Commission, 2023). To support farmers financially, until 2024 the annual Dutch CAP-budget of base-income support and eco-schemes is €447 million and €152 million respectively (Ministerie van LNV, 2021a). In eco-schemes farmers accumulate points across five topics: climate, soil, water, landscape and biodiversity based on practices that they apply.

Points that farmers have accumulated across the five aforementioned topics help farmers to reach a threshold value that represents a certain payment: bronze (€60/ha), silver (€100/ha) and gold (€200/ha) (RVO Nederland, 2024a). This is put in place to motivate farmers to apply more sustainable practices across their farm, to receive more money from the government. Eco-scheme paayouts, however, vary across regions, based on factors like labour costs and environmental risks, leading to disparities in practice adoption and compensation (RVO Nederland, 2024b).

1.4 Adoption of soil carbon sequestration practices

Dutch agriculture is on the brink of significant changes in farming practices (Visser et al., 2019; Westerink et al., 2020). While the potential for climate change mitigation through cover cropping and reduced tillage has been extensively researched (Kaye & Quemada, 2017; Krauss et al., 2022; Lessmann et al., 2022), the adoption of these practices to replace current ones remains a challenge (Mills et al., 2019; Bakker et al., 2023). Adopting alternative practices is challenging, influenced by various factors affecting farmers' ability to change behaviour (van der Wal et al., 2014; Hijbeek et al., 2018; Sok et al., 2021). Support for farmers is crucial in this transition, but understanding the realities faced by farmers across the Netherlands is essential to bridge the gap between current adoption levels and potential (Adger et al., 2007; van der Wal et al., 2014).

1.4.1 Behavioural change and adoption

Trade-offs, like those previously discussed, are known to influence behaviour and change, yet quantifying this shift when adopting alternative practices remains complex (van der Wal et al., 2014; Hijbeek et al., 2018; Sok et al., 2021). Hijbeek et al. (2018) applied two key theories to analyse adoption of alternative practices by farmers: Theory of Reasoned Action (TRA) (Fishbein, 1979) and Theory of Planned Behaviour (TPB) (Ajzen, 1991). TPB identified three crucial components: perceived benefits, social norms, and anticipated obstacles. Anticipated obstacles, as highlighted by Madden et al. (1992), are pivotal as they reflect individuals' belief in controlling their behaviour's success, improving explanatory and predictive capabilities compared to TRA. Subsequent research by Sok et al. (2021) emphasized the importance of understanding farmers' beliefs for comprehensive insights into behaviour and change. These findings underscore the necessity of prioritizing the identification and understanding of these components and beliefs in behavioural research (Sok et al., 2021).

1.4.2 Drivers and constraints

To delve deeper into understanding the driving forces, it is essential to consider factors from the farmers' environment (Mills et al., 2019; Bakker et al., 2023). These factors, rooted in the components of Fishbein (1979) and Ajzen (1991) behavioural theories, can either incentivize or impede the adoption of alternative behaviour. Mills et al. (2019) emphasize that these factors are often regionally specific, but can be broadly categorized into two classes: agronomic and socio-economic factors.

Agronomic factors

Mills et al. (2019) highlight that agronomic factors directly affect a farms' productive capacity, such as changes in management of the farming system, complexity of the farming system and incompatibility of practices. Additionally, Bakker et al. (2023) emphasize that these factors are not only constraints, but also drivers of behavioural change. Constraints are i.e.: presence of weeds, crop establishment and incorporation into the soil. Drivers are i.e.: increased biodiversity, improved yields, and soil enhancement. These co-benefits drive the adoption of soil carbon sequestration practices like cover cropping and reduced tillage (Amelung et al., 2020; Buck & Palumbo-Compton, 2022).

Socio-economic factors

In addition to agronomic factors, socio-economic factors also play a crucial role in driving or constraining behavioural change among farmers (Mills et al., 2019; Amelung et al., 2020; Buck & Palumbo-Compton, 2022; Bakker et al., 2023). These factors include monetary costs and benefits, societal norms, and institutional support, such as the cost of adoption, farmers' attitudes, and knowledge gaps (Mills et al., 2019; Bakker et al., 2023). However, Bakker et al. (2023) also highlight socio-economic factors that motivate farmers to change, such as subsidies, social appreciation, and a sense of momentum for change.

1.4.3 Future perspective

To better understand farmers' motivation and beliefs, it is important to consider their future perspectives and the driving factors behind their perceptions (Adger et al., 2007; van der Wal et al., 2014). As varying opinions on risks regarding climate change lead to diverse responses to environmental challenges (Clayton, 2019; van Valkengoed et al., 2022). Understanding individual perceptions is crucial for facilitating behavioural change and increasing adoption (Adger et al., 2007). Insights into this variation shed light on current policy instruments' effectiveness in facilitating change (van der Wal et al., 2014).

1.5 Research objective

Previous studies (Hijbeek et al., 2018; Mills et al., 2019; Bakker et al., 2023) have focused on the drivers and barriers to adopting soil carbon sequestration practices among Dutch farmers. The aim of this study is to uncover farmers' perceptions and perspectives of agronomic and socio-economic constraints and incentives, and how these can explain under-utilized agronomic potential of adopting cover cropping and non-inversion tillage and find possible correlations to soil characteristic differences.

This study aims to answer the following research questions:

1. What is the current variation in the adoption of cover cropping and non-inversion tillage on both farm- and field level amongst Dutch arable farmers, depending on soil characteristic differences?
2. What are the agronomic- and socio-economic factors that can explain this variation of adoption on farm- and field level in relation to these soil characteristic differences?
3. What is the impact of Dutch arable farmers' perspective of farming in the future on the adoption of cover cropping and non-inversion tillage?
4. What are the perceptions of Dutch arable farmers regarding the effectiveness and improvements of current Dutch- and common EU-27 agricultural policies to incentivise and support adoption of cover cropping and non-inversion tillage on both farm and field level?

2 Methods

2.1 Study site

The study site was defined with the aim to obtain a representative population of arable farms across the Netherlands. As mentioned in *Variation of soil types*, the climate in the Netherlands is generally homogeneous, and the focus was rather put on soil characteristic differences. For this study, arable farmers across the Netherlands were able to take part, and the eventual spread of respondents across the arable farming regions can be found in *Figure 3* below.

2.2 Data collection

To answer the research questions posed in *1.5 Research objective*, insights were needed from Dutch arable farmers directly. Two methods were used: qualitative data was collected form in-person interviews (N=12) and quantitative data was collected through an online survey (N=47), across the Netherlands. Environmental effects were furthermore assumed to be homogeneous across the Netherlands and were therefore not a part of this study. From *1.2 Arable farming in the Netherlands,* it became clear that peat soils have an inherently high SOM content, and cover cropping and reduced tillage are unfit practices to increase SOM content and mitigate carbon losses from this specific soil type. Furthermore, these soils are commonly found in grasslands which are part of animal production systems and fall therefore outside of the population criteria (Clarke & Rieley, 2019).

Soil types are further aggregated to fall in three distinct types: *clay, loam and sand*. In further analysis farms with varying soil types across- and within fields are classified as *mixed* soil. As can be seen in *Figure 3*, not every soil type is not equally represented. This led to the population of this study to not being entirely representative of arable farmers across the Netherlands. Unequal representation and implications of this will be further discussed in *4. Discussion*.

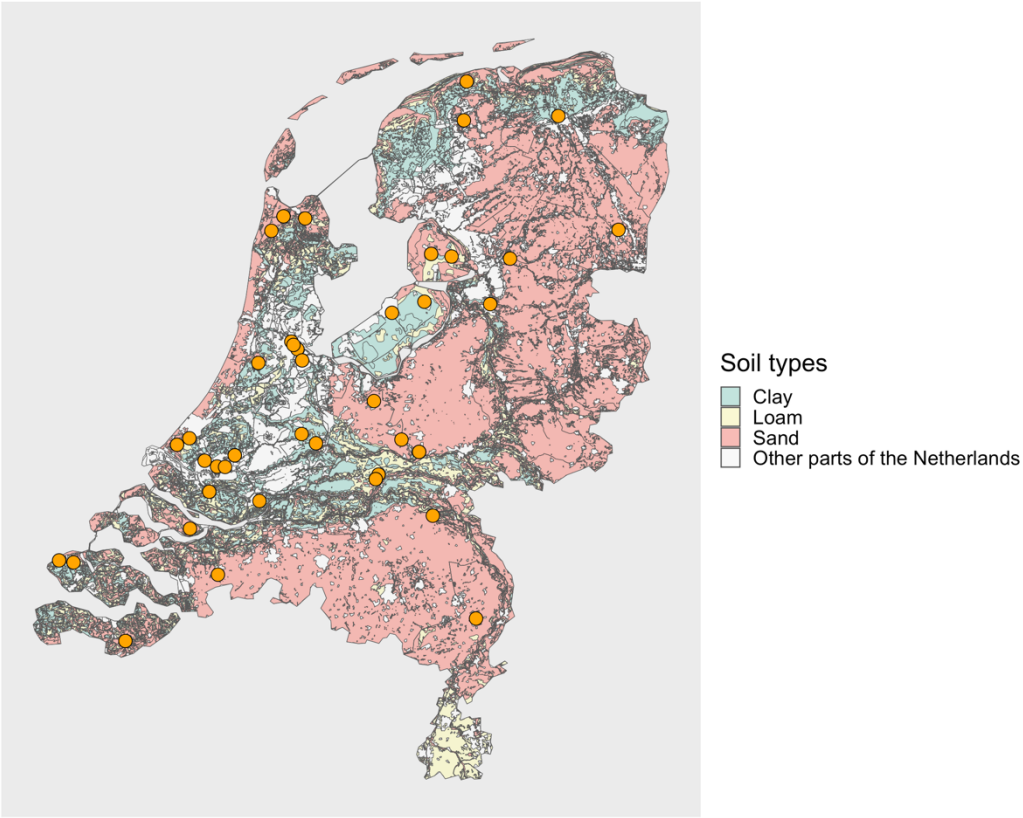

Figure 3: Responses on the online survey across the different soil types of the Netherlands (N=47).

2.2.1 Expert interviews

To gain a better contextual understanding of the Dutch arable sector and how cover cropping and reduced tillage fit in, the first phase of the study consisted of semi-structured interviews with experts. Through this applied understanding of the specific context in which Dutch arable farmers operate, better fitting questions could be formulated for both the farmers' online survey and in-person interviews.

Three experts were selected for these semi-structured interviews: (1) an uninvolved academic with region-specific field-work experience; (2) and advisor and (3) a knowledge coordinator. Besides gaining a better understanding of the regions, it was the goal to get their perception on the feasibility of adopting cover cropping and reduced tillage by farmers for the specific regions. Compared to farmers, experts were thought to have a better overview of agronomic- and socio-economic constraining and incentivising factors for farmers across the regions. Contacting these experts was done through a network approach, beginning with existing contacts from earlier research (Vidal Morant et al., 2023). Furthermore, it was important to strike a balance between (1) gaining a broad perspective of the regional-specific context and (2) gaining in-depth insights into constraining and incentivising factors. To ensure that enough contextual insights were gained and not the same information would be repeated, the choice was made to interview three experts (Crouch & McKenzie, 2006). To enable a structured process of interviews an interview protocol was designed, following specific questions that are in line with the aim of this study (*Appendix 1: Interview Protocol)*. The semi-structured interviews allowed to pursue in-depth questions regarding specific themes beyond the ones stated in the protocol; allowing for the diversity of input that was sought (Galetta, 2013).

2.2.2 Farmers' online survey and -interviews

In the second phase of the data collection, both qualitative and quantitative data were collected from farmers. Qualitative data from farmers was collected through semi-structured interviews (N=12), and additional quantitative data was collected through an online survey (N=47). The aim of this approach was to gain insight into regional differences in drivers, constraints, individual perspectives and their influence on behaviour.

As mentioned earlier, the aim was to collect data from a representative group of farmers from the different soil types found in the Netherlands (*Variation of soil types)*. In this manner, the different soil types could be included in the data analyses and the adoption between soil types could be compared. Sampling of farmers began using a network approach, contacting farmers through targeted organizations and -advertisements in newsletters or websites to reach the desired population to fill in the survey. In the survey, farmers had the option to indicate if they would be willing to be interviewed and if they were to then leave contact details. In *Table 2* an overview is given of the organizations and companies that were approached and enabled distribution of an online survey and to reach farmers willing to do an interview.

Table 2: Channels used to get in contact with farmers, adapted from (Vidal Morant, 2023). NA = not applicable.

Organisations contacted/visited	Survey distributed	Means of distribution
Agrifirm	No	NA
Akkerbouwbedrijf	Yes	Online article
BO Akkerbouw (contact person)	Yes	Personal network
Boerderij	Yes	Magazine advertisement
Biokennisweek	Yes	Flyers
Delphy	Yes	Flyers
Heeren XVII	Yes	Newsletter
Land en Tuinbouw Organisatie	No	NA
Nederlandse Akkerbouw Vakbond	No	NA
Nieuwe Oogst	Yes	Online advertisement
PPS BAAT	Yes	Newsletter
Rijk Zwaan (contact person)	Yes	Personal network
Slim Landgebruik	Yes	Newsletter
Topbodem	Yes	Online article
Zuidelijke Land en Tuinbouw Organisatie	No	NA

To enable a structured process of collecting data through the online survey, a survey protocol was designed following specific questions that were identified beforehand based on pre-liminary literature reviews (*Appendix 2: Survey Protocol)*. In the proposal phase of this study, it was aimed to have at least 100 farmers fill in the survey; to reach this, the first 100 would be rewarded with a €20 gift card. This was however less successful than was anticipated and a sample size of 47 useful responses was reached. Interviews were then used to obtain qualitative data to give the quantitative data a contextual background to understand the motivations behind the responses of the farmers. It was hypothesised beforehand that most likely between 15 and 20 farmers needed to be interviewed to gather all the possible qualitative insights and at which no new insights will be gathered for the analysis (Guest et al., 2006); during the interview phase this was reached at 12 interviews. These interviews followed the structure of the same general interview protocol (*Appendix 1: Interview Protocol)*, with changes in questions based on answers given in the online survey.

2.2.3 Theoretical and analytical framework

To develop the framework of the online survey, a theoretical framework devised by Vidal Morant et al (2023) was used. This framework was based on the premise that adoption of soil carbon sequestration practices is unavoidably constrained by non-leverageable factors (e.g. soil type, climate and geographical features). In the theoretical framework this theoretically constrained adoption is referred as *maximum agronomic adoption*: A_{max}. This A_{max} represents the highest level of adoption possible as a percentage, when all constraints a farmer is subjected to are optimised. The potential for increased adoption can be measured as the gap between *actual adoption* (A_a) and A_{max}, this is explained further in *Figure 4* below.

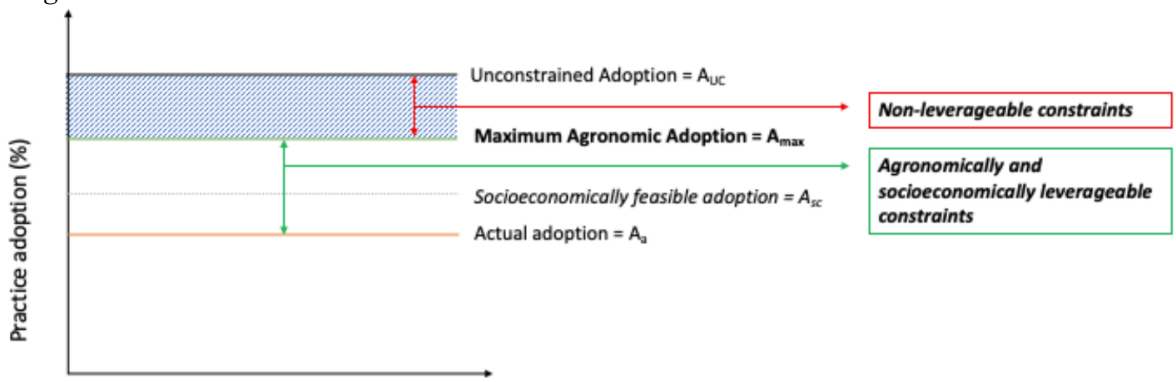

Figure 4: Graphical representation of the different levels of adoption and how the adoption gap can be the result of both agronomic- and socio-economic leverageable constraints (Vidal Morant et al., 2023).

This model was expanded with the addition of a temporal and spatial dimension to understand the maximum adoption of a specific practice as cover cropping and reduced tillage. In other words, applying practices whenever and wherever is possible (Figure 5, below). These dimensions are indicated by the following abbreviations: t_{max} (potential adoption) representing the number of occasions within a year that a farmer can apply the practices, and f_{max} (potential share of land suitable for the practice) representing the maximum area of farmland suitable for applying the practices. This model made it possible to theoretically estimate the A_{max} in a specific context (non-leverageable factors), and further analyse adoption values lower than A_{max} to find the constraining factors for adoption of cover cropping for this specific farmer. Information regarding tmax was gained from the online survey by asking about the specific crop rotation and information regarding f_{max} was gained from either the interviews or online survey by asking about non-leverageable constraints and how those influence the choice of practices.

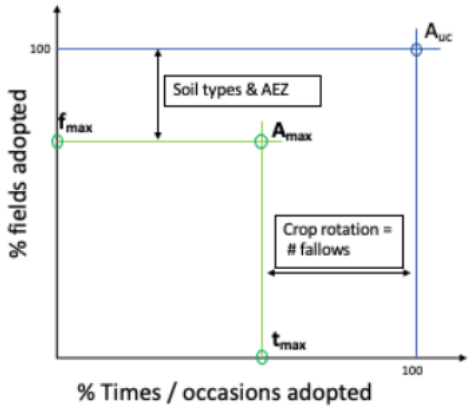

Figure 5: Specification of maximum agronomic adoption (A_{max}) into potential adoption (t_{max}) and potential share of land suitable for the practice (f_{max}), giving an example of how the adoption gap can be quantified for specific practices (Vidal Morant, 2023).

2.3 Data analysis

2.3.1 Qualitative data analysis

Analysis of the data from the farmers' interviews was done through a contextual analysis. Interviews were recorded and transcribed afterwards using *TurboScribe*, where the text has been looked through for relevant answers regarding the topics from the research questions (*Appendix 3: Interview contextualisation*). These answers have been used to contextualize observations from the online survey.

2.3.2 Quantitative data analysis

To analyse the online survey, response- and co-variables were calculated based on the research questions, see *Table 3*.

Table 3: Variables used in quantitative data analysis as indicated in *2.2.3 Theoretical and analytical framework*. ha_{cc} = hectares cultivated with cover crops, ha_{bw} = hectares without winter sown crop, ha_{arable} = total hectares of arable farm land, A_a = actual adoption and tmax = potential adoption.

Response variables

Name	Type of data	Definition	Equation
perc_cc	Continuous variable	Actual cover crop adoption, percentage cover crops grown on total area of farmland annually.	ha_{cc} / ha_{arable} * 100 = A_a
tmax	Continuous variable	Potential cover crop adoption, based on farmland management as crop rotation and cultivation plan.	ha_{bw} / ha_{arable} * 100 = tmax
adoption_gap	Continuous variable	Cover crop adoption gap, percentage of total farmland theoretically left underutilized for cover crop adoption.	tmax – A_a / ha_{arable} = adoption_gap
relative_adoption_gap	Continuous variable	Relative adoption gap, adoption gap relative to the maximum potential cover crop adoption	100 - (A_a / tmax * 100) = relative_adoption_gap
t_sort_nit	Factor with levels	1) half-adopters, farmers that apply non-inversion tillage but sometimes plough their fields; 2) full-adopters, farmers that solely use non-inversion tillage and 3) non-adopters, farmers that always plough their fields.	
cc_constraints_ad_bp	Nominal variable	Agronomic constraints for cover crop adoption.	
cc_constraints_ad_se	Nominal variable	Socio-economic constraints for cover crop adoption.	
cc_drivers_ad_select	Nominal variable	Agronomic and socio-economic drivers for cover crop adoption.	
nit_pl_field_reason	Nominal variable	Agronomic and socio-economic constraining further NIT adoption for NIT half-adopters.	
na_constraints	Nominal variable	Agronomic and socio-economic constraining NIT adoption for NIT non-adopters.	

Co-variables

Name	Type of data	Definition
soil_aggregate	Factor with levels	1) clay, soil types loamy clay and clay; 2) loam, soil types loam and heavy loam; 3) mixed, more than one dominant soil type and 4) sand, soil types sand, loamy sand and sandy loam.
income_category	Factor with levels	1) low, income share between 0-25%; 2) low mid, income share between 25-50%; 3) high mid, income share between 50-75% and 4) high, income share between 75-100%.

2.3.3 Statistical tests

Data from the online survey was analysed with the computer programming language *R 4.2.2*. Further statistical analysis has been applied to multiple research questions, but not all, due to results often being frequency distributions as a result of the nature of the survey questions. Statistical tests that have been applied and for which purpose were:

- *ANOVA* tests have been used to analyse results of *3.2 Adoption*.
- *Chi-squared* test on homogeneity has been used to analyse results of *3.4 Future perspective*.

3 Results

In this chapter the most important results are represented, the topics will follow the order of research questions as they are described in *1.5 Research aim*. Results will be described through multiple graphs, along with contextual information from interviews as well as statistical tests.

3.1 Representation of respondents

The respondents' median age is 53 years, with a mean of 48 (*Figure 6a*), indicating that, on average, farmers in this study are younger than the typical Dutch arable farmer, who is 59 years old (AgriDirect, 2023). However, the violin plot reveals that a significant portion of farmers fall within the national average age of 59, with another peak around 30 years, and ages ranging from 20 to 75 years. The median income share from farming is 90% with a mean of 75%, a lower quartile of 50% (*Figure 6b*). This suggests that 75% of the represented households rely on farm-generated income for at least 50% and up to 100% of their total income. The remaining 25% of farmers depend on the farm for a maximum of 50% of their income, with the remainder sourced elsewhere. The violin plot displays this distribution of high- and low income dependency among farmers nicely with a funnel shape. Finally, the median farmland size is approximately 68 hectares with a mean of 94 hectares (*Figure 6c*), making the average farmers' farmland larger than the average Dutch arable farmland size of 60 hectares. Besides that, 50% of the farmers have more farmland than the national average with three outliers with >300 hectares, thus increasing the mean while the majority of farms are smaller in reality. The violin plot displays the distribution nicely, although showing that the majority of farmers with a farm size closer to the national average.

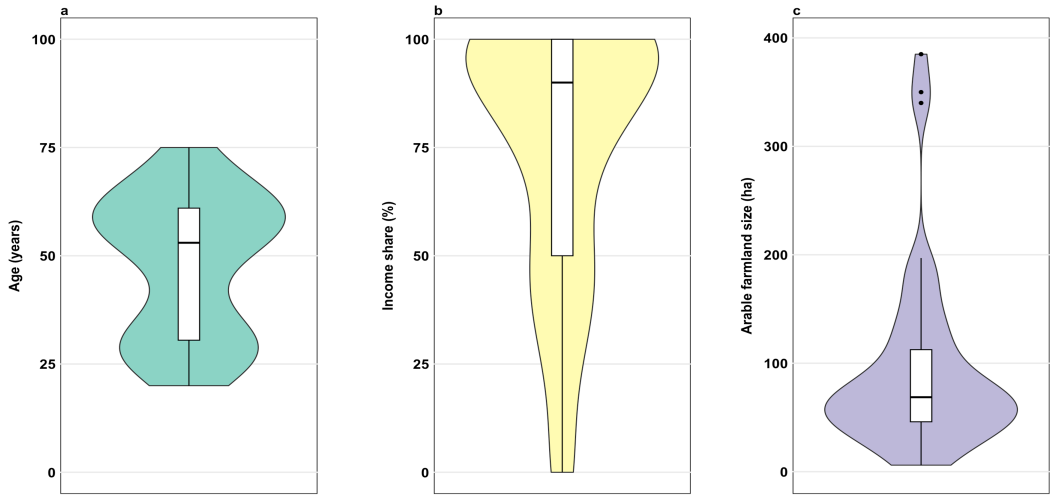

Figure 6: Descriptive statistics of the respondents on the online survey: a) distribution of respondent age in years, b) distribution of household income share from farming in percentages and c) distribution of arable farmland size in hectares.

Cereals, potatoes and sugar beets are among the most cultivated crops for all soil types, followed by seed onions, other arable crops, protein crops and vegetable crops (*Figure 7, next page*). This is in line with the national results shown in *1.2 Arable farming in the Netherlands* (*Figure 1*). It is however notable that farmers on heavier soils tend to cultivate more cereals than lighter soils and farmers on lighter soils more sugar beets than farmers on heavier soils, with almost all farmers on sandy soils cultivating sugar beets.

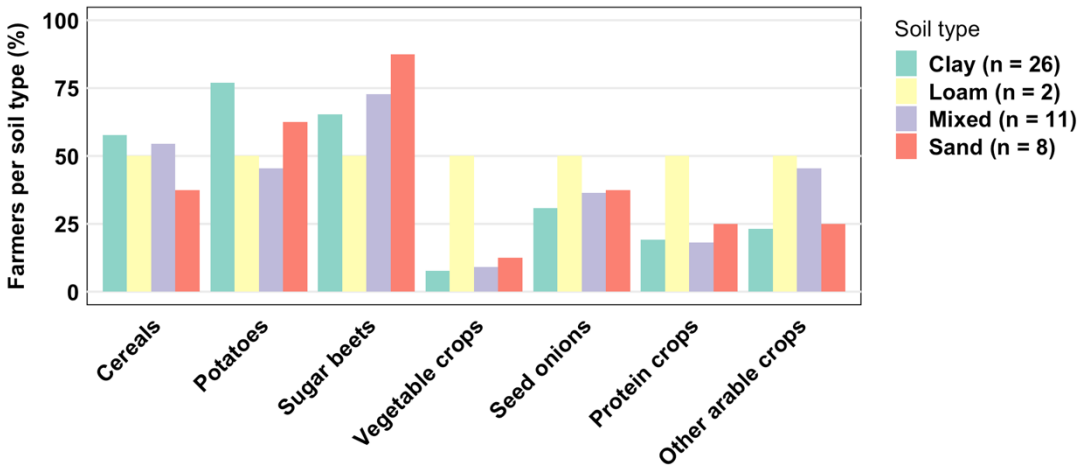

Figure 7: Crops grown in percentage of the total respondents per soil type.

3.2 Adoption

One of the primary aims was to identify the level of cover crop- and non-inversion tillage adoption, and to find possible variation. Survey results have shown that 46 out of 47 respondents are adopters of cover crops and 42 out of 47 respondents are adopters of NIT. The level of adoption of each practice will be discussed in different ways. Adoption of cover crops will be analysed based on continuous variables and NIT adoption on nominal variables (*2.3.2 Quantitative data analysis, Table 3*).

3.2.1 Cover crops

The median adoption area of cover crops is ±45% for all soil types except *sand* which is 32.05% (*Figure 8* and *Table 4*). It is shown as well that the total range of adoption area for sand is the largest ranging from 9.1 to 100%; followed in order by mixed (24.18-100%), clay (19.4-93.5%) and loam (40-51.19%). The mean adoption area ranges from 43.94 to 49.33%, suggesting no significant difference between the soil types in an ANOVA-test (p-value 0.951 (α=0.05)). Violins show that the distribution, of data for soil types except *loam*, follow an equal pattern of higher frequency of observations towards the first quartile with an overall lower area of adoption as compared to the third quartile, lowering the mean as can be observed.

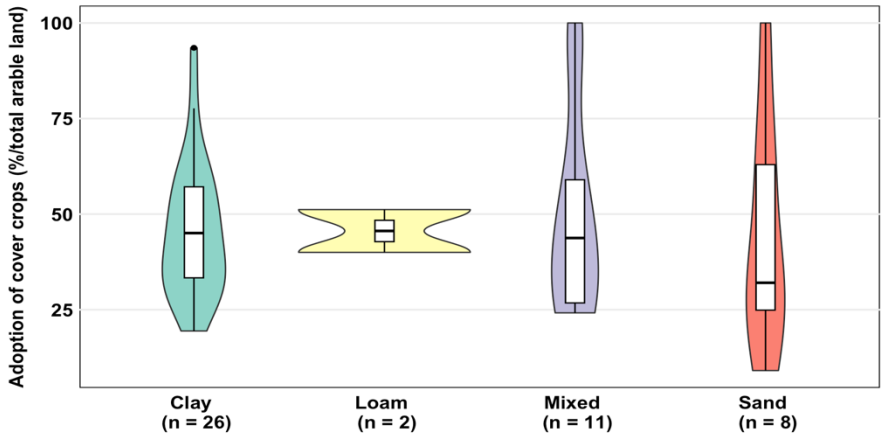

Figure 8: Distribution of percentual actual cover crop adoption on the total area of farmland in hectares for each of the different soil types found on farms. Data obtained through the online survey.

Table 4: ANOVA test for significant differences between soil types for the percentage area adoption of cover crops as shown in *Figure 9*.

ANOVA

	df	Sum Sq	Mean Sq	F value	Pr(>F)
Soil-type	3	169	56.4	0.115	0.951
Residuals	42	20646	491.6		

Among the surveyed farmers, 22% have allocated less than 50% of their farmland for potential cover crop cultivation, as per their land management practices, while 35% have designated over 75% of their total arable land for potential cover crop adoption (see *Figure 9a&b*). Additionally, it's notable that variations in available land do not appear to affect the actual adoption rates. However, a linear regression analysis suggests that there is no significant difference between the potential- and actual adoption of individual farmers (p-value 0.4552, with α=0.05). In terms of adoption gaps, 32.5% of all farmers have an adoption gap of at least 50%, 27.5% have an adoption gap between 50% and 0%, and 40% have an adoption gap of 0%; resulting in a mean adoption gap of 24.6% and a maximum adoption gap of 75.8%. Overall the actual adoption of cover cropping, with 32.5% having the largest theoretical potential to further increase their cover crop adoption. Lastly, it's observed that 20% of the farmers exhibit a negative adoption gap, theoretically impossible but likely due to inaccuracies in farmers' area estimations.

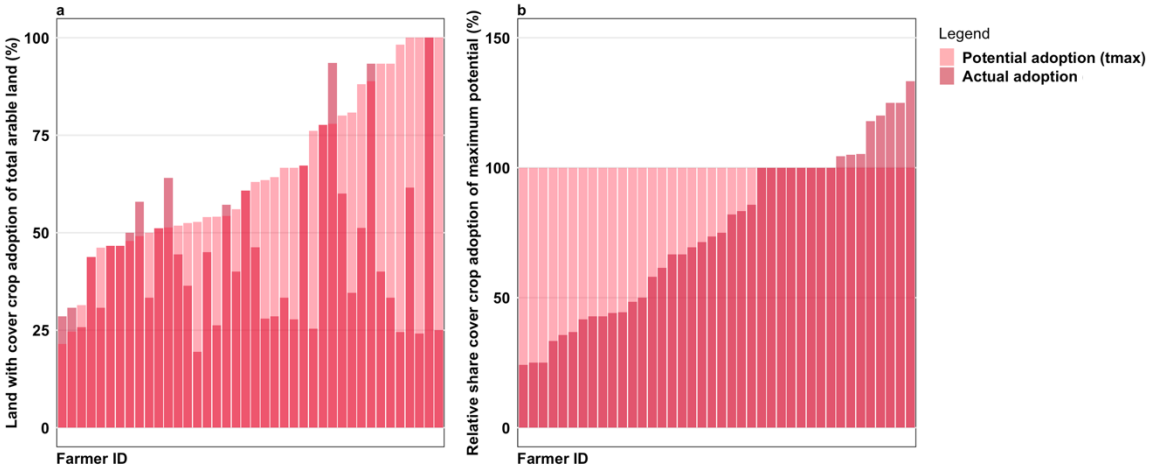

Figure 9: Cover crop adoption relative to potential adoption based potential cover crop adoption (tmax): a) Actual and potential adoption of cover crops, expressed as percentages of total arable land and b) Relative values for actual and potential cover crop adoption, where actual adoption from *Figure 8a* is made relative to potential adoption and the potential adoption is set to 100%.

Table 5: Linear regression-model to *Figure 8a* with adoption as response variable and tmax (potential adoption) as independent variable.

Linear Regression-model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	40.9012	8.0165	5.102	7.64e-06 ***
tmax	0.0844	0.1120	0.754	0.4552

From interviews more insights was gained regarding the field-to-field, in-year and year-to-year differences causing a smaller adoption area. Not regarding weather conditions, yet, a crop rotation limits the capability to apply cover crops after- or before every crop: *"So if you know you are going to plough in December, you don't actually need to sow a cover crop after mid-September." - Farmer 1, half adopter NIT, clay* (Personal communication, 2024). For other farmers across the Netherlands, the wet autumn and winter of 2023 were reasons for failed cover crops or made it even impossible for farmers to sow a cover crop without destroying the soil completely: *"And the wetness, because of that you can't go out into the field with the seeder, spit machine to loosen the soil, and then sow cover crops. But it was also a very wet autumn this year, so then it's also worse." - Farmer 2, non-adopter NIT, mixed* (Personal communication, 2024). For other farmers across the Netherlands this was not always a problem, but this was due to other factors which will be discussed in later paragraphs.

3.2.2 Non-inversion tillage

Results show that the majority of farmers are half-adopters (n=26), followed by full-adopters (n=16) and non-adopters (n=5); of these the majority of half-adopters can be found on *clay* 57.7 and majority of non-adopters on *mixed* 27.3% (*Figure 10*). Remarkable is that *loam* and *sand* do not have any reported non-adopters, and that the other adoption levels are represented equally within the soil types.

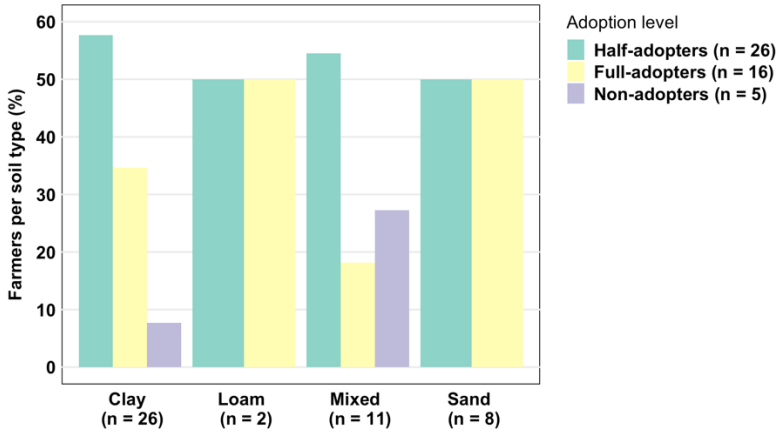

Figure 10: Percentage of different adopters of Non-Inversion Tillage (NIT) for the total number of farmers of the different soil types found on farms. Green: half-adopters are farmers that apply non-inversion tillage; but sometimes plough their fields, yellow: full-adopters are farmers that solely use non-inversion tillage and purple: non-adopters are farmers that always plough their fields.

From the interviews, it became clear that farmers on all soil types experience similar problems with their soils, and that there is no distinguishable difference between answers farmers on sand soils gave compared to farmers on clay soils. The reasoning for the adoption level lies beyond soil-characteristic differences and more in the secondary benefits NIT brings: *"Yes sure you always think about NIT. (...) Some things work out really well one year and some things don't the other." - Farmer 3, half-adopter NIT, clay* (Personal communication, 2023). Benefits and reasons that it works out one year and not the other are part of the constraints and incentives determining adoption.

3.3 Constraints and incentives

3.3.1 Cover crops

Results show that agronomic factors are more constraining for cover crop adoption than socio-economic constraints, as agronomic factors are picked more frequently than socio-economic factors (*Figure 11a&b*). 'Higher incidence of weeds' is a constraint that is present for farmers on all soil types, albeit in a lower frequency, and 'Nutrient competition' is a constraint only for *sand* soils. For the agronomic factors, 'Poor cover crop establishment' and 'Difficulties incorporating the cover crop into the soil' are the most common given constraints for all soil types except *loam* (*Figure 11a*). Besides the previously mentioned constraints, the text box indicated that there are other constraints as well. These constraints encompass: 'Crop rotation with a winter crop', 'Required weathering of the soil' and 'Regional agreements'

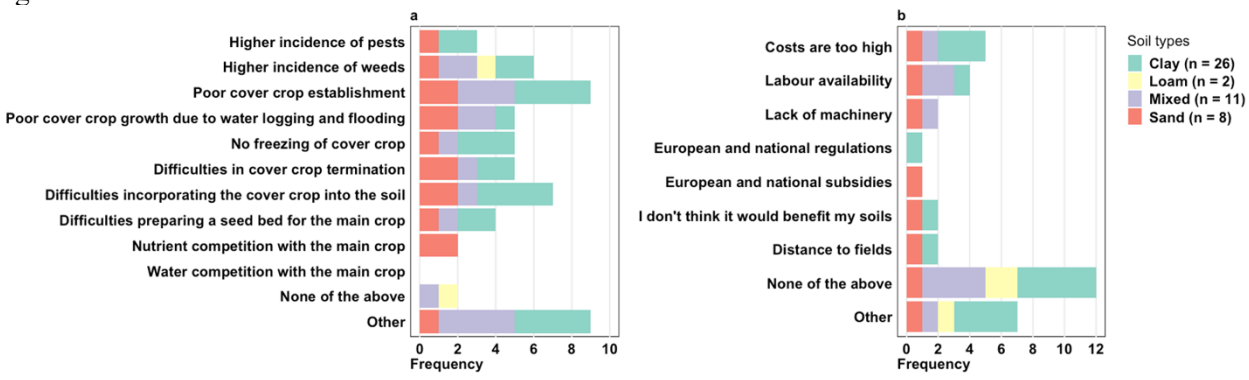

Figure 11: Frequency of factors that constrain adoption or further adoption of cover crops for each of the different soil types found on farms: a) agronomic constraints and b) socio-economic constraints. Data was obtained through the online survey. *Other was followed by a text box to write an alternative answer.

Regarding socio-economic constraints it becomes clear that farmers do not find themselves in the given constraints. 'None of the above' is chosen the most for all soil types, followed by 'Other' (*Figure 11b*). All farmers that chose 'Other' do emphasize the constraint of 'Economically unviable after a late crop'. It becomes clear that the chosen agronomic and socio-economic constraints concern the cover crop establishment.

In interviews these motivations were given as well: *"Look, after sugar beets, it is often not possible, because it is far too late. That cover crop doesn't have a chance to develop at all. (...) Then after potatoes, we sow wheat then you don't have a cover crop in between. Then the wheat itself is the next crop and then the field goes green over the winter." - Farmer 4, half-adopter NIT, mixed* (Personal communication, 2024).

Results show that 'Increased soil organic matter' is the most common incentivizing factor for all soil types (*Figure 12)*. This is followed by 'Increased soil nitrogen (N) supply', 'Increased crop productivity for the main crop' and 'Reduced nitrate leaching'. From there on, the difference between the next important incentives is large; but still applicable for all soil types except for socio-economic factors. It can be observed that regulations and subsidies are equally important incentives for cover crop adoption as the least important agronomic incentives. 'Availability of machinery' and 'Training workshop or knowledge resources' are shown to be the least important incentives for farmers. 'Other' incentives for cover crop adoption that came forward from the different soil types are 'Improvement of soil structure' and 'Improved water management'.

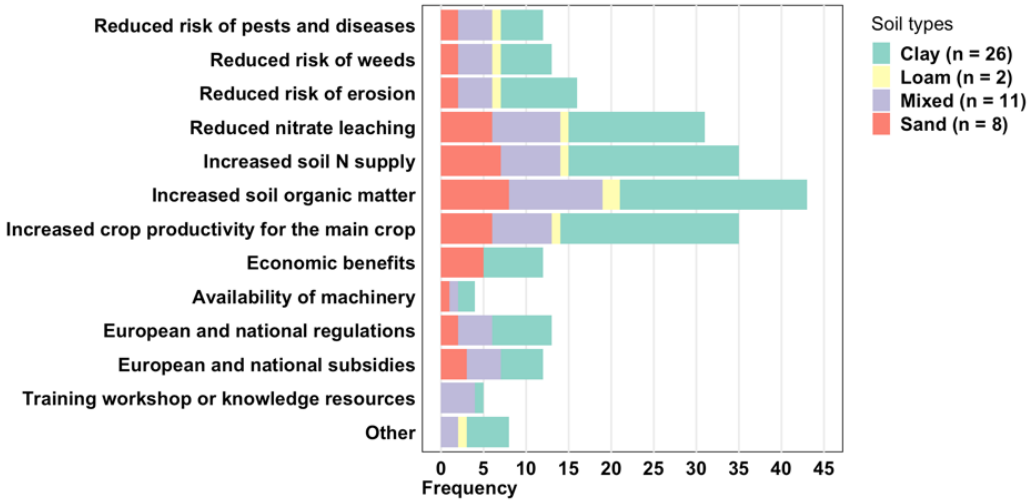

Figure 12: Frequency of agronomic and socio-economic factors that incentivize the adoption of cover crops for each of the different soil types found on farms, where other is followed by a text box to write an answer.

In interviews another mentioned incentive was the benefit of providing biodiversity services: *"Also for a bit of biodiversity, just keep your fields green." – Farmer 5, half-adopter NIT, loam* (Personal communication, 2023).

3.3.2 Non-inversion tillage

Results show that 'Effective control of weeds' and 'Concerned that it will diminish my crop productivity' are the most important factors that prohibits NIT adoption for non-adopters on the different soil-types present (*Figure 13, next page)*. Furthermore, for non-adopters 'Crop establishment problems', 'Soil water content regulation' and 'Soil compaction' are important for *clay* soils and 'Labour' for *mixed* soils. Remarkably, not one non-adopter thinks that 'Acquiring the required knowledge and skills' is a constraint.

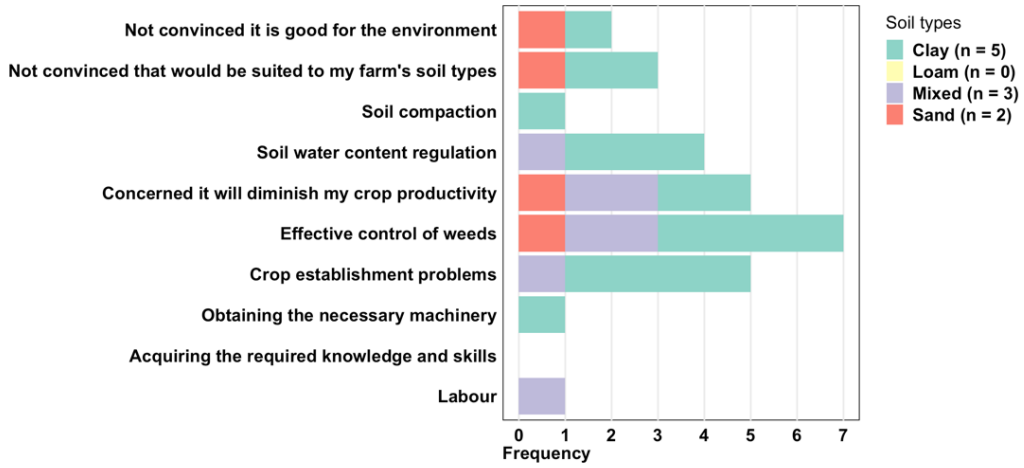

Figure 13: Frequency of agronomic and socio-economic factors that prohibit adoption of non-inversion tillage (NIT) *for non-adopters* for each of the different soil types found on farms.

Results show that 'Improve crop establishment', 'Soil compaction' and 'Suppression of weeds that affect that particular crop' are the most important factors that limit the adoption of NIT for half-adopters (*Figure 14*). Other constraints are applicable for all the soil-types as well, but are less important as the graph shows. On the other hand, 'Controlling soil water balance' and 'Untidy field' are not chosen by farmers on *mixed* soil type. 'Other' constraints have to do with the top soil layer being too dry for *clay* or either too wet for *mixed* to prepare an adequate seedbed.

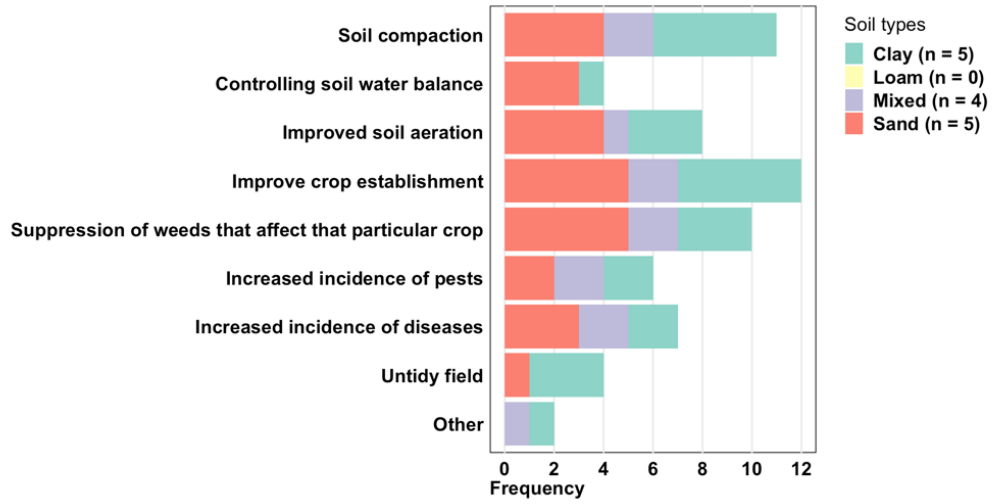

Figure 14: Frequency of agronomic and socio-economic factors that constrain further adoption of non-inversion tillage (NIT) for *half-adopters* for each of the different soil types found on farms.

3.4 Future perspective

To further reason as to why the adoption of cover crops and NIT may vary from farm to farm, this section will look into the perspective on the future of farming in the future and how this translates to choices made on farm- and field level combined with the household income generated by the farm.

The results indicate that the majority of farmers, excluding those with a low income share, are uncertain about feeling in control over the future of their farm (*Figure 15, next page*). The homogeneity test between income share groups produced a p-value of 0.115 (with α=0.05), suggesting that there is no significant difference (*Table 7*). Farmers who are unsure about feeling in control or express a lack of control often cite doubts about factors beyond their control as the reasons.

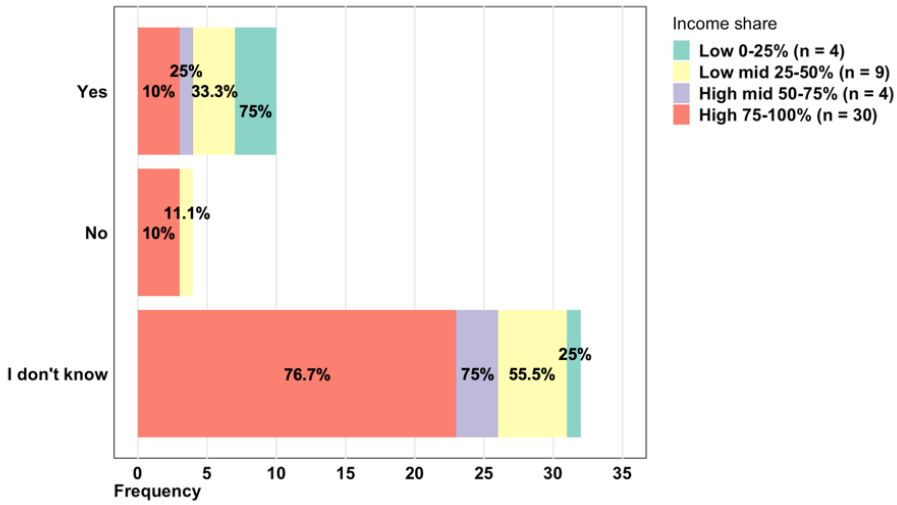

Figure 15: Perspectives of control over the future of the farm as perceived by respondents aggregated by income share originating from the farm itself. The percentage inside the bars indicates farmers within a category of income share with the same perspective.

Table 6: Contingency table for *Figure 15*.

	Yes	No	I don't know	Total
Low	3	0	1	4
Low mid	3	1	5	9
High mid	1	0	3	4
High	3	3	23	29
Total	10	4	32	46

Table 7: Pearson's Chi-squared test for homogeneity corrected for population size for *Figure 15*.

Pearson's Chi-squared test		
X^2	df	P-value
10.18	6	0.1171

Results show that the majority of farmers felt that 'Policy and regulation' would have the largest impact on the future following the question what they feel is the most impacting factor for their future (*Figure 16*). Interestingly enough, this differs amongst income share categories. Where the majority of low mid-income share farmers feel that 'Climate change' and 'Own urge to change' would impact their farm the most in the future, the majority of high mid-income share farmers are more concerned with the 'Productivity of their farm'. To gain more insight into other factors, answers given under the 'Other' answer are: 'Availability of farmland', 'Market', 'Ban on chemicals', 'No future vision from the government', 'Access to freshwater' and 'Succession'.

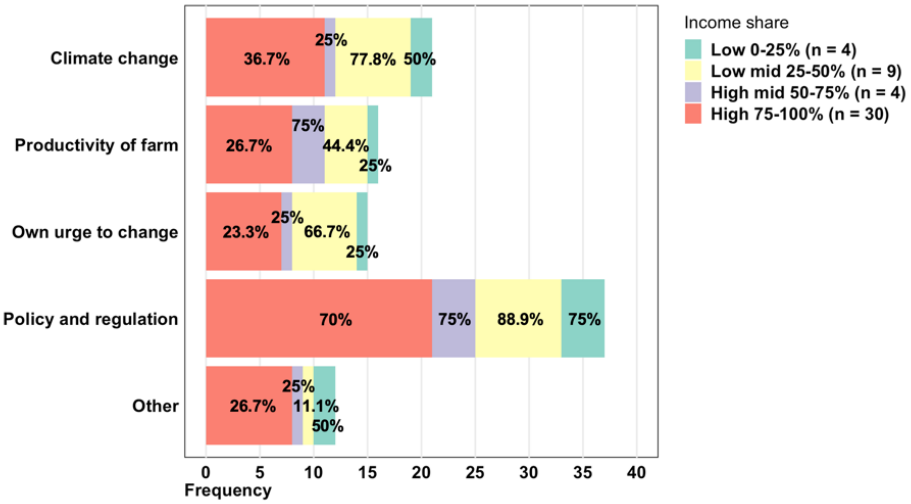

Figure 16: Farmers perspectives on factors impacting the future of their farm for varying categories of household income share originating from the farm itself, with percentage of farmers from the same category of income share with the same perspective.

For this question, more emphasis was put on the interviews to gain a more contextual explanation. As to how farmers look to the future, there was one overarching answer relating to farming itself: *"I see the future when it comes to food production, I see a rosy outlook. (...) the availability of good agricultural land in the world, is getting smaller and smaller and more people are coming in. So that can mean one thing there: that food will only get more expensive." - Farmer 7, high income share, sand and Farmer 8, high income share, clay* (Personal communication, 2024). That does however not mean that there are no worries as can be read in the next quote: *"Yes, ultimately you make your own choices, but the weather extremes make it difficult and we are on relatively good ground here. So I think we can consider ourselves lucky with that. We can generally irrigate well here. We have never had to deal with the situation where we were no longer allowed to irrigate because there was too little water. Other parts of the country do." - Farmer 5, low income share, loam* (Personal communication, 2023). Along with the worries regarding a changing climate, interviews show the importance of future vision and the effect of lack thereof: *"And yes, we are trying to switch gears in advance. So that you will soon be ready for any new regulations. Or whatever is coming, sometimes it doesn't really help that there is little vision. Where we should be in the Netherlands in 10 years with agriculture." - Farmer 3, high income share, clay* (Personal communication, 2024).

3.5 Policy perception

To understand how policy and regulations are influencing the adoption of cover cropping and NIT, this section will look into the perception of policy by farmers. This is again done to see how this translates to choices made at farm and field-level combined with the household income generated by the farm.

Results show that all except one farmer from the *high* income share category use subsidies (*Figure 17*). To further understand as to why this number is this large the following quote gives an answer: *"But of course I do pay the benefits and the burdens of that land. So you can also say, let's say: I want to do that, but there has to be something in return." - Farmer 1, high income share, clay* (Personal communication, 2024).

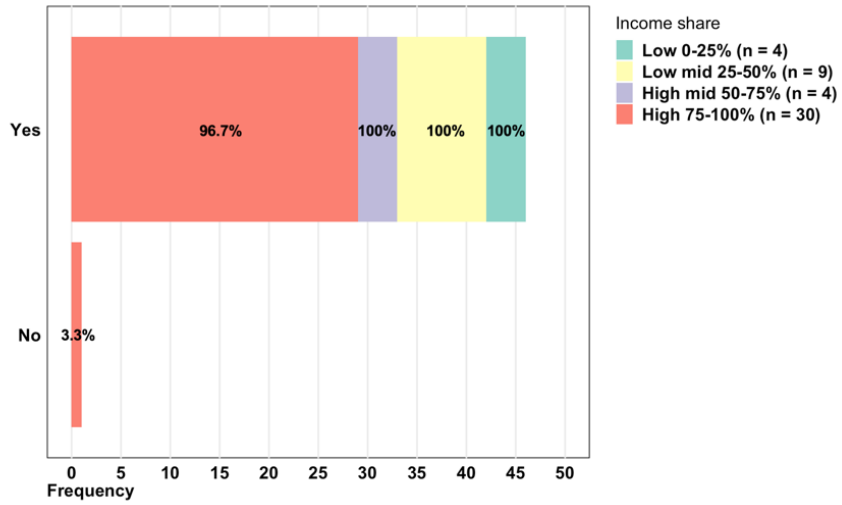

Figure 17: Farmers that use EU subsidies and other financial aids to run their farm, with the corresponding percentage of farmers sharing the same perspective within each income share categories.

Results show that the majority of farmers for all income share categories think that the EU does not support farmers enough to make sustainable changes (*Figure* 18, next page). With two farmers from the high-income share and two from the mid and low-income share category thinking that the EU support is enough. Insufficient support is reflected by the quote: "*What I find a big challenge at the moment is that the rules are changing rapidly and also faster than the market situation changes. (...) Only that has to be paid for by someone. I'm not going to do it from my savings." - Farmer 6, low-mid income share, clay* (Personal communication, 2024).

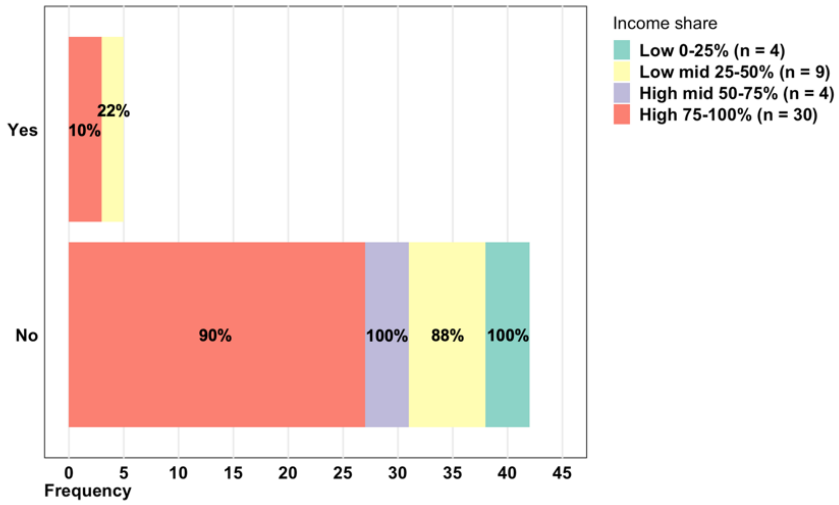

Figure 18: Farmers that think the EU incentives to make sustainable changes are enough, with the percentage of farmers sharing the same perspective for each income share class.

Another aspect with regards to subsidies is the lottery aspect of it and the lack of control: *"But yes, they want to set everything in concrete terms of rules and then you get these kinds of burdens that there are people who say: 'Well, I've found a hole here.'. We're trying to implement sustainable practices, but yes, that's what is granted and then often comes the indiscretion of those who award the subsidies." - Farmer 4, high income share, mixed* (Personal communication, 2024). However, for a minority it is sufficient, as becomes clear from the following quote: *"We have a subsoiler and a GPS-controlled fertilizer spreader and a GPS system. At the time, we also received a 40% subsidy on that. Yes, I think that's serious. But I also think that this is a material with which you can really farm more sustainably." - Farmer 9, low-mid income share, clay* (Personal communication, 2024). A follow-up question was posed as to what could then be improved to make regulation sufficiently supportive for change.

Results show that a majority picks 'Realistic regulation' and 'Other' on the question to what can be improved on current policy (*Figure 19*). From the latter, a variety of answers were given which encompass the other answer options slightly: 'No lottery for high subsidies, but allocate money based on applied practices', 'Region specific regulation', 'Money needs to come from the market' and 'Trust'. Comments made on the current policy in the online survey as well as the interviews boils down to: 'Vague policy', 'No contact between government and farmers', 'Policy that is too general' and 'Too many, strict and contradicting rules'.

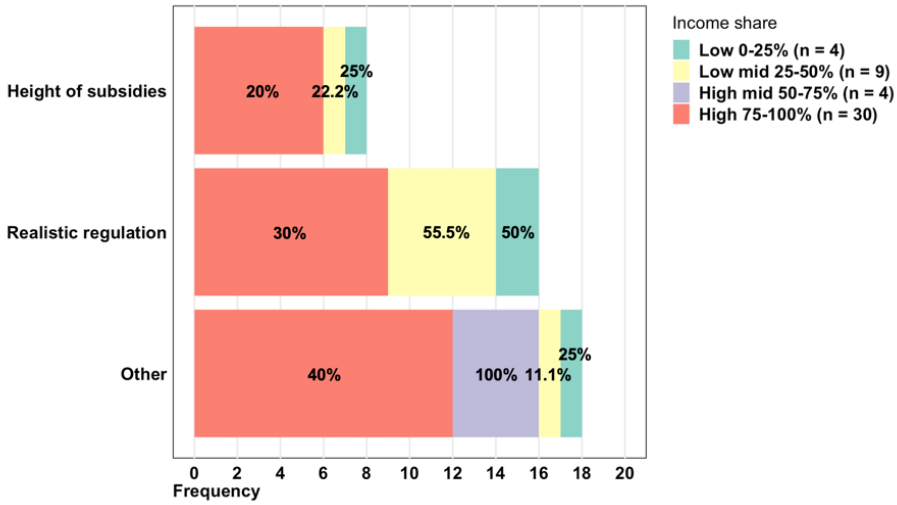

Figure 19: Selected improvements on the current policy and financial aids to provide enough support for sustainable changes. The percentage indicates farmers sharing the same perspective within the same class of income share class.

Interviews can further emphasize this: *"But I miss that goal steering a bit. There must be a purpose behind it, but now a number of pre-cold building blocks are thrown on the table and that's it. Whereas if you understand better what the goal is, and there is some room for your own entrepreneurship, then you might be able to get to the goal much faster." - Farmer 6, low-mid income share, clay* (Personal communication, 2024). To reach this point it is proposed in the interviews to apply a bottom-up approach: *"You can also say, trust is good, and someone who makes a mistake receives a fair punishment, and publish what the punishments are. Then it is better for society than to be controlled on everything. That's breaking us." - Farmer 7, high income share, sand* (Personal communication, 2024). Finally, another approach may be to look at our Eastern neighbours: "*Personally, I have the idea that you have to work towards a soil pointing system (which they also have in Germany). Reasoning is, the higher the soil points, the higher the value of the land. Perhaps KPIs [nt.: key performance indicators] would complement this. Indicate in advance what you are going to do, execution (proof) and result." - Farmer 10, low-mid income share, mixed* (Personal communication, 2024).

4. Discussion

In this chapter, notable results from both the online survey and interviews will be discussed based on similarities and contrasts in corresponding literature and findings in the online survey and farmer interviews. Furthermore, the limitations of this study will be addressed followed by the possible implications. The aim of this study was to dive deeper into farmers' perceptions and perspectives regarding the agronomic potential of adopting cover cropping and reduced tillage and find possible correlations to soil characteristic differences.

4.1 Adoption and soil types

At the start of this study, it was hypothesized that soil characteristics would influence the adoption of cover crops and NIT. This was attributed to differences regarding their farm management characteristics, sequestration potential and susceptibility to increased environmental risks such as leaching (RVO Nederland, 2022; Silva et al., 2017; Smit & Jager, 2018; Knotters et al., 2022). This study showed that there are little to no differences in constraining or incentivizing factors for the adoption of soil carbon sequestration practices between soil types in the Netherlands. From results alone it may difficult to reason for this difference, besides allocating the difference in potential to agronomic constraints and weather conditions experienced by farmers.

Beginning with cover crop adoption and adoption gap, incentives for cover crop adoption show that 50% of the respondents for all soil types gave 'Reduced nitrate leaching' as an incentive to adopt cover cropping. As indicated in RVO Nederland (2022) cultivation of cover crops on farm land once every four years is deemed mandatory for farmers on lighter soils. A farmer on clay soils clarified however that these regulations not only apply for sand: *"The regulations have and are changing, with fertilization, leaching and NV-areas and you name it. I think I've got that, so to speak, well, my soil pretty much in order." - Farmer 8, full-adopter NIT, clay* (Personal communication, 2024). This relates to the recently published areas that are contaminated with nutrients, which are spread across the Netherlands, and determine the amount of nutrients that may be applied and when cover crops are required to be grown (RVO Nederland, 2023). These regulations however may cause farmers to further adopt cover cropping on lighter soil types as sand and loam. Because of stricter rules due to inherent soil characteristics, farmers are being cut in the amount of nitrogen that can be applied during a year (RVO Nederland, 2023). This explains the motivation for farmers on all soil types to adopt cover crops to abide by the stricter regulations regarding leaching and fertilization.

Similarly, the uniformity of crop rotation practices across different soil types in the Netherlands, driven by the prevalence of the same crops, may explain the similarities observed between soil types (Silva et al., 2017). This uniformity limits the opportunities for farmers to incorporate cover crops into their rotations, potentially outweighing the impact of soil type variations. This fact together with the noticeable wetter autumn and winter could be important explanations for the adoption gap and the perspective of future uncertainty. Weather patterns are difficult to predict, but dictate the ability to grow cover crops. The wet autumn and winter of last year prevented farmers in all regions to sow their cover crops at the usual time from mid-September and early October. It is noticeable that it is the aim to incentivise cover crop adoption to mitigate climate change (European Commission, 2022; Kathage et al., 2022), while the effects of climate change can already prevent further adoption. Farmers think about solutions themselves already and try to prepare for bad weather conditions: *"It is becoming more and more necessary to have excess capacity. That you actually have machines that are bigger than you, or that can do more, because the number of days that you can sometimes perform certain activities is more limited. That is why we are now happy, for example, that we have not had to do anything about the cover crops that we sowed in August." - Farmer 3, half-adopter NIT, clay* (Personal communication, 2023). However, it's challenging to determine the true influence of weather on adoption rates. The survey did not specify whether farmers consistently cultivated cover crops at the reported levels each year, or if they adjusted their practices due to varying weather conditions over the years.

Regarding the adoption of NIT, it is shown that there are very few non-adopters of NIT as compared to half- and full-adopters. This is mainly driven by agronomic constraints such as effective control of weeds, crop establishment problems, diminished crop productivity, soil quality and water management. Bakker et al. (2023), Amelung et al. (2020) and Buck & Palumbo-Compton (2022) on the other hand suggested in their research that applying practices as NIT can lead to co-benefits, as improved soil quality and crop productivity.

From an interview with a full-adopter incentives as suggested by Bakker et al. (2023), Amelung et al. (2020) and Buck & Palumbo-Compton (2022), are corroborated: *"When sowing, so that the straw pieces are still on top, that dampens the rain, and the susceptibility to sludge I can notice that it gets better that way." - Farmer 10, full-adopter NIT, mixed* (Personal communication, 2024) and *"That is, of course, your soil's ability to hold on to water. That's much longer in the summer before I have to start irrigating here." - Farmer 11, full-adopter NIT, clay* (Personal communication, 2024). Although these are just two examples of full-adopters acknowledging the existence of these co-benefits, it is acknowledged by a half-adopter that weather effects are constraining further adoption of NIT and that there is a connection with soil characteristics: *"I also believe, when I look at the wet weather conditions now, that you also have to bring air into that soil. That it is also good for that soil life." - Farmer 3, non-adopter NIT, sand* (Personal communication, 2024). As soils with lower densities have larger pore sizes, soils become more prone to compaction (Smit & Jager, 2018; Knotters et al., 2022).The results however showed that the soil types sand and loam did not contain any non-adopters of NIT, thus it cannot be said if non-adopters on these lighter soil types exist and how they experience problems regarding crop productivity and soil quality.

4.2 Intertwined factors

This study showed that agronomic constraints are more important incentivizing and constraining factors for cover crop and NIT adoption than socio-economic constraints. As discussed by Mills et al. (2019), agronomic factors affect a farms' productive capacity directly. It is however noticeable that productivity is inherently linked with socio-economic factors, as constraints like poor cover crop establishment and higher incidence of weeds are either a waste of money or require extra labour. Furthermore, abiding to regulations that force the application of more cover crops causes problems as well: *"Then you have to sacrifice production land for abiding to the regulations and depending on what you grow, that's just a financial consideration." - Farmer 6, half-adopter NIT, clay* (Personal communication, 2024). Another point of discussion that was raised in interviews was the fact that an increase in soil organic matter is a slow process, that effort put in pays out over longer periods and that intensification can cause a setback: *"But nevertheless, you will notice that your organic matter content of your soil is making steps and faster than many people think. (...), but you see with most that if an intensive crop is grown, it will fall back." - Farmer 11, full-adopter NIT, clay* (Personal communication, 2024). This indicates that the aspect of costs and benefits can be crucial socio-economic factors in changing a farming system, as is discussed by Mills et al. (2019) and Bakker et al. (2023) even though the online survey results indicate otherwise. This can possibly be explained by the missing opportunity to give an explanation on all answers in the online survey. Where it is possible to make contextual connections in interviews and deepen understanding, the online survey poses a rigid format where an answer cannot be corroborated.

4.3 Certainty for the future

This study showed that the majority of farmers do not know if they feel in control over the future of their farm. As Adger et al. (2007) discussed, it is important to understand the perception of people towards control over their farm in the future when aiming to increase adoption. Farmers' interviews showed that the main reason for this uncertainty regarding the future is grounded in a lack of direction from the government: *"It's too complicated now. One rule works against the other. Farmers and enforcers themselves do not know what is or is not allowed." - Farmer 12, low-mid income share, mixed* (Personal communication, 2024). Because it was thought that adoption of alternative practices like NIT are perceived as a risk compared to the more traditional practices, income dependency was thought to be a useful co-variable. This, however, proved not to be the case and yielded no observable differences between income category groups.

The notion of Clayton (2019) and van Valkengoed et al. (2022) regarding individual opinions regarding climate change risks and how this leads to varying responses to environmental challenges is hard to grasp. As climate change did not turn out as the most important factor impacting the future of the farms, the interviews shed more light on this. On one hand there are the farmers that follow the minimum sustainability requirements set by agricultural policies and nothing more: *"I think people still have to eat and there are more and more people, and we produce relatively simple food here, so I think there is something that can be adjusted every time." - Farmer 4, high income share, mixed* (Personal communication, 2024), and on the other hand more pro-active farmers that think a step further than the sustainability requirements dictates: *"That they still think, it's just fine like it is going on now. So no reason for change. But then I would look for the risk, and I also understand it, because if the risk goes in the wrong direction, it can also cost a lot of money." - Farmer 9, low-mid income share, clay* (Personal communication, 2024). Besides acknowledging the fact that seeing the risks and being constrained by them, this quote highlights the intertwining of constraints and incentives again. It is furthermore interesting to see how this can be a reason for the observed variation in theoretical potential to further increase cover crop adoption. This can also explain a larger potential for increased adoption of either practices to farmers that follow the minimum requirements, and a small to no potential to increase adoption of either practices. Where there is 'room left for improvement' to expand adoption to a larger share of farmland for farmers that follow the minimum requirements; pro-active farmers may seek to maximize the practices they deem practices beneficial for their farm, now and in the future.

4.4 Improvements for policy

This study gave an interesting insight in the attitude of farmers towards governance of soil carbon sequestration practices. As discussed by Mills et al. (2019) and Bakker et al. (2023), institutional support is an important socio-economic factor that can both constrain and incentivize change. It was however shown that government support is, according to the respondents, insufficient and the policies executed by the government contradictory and without perspective. This is however not agreed upon by all farmers: *"I'm not the kind of person to complain about the EU or the government all day long. I just think that's a waste of energy, so yes, like I said, just accept it. Otherwise you have to put your company up for sale and move to another country or you have to stop being a farmer." - Farmer 9, low-mid income share, clay* (Personal communication, 2024). As discussed in the previous paragraph future perspectives and attitudes towards risk shed light on the effectiveness of current policy instruments (van der Wal et al., 2014). It is shown that the majority of farmers do not think that current policy instruments are effective; but they do raise ideas for improvements and most of them regard reducing government control, multi-stakeholder collaboration, performance-based subsidies and region-specific regulation as potentially beneficial.

4.5 Interpretation and integration

The study revealed limited differences between soil types concerning the adoption of cover crops and NIT. Despite initial expectations, soil characteristics did not strongly influence adoption patterns. Instead, agronomic factors emerged as more influential determinants, impacting both the level of adoption and the constraints faced by farmers. Notably, there was a prevalent uncertainty among farmers regarding the future of their farms, rooted in ambiguous government regulations and perceived risks associated with alternative practices. These findings have broader implications for agricultural practices and policies.

Moreover, importance of clear and supportive government policies to incentivize sustainable agricultural practices was observed to be of great importance to farmers. The identified uncertainties regarding future farming practices highlight the need for proactive measures to address climate change adaptation and mitigate risks associated with shifting agricultural norms. Patterns observed in the data indicate a complex interplay between agronomic constraints, socio-economic considerations, and government policies. While agronomic factors such as soil quality and water management significantly influence adoption, socio-economic factors like cost-benefit deliberations and government regulations also play pivotal roles. Furthermore, the study illuminates the interconnectedness of constraints and incentives, suggesting that addressing one aspect may have ripple effects across others. The diverse perspectives of farmers regarding policy effectiveness underscore the need for nuanced bottom-up approaches that accommodate varying needs and preferences within the agricultural sector.

4.6 Limitations

Within the study certain limitations may have influenced the outcome. As became clear from the methods, the population of farmers that filled in the online survey (n=47) was lower than the initial (n=100) that was aimed for. This together with the fact that aggregation of soil types revealed varied populations within the soil-type subpopulations (clay n=26, loam n=2, mixed n=11 and sand n=8), could be reasons that comparisons between populations led to no outstanding differences and statistical tests to perhaps lead to insignificant differences. Analysing online survey results can also lead to misinterpretations of differences between answers in interviews and survey results. Due to the lack of opportunity to explain every answer it may look like there are contradictions while these may not even be present. There has not been an analysis of adoption level for a specific farmer ID, and connecting this to their personal perceptions. So deliberating for individual adoption levels being as they are may not possible, but contextual information regarding the perceptions of individual farmers have helped to shed light on this. As could be seen in the results, actual and potential adoption were only shown for cover crop adoption. Making similar figures was not possible for NIT, because of the intricate design of the online survey. It was not straightforward to answer how many hectares NIT was applied; because there were multiple forms of tillage practices identified being: mouldboard ploughing, direct seeding and NIT. This was furthermore coupled with a question as to what challenges lead farmers to apply a certain practice on all, some or none of their fields. Additionally, the surveyed farmers were found not to be representative of the average Dutch arable farmer, with an average age of 48 compared to the national average of 59 and average arable land of 94.3 ha versus 60 ha nationally. It was furthermore challenging to acquire valuable co-variables which can predict or explain the different levels of adoption. Furthermore, the freedom of farmers to enter answers freely may have caused discrepancies between data as can be seen in *Figure 9a&b* where the actual adoption exceeds potential adoption.

4.7 Future directions

As was observed in interviews the core reason for non- or half-adoption was facing risks regarding the switch to an alternative practice, leaving a question as to what could cause farmers to act differently besides intrinsic motivation. Furthermore, it can be of value to look into successfully quantifying actual and potential adoption of NIT. This will give a more accurate insight as it would be possible to describe farmers with a precise amount of hectares used for NIT instead of classifying them as non-adopter, half-adopter and full-adopter. Within a co-variable as income share there was not an outstanding difference between income share categories, the perception of risk and how this translated to the level of adoption. Future research should focus on selecting relevant co-variables and improving farmer outreach, with collaborations with websites and organizations proving effective. Increasing the total sample size may mitigate skewed co-variable populations. Lastly, disentangling agronomic and socio-economic factors by analysing their effects on economic costs and benefits for farmers is recommended.

5. Conclusion

This study aims to explore farmers' perceptions and perspectives on agronomic and socio-economic constraints and incentives. It investigates how these factors contribute to the under-utilization of agronomic potential in adopting cover cropping and non-inversion tillage, and seeks correlations with differences in soil characteristics. To evaluate the aim of this study, the research questions and their corresponding answers will be presented.

1. What is the current variation in the adoption of cover cropping and non-inversion tillage on both farm- and field level amongst Dutch arable farmers, depending on soil characteristic differences?
    - There is no evidence for a significant difference between soil type and adoption of cover cropping and reduced tillage. Results show that soil characteristics did not influence cover crop adoption, but were a determining factor for non-inversion tillage.
2. What are the agronomic- and socio-economic factors that can explain this variation of adoption on farm- and field level in relation to these soil characteristic differences?
    - Agronomic constraints affecting cover crop adoption are: higher incidence of weeds across all soil types, nutrient competition specifically in sandy soils, and challenges related to cover crop establishment and incorporation into the soil for all soil types except loamy soils. Socio-economic constraints primarily revolve around the economic viability of cover cropping, which is intertwined with agronomic factors.
    - The incentivising factors that explain variation in cover crop adoption are: ‘Increased soil organic matter’, ‘Increased soil nitrogen (N) supply’, ‘Increased crop productivity for the main crop’ and ‘Reduced nitrate leaching’.
    - The factors that explain variation in non-inversion tillage adoption for non-adopters are: ‘Effective control of weeds’ and ‘Concerned that it will diminish my crop productivity’ for all soil types; ‘Crop establishment problems’, ‘Soil water content regulation’ and ‘Soil compaction’ for clay soils; ‘Labour’ for mixed soils.
    - The factors that explain variation in non-inversion tillage adoption for half-adopters are: ‘Improve crop establishment’, ‘Soil compaction’ and ‘Suppression of weeds that affect that particular crop’ for all soil types; ‘Controlling soil water balance’ and ‘Untidy field’ for all but mixed soil type.
    - Additionally, other constraints have to do with the top soil being too dry for clay or either too wet for mixed to prepare an adequate seedbed.
3. What is the impact of Dutch arable farmers’ perspective of farming in the future on the adoption of cover cropping and non-inversion tillage?
    - All farmers acknowledge that the future is uncertain, but not all farmers take matters in their own hands. Some are pioneers that take risks and go all-in with regards to cover crop and NIT adoption, while others abide to the rules and nothing more leading to a higher potential for increased adoption of cover crops and NIT.
4. What are the perceptions of Dutch arable farmers regarding the effectiveness and improvements of current Dutch- and common EU-27 agricultural policies to incentivise and support adoption of cover cropping and non-inversion tillage on both farm and field level?
    - Policy is deemed ineffective and needs to be unambiguous and goal orientated, but above all, offer long-term stability. Improvements consist of: reducing government control, multi-stakeholder collaboration, performance based subsidies and region specific regulation.

While soil variations had minimal impact on cover cropping, they did affect non-inversion tillage adoption. Key influences for cover crop adoption included agronomic constraints like weed incidence and nutrient competition, alongside socio-economic factors related to economic viability. Incentivizing factors such as increased soil organic matter and crop productivity also played a role. Additionally, farmers' perspectives on farming's future influenced adoption behaviours, with some taking risks while others adhered strictly to regulations. Regarding policy, farmers advocated for clearer, goal-oriented, and stable agricultural policies, proposing improvements like reduced government control, multi-stakeholder collaboration, performance-based subsidies, and region-specific regulations.

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Appendices

Appendix 1: Interview protocol

Main domains of inquiries and examples of knowledge gaps and corresponding questions of the expert interviews and farmers, adapted from Vidal Morant et al (2023).

Interviewees	Domain of inquiry	Knowledge gap	Example questions
Experts	Descriptive information on the context	Understand the current situation: management practices, crop rotations, farm- and soil types	Could you describe what a production season with regards to operations and working period for a local arable farmer looks like? What would you say are the main production constraints in the region?
	Feasibility of cover cropping and reduced tillage	General opinion on cover cropping and reduced tillage, and accompanying constraints	How much do you think cover cropping and reduced tillage can contribute to climate change mitigation? What practice would you think could/could not be implemented in the region? And why?
	Co-benefits	Assess which synergies farmers can experience from adoption of cover cropping and/or reduced tillage	What direct benefits do you think farmers can experience from adopting cover cropping and/or reduced tillage? Do you think that cover cropping or reduced tillage would be best suited for a specific region besides soil carbon sequestration? And why?
	Adoption of soil carbon sequestration practices	Successful adoption of cover cropping and reduced tillage, and involved drivers	Are you aware of widespread use of cover cropping and or reduced tillage? What were the drivers behind this adoption of cover cropping and reduced tillage? And why?
	Variation due to soil characteristics	Existing discourse on effects of soil type on implementation of practices and hight of subsidy	Are farmers experiencing challenges with regards to applying for subsidy and the effort that it takes? How much are soil types of different fields constraining farmers in the practices that they can/must apply?
	Perspective of farmers on future farming	Gain insight on how much farmers worry about the future and if this influences their behaviour	What is it that worries farmers the most about the future of their farm with regards to climate change? And why? Do you think that farmers' worries about the future influence their choices of practices? And how?

Farmers	Descriptive information on the context	Gaining insight in the workings of the farm: crops, fields, soil type and management practices	What does your farm look like and what crops do you grow? What does your year look like with regards to management practices like rotations and ploughing? Is this the same for all of the fields?
	Feasibility of cover cropping and reduced tillage	General opinion on cover cropping and reduced tillage, and accompanying constraints	What is your opinion on the use of cover cropping and reduced tillage on your farm? Are you doing it/do you want to do it, yes or no, and why? What are factors for you that constrain the use of the previously mentioned practices?
	Co-benefits	Assess if farmers experience and know of synergies from adopting cover cropping and/or reduced tillage	Did the adoption of cover cropping and/or reduced tillage bring you any benefits? Or do you know what it could bring you when you would use them? Do you think cover cropping and reduced tillage could be/is beneficial to the productivity of your farm?
	Adoption of soil carbon sequestration practices	Status on adoption of cover cropping and reduced tillage, and involved drivers	Have you adopted cover cropping and/or reduced tillage on your farm? And on some or all fields? What are for you the driving factors to adopt these practices?
	Variation due to soil characteristics	Gaining insight into the variability of soil types between fields on the same farm and the implications	What is the type of soil that your fields are on and is this the same among all of your fields? (Homogeneous or heterogeneous) Do the characteristics of the field soils influence the different practices that you can and must apply?
	Perspective of farmers on future farming	Gain insight on how much farmers actually worry about the future and if this influences their behaviour	What is it that worries you about the future of your farm with regards to climate change? And why? Do these worries about the future influence your choice of practices? And how?

Appendix 2: Survey protocol

Part 1: General questions

Question code	Question	Answer model
Age	What is your age?	…… years
Gender	What is your gender?	Female / Male / Other
Income_share	What percentage of your household income comes from farming?	….%
Organic	Do you operate as a certified organic farm?	Yes / No
Farmsize	What is the total area of farmland that you manage?	…. ha
Own	Of the total farm area, which percentage do you own?	…. ha
Short_rent	Which percentage is under a short-term lease?	…..ha
Long_rent	Which percentage is under a long-term lease?	……ha
Farmsize	What is the total area of farmland that you manage?	……ha
Rotation	Which crops do you cultivate? Can you give an estimate of the ha for each crop?	…….. : …..ha …….. : …..ha …….. : …..ha …….. : …..ha …….. : …..ha …….. : …..ha
Bodem_1	Do you have more than one predominant soil type on your farm? • (If not) What is the predominant soil type on your farm? • (If yes) Could you indicate how many hectares fall into each soil type?	Dominant soil texture: Sand: ……..ha Loamy sand: …….ha Sandy loam: …….ha Loam: …….ha Heavy loam: …….ha Loamy clay: …….ha Clay: …….ha

Part 2: Cover crops

Question code	Question	Answer model
CC_tmax_1	Based on your current crop rotation, could you specify the (average) frequency of spring-sown crops?	../.. years
CC_tmax_2	Based on your current crop rotation, could you specify the (average) frequency of a winter without a main crop sown?	../.. years
CC_adopt_1	Do you grow cover crops when approaching a winter fallow in the crop rotation?	A)Yes, in some fields. B) Yes, in all fields where a crop was sown in spring. C) No.
CC_act_1	On which share of your land (ha) do you grow cover crops in one year?	.. ha
CC_crop_1	Are there any specific crops before which you never plant cover crops?	
CC_crop_2	Are there any specific crops after which you never plant cover crops?	
CC_weather_1	Are there any weather conditions which prevent you from growing cover crops?	
CC_weather_2	How often do such weather conditions take place	…/… jaar
CC_ad_fields	Are there fields where you never grow cover crops?	
CC_fields_soil	(If yes). Do the soil types of these fields differ from other fields on your farm? If yes, which soil type do these fields have?	
CC_constraints	Which of the following agronomic constraints do you (expect to) encounter that makes the expansion of cover crops to all of your fields difficult? a) Not suitable for my crop rotation b) Higher incidence of pests	

	c) Higher incidence of weeds d) Too difficult to prepare an adequate seedbed after the cover crop. e) Nutrient competition with the main crop. f) Water competition with the main crop. g) Other negative effects to the main crop. h) Poor cover crop establishment. i) Difficulties in cover crop termination. j) Difficulties incorporating the cover crop into the soil. k) Waterlogging and flooding (causing poor cover crop growth). l) Costs are too high m) Labour availability n) Lack of machinery o) I am unaware of the specificities of cover crop management. p) I don't think it would benefit my soils. q) Distance to fields r) Other:	
CC_drivers	What (may) motivate you to adopt cover crop? a) Increased soil organic matter b) Reduced risk of soil erosion c) Reduced risk of weeds d) Reduced risk of pests and diseases e) CAP regulations f) National policies g) Economic benefits h) Increased crop productivity for the main crop i) reduced nitrate leaching j) increased soil N supply k) Other: (specify)	
CC_field_adoption	Can you fill in Table 1 below?	

Table 1: Frequency of cover cropping.

Soil type	Frequency of cover crops (1 in xx years)	What is the main obstacle for growing cover crops in this soil type?
Soil type 1:…..		
Soil type 2:……		
Soil type 3:…..		
Soil type 4:…..		

Part 3: Tillage

Question code	**Question**	**Answer model [code]**
	Have you ever tried or are you currently using any cultivation technique that does not involve ploughing a field for a whole year? a) No, I always plough all my fields. b) Yes, I have tried not ploughing before, but now I prefer to plough all my fields yearly. c) Yes, I regularly **not** plough some or all of my fields for at least a year.	a. [non_adopter] b. [abandon] c. [adopter]
	Do you find that some crops require ploughing before planting or after harvest? (multiple possible) a) Yes, I usually plough before planting a specific crop Please specify which crop(s): b) Yes, I usually plough after planting a specific crop Please, specify which crop(s) c) No, my crop rotation does not influence my decision to plough	

	Plough before		Plough after	
Crops	Always	Sometimes	Always	Sometimes
e.g.: Potatoes	*X*			*X*

Question code	Question	Answer model
	Do you need to plough some of your fields from time to time? For instance, to deal with a specific problem or constraint? a) No, I practice continuous non-inversion or no-till. b) Yes, I sometimes needed to mouldboard plough to deal with a specific constraint. (Please specify the reason that applies) a. Improve crop establishment. b. Suppression of weeds that affect that particular crop. c. Increased incidence of pests. d. Increased incidence of diseases. e. Untidy field. f. Pest control. g. Controlling soil water balance. h. Improved soil aeration i. Other: Please specify	
	Are any of your fields more prone to suffer from these constraints than others on your farm? a) Yes, some of my fields perform less well under continuous no-till or non-inversion tillage. Therefore, they require more frequent cultivation operations than the others. b) Yes, some of my fields suffer from specific constraints, but they can be managed without ploughing ever required. c) No.	
	(if yes) Could you fill in Table 2 below?	

Table 2: Field information: soil type, size, accompanying constraints and frequency of ploughing.

	Soil type (heavy clay, clay loam, loam, sandy loam, sand)	Hectares	Constraint: Please specify which specific constraint requires ploughing as a correcting measure in that field (compaction, weeds, soil water-related problems, inadequate soil tilt, others)	Frequency of plough: Specify the number of times per year or once in how many years the field is ploughed. (e.g.: twice a year or once every five years).
Field 1				
Field 2				
Field 3				
Field 4				

Question code	Question	Answer model
	What changes have you observed from using non-inversion or no-till? (Table)	

	Increased	Decreased	No change	NA
Yield				
Fertiliser				
Herbicides				
Pesticides				
Costs				
Crop establishment				
Soil compaction				
Soil Organic matter				
Workload				
Soil erosion				
Water infiltration				
Waterlogging				
Soil water content				

Question code	Question	Answer model
	What factors prevent you from adopting no-till /nit? a. Obtaining the necessary machinery b. Acquiring the required knowledge and skills c. Labour d. Effective control of weeds e. Soil compaction f. Soil water content regulation g. Crop establishment problems h. Not convinced that would be suited to my farm's soil types i. Not convinced is good for the environment j. Concerned it will diminish my crop productivity k. Others:	

Part 3: Behavioural change and future perspectives.

Question code	Question	Answer model
Future_Perspective_1a	Do you think that you can continue farming the way you do in the future, without changing your current practices?	Yes / no
Future_Perspective_1b	If you've answered no on the question above: Is your main concern the effects of the changing climate on your operation?	Yes / no
Future_Perspective_	Do you	
Future_Perspective_	Do you feel that you are supported by current agricultural policy to enable you to be	Yes / no

Part 4: Policy.

Question code	Question	Answer model
European_Policy		
Dutch_Policy		
Eco_Schemes		
Improvements		

Appendix 3: Qualitative overview interviewed farmers

Table 8: Qualitative overview of the interviewed farmers.

Farmer	Soil type	Cover crop adopter	Type of NIT-adopter	Income share category
1	Clay	Yes	Half-adopter	High
2	Mixed	Yes	Non-adopter	High
3	Clay	Yes	Half-adopter	High
4	Mixed	Yes	Half-adopter	Low-mid
5	Loam	Yes	Half-adopter	Low
6	Mixed	Yes	Full-adopter	Low-mid
7	Sand	Yes	Non-adopter	High
8	Clay	Yes	Full-adopter	High
9	Mixed	Yes	Half-adopter	Low-mid
10	Mixed	Yes	Full-adopter	High-mid
11	Clay	Yes	Full-adopter	Low-mid
12	Mixed	Yes	Half-adopter	Low-mid

Appendix 4: Supplement figures and tables

Table 9: Descriptive statistics of *Figure 6.*

	Min	Q1	Median	Mean	Q3	Max
Age	20	31	53	48	61	75
Income share	0	50	90	75	100	100
Arable farmland	6	46	68.65	94.3	112.5	385

Table 10: Descriptive statistics of *Figure 8*.

Soil type	Min	Q1	Median	Mean	Q3	Max
Clay	19.4	33.33	45.04	45.28	57.14	93.5
Loam	40	42.8	45.6	45.6	48.39	51.19
Mixed	24.18	26.78	43.75	49.33	58.98	100
Sand	9.1	24.9	32.05	43.94	62.95	100

Table 11: Descriptive statistics of *Figure 9.*

	Min	Q1	Median	Mean	Q3	Max
Potential adoption (tmax)	21.4	53.6	63.3	63.2	76.3	100
Actual adoption	19.4	31.9	43.6	48.8	54.3	100
Actual adoption (relative)	24.2	44.4	74.3	75.6	100	133.3

Table 12: Extracted data from *Figure 10.*

Soil type	Adoption level	Percentage
Clay	Non Adopters	31.91
	Half Adopters	19.15
	Full adopters	4.25
Loam	Non Adopters	2.13
	Half Adopters	2.13
Mixed	Non Adopters	12.77
	Half Adopters	4.25
	Full adopters	6.38
Sand	Non Adopters	8.51
	Half Adopters	8.51