Norwegian University of Life Sciences

Master's Thesis 2021 60 ECTS
Faculty of Biosciences

Increasing Cover Crops in Norwegian Small-Grain Production – A Significant Step Toward Sustainable Farming Systems

Amélie Neault
Master of Science in Agroecology

ABSTRACT

Cover cropping has been recognised as a farming practise benefiting various ecosystem services and as such, it can help mitigate climate change and soil degradation. In Norway, despite an initial enthusiasm in the early 2000s, the use of cover crops has remained low among small-grain (i.e., cereals, legumes and oilseeds) farmers. This research study investigated what selected small-grain farmers think about cover crops, how and why they started and continue to use them, in the hope that the scaling-up occurs faster. The study showed that farmers viewed cover crops as a multi-functional tool that fitted well into their operation. Cover crops enhanced ecosystem services. They were also suitable with other farm components on a technical level and on a practical level. The adoption process was rooted in individual factors, where farmers changed their perceptions, beliefs and farming system. Collective-contextual factors, such as the growing popularity of cover crops in the country also influenced individual factors. Farmers expressed the ease of integrating cover cropping into their farming system. For them, the idea of a successful cover crop integration involved the concept of sustainability. The purpose of cover crops was seen with a long-term vision for a healthier and a more robust farming system. Practitioners showed a system thinking mindset, where cover crops were an integral part of their farming system. Based on these results, scaling-up the practice suggests taking a different approach when generating knowledge and sharing it among the agricultural sector. When dealing with wicked problems such as climate change and soil degradation, a systemic-horizontal learning approach should be taken as a path forward.

ACKNOWLEDGEMENTS

First, I would like to thank all the farmers who have been kind enough to speak with me (and to do so in your second language!). Having the pleasure to interview you made me appreciate the work you do even more. Farming is a rewarding livelihood, necessary for our society and it's not recognised enough, so I hope this small piece of work can, somehow, show to others how your work is valuable for all of us.

Thanks to my supervisor, Tor Arvid Breland, I appreciated your insightful feedback and being constantly questioned about my decision process. Thanks to the agroecology team, Geir, Chuck, Tor Arvid, Anna Marie, Åsmund and Vebjørn. I arrived here with a simple toolbox and I'm leaving this place with the deluxe version. I would also like to thank Alice Budai for the initial help and support.

Un merci tout particulier à mes parents et Chloé pour votre soutien à distance! Merci aussi l'émission culte Le coeur a ses raisons et à Josée Di Stasio.

But, in the end, I don't think these past two years and especially this past one of thesis-Covid-despair-relief would have been possible without the Office Ladies. Thank you, like a good old moldy cheese, we have aged quite well together.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFN	Alternative food network
AMF	Arbuscular mycorrhizal fungi
CC	Cover crop
C/N	Carbon-to-nitrogen ratio
CO_2	Carbon dioxide
N	Nitrogen
NIBIO	Norsk institutt for bioøkonomi, the Norwegian Institute of Bioeconomy Research
NLR	Norsk Landbruksrådgiving, the Norwegian agricultural advisory services
NMBU	Norwegian University of Life Sciences
N_2O	Nitrous oxide
NO_{3-}	Nitrate
P	Phosphorus
RMP	“Regionalt miljøprogram”, the regional environmental programs
SOC	Soil organic carbon

1. INTRODUCTION

1.1 PROBLEMATIC & CONTEXT

Climate change represents a serious threat to society. Since the 1850s, the mean land surface air temperature has considerably increased by 1,53°C (IPCC, 2020). The link between human activities and degradation of the climate is well documented. According to the FAO (2014) report *Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks*, in the 1990s the yearly greenhouse gas emissions for this sector represented 4,6 Gt CO_2 eq and increased to 5,3 Gt CO_2 eq in 2011. The report projected 30% CO_2 emissions increase by 2050 if no mitigation tools are adopted in the agricultural sector.

Furthermore, soil degradation should be considered as big a threat as climate change (Sustainable Food Trust, 2015). It threatens society because plants need soil to grow and they are at the foundation of the food supply chain. For example, the UNCCD (2014) estimated that one third of land producing feedstock or food is somewhat degraded or very degraded around the world. Every year, millions hectares of fertile soil are permanently lost (Sustainable Food Trust, 2015). Lal (2015) states that different reasons lead to soil degradation, but it is typically a downward spiral accelerated by anthropogenic factors. For instance, soil management practices (e.g. tillage practice such as plowing) deteriorate the soil structure. Then, additional degradation via natural factors (e.g. soil biodiversity loss) occurs, which reduces soil quality over time (Lal, 2015). This detrimental process increased with the advent of a modernised society in the 20th Century. It took place primarily in Occident, where agriculture was subjected to a revolution on how food is being preserved, processed, transformed, distributed and notably on how it is produced. Nowadays, this model is commonly called conventional agriculture.

As Gliessman (2015) explains, conventional agriculture is defined by the considerable input of external resources (e.g., pesticides, synthetic fertilizers, water irrigation and fossil fuel) to produce monocultures (a single crop grown at a time) with a fast turnover to obtain a quick economic return. Also, farmers plow the soil following the end of the growing season, leaving it

bare and exposed for many months. Besides, farms are often producing a limited number of diversified crops to comply with the commodity market in place. The Norwegian agricultural sector reflects the global trend, where the majority of the agricultural production is done through conventional agriculture. Organic production represented only 4,2% of farmland in 2018[1] (Knutsen, 2020).

Additionally, about seventy years ago, the Norwegian government decided to modify the agricultural sector to promote areas producing higher cereal crop yields based on an environmental suitability factor and based on urban agglomerations proximity (i.e., cities such as Oslo and Trondheim) (Arnoldussen et al., 2014; Knutsen, 2020; Lundekvam et al., 2003). The government gave monetary incentives to encourage farmers to transition their focus from roughage-based livestock production to cereal production (Arnoldussen et al., 2014; Lundekvam et al., 2003). Today, the counties producing the vast majority of cereal and oilseed crops are located in the southeastern and central parts of the country. Subsequent to the transition, which is intertwined with conventional farming practices, this part of the country experienced negative environmental impacts such as the increase of soil erosion (Lundekvam et al., 2003). Another example is the county Akershus (now part of the county Viken since January 2020), which was the second biggest producer of small grains and emitted 24% of all CO_2 emissions in the country and in the agricultural sector between 1999 and 2009 (Borgen, Grønlund, et al., 2012).

The societal decisions taken in the past, shifting from a localized agriculture to a conventional setting and the channeling policy put in place by the Norwegian government in the 1950s resulted in an agricultural system where long-term consequences on the environment and on the farmers are overlooked to prioritize short-term results. While the Norwegian agriculture represents a small fraction of the worldwide agricultural land used today, the practices and methods have to evolve and adapt to the current issues enclosed with climate change and soil degradation. Furthermore, at a local level, agriculture carries an important cultural heritage and it constitutes

[1] Producing organically does not automatically represent a more sustainable agriculture, but it remains the most popular way of farming alternatively. It is the only measurement available to compare with. Therefore, comparing it to conventional agriculture gives a blurry picture of the current situation.

a livelihood for thousands of individuals. To address several problems emerging from conventional agriculture, mimicking what nature does can be one path forward for a sustainable agriculture.

Gliessman (2015) states that a natural ecosystem has the capacity to self-regulate various cycles, such as the nutrient cycles. In theory, this model is 'ideal' because it ensures resources that are never truly lost, as they keep a shape or form in the system, despite constant internal and external changes. The author draws a parallel with a desired sustainable agroecosystem as followed:

> […] one that maintains the resource base upon which it depends, relies on a minimum of artificial inputs from outside the farm system, manages pests and diseases through internal regulating mechanisms, and is able to recover from the disturbances caused by cultivation and harvest. […] Ultimately, sustainability is a test of time: an agroecosystem that has continued to be productive and support local livelihoods for a long period of time without degrading its resource base […]. (Gliessman, 2015, p. 287)

There is not a sole model to follow as every farm and local contexts are unique. Cover cropping has the potential to help farmers reach a desired sustainable agroecosystem.

1.2 CURRENT SCOPE OF COVER CROP USE

Cover cropping was a common farming practice before World War II, with records tracing its uses two hundred years prior, but it was abandoned as the world modernised agriculture (Groff, 2015). Cover crops are sown in-between the traditional growing season or interseeded with the cash crop. While farmers grow cash crops for economic return (i.e., human feed, animal feed or biofuel), cover crops can improve various ecosystem services. The role they play will be influenced by different factors (e.g., the species used, the method and the date of sowing, the method and the date of termination and the compatibility with the growing environment).

Additionally, production of food relies on a man-made environment with the aim of serving humans. Consequently, to achieve a sustainable future, human well-being and human health are critical to account for. According to the Millennium Ecosystem Assessment (2005), ecosystem services viewed from a human well-being perspective is divided in four categories as seen in Figure 1.

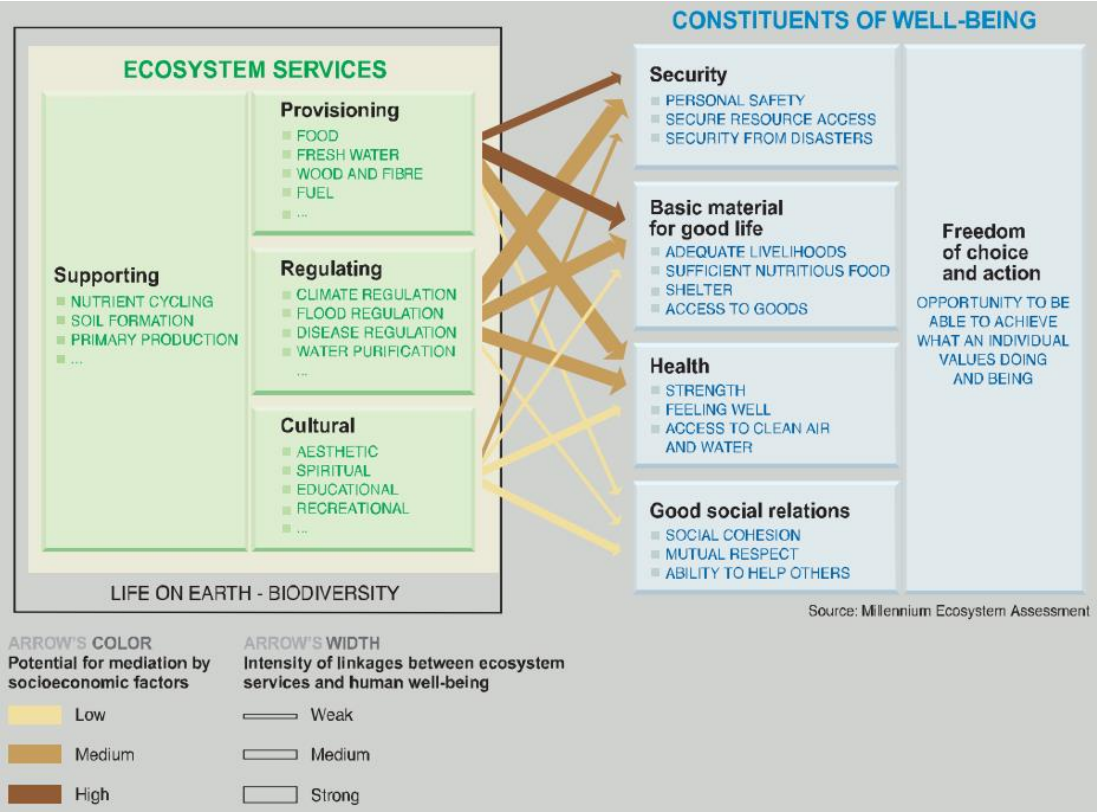


FIGURE 1 MILLENIUM ECOSYSTEM ASSESSMENT CONCEPTUAL FRAMEWORK (MILLENIUM ECOSYSTEM ASSESSMENT, 2005)

Cover crop ecosystem services based on these categories (i.e., provisioning, supporting, regulating and cultural) can help understand how they can influence an agroecosystem.

1.2.1 PROVISIONING

Provisioning in the Millennium Ecosystem Assessment (2005) context relates to the supply of resources. Often, scientific research investigates cover crops' influence on cash crop yields or as a source of food for livestock production.

The cover crop effect on cash crop yields, either interseeded or used after the growing season is disputed in the literature. While Schipanski et al. (2014) observed no difference between cash crop yields with or without cover crops, having a mixture of cover crop species containing a low ratio of carbon-to-nitrogen (C/N), affected positively the following cash crop yields (Finney et al., 2016). In a simpler experimental design, Lyngstad and Børresen (1996) and Breland (1996a) obtained mixed results, however legumes cover crop species generally provided more nitrogen, therefore achieving higher yields from the main cereal crops.

Cover crops can also provide an additional source of feed for livestock production. Removing residues for haying or animal grazing the fields after harvest does not seem to affect soil properties on the short-term basis (Blanco-Canqui et al., 2013; Blanco-Canqui et al., 2020).

1.2.2 Supporting

Supporting from the Millennium Ecosystem Assessment (2005) refers to how cover crops can reinforce or impede the soil environment.

Various components impact the soil physical environment and they are assessed by different measurements. For instance, in experiments cover crops helped reduce the soil compaction level, especially with tap-root species like forage radish (Blanco-Canqui et al., 2011; Chen & Weil, 2010). Studies found mixed results to reduce bulk density. A long-term experiment revealed a beneficial effect (Blanco-Canqui et al., 2011), but other short-term studies came to the conclusion of a small positive impact (Breland, 1995), or no influence at all (Blanco-Canqui et al., 2013; Børresen, 1993).

Soil moisture content can potentially increase following the presence of cover crops, especially when using mixtures with a higher diversified number of species (Chu et al., 2017; Wortman et al., 2012). Supplying enough water to both a cash crop and a cover crop can be a concern, but terminating the cover crop early in the season can reduce the risk of stealing water to the following cash crop (Blanco-Canqui et al., 2015).

From different experiments, cover cropping increased earthworms count, which increased soil water infiltration (Blanco-Canqui et al., 2011; Roarty et al., 2017). Also, in a meta-analysis evaluating 60 research studies, cover crops showed enhancing soil microbial properties (e.g., colony forming unit, microbial biomass carbon, phospholipid fatty acid) (Kim et al., 2020). Using cover crops positively impacted the arbuscular mycorrhizal fungi (AMF) colonization, which has a symbiotic relationship with roots and provides different ecosystem services (Rosner et al., 2018; Schipanski et al., 2014).

Various research conducted on the nitrogen (N) supply from legume cover crop species presented mixed results in regard to being able to supply cash crops exclusively with legumes cover crops (Borgen, Lunde, et al., 2012; Breland, 1996b; Finney et al., 2016; Lyngstad & Børresen, 1996; Mahama et al., 2020; Tonitto et al., 2006; Tzanakakis et al., 2017; White et al., 2017). They are the only plant family fixing N directly from atmospheric N, therefore important for farmers since N is an essential nutrient. Furthermore, cover crops and more specifically non-legume species, such as ryegrass, effectively caught and retained N over the winter season, which reduced nitrate (NO_3-) leaching often caused during off-season when the soil remains exposed (Breland, 1996b; Finney et al., 2016; Lyngstad & Børresen, 1996; Norberg & Aronsson, 2020; Schipanski et al., 2014; Tonitto et al., 2006; White et al., 2017). This can have an adverse effect, as N may become unavailable for the cash crop (N mineralization) or N immobilization can occur, but an appropriate cover crop management seems to be the best way to reduce the effect (Breland, 1996b; Finney et al., 2016). Moreover, studies have shown that to reduce N losses, cover crop termination practices and tillage practices should be delayed, either late in the autumn or the following spring (Borgen, Lunde, et al., 2012; Breland, 1994; Lyngstad & Børresen, 1996). Also, complementarity N transfer has been shown in mixtures between legume and non-legume species (Finney et al., 2016; Tzanakakis et al., 2017; White et al., 2017).

1.2.3 REGULATING

Regulating according to the Millennium Ecosystem Assessment (2005), in regard to cover crops, addresses different factors that make the environment of the agroecosystem stronger or weaker. Literature has established suppressing weeds as a common advantage to use cover crops (Dorn et al., 2015; Finney et al., 2016; Schipanski et al., 2014). Research articles comparing mixtures and monocultures of species vary to distinguish the preferred one for aboveground biomass productivity and stability, because plants compete for light and nutrients and they are closely link with diminishing weed counts (Finney et al., 2016; Florence et al., 2019; Holmes et al., 2017; Smith et al., 2014). Nevertheless, suppressing weeds depend very much on the type of species used (both for cover crop and cash crop), the growing conditions and the type of farming management (Finney et al., 2016; Florence et al., 2019; Holmes et al., 2017; Schipanski et al., 2014; Sjursen et al., 2012; Smith et al., 2014).

Reddy (2017) gathered various studies showing the use of cover crops as a biological management tool for diseases, insect pests and nematodes. Additionally, Mallinger et al. (2019) found that cover crops provide a beneficiary environment for pollinators, such as honey bees, bumble bees and the type of pollinators attracted will depend on the species used.

Offering a wildlife habitat is an indirect effect of using cover crops. Having a coverage in the fields in the spring proved to increase the presence of birds (Wilcoxen et al., 2018). Also, Goławski et al. (2013) demonstrated that cover crops sowed as a catch crop provided more opportunities for birds to feed over the winter (as opposed to plowed fields), but less than with cash crop stubbles who grew taller, thus remaining accessible despite a cover of snow.

An emerging problem in the no-till system is the increasing presence of slugs proliferated with a favourable environment with little or no soil disturbance and the extended plant growth in a season (Douglas & Tooker, 2012; Raudenbush et al., 2021). Few methods completely eliminate slugs, but a variety of tactics should be employed to diminish their impact on the cropping system (Douglas & Tooker, 2012).

Cover crops can sequester carbon by producing above and belowground biomass (Amsili & Kaye, 2020; Blanco-Canqui et al., 2013; Blanco-Canqui et al., 2011; Schipanski et al., 2014). In a meta-analysis, Poeplau et al. (2015) reviewed 30 research studies and they concluded that cover crops effectively sequester soil organic carbon (SOC). They found that 8% of the yearly greenhouse gas emissions emitted directly from agricultural activities could be reduced with cover crops.

Studies showed that cover crops had an alleviating effect on the loss of sediments during periods of rain, which reduced soil erosion (Blanco-Canqui et al., 2013; Schipanski et al., 2014). Soil erodibility is also linked with nutrients leaching. Mixed results were found in reducing phosphorus (P) leaching (Blanco-Canqui et al., 2013; Norberg & Aronsson, 2020). Leaching of P from cover crop plants due to the freeze-thaw process occurring in the spring could deteriorate the environment, especially in cold temperate environments such as Norway, but research hasn't established a clear relationship thus far (Liu et al., 2019).

Calculating accurately greenhouse gas emissions in relationship with cover crops lacks data, as the budgeting needs to take into account all factors included in the release and capture of emissions (Basche et al., 2014; Blanco-Canqui et al., 2015; Schipanski et al., 2014). Nitrous oxide (N_2O) emissions constitute the primary concern in the agricultural sector, as it emits the highest amount comparatively to any other sector and N_2O emissions are much more potent than CO_2 emissions (Basche et al., 2014).

In Norway, cover crops' popularity started in 1998-1999 following a larger governmental subsidies scheme for various preventive measures against environmental disasters, which occurred mainly in the Southeast (today enclosed in the "Regionalt miljøprogram", the regional environmental programs (RMP)) (Arnoldussen et al., 2014; Lundekvam et al., 2003; NIBIO, 2019). The program succeeded in increasing the cover crop land area to 34 000 hectares in 2002-2003, which represented about 10% of the cereal production (NIBIO, 2019). It became popular especially in the counties of Akershus and Oppland (part of Innlandet since January 2020). The subsidies were largely reduced in 2003 and represented only 3 470 hectares in 2018 (Bye et al.,

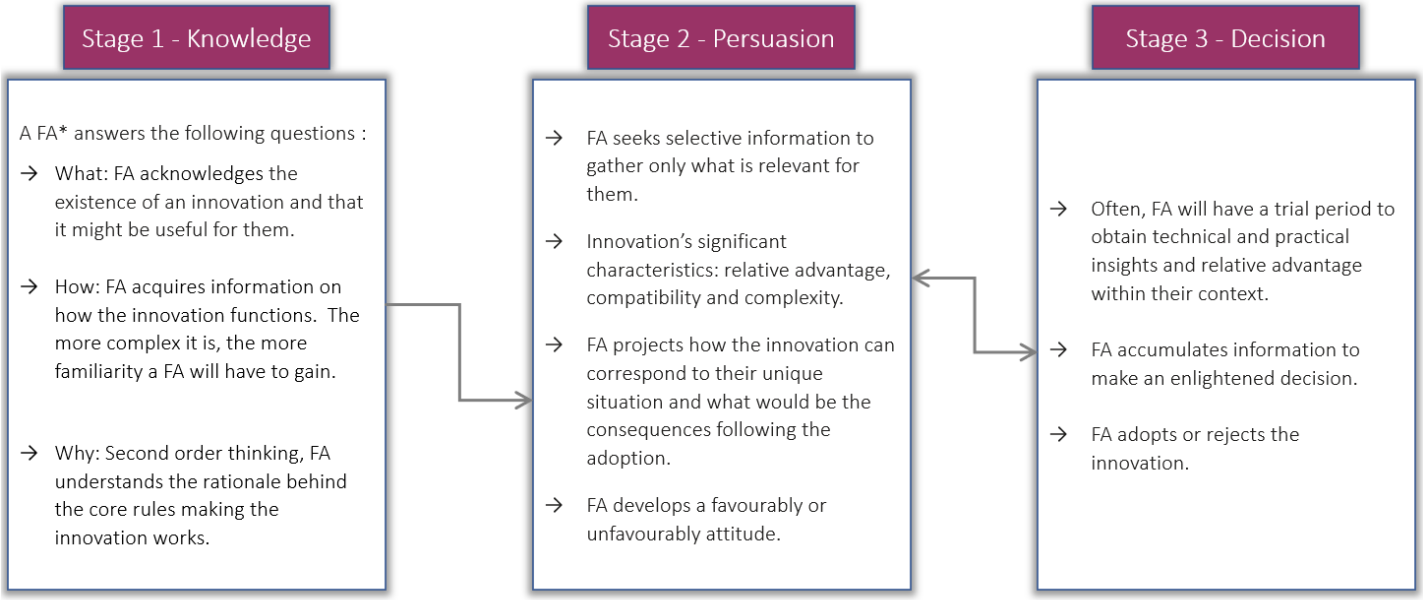
2020; NIBIO, 2019). As shown by Aronsson et al. (2016), this number is modest compared to neighbouring countries. In Denmark the government made cover crops mandatory and represent 8% of arable land and in Sweden they represent 5% of arable land. The review also highlights the importance of focusing on cereal crops, as it constitutes between 22% and 55% of all arable land in the Nordic countries.

Researching the current second wave of cover crop use in Norway will be beneficial on a national level, where sustainable farming practices must be adopted to mitigate greenhouse gas emissions leading to climate change. It will also be beneficial at an individual farm level, to help provide a respectable livelihood for farmers playing an essential role in the society. Furthermore, from an individual perspective, the theory Diffusion of Innovations (Rogers, 2003) can be used as a framework to understand the reasoning of adopting and using the practice as it describes a 'universal process of social change'.

1.3 THE PROCESS OF ADOPTING NEW PRACTICES

Rogers (2003) defines the concept of diffusion as individuals becoming aware of an innovation through different communication channels, while existing and interacting in a social system. Rather than being genuinely new, an innovation relates to someone's perceived novelty, since the concept might be a common practice in other social systems. Furthermore, there is always a level of uncertainty when being introduced with a new idea and Rogers (2003) explains the main characteristics describing an innovation as follows: relative advantage, compatibility, complexity, trialability and observability. The process leading to the complete adoption of an innovation is called the innovation-decision process.

The innovation-decision process consists of five stages in total (Rogers, 2003). To understand the links between the innovation-decision process and the adoption of cover crops, the initial stages and the later stages are divided according to the literature on the research topic.



*FA: Future adopter

FIGURE 2 INITIAL STAGES OF THE INNOVATION-DECISION PROCESS FROM THE THEORY DIFFUSION OF INNOVATIONS (ROGERS, 2003)

Rogers (2003) points out that the second and third stages are not strictly subsequent and they depend on the cultural social system (e.g., individualistic cultures versus collectivistic cultures). Also, both stages attempt to reduce the uncertainty level. In that respect, research has investigated different factors related to farmers' cover crop adoption.

First, farmers had environmental concerns, which (Arbuckle & Roesch-McNally, 2015; Roesch-McNally et al., 2018) promoted trying cover crops, or at least they acknowledged how they should do more to prevent nutrients leaching for example (Arbuckle & Roesch-McNally, 2015; Clay et al., 2020; Ranjan et al., 2019). Also, having access to resources, both educational and technological, indicated a likelihood in adopting cover crops (Arbuckle & Roesch-McNally, 2015; Roesch-McNally et al., 2018).

Producers were motivated to adopt cover crops because of potential ecosystem services benefits such as the reduction of soil erosion, the nutrients leaching (N & P) catching effect and a better

soil health (Arbuckle & Roesch-McNally, 2015; Ranjan et al., 2019). Farmers also producing livestock mentioned the additional source of animal feed supplied by cover crops (Arbuckle & Roesch-McNally, 2015).

Additionally, connecting with a trusty leader (e.g., a successful practitioner) was key to start cover cropping (Ranjan et al., 2019). Furthermore, the authors said that having a prior experience or observing neighbours deal with the practice influenced the adoption process, whether it was a positive opinion or a negative opinion. Farmers felt like a sense of collectivity, with a supporting network, enhanced their will to try different approaches (Roesch-McNally et al., 2018).

Findings in the literature showed that producers adopted cover crops when a cost-sharing scheme (e.g., governmental subsidies) existed and was advertised within the community (Arbuckle & Roesch-McNally, 2015; Ranjan et al., 2019).

Second, among the negative factors found in research studies, participants expressed problems with the availability of seeds and equipment (e.g., a roller-crimper) (Arbuckle & Roesch-McNally, 2015; Clay et al., 2020; O'Connell et al., 2015).

Also, they talked about the cost constraints related to; the seeds, the establishment method, the termination method, a potential lower cash crop yields, no method to assess economic return and less short-term revenues when cover crops take the place of the main crop (Clay et al., 2020; Roesch-McNally et al., 2018; Snapp et al., 2005). However, O'Connell et al. (2015) found opposite results where farmers didn't see cost as a limit to start using cover crops and they did not believe it impacted the following cash crop.

Besides, producers found it difficult to make space in their busy schedule to sow and manage cover crops (e.g., taking care of crop residues, sowing cover crops after the cash crop harvest) (Arbuckle & Roesch-McNally, 2015; O'Connell et al., 2015; Ranjan et al., 2019; Roesch-McNally et al., 2018; Snapp et al., 2005).

Moreover, farmers expressed uncertainties related to ecosystem services enhancements or impediments; the inadequacy in evaluating the nitrogen input and potential diseases when using

legume cover crops, soil moisture competition, and cover crops coming back as weeds the following season (Arbuckle & Roesch-McNally, 2015; Snapp et al., 2005).

Furthermore, Ranjan et al. (2019) identified limits with farmers' perceived risks in integrating a new conservation practice and within the farm's characteristics boundaries. For example, if a farm didn't experience a problem (e.g., soil prone to erosion), then the participant didn't try cover cropping because it didn't concern them.

The later stages of the innovation-decision process relate to the complete integration of an innovation and they are described as followed (Rogers, 2003):

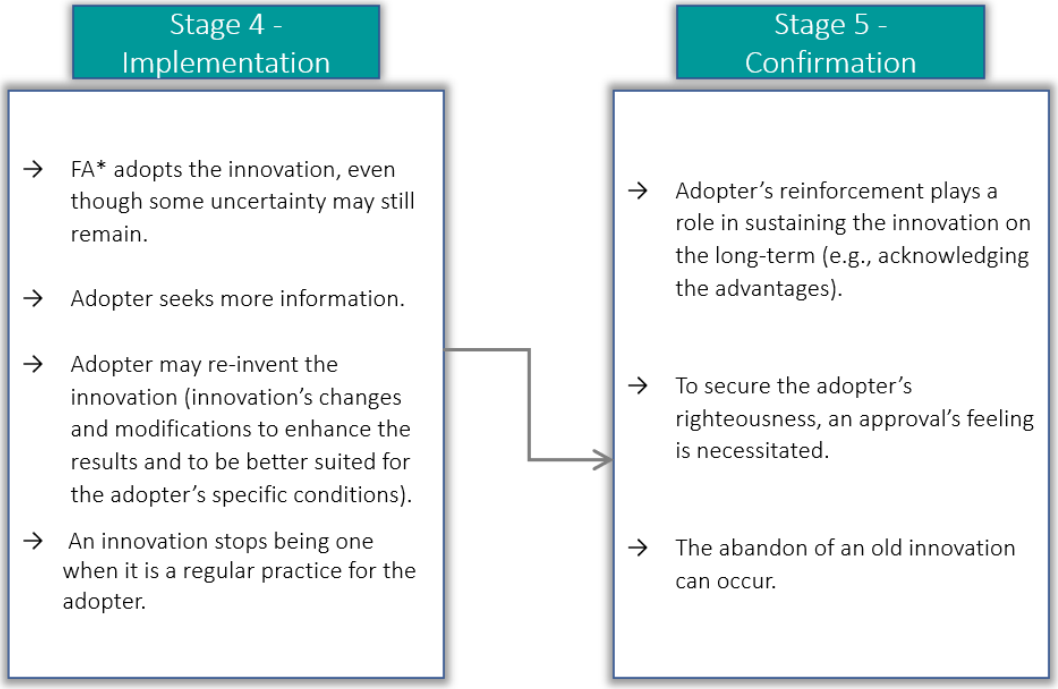


FIGURE 3 LATER STAGES OF THE INNOVATION-PROCESS FROM THE THEORY DIFFUSION OF INNOVATIONS (ROGERS, 2003)

Rogers (2003) states that while an innovation is an entity with defined characteristics, created to serve a specific purpose, the adopters form a complex social system in continuous evolution. An innovation pertains to a permeable system. Different components related to the two last stages were researched in the past.

Farmers stated that having more help from extension services would likely increase cover crop use (Arbuckle & Roesch-McNally, 2015). Also, there are positive factors related to the practice expressed by practitioners and non-practitioners such as the prevention of soil erosion and nutrient losses, weed suppression, soil water holding capacity, SOC increase, N supply and a suitable environment for beneficiary insects (Arbuckle & Roesch-McNally, 2015; Clay et al., 2020; O'Connell et al., 2015; Snapp et al., 2005).

Roesch-McNally et al. (2018) described how farmers saw the challenges involved with cover cropping as an opportunity to change their style of management on the farm by trial and error. The authors pointed out that participants changed their farming system, following the integration of cover crops (e.g., changing their tillage practices). They also showed intrinsic value in conserving their land, which translated by wanting a sustainable land for the future.

Additionally, when it comes to integrating conservation farming practices, such as cover cropping, farmers valued short-term and long-term added benefits (Kennedy et al., 2016; O'Connell et al., 2015). Also, a diversified farming system, either via growing several types of crops or via the inclusion of livestock production, had a high compatibility factor with cover crop use (Arbuckle & Roesch-McNally, 2015; Ranjan et al., 2019). Moreover, farmers valued cover crops multi-functionality, by having different cover crop species and various management methods to choose from to accommodate their needs (O'Connell et al., 2015; Snapp et al., 2005). Besides, they viewed the use of cover crops as part of a whole farming unit and adopters were more likely to be system thinkers (Church et al., 2020; Roesch-McNally et al., 2018).

1.4 A FARMING SYSTEM

Cover crops represent one component in a farming system. A system includes five elements: “the boundary, the inputs, the outputs, the subsystems (or components) and the internal structure (how the subsystems are interrelated and interact)” (Giller, 2013, pp. 149-150). A farming system contains social components (e.g., farmers’ beliefs and perceptions, farmer’s family, legacy of the land where the farm stands) and physical components (e.g., buildings,

animals, land) (Darnhofer et al., 2012). The authors point out that it also involves environmental components (e.g., the local network where farmers evolve in, the regulations established by governmental instances, the location of the farm, the market outlet). Besides, a farming system is "[…] about interaction, entanglement, dependencies, exchange, connections, relationships and co-evolution" (Darnhofer et al., 2012, p. 9).

Every individual farming system is embedded in bigger systems. In this case, the Norwegian agricultural system represents the next sub-system, which takes part of the Norwegian food system included in the Norwegian society. Humans build systems to make sense of their world, therefore the five elements described by Giller (2013) are subjective to interpretation about what constitutes a system. Overall, it illustrates a complex unique dynamic network, where one changing component will inevitably affect the rest of the system or the 'whole' and parts cannot be seen as isolated islands (Bawden et al., 1984; Checkland & Poulter, 2006; Darnhofer et al., 2012).

1.5 THE CHALLENGE OF SCALING-UP

Scaling-up cover cropping on a national level, in the perspective of climate change and soil degradation, addresses a broader challenge entangled with the mainstream research model and learning process in place.

Researchers study normal science with a reductionist approach and it is unfit for wicked problems (Batie, 2008; Funtowicz & Ravetz, 1993; Huesemann, 2001). Normal science is puzzle-solving a problem from the perspective of a scientist evolving in their discipline (Kuhn, 1963, as cited in Batie, 2008; Funtowicz & Ravetz, 1993). A reductionist approach divides and assesses individual parts separately from one another (Funtowicz & Ravetz, 1993). It represents the predominant research model generating knowledge and policy in western societies (Batie, 2008; Funtowicz & Ravetz, 1993; Huesemann, 2001). Also, Weber and Khademian (2008) state "Wicked problems, by their nature, defy categorization within a strict rules-based system that seeks to divide complex systems and problems into more manageable parts and assumes that the causal

relationships within the wicked problem set are clear and identifiable" (p.342). The nature of a wicked problem is in constant evolution, unstructured, never-definitive and the stakeholders involved have divergent opinions (Batie, 2008; Weber & Khademian, 2008). Therefore, climate change and soil degradation can be labelled as wicked problems.

Furthermore, in the agricultural sector, Vaarst et al. (2007) describes how the learning process is generally an asymmetrical power relationship between the advisory service and the farmer. They state that farmers have the burden to change their approaches. The advisor stands from a position of truth and they focus on specific elements, their area of expertise (Bawden et al., 1984; Vaarst et al., 2007). Advisors are defined by their employer and not by the person they offer services to (Funtowicz & Ravetz, 1993). Funtowicz and Ravetz (1993) mention that experts advising a client typically act with a low level of uncertainty, given how they interact with the issues from an outsider perspective. Hence, they frequently omit to look at the broader picture Vaarst et al. (2007).

Moreover, the adoption of a practice such as cover cropping is based on the local context it evolves in (Bultena & Hoiberg,1983, as cited in Bossange et al., 2016). Bossange et al. (2016) write: "[…] each agricultural community needs to understand the local reasons for adoption and non-adoption of desired practices" (p.4). The process is complex and not easily characterized for research purposes (Ranjan et al., 2019). It is complex because, at its core the research addresses a messy situation entailing individuals evolving in a farming system, which in itself involves sub-parts (Bawden et al., 1984). Those farming systems are also part of a bigger social system, in this case the Norwegian agricultural sector. As mentioned by Checkland and Poulter (2006), the different components interact and alter the 'whole', so they are intertwined with the society and its challenges at large, while remaining a unique situation for every farming system.

1.6 RESEARCH AIM & RESEARCH QUESTIONS

Understanding how farmers initially learned and acquired knowledge about the practice will provide tools and information to the farming community in the hope that the scaling-up occurs faster (Carlson & Stockwell, 2013). The aim of this research investigated what selected small-grain farmers in Norway think about cover crops, how and why they started and continue to use them. This was done by means of a qualitative study in which the following research questions were asked:

1. What are the advantages and disadvantages that selected farmers observed from their use of cover crops?
2. Which factors do the selected farmers identify as key for increased use of cover crops in Norway?
3. How do selected farmers think the practice can be successfully integrated in different farming systems?

2. METHOD & BACKGROUND INFORMATION

2.1 CHOICE OF PARTICIPANTS

2.1.1 CRITERIA

I used purposive sampling where three criteria were considered to choose participants. First, participants needed to be farmers operating in Norway with a production of small grain (i.e., cereals, legumes or oilseeds) as one of their farming activities. Second, farmers interviewed had to use cover crops on a regular basis or they had to plan to use them in 2021. Third, participants needed to speak English since I don't speak Norwegian. With purposive sampling, I obtained rich information for in-depth analysis (Bryman, 2012; Patton, 2002).

Moreover, I selected farmers located in the Southeastern-Central part of the country due to the prevalence of small-grain production. Participants represent innovators or early adopters (see Table 1), given the small cover crop use among the national small-grain production.

TABLE 1 CATEGORIES OF ADOPTER ACCORDING TO THE THEORY DIFFUSION OF INNOVATIONS (ROGERS, 2003)

Category of adopters	Representation in a social system (%)
Innovators	2,5
Early adopters	13,5
Early majority	34
Late majority	34
Laggards	26

As their titles indicate, innovators and early adopters adopt an innovation before everyone else in their social system. Rogers (2003) argues that innovators are somewhat perceived as 'aliens' because they frequently remain on the margin and they can tolerate a higher amount of uncertainty compared to the others. They represent the train's locomotive, as leaders trying out new innovations. The author says that early adopters are more integrated among their peers, but still prone to take more risks. Their opinions matter to the majority who respect them.

Therefore, they influence others more easily. However, these are generalities attributed to each category and one individual labelled as an innovator might not identify as such. I didn't categorize the farmers, as it didn't have any implications in the analysis process.

Additionally, for the purpose of this thesis, interviewing farmers from the early majority, late majority and laggards wouldn't have been insightful. They either haven't thought about cover cropping, or they belong in the early stages of the innovation-decision process. Accordingly, they would have provided a limited amount of information on the topic. Therefore, the results found in this research study cannot be translated as a general opinion for all Norwegian farmers.

2.1.2 LANGUAGE

I conducted all the interviews in English which might have been a barrier, as none of the interviewees had English as a mother tongue. Some participants might have felt restrained in the way they expressed themselves, as we discussed detailed topics commonly only spoken in Norwegian. If I didn't understand a word or a sentence, I asked the participant to repeat it and I looked for the word online afterward during the transcription process to confirm my comprehension. Furthermore, if potential interviewees didn't speak English or if they felt like they didn't have a sufficient level to speak for an hour about cover crops, it might have hindered their will to become a participant.

2.1.3 PROCESS OF RECRUITMENT

The participants' selection started with personal communication with stakeholders from the Norwegian agricultural sector; NMBU's agroecological teaching body, Norsk institutt for bioøkonomi (NIBIO, the Norwegian Institute of Bioeconomy Research), Norsk Landbruksrådgiving (NLR, the Norwegian agricultural advisory services) and farmers whom I've worked with in the past. I also used the snowball sampling method (Bryman, 2012). Following an interview with a farmer, I asked if they knew other colleagues also using cover crops and so on. The majority of farmers interviewed were located in the county of Viken. Additionally, all key informants and I

are living and operating in this county, which shaped the participants' recruitment. I didn't know and I had never worked with the farmers interviewed previous to the start of this thesis.

2.2 DATA COLLECTION

2.2.1 SEMI-STRUCTURED INTERVIEWS

I chose semi-structured interview with open-ended questions as the research method. While being reliant on an interview guide to yield comparable results among the respondents, the research method allowed the participants and I for an open interactive exchange (Bernard, 2017; Bryman, 2012). I designed the interview guide based on; topics to be covered, promoting a dynamic interview and favouring a comfortable environment for interviewees to expand on their thoughts and opinions if they wished (Kvale, 1996).

Before starting the proper interview, I asked the participants if they had any questions. Here were the main topics covered (see Appendix II for the complete interview guide):

1. Background information about the farmer, the farm and initial discovery of cover crops
2. Implementation phase of cover crops
3. Current use of cover crops
4. System inquiry between cover crop interactions with other farm components
5. Future use of cover crops
6. Learning gaps to fill about cover crops

2.2.2 HOW THE INTERVIEWS WERE CONDUCTED

The initial contact with participants was done via an introductory email. I briefly explained the scope of the research and once I received a positive reply, we scheduled an interview. The interviews took place from November 2020 to March 2021. As a result of the Covid-19 pandemic, I conducted all the interviews either by online video or by phone call. The interviews lasted around one hour and everyone consented to be audio recorded. One interview was cut short

because the participant needed to leave for another meeting and we covered about two thirds of the interview guide content.

2.2.3 LIMITATION

Another research method would have enriched the data collected with semi-structured interviews. I could have carried out triangulation, which refers to using different research methods to cross-check the results observed from different angles (Bryman, 2012). However, I believe the information collected through semi-structured interviews yielded an appropriate amount of data to code, which resulted in a comprehensive analysis.

2.3 DATA ANALYSIS

2.3.1 PROCESS OF TRANSCRIPTION

I transcribed all the interviews manually in a Microsoft Word document, which gave me a better understanding of what was said during the interview. I did it systematically and as such, I didn't change or re-phrase to keep the content as articulated by participants. I started transcribing, while continuing doing interviews, and I reformulated some questions and changed details in the interview guide for a better comprehension across the screen with the interviewees.

2.3.2 PROCESS OF CODING

I also coded manually in the same spirit of the transcription process. I highlighted the content of interest based on each research question and transferred all the content of interest of each interview in a Microsoft Excel document. I relied on the content analysis process explained by Graneheim and Lundman (2004), where I designed the coding as followed (see Appendix III):

a. Meaning unit: Sentences representing one or many ideas or explanations (content extracted directly from the transcripts)
b. Condensed meaning unit: A description close to the original meaning unit, without unnecessary words not conveying ideas or explanations

c. Code: Abstraction of the content or the condensed meaning unit was further condensed
d. Sub-category: An abstraction of the codes
e. Category: Sub-categories related to each other
f. Themes: Different meanings among the categories

From the initial meaning units to the codes, some units were further broken down, as the distillation process revealed they represented two different ideas or explanations.

2.3.3 PROCESS OF WRITING THE RESULTS

I wrote the results (from section 3.1 to section 3.3 inclusively) according to the number of participants expressing the same ideas to provide a detailed account emerging from the coding process (see Table 2). This is strictly an approximation, as I chose a research method that cannot reliably quantify results, as the interviewees' answers guided the interviews. However, omitting the numbers completely would have left some information out that can help better understand the data collected.

TABLE 2 TERMINOLOGY FOR THE RESULTS SECTION USED FOR COMMON IDEAS SHARED BY PARTICIPANTS

Terminology	Number of participants
One	1
A few, a minority of, a small number	2 – 3
Some	4 – 7
Many, several, a great number	8 – 11
Majority	12 – 17
Nearly all	18 – 19
All	20

2.4 RELIABILITY

2.4.1 RECALL CHALLENGE

Some farmers have used cover crops for many seasons. Asking specific information about how they first encountered cover cropping or about the process of using them during their first season

was somewhat difficult to give a detailed answer. Long-time practitioners expressed a strong positive attitude, so they might have unintentionally diminished the initial difficulties encountered. To address this potential challenge, I also conducted interviews with farmers who have started using cover crops only a few seasons ago (3 seasons or less) and they recalled the adoption process more accurately (see section 2.5.3 for more details). However, they were less able to elaborate on the advantages, disadvantages and long-term consequences.

2.4.2 BIAS EXAMINATION

Interviewees, in the vast majority, had a favourable attitude toward cover crops. I collected participants' experiences based on their honesty and integrity. To prevent a positive bias, regardless if farmers purposely did it or not, I juxtaposed participants' observations and perceptions with published research. It allowed me to compare the results to examine their trustworthiness.

2.5 BACKGROUND INFORMATION

2.5.1 DESCRIPTION OF THE PARTICIPANTS

I interviewed 20 participants in total. Two interviews were conducted with two persons and they were the only ones with females. To avoid confusion, the two interviews with two participants represent one participant in the results section as I coded their thoughts and ideas as one individual. The other interviews were conducted with only one male farmer. Their age group ranged between 32 years old and 70 years old, while the majority were in their 40s or 50s. All participants had grown up either on a family farm or in a rural farming community. One farmer bought the farmland and another one rented the land from the county. All the others acquired their farm through the "odelsrett" (allodial right, either they or their partner had the priority to buy their parents' farm). All farmers had extensive farming experience due to their upbringing on a farm. Still, when asked about the time they started considering themselves as farmers, most of them mentioned when they bought or took over the farm operation. The years of experience

with the title 'farmer' ranged between 7 years to 44 years. In total, 12 farmers were full-time farmers and the 8 others were part-time farmers.

2.5.2 DESCRIPTION OF THE FARMS

There were 11 farms who were operating organic (one was completing the conversion in 2021) and 9 farms who were operating in a more conventional setting (i.e., the use of non-negligeable inputs like synthetic fertilizers or herbicides). The range of farmland varied approximately between 25 hectares and 2000 hectares and it included; cropland, grassland, pastureland and forestland. The cropland area for small grain production (i.e., cereals, legumes and oilseeds) varied approximately between 25 hectares and 405 hectares among the farms. The main cash crops produced were oat, barley, wheat, bean, pea, rapeseed oil and old species such as emmer, rye and spelt. Other types of production varied from livestock (i.e., beef cattle, dairy cattle, pig and sheep) and vegetables (e.g., root crops, corn, cabbage, market garden). Also, numerous farms had other activities onsite such as the production of Christmas trees, the production of bioenergy from wood residues, rental properties, a working-learning collaboration with high schools, leisure activities, a marina and a slaughterhouse.

2.5.3 DESCRIPTION OF COVER CROP PRACTICE

The years of experience with cover crops varied (see Table 3). It ranged between re-introducing cover crops into the farm for the upcoming 2021 season, in contrast to 20 years of experience. Generally, participants farming organically had more experience, with a median of 11 years, while non-organic farmers had a median of 4 years. A few participants tried cover cropping in the early 2000s when it was introduced as part of the RMP, but they abandoned it later on.

TABLE 3 FARMERS' YEARS OF EXPERIENCE PRACTISING COVER CROPS

Number of years practising cover crops	Number of farmers
3 or less	7
4 or 5	6
6 and more	7

Additionally, a majority of farmers used a mixture of ryegrass and white clover, a well-known and popular mix in Norway. They also used different mixtures provided from the company Strand Unikorn, from the cooperative Felleskjøpet or by doing their own mix. Different species were included such as meadow fescue, chicory, radish, vetches, phacelia, ryegrasses and clovers.

Furthermore, the sowing methods depended on the farming system in place and the machinery available. Methods included the use of a direct-drill seeder, a fertilizer spreader, a weed harrow machine and a spreader equipment installed on the combine harvester. Farmers sowed cover crop seeds both in the spring and in autumn.

Also, the termination methods included spring plowing, herbicides and the use of winter-killed cover crop species. Besides the traditional methods, a minority of producers used a 'flat composting' terminating method. It consisted of cutting cover crop plants close to the ground level, adding lactic acid bacteria and mixing both with a harrow machine. This decomposed the residues directly on the field.

2.5.4 REASONS TO BECOME A FARMER

Different reasons motivated participants to carry on the family farm or to become farmers. For example, the majority of them expressed an interest in topics related to owning a farm such as food production, plant science and the financial-business aspect. Some farmers enjoyed the job and they liked working manually. Others mentioned their attachment to the place where they grew up and it was their responsibility to keep the tradition alive. For a few, farming was part of their identity. One farmer took over the farm by necessity. Also, a minority of participants talked

about being a farmer because it gave them a meaningful life, by providing an essential human need.

3. RESULTS

3.1 RESEARCH QUESTION 1

RQ1: What are the advantages and disadvantages that selected farmers observed from their use of cover crops?

The advantages and disadvantages from the selected farmers are divided by categories (i.e., provisioning, supporting, regulating and cultural) in accordance with the Millennium Ecosystem Assessment (2005) (see Figure **1**) because it provides a logical structure. Two additional categories relate to the environment and factors in relationship with the farming system.

3.1.1 PROVISIONING

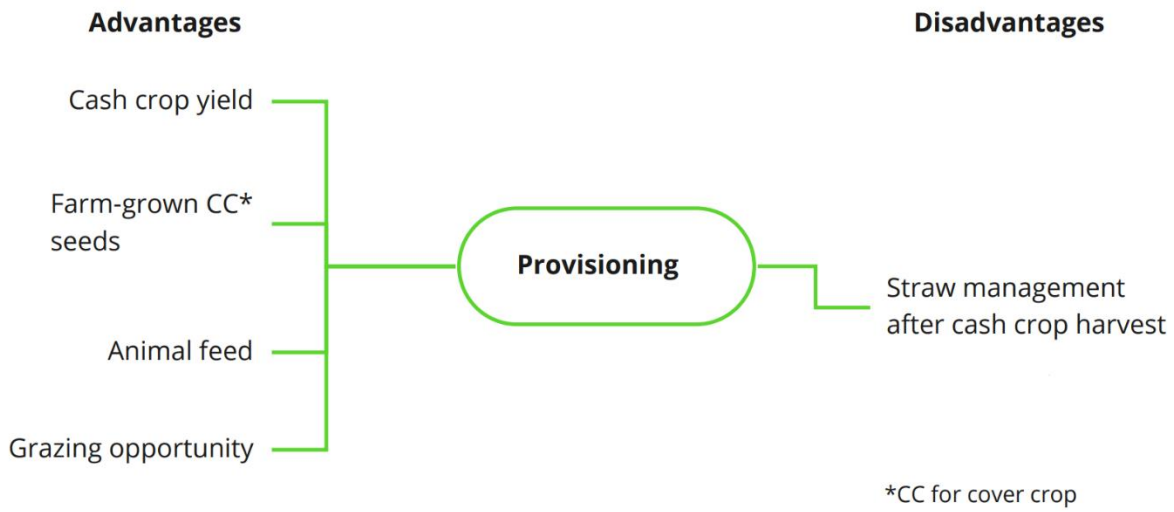


FIGURE 4 KEY SUB-CATEGORIES FOR THE CATEGORY 'PROVISIONING'

Many farmers observed a cash crop yield increase. They didn't take any measurements, but they visually assessed the growth throughout the season or from one year to the following one. One participant attributed the yield increase to the different changes occurring on the farm in the last 20 years, such as stopping plowing, integrating a variety of cash crops and implementing cover

crops. However, one producer stated that it was difficult to pinpoint a specific element influencing cash crop yields.

A few interviewees had challenges with the management of straw after harvesting the cash crop. It could be difficult to straw bale because the straw didn't dry quickly enough with the high moisture content on the ground provided by cover crops who had a good growth. Then, the window to straw bale became narrower as weather conditions were less favourable to work in the fields.

Furthermore, a minority of participants harvested cover crop seeds for the following season in incidents where they had grown at the same rate as the cash crop and where they could separate the seeds afterward (by sieving the seeds according to their size).

A few farmers producing livestock took advantage of the cover crops as extra animal feed. For example, one producer could harvest cover crops, if they survived the winter. Another one straw bale cover crops following a resting period after the cash crop harvest and an additional farmer used cover crops as a forage crop if needed.

Moreover, some participants used cover crops as a grazing area. They did it in the autumn, after the main crop harvest. For instance, one farmer found it more difficult to plow plant material of 30-40 cm as opposed to 5 cm, so grazing reduced cover crops height. Also, animals had a beneficial impact since they provided a natural fertilizer. Another one used them as a termination method combined with herbicide. Nevertheless, a few farmers expressed their concerns over the use of livestock. They lacked the knowledge on how to do it correctly and they believed the cattle were too heavy. They said it would have a detrimental effect on the soil, especially coupled with bad weathers often occurring in autumn.

3.1.2 SUPPORTING

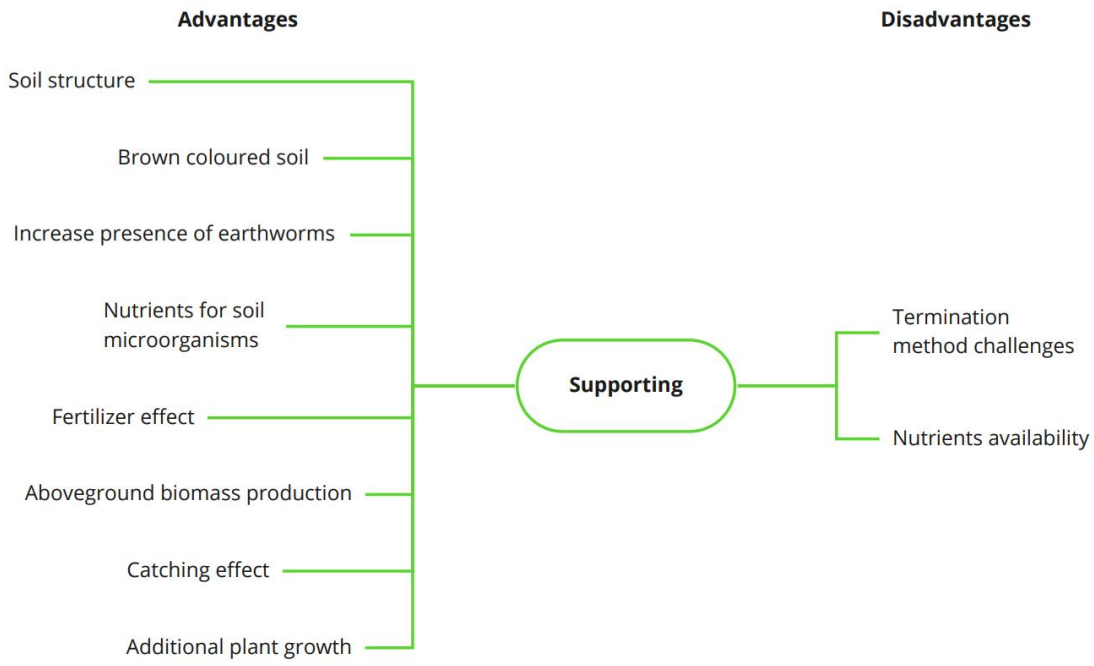


FIGURE 5 KEY SUB-CATEGORIES FOR THE CATEGORY 'SUPPORTING'

Several participants agreed that cover crops positively affected the soil structure. For example, for a few interviewees, the soil was easier to work with when tilling and they were impressed with the root growth. One producer said that the roots had a healing effect on the damages caused during plowing. A minority of farmers witnessed how the soil became looser, with a better air-flow. Improving the soil structure helped farmers when work had to be done the following season.

One interviewee noticed the brown-ish colour of his soil versus a grey-ish colour observed on the neighbouring fields. He attributed it to the addition of cover crops and to the no-plow practice.

A few participants mentioned the increased presence of earthworms in the soil. They observed how cover crops left in the fields decomposed rapidly and one producer valued earthworms' function when they penetrated the heavy clay.

A minority of farmers discussed the termination methods which can be a disadvantage when cover cropping. For instance, one farmer expressed concerns, regardless if weed emerged, sometimes he needed to plow if cover crops survived through the winter. Another participant found it difficult to find an efficient method to kill cover crops without soil disturbance or herbicides.

The majority of farmers acknowledged that cover crops provided nutrients for soil organisms as they integrated more biomass, which in turn increased the life underneath the ground. Also, a few of them believed in the importance of increasing the carbon content.

Many interviewees explained how cover crops had a fertilizing effect on the cash crops, but relying on them varied a lot. For example, a few said it represented their main fertilizer. A minority of participants reduced their synthetic fertilizer input (it depended on the previous season's results) and another one believed in a small fertilizing effect (not substantial enough to take into account in the fertilizing plan). However, one farmer didn't see any difference thus far. Furthermore, some interviewees had a productive aboveground biomass of cover crops. A few of them said the height could reach more than one meter. One producer stated that cover crops could potentially steal nutrients (such as nitrogen) to the cash crops.

Some producers also talked about the cover crops catching effect in the autumn season. They retained nitrogen left in the soil and stored it for the following season. One farmer declared:

> […] We can catch nutrients and use them again for next season instead of letting them go out to the sea […]. (Révérend MacDougall)

Some participants pointed out the additional plants growing in their fields. Including cover crops meant producing photosynthesis for an extra 2 to 4 months. They covered a 'dead window period', where nothing used to grow.

3.1.3 REGULATING

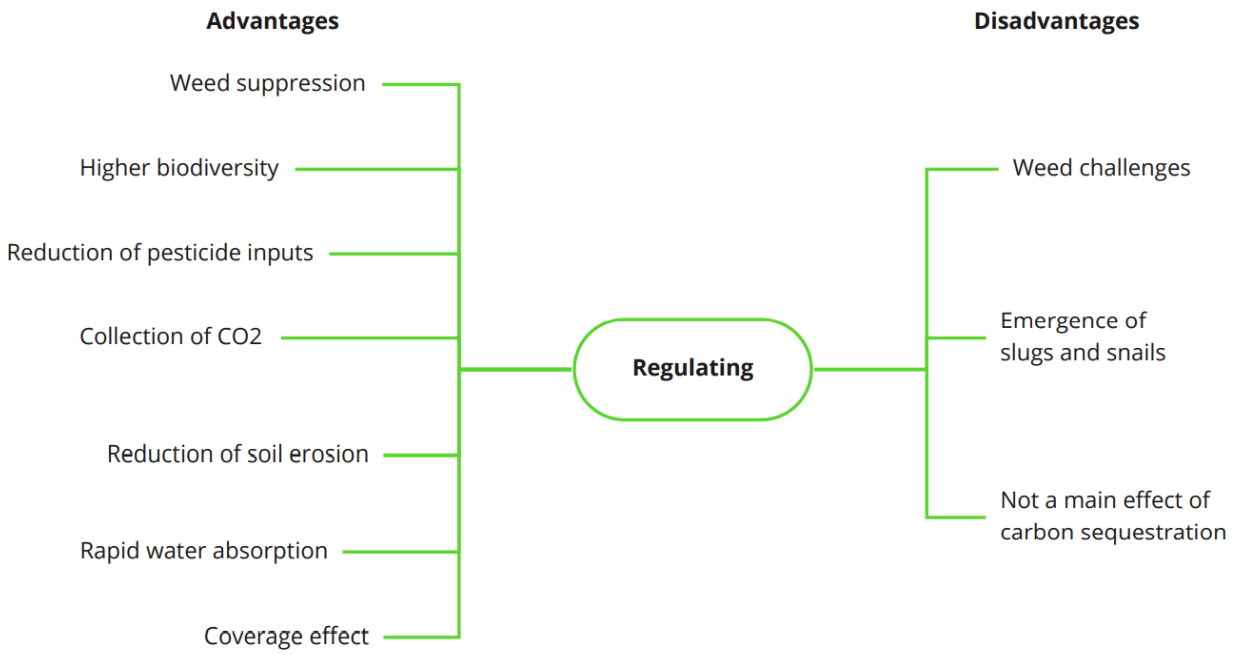


FIGURE 6 KEY SUB-CATEGORIES FOR THE CATEGORY 'REGULATING'

Many farmers used cover crops as a weed suppressor because they competed for nutrients and space. However, a few participants recalled anecdotal events, where cover crops made it difficult to control weeds. Additionally, sometimes they survived the winter season and came back as weeds the following year. For example, a minority of producers had difficulties when they harvested peas.

A majority of farmers expressed their focus to become more biodiverse on their farm with the help of cover crops. Some producers provided a desirable environment for insects and bees. A few of them indicated that attracting more insects was a natural control measure against undesirable ones. A small number of participants observed having a friendlier environment toward wild animals such as roe deer and seagulls. A minority of interviewees spoke about the advantages of having a high diversity belowground. For instance, one farmer believed it lowered the pressure disease. This producer summarized the idea:

> My goal is to make this biodiversity very high to have an ecosystem that supports us. (Brittany)

A few participants reduced their pesticides inputs over the seasons. For example, one farmer stopped using insecticides. However, a small number of interviewees, practicing both reduced tilling and cover cropping, noticed snails or slugs being intrusive in some fields. They attributed this issue to a warmer climate, the species chosen and the no-till practice.

Several participants believed in the positive effect of cover crops by collecting CO_2. They thought it was a simple and efficient way to help mitigate climate change, by capturing more carbon via a longer growing season. A few farmers also touched upon the idea of being more socially accepted in the society with a low-cost practice contributing positively to the environment. However, a minority of interviewees didn't use cover crops on their farm to collect carbon and they didn't think it has the primary purpose of sequestering carbon.

Using cover crops, critically reduced soil erosion. Many farmers mentioned how the practice helped them stabilize the soil by reducing its loss with the influx of water in autumn and spring. For instance, one participant noticed the colour of his drainage system. While it used to be grey-blue from the loss of clay, nowadays the water was clear coloured.

After introducing cover crops, some producers saw a rapid water absorption on their fields, with one stating that he could hear the water being absorbed. One participant recalled:

> […] We can now live through a longer period without the rain because the ground is like a sponge, it's holding the water very well. (Révérend McDougall)

Some interviewees talked about the coverage effect. Cover crops, as the name indicates, covered successfully the space. Among other things, one farmer used them because he had fields unsuitable to grow cash crops due to the difficult position and he put something there rather than leaving the soil bare.

3.1.4 CULTURAL

A few farmers spoke about having an enjoyable landscape. Aesthetically speaking, participants appreciated having a green area for much longer. One farmer also referred to his neighbours who preferred seeing green fields compared to brown ones.

3.1.5 ENVIRONMENT

Environmental factors shaped the decision-process when managing cover crops.

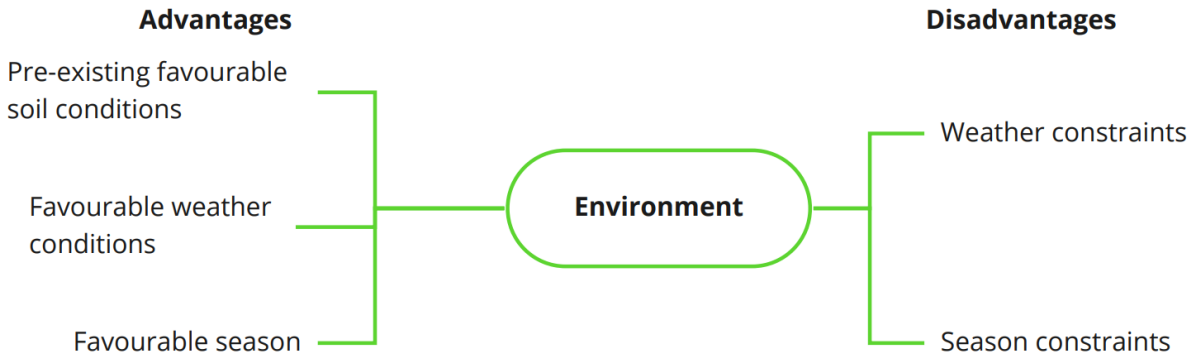


FIGURE 7 KEY SUB-CATEGORIES FOR THE CATEGORY 'ENVIRONMENT'

A minority of participants also producing cattle mentioned how the organic manure applied in the fields was a good source of fertilizer. Therefore, the quality of their soil seemed favourable to grow cover crops.

Additionally, several famers voiced out how the season impacted cover cropping. For example, a few interviewees expressed the long daylight season as an advantage to grow plants instead of having a 'dead field'. However, in Norway the growing season is short. One participant waited longer than his neighbours to start his farming season to have a soil completely dry and to invigorate microorganisms. Toward the end of the summer season, some producers sowed cover crops as early as possible to benefit from the weather conditions. If the weather conditions delayed the cash crop growth, the harvest could happen in early October and no time remained

to establish cover crops. One participant also said that the autumn season is unpredictable and short. A few others stated that the Norwegian climate is not the best to practice cover cropping.

Farmers talked about how the weather conditions were in their favour or in their disfavour. For instance, one participant appreciated having a lot of moisture in the soil in the spring. Furthermore, the summer of 2018 was a very dry year. Some producers harvested cash crops early in the season, therefore cover crops had the chance to grow for a longer period of time. A few interviewees mentioned how supplying water can be challenging. For example, seeds germination became difficult when the predicted rain didn't fall. Additionally, one participant indicated that if bad weather came between the sowing period of the cash crop and the cover crop, the waiting period made the cash crop grow too much, which left not enough light through the canopy for cover crop to properly establish.

3.1.6 FACTORS IN RELATIONSHIP WITH THE FARMING SYSTEM

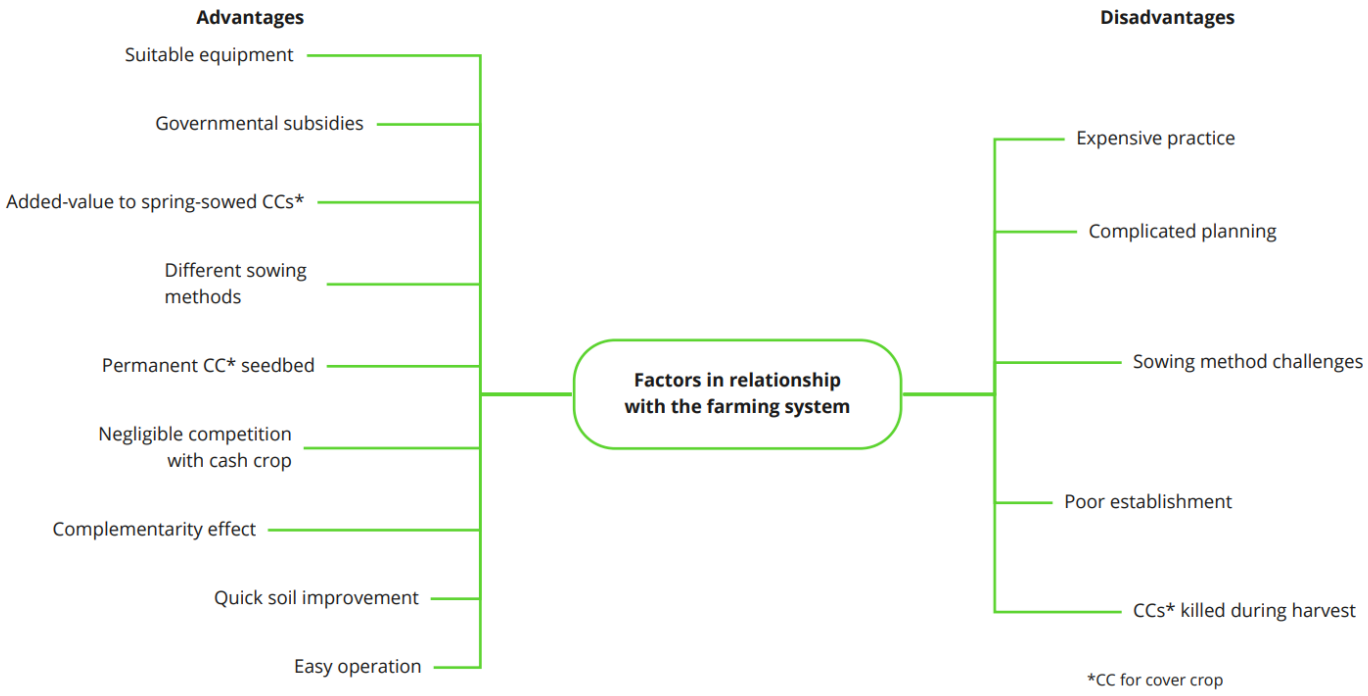


FIGURE 8 KEY SUB-CATEGORIES FOR THE CATEGORY 'FACTORS IN RELATIONSHIP WITH THE FARMING SYSTEM'

Several farmers already had the suitable equipment for the implementation of cover crops. The machinery on the farm served different purposes. For example, few participants sowed cover crops, while simultaneously harrowing the soil with a weed harrow. Also, many farmers used direct-drilling equipment to sow all types of seed (both cash crop and cover crop seeds).

Interviewees identified the governmental support as an advantage, where all of them received money to use cover crops under the RMP scheme. The opinions on what the subsidies reimbursed varied. Some claimed that subsidies covered approximately the cost of the seeds. One said that it paid for the establishment cost and another one mentioned that it covered only half of the seeds cost. One more stated that it reimbursed the cost for the seeds and the work to sow them. Furthermore, a few participants pointed out that it depended on the type of species bought. A mix of ryegrass and white clover costs less than a mix containing multiple species. A small number of interviewees said that cover cropping was not costly, but many farmers expressed the opposite. Cover crops were quite expensive, especially the cost of the seeds and participants paid attention to how they managed them.

A great number of participants indicated that practically and technically, implementing and using cover crops was an easy operation. For instance, few farmers said integrating the practice was cheap to do. A minority of them said transitioning happened quickly and didn't disrupt the cash crop production, or, and starting to convert to produce organically made cover cropping an integral part of the package deal. One interviewee didn't feel stressed to learn the practice and another one discussed his pre-existing familiarity, since he produced grassland for livestock. A minority of farmers saved time using cover crops compared to the previous practices done on the farm. However, a few of them worked more when they began. They had a learning curve to reach.

Nonetheless, many farmers declared that the crop rotation planning became more complicated. Specifically, some participants spoke about the species choice that needed careful

consideration. They wanted to avoid transmitting diseases between cover crops and cash crops. As one farmer communicated:

> But, the disadvantage with these two cover crops (oilseed radish or radish) is that they are in the same family as cabbage and therefore I had to find something else because growing this type of cover crops doesn't go very well with a cabbage rotation. I can either have this crop rotation or cabbages, not both. (Megan)

Also, a few farmers talked about the regime of herbicides. They had to adapt it to fit with cover cropping, as some herbicides could kill them. One farmer mentioned that it could nurture a mental blockage for other colleagues to start using cover crops, because it perpetuated the status quo.

Some producers expressed preferring spring-sown cover crops compared to autumn-sown cover crops. For example, they believed in the added-values of using them earlier during the growing season. They ensured enough time for establishing a good coverage, they maximized a favourable insects' habitat and filled the gaps when the main crop ripened by continuing the photosynthesis reaction. Additionally, one organic farmer stated that weeds emerged too strongly throughout the summer and cover crops were difficult to sow in the autumn.

During the interviews, the participants explained different sowing methods. It depended on; the equipment used, the intentions desired from the cover crops and the crop rotation plan. In the spring, farmers favoured an initial cash crop growth. They waited before sowing cover crop seeds. In the autumn, one farmer discussed about the options he considered:

> In the late summer time, I spray (cover crop seeds) before I harvest, that's one system I use. I take them out two weeks before I harvest (the cash crop). The other system I try to use is the day after harvesting, I take my sowing machine and put them in the soil immediately after harvesting. (Melody)

Moreover, one participant seemed to have a permanent cover crop seedbed in the fields. He started to sow less per hectare compared to 4-6 years ago. This past autumn, he noticed that one of the fields was green, while he hadn't sown anything on it.

Despite the variety of sowing techniques practiced, some farmers had challenges with the sowing method. For instance, timing to sow cover crops didn't necessarily match the timing to perform the weed harrowing. A few farmers experienced this problem. Occasionally, one participant had difficulties with wind condition, which made it hard to sow with the equipment he had.

Some farmers disclosed sporadic problems when establishing cover crops. Different reasons included; a lack of rain following the sowing period, the inappropriate sowing method used and other mistakes farmers attributed to their management. If he had enough time left, one producer would sow cover crop seeds again to obtain an establishment and subsequent growth.

Many participants recalled a good interaction between the undersown cover crops and the main crop. Cover crops didn't compete too much for nutrients or with the cash crop during the growth phase. Nonetheless, one producer experienced some challenges when he harvested the cash crop. If cover crops had grown too high, they couldn't grow again following an involuntary cut by the combine harvester.

Several interviewees mentioned how cover crops had a complementarity effect both between different species among cover crops and cash crops. A mixture provided a broader addition to the soil because a variety of species acted on different factors. Here's an example:

> […] It has this perfect mix of species with this oil radish, it's a root crop that would loosen the soil and this vetch, which fixes nitrogen. (Brett)

Another farmer discussed the interaction between a cover crop and a cash crop:

> The vetch is collecting the nitrogen and the wheat plant is absorbing it, so it's a perfect mix. (Bo)

Furthermore, a few of them talked about the possibility of adding the remaining cash crop seeds into the mixture of cover crops, which reduced the cost.

A minority of producers were quite impressed and surprised by the soil improving rapidly following the implementation of cover crops.

3.2 RESEARCH QUESTION 2

RQ2: Which factors do the selected farmers identify as key for an increased use of cover crops in Norway?

3.2.1 INDIVIDUAL FACTORS

Individual factors represent key categories contributing to farmers' adoption of cover crops. They also encompass the three initial stages (i.e., knowledge, persuasion and decision) from the innovation-decision process of the theory Diffusion of Innovations (Rogers, 2003).

3.2.1.1 Stage 1 - Knowledge

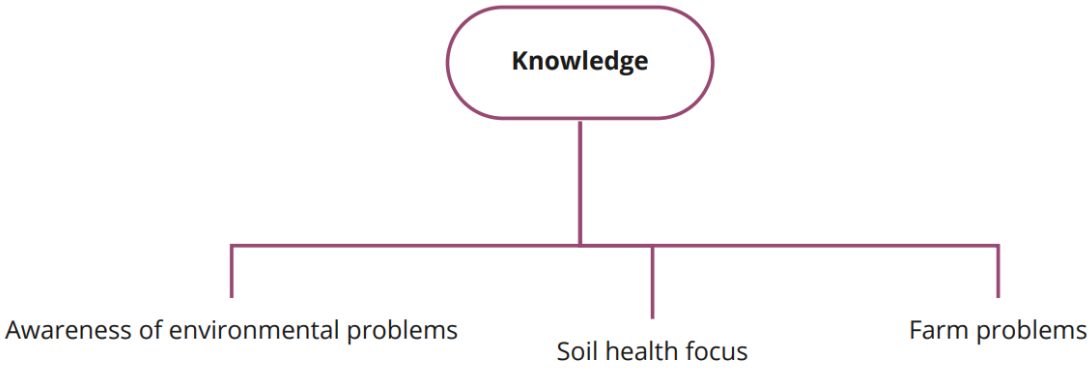


FIGURE 9 KEY SUB-CATEGORIES FOR THE CATEGORY 'KNOWLEDGE'

Farmers started cover cropping for various reasons. Many participants talked about an awareness toward environmental problems with concerns over climate change. For example, a few of them mentioned how tilling had a detrimental effect on the soil. Also, some producers became much more focused on soil health. In order to farm in a better way, they concluded that soil health was a critical factor, which led to cover cropping among other things.

Additionally, several participants discussed an inherent problem that occurred on their farm, which promoted a desire to change how they farmed. A few of them had challenges, such as erosion problems due to corn production, or due to a low soil carbon content following decades of conventional farming. Economically speaking, some interviewees had income problems or they believed fertilizer prices became too expensive. Moreover, some participants disliked using chemicals as it felt counter-intuitive. The municipality prohibited one farmer to use chemicals around a lake in the middle of a field and he decided to find an alternative. These reasons led to search for different ways of farming.

3.2.1.2 Stage 2 - System modification

Using cover crops followed a point of entry to modify the farming system. It was a consequence rather than the cause. Very few farmers knew what cover crops were before implementing the practice. Only a minority of farmers learned about cover crops from their parents or close relatives when growing up. Most farmers discovered them either from their close circle (i.e., partner, colleagues, students) or through an organisation, such as farming advisors, agronomist, farming magazines, farmers' organisation such as the Oslo og Akershus Økologisk Fylkeslag (the Oslo and Akershus organic county's association) and the Foreningen for Reduceret Jordbearbejdning i Danmark (the association for reduced tillage in Denmark).

Every farmer interviewed made some modifications to their farming system. For example, many organic farmers indicated that cover crops prevented weed invasion and they became an integral part of their operation for that reason. Some non-organic farmers started implementing

different elements of conservation agriculture by reducing tillage or by sowing directly into the soil. One participant said:

> […] My year-long experiment of not plowing, just reduced tilling didn't work out because I didn't use cover crops. So, then I started to understand that I needed cover crops to prepare the soil when I don't till or plow. (Googy)

As presented later on, changing the system made the cover crops integration easier for farmers. From the initial cover cropping discovery, farmers also persuaded themselves to try it out.

3.2.1.3 Stage 3 - Persuasion

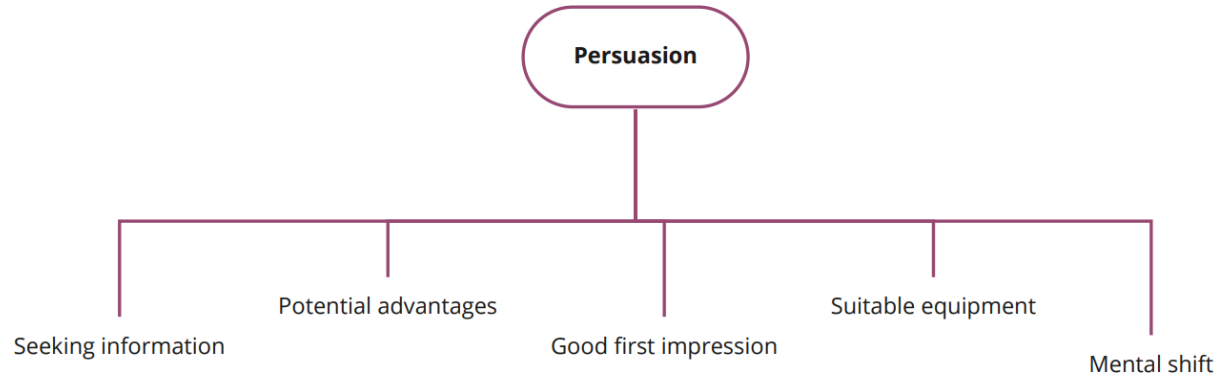


FIGURE 10 KEY SUB-CATEGORIES FOR THE CATEGORY 'PERSUASION'

Participants elaborated on how they sought more information once they learned about cover cropping. All of them acquired knowledge via multiple channels. NLR was prominent for the majority of the farmers and especially with the advisors (counselling service). Interviewees also used different services offered such as the farmers' meetings, the newsletter and other information found on their website. In the early stages of using cover crops, a few farmers said that NLR advisors didn't have the knowledge required, so they sought information elsewhere in the meantime. Many producers gathered knowledge from their peers and from resources

abroad, especially in Denmark where cover crops have been implemented for a longer period of time. Furthermore, several participants found a substantial amount of information online and on Youtube more specifically. Some interviewees also read books and others were inspired by the work of Gabe Brown, a well-known American rancher practising conservation agriculture. A minority of farmers worked with VitalAnalyse, an alternative agricultural advisory consultancy company in Norway. Additionally, a few of them considered using cover crops because they were offered free counselling hours when they started converting to organic production.

In terms of potential advantages, participants expressed different motivations to consider cover cropping. For example, some farmers hoped to lower weed counts in the fields. Some others wished cover crops would help improve their soil, either by reducing the erosion or by providing a more fertile soil by including more biomass, thus bringing additional nutrients. Also, farmers had heard that cover crops could increase the cash crop yield. One farmer mentioned his hope for less labour with direct drilling seeds (cash crops and cover crops).

Additionally, to help define their opinion about cover crops, some farmers had a good first impression, when they saw results on other farmers' fields. They were impressed by the growth of cover crops, by the cash crop yields and by the quality of the soil. One farmer said:

> […] the cover crops were big and it was really impressive to see and the farmers that were using cover crops in that system and had good growing crops, […] and winter wheat, winter rape and cover crops in the system, they had really nice soil, so we understood that we had to try. (Brad)

Another producer mentioned that his neighbouring farmer reduced external inputs, while experiencing a better soil health and a better crop yield, which boosted his enthusiasm.

Moreover, many participants already had the suitable equipment on the farm to start using cover crops, which lowered the investment for the first season. For instance, some farmers pointed out that when they converted to organic, they purchased a weed harrow, which could also be used to sow cover crops. A minority of participants didn't have the right sowing equipment

before starting using cover crops. They bought one, but they didn't consider it as a big investment. They could always sell it again if it didn't suit their operation. One farmer expressed the difficulty to share equipment as the right time to sow cover crops was the same for neighbouring farmers. Alternatively, a small number of participants hired or borrowed the equipment from a colleague during the first season to avoid spending money.

A mental shift subsequently occurred. For example, one participant recalled how he found stupid to grow plants without harvesting them. Growing things in the field meant harvesting them at the end of the season. Another one had an initial negative impression due to the costly nature of the project. As they built their knowledge and became familiar with how cover crops work, they still had a mental blockage to overcome. A few of them talked with colleagues, others learned more about how the soil and plants interact with each other and one farmer explained:

> If you ask me 6-7-8 years ago, I would have said that my most important tool was my tractor, but these days I will say my shovel is my most important tool […]. (Flatsy)

The time length of the mental shift was different for every participant, one stating that it took him a couple of years to process the information. Generally, interviewees couldn't remember an exact moment when it happened. Overall, farmers expressed different factors pivotal to take the decision to start using cover crops.

3.2.1.4 Stage 4 - Decision

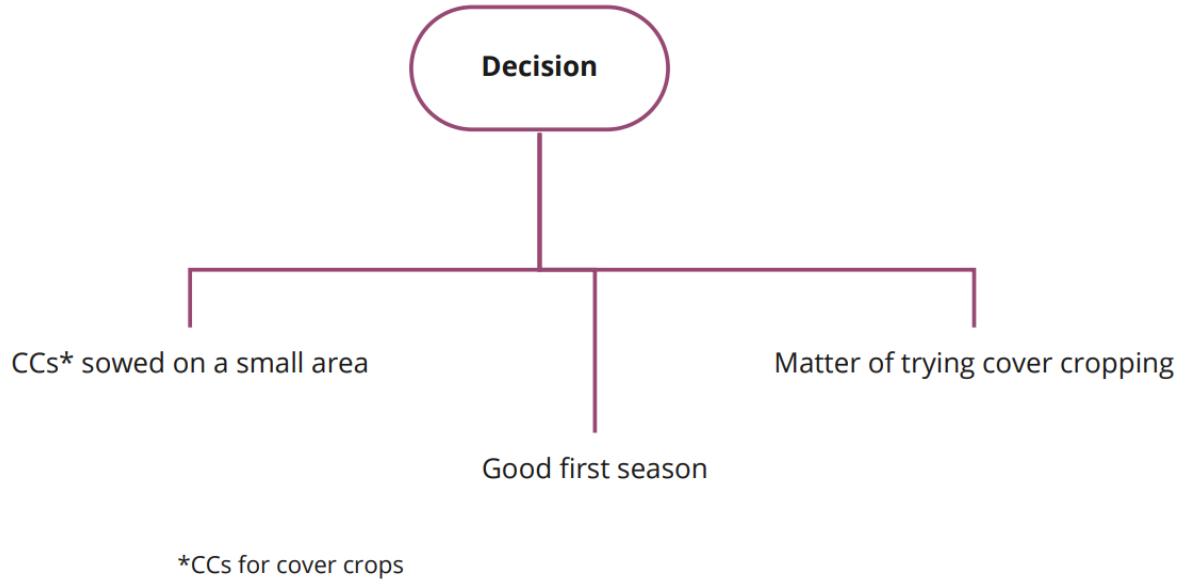


FIGURE 11 KEY SUB-CATEGORIES FOR THE CATEGORY 'DECISION'

At first, some participants only sowed cover crops on a small area to get experience before scaling-up. One farmer recommended starting on a field with controlled weed. Yet, one participant used the full-scale of his fields available to sow cover crops during his first year.

A great number of farmers experienced a good first season with cover crops. Some mentioned how they established themselves well and grew a lot. One interviewee even improved the soil during the first season. However, a few participants didn't have a great first season and acknowledged that improvements were needed.

A few producers also said that starting cover cropping is a matter of trying, of feeling and understanding what works for you and for your farm. They didn't make a fuss about it, they wanted to get experience and they could always make changes afterward.

In the end, farmers felt like getting practical experience led them one step closer to the adoption of cover crops. Other collective-contextual factors influenced the individual factors.

3.2.2 COLLECTIVE-CONTEXTUAL FACTORS

Collective-contextual factors pertain to the social system in place.

In the early 2000s, farmers who rejected cover cropping or those who didn't use them attributed different reasons for the failing to adopt the practice. Some producers expressed that the purpose of cover crops was different. A minority of participants remembered that the government wanted to reduce soil erosion leading to nutrients leaching in the water stream, which deteriorated local ecosystems. Besides, they didn't receive any information on other benefits provided by cover crops. A few of them used cover crops to get governmental subsidies, without really understanding the core principles behind cover cropping and one farmer didn't have any problems with nutrients leaching, therefore he didn't feel engaged. Furthermore, some farmers had difficulties with cover crops, mainly with spring-sowed ryegrass that grew too much and affected the harvesting process. Also, they could come back as weeds the following season. Some interviewees didn't want to take the risk of compromising the cash crop, especially after the government reduced subsidies significantly.

The majority of farmers spoke about the growing popularity of cover crops in Norway in recent years. For example, some participants discussed how NLR advisors learned and started promoting the practice. A few interviewees mentioned the pilot project Karbon Agro launched by NLR Øst, where advisors collaborate with a few farms located in Viken to farm in line with conservation agriculture principles (i.e., minimum tillage, always keeping the soil covered and crop rotation). Several farmers expressed the wider species varieties and mixtures available, however some have mentioned the opposite. They thought the Norwegian market lacked diversity of seeds and mixtures suitable for the local climate. Also, a few participants indicated that they tried cover cropping because other farmers tried as well. One farmer discussed the current research focus at NIBIO and another one talked about a recent governmental project

emphasizing on soil health. Many participants talked about this growing popularity as a good thing for Norway and for the promotion of the practice among other farmers.

Some farmers believed subsidies should be increased to scale-up cover cropping nationally. It would act as a bigger incentive and as a buffer for the risks taken by farmers who start to use them.

3.3 RESEARCH QUESTION 3

> RQ3: How do selected farmers think the practice can be successfully integrated in different farming systems?

The two last stages of the innovation-decision process from the theory Diffusion of Innovations (i.e., implementation and confirmation) (Rogers, 2003) help understand the successful cover crops integration in different farming systems.

3.3.1 STAGE 5 – IMPLEMENTATION

Given the growing popularity in Norway, nowadays farmers indicated addressing their cover crops questions to local sources of information. For instance, a great majority of them turned to NLR advisors. Several participants also mentioned their peers as a source of knowledge. Also, a few participants talked about the following resources: NIBIO, Karbon Agro, VitalAnalyse, seed suppliers and sources abroad (e.g., taking inspiration from work done in Denmark).

While a minority of farmers wanted fixed solutions, several farmers talked about their work in progress. For example, a few of them mixed different cover crop species to sow different mixtures based on their needs. Some tried various sowing techniques, such as direct-seeding or they tried sowing autumn cover crops. They wanted to become more adaptable to the local conditions unique to their farming system. As one interviewee said:

> It's a work in progress all the time for the rest of my life. (Ashley)

A majority of farmers expected enhancing their entire agroecosystem in the future with cover cropping. For instance, some interviewees anticipated increasing the organic matter, the diversity and the number of microorganisms. Some producers hoped for a better soil structure, which would reduce leakage of nutrients and help them manage the soil. Some participants wished for a better cash crop yield in the future. Furthermore, a minority of farmers managed the cover crop production and the livestock production in a more efficient way to get a better soil health. Also, a few interviewees mentioned how adding cover crops would provide better cycling between nutrients, air and water, which would help reduce fertilizer needs. One participant talked about establishing a stimulating environment for biodiversity. One person summarized well the expected results in the future:

> […] it will provide a much more stable environment and make sure that it will be a more robust place to do farming. (Becky)

3.3.2 Stage 6 - Confirmation

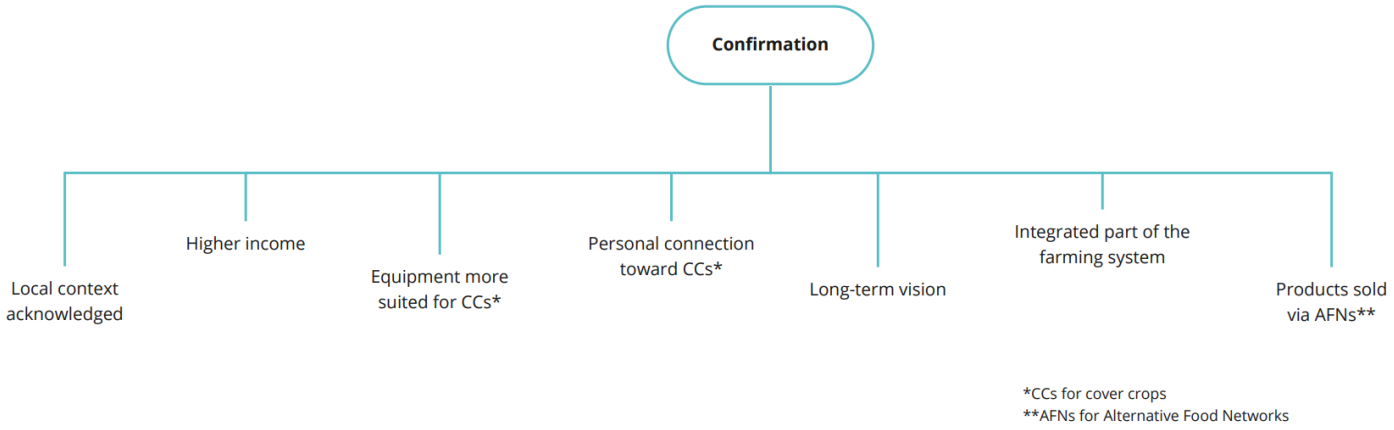


Figure 12 Key sub-categories for the category 'Confirmation'

A minority of farmers declared acknowledging the local context when using cover crops. For example, a few interviewees knew they had to adapt the information received to the Norwegian context when reading resources from abroad. A small number of producers mentioned the importance of finding cover crops suitable for their local environment.

Many participants earned more money as opposed to when they didn't use cover crops. For instance, a few producers spent less money on external inputs, such as fertilizers. One organic farmer got lower yields over the years, but he earned more because the price of organic crops was fixed at a higher rate.

Eventually, some farmers started acquiring equipment more fitted for cover cropping, which provided more accuracy and in turn increased the likelihood of a successful establishment. For example, a minority of participants bought a direct-drilling sowing machine (while having another sowing machine) to experiment with different sowing dates or because it worked with the implementation of reduced tilling. Also, one producer needed a specific sowing equipment when producing corn. Furthermore, a few farmers had an irrigation system to ensure a good establishment in case of drought following the sowing period.

Additionally, nearly all farmers expressed or demonstrated a personal connection toward cover crops. A majority of participants communicated their positive attitude when using cover crops. This translated by having some kind of revelation, as said by one farmer, or by having an eye-opening moment of realizing how interesting and fascinating it was to learn and experience something different. One farmer declared:

> […] you go into another direction and you don't know what to do so it's kind of frightening you know.. But it's also exciting […]. (Ashley)

Also, others mentioned their feeling of happiness and accomplishment following a good season of cover crop growth. They had a satisfactory feeling, because they farmed in a friendlier manner for the environment.

A lot of interviewees communicated that cover cropping made a lot of sense to them. The process logically benefited the whole system, especially for a healthier soil. Many spoke about how they had become persuaded by cover crops benefits. For example, one farmer explained

how he was accustomed to grow grassland and he noticed the soil quality difference with growing annual crops. He was convinced that cover crops would act in a similar manner, by improving the soil quality. Another one spoke about his belief of an improved soil both with cover cropping and cows grazing the fields.

Some farmers mentioned the intrinsic value associated with new or alternative farming methods. For instance, one farmer talked about how he always disliked chemical application on the family farm as a youth, even without really understanding why. That feeling was one of the reasons he converted to organic farming and started practicing cover cropping. Another one described how he chose a weed harrowing machine as a topic of interest as a student. Participants used cover crops for different motives and merely for an economic return.

A vast majority of producers agreed on the fact that using cover crops was for a long-term vision. They didn't worry about getting outstanding results right at the beginning. For example, a few of them talked in a timeframe exceeding their lifetime, with one wanting to make his farm a better land for his children and grandchildren. Others imagined observing significant results in a lapse of a few years. One farmer used cover crops as an investment for his soil, while another one aimed to be self-sufficient like nature is.

A majority of participants concluded that cover crops were an integrated part of their farming system. For instance, a few farmers practised conservation agriculture and they could not see any other options other than using cover crops, because it was complementary with direct drilling. One interviewee had a rule of always having cash crops with cover crops undersown. Another one explained the interdependence between the animal production which provided manure as a source of cover crop feed. Then, cover crops provided animal proteins with the straw and this made a full cycle. Some participants also articulated the topic as part of a holistic way of seeing how they ran their farm. To summarize the general opinion of farmers interviewed, one producer said:

> […] you can't really have a production like we do without it, so it's completely natural. (Brittany)

Some interviewees producing both livestock and small grains planned to graze cover crops in the future (for those who didn't graze already). Also, they were conscious about the type of cover crop species they would use to satisfy the animals, while also answering other needs related with the soil and the crop rotation in place.

As part of a good integration into their farming system, a few participants discussed the benefits of using old cereal grains, such as spelt, rye or emmer. For example, they noticed that old species needed less fertilizer compared to the modern varieties. Also, the plants grew much higher, up to 2 meters according to one farmer, which made cover crop height irrelevant. Instead of adapting cover crops to the cash crop production, producing old species was more complementary when using cover crops. Producers would get lower yields compared to modern species, but old species were valued at a higher price range due to their exclusivity and their intended market. As explained by one interviewee, especially with the Covid-19 pandemic, more consumers became aware of the origin of their food. People desired a flour procurement from local milling companies, which is what those old species were grown for.

Some farmers cut the middle-man in the food supply chain by selling their products through an Alternative food networks (AFNs), either via REKO (i.e., a monthly distribution of products from local farmers where exchanges take place on a Facebook group), by selling directly on the farm or through small local milling companies. The interview guide didn't emphasis on this specific topic, but it also pertains to the whole system overview. Farmers and consumers could connect with one another. One interviewee expressed his wishes to be recognised from his customers on how the farm used cover crops and another one said he enjoyed the direct contact with them.

3.4 TRADE-OFFS

Farmers discussed different trade-offs from an economical perspective, from an agricultural management outlook and from an environmental point of view.

3.4.1 ECONOMIC

Farmers believed that cover crops are an economical investment in the long-run. For example, they preferred investing money on cover crops, rather than paying for external inputs such as synthetic fertilizers or natural fertilizers such as chicken manure. One farmer spoke about how the money he used to spend on his tractor (for fuel) shifted to the money invested in cover crops. Also, to lower the costs, participants purchased cheaper seeds. Over the years, some interviewees started to acquire different equipment more suited for cover crops to enhance their advantages. It also diminished the risk and potential disadvantages. If cover crops overtook the main crop due to a stronger growth, farmers often expressed a positive reaction. They got a fertilizer effect, they harvested the cover crop seeds for the following season or they used it as animal feed. In the end, farmers assessed what should be prioritized on the farm and made decisions based on their beliefs such as getting an immediate effect versus getting some effects in the future.

3.4.2 TIME MANAGEMENT

Participants talked about agricultural management decisions in regard to the time available. For instance, the season planning was much more complex than before. They had to consider; The disease transferability between subsequent crops, the regime of herbicides, the supply of nutrients, the complementarity between cash crop and cover crop and the subsequent cover crop effects in the soil. One farmer chose cash crop species finishing early to sow cover crops in August to ensure good growing conditions at the end of the summer.

Time also played a role in choosing different actions which impeded on different components of the farm. For example, participants reduced the window to straw bale in presence of cover crops

underneath due to the high moisture content on the ground. They favoured a better soil health, but jeopardised harvesting animal feed for the winter. Also, farmers weed harrowing and sowing cover crop seeds at the same time saved working hours and limited heavy weight on the field, but neither were supposed to be done simultaneously for a maximum desired effect. Furthermore, weed management brought extra costs with the machinery involved, additional workload and more soil disturbance.

Overall, farmers needed to find a balance in their management-decision process. They juggled between having the perfect cover crop growing conditions for soil health and related effects, while also producing a good cash crop yield for economic return.

3.4.3 ENVIRONMENT

Farmers acknowledged the environment they evolved and its related constraints in regard to cover cropping. For example, they took advantage of winter to kill cover crops species that didn't survived the frost. They planned their crop rotation based on the required time needed for cover crops to establish themselves before reaching a limited daylight and harsh weather conditions. They lowered their expectations, by understanding the difficult climate they operate in.

3.5 THEMES

3.5.1 RQ1 - MULTI-FUNCTIONALITY

Farmers expressed cover crops multi-functionality as a common thread. They enhanced different ecosystem services. They also blended with other farm components on a technical level and on a practical level. Due to their multi-functionality, participants couldn't maximize their cover crop use on every single factor described above. Different actions could be implemented to reduce the disadvantages (e.g., investing in equipment more suited for cover cropping, re-assessing the expected results, using mixtures to fill different needs). With years of experience, farmers

became more accustomed with the practice. In the end, producers accepted the potential trade-offs by weighing the advantages over the disadvantages.

3.5.2 RQ2 - Individual factors & collective-contextual factors

Interviewees demonstrated how factors both from an individual perspective and from a collective-contextual perspective were involved in adopting cover crops. Farmers related individual factors with the process of modifying their operation to address different issues. They challenged their way of thinking and their farming practises. They figured that cover cropping would be more in agreement with their beliefs and values.

Even though individual factors played a significant role in the adoption and in the increased cover crop use, farmers spoke about collective-contextual factors influencing their own perception. From a Norwegian governmental standpoint, cover crops have been encouraged since the early 2000s. Farmers have gained a positive attitude, partly because more knowledge has become available in the Norwegian farming sector. It proceeded with a snowball effect on other farmers, seed suppliers, extension services and research institutions. Due to this collective-contextual pressure, producers became motivated to get knowledge and start using cover crops.

3.5.3 RQ3 - Patience & uncertainty management

Patience and uncertainty management emerged as themes, as prerequisites for being successful. First, farmers expressed how cover cropping turned out to be a relatively straightforward and accessible practice to integrate. However, they mentioned that the results counting the most would come in the future. They didn't expect them after one or even after a few seasons. Second, participants showed how they lowered uncertainty associated with a new practice, by using resources available, such as knowledge, money and time. They also used those resources as an investment for a desired future.

3.5.4 STEWARDSHIP

Stewardship, in this case, where one has the responsibilities to manage the resources of a farmland, emerged as a theme to adopt and successfully integrate cover crops. Farmers wanted to preserve and manage resources in a more sustainable manner.

Participants started to use cover crops or they decided to re-integrate them in their farming system and the main reason was not motivated by monetary gain. They worried about the state of our world and they acknowledged the damages created by their farming practices. They had unsolvable problems that could only be resolved by drastic changes and as individuals they could turn around and transform their farming management style. Also, interviewees displayed a holistic mindset when speaking about the management of their land. Cover crops participated in the bigger picture of making a more resilient agroecosystem.

Often, farmers spoke about their feelings toward cover cropping. From a purely conventional setting, cover cropping was quite illogical. Like one farmer mentioned above, investing money in growing plants that would not be harvested was counter-intuitive, but once participants acquired knowledge, their perceptions changed favourably. They convinced themselves that it made sense, especially when you envision the use of cover crops such as running a marathon, rather than a 100 meters sprint.

Additionally, farming is a family affair in Norway. For farmers, preserving the land they inherited bears invaluable worth that they wish to perpetuate. Often, participants were the X generation of farmers on the farm and they took pride in taking care of such legacy and tradition. Furthermore, participants wanted an improved future for the coming years and they wanted to leave a better place for future generations to come.

4. DISCUSSION

4.1 RESEARCH QUESTION 1

Farmers talked about the effect of cover crops on different ecosystem services categorized according to the framework developed by the Millennium Ecosystem Assessment (2005). To assess their perspectives, literature is used to compare with (see Table 4).

TABLE 4 COMPARISON BETWEEN FARMERS' PERCEPTIONS AND PUBLISHED LITERATURE ON COVER CROPS' INFLUENCE ON ECOSYSTEM SERVICES

Ecosystem service	Agreement with literature	Disagreement with literature	No mention	References
Provisioning				
Cash crop yield	X			Breland (1996a); Finney et al. (2016); Lyngstad and Børresen (1996); Schipanski et al. (2014)
Animal feed	X			Blanco-Canqui et al. (2013); Blanco-Canqui et al. (2020)
Supporting				
Improved soil structure	X			Blanco-Canqui et al. (2013); Blanco-Canqui et al. (2011); Børresen (1993); Breland (1995); Chen and Weil (2010); Chu et al. (2017); Roarty et al. (2017); Wortman et al. (2012)
Increased presence of earthworms	X			Blanco-Canqui et al. (2011); Roarty et al. (2017)
Input of nutrients for soil organisms	X			Kim et al. (2020); Rosner et al. (2018); Schipanski et al. (2014)
N supply	X			Borgen, Lunde, et al. (2012); Breland (1996b); Finney et al. (2016); Lyngstad and Børresen

				(1996); Mahama et al. (2020); Tonitto et al. (2006); Tzanakakis et al. (2017); White et al. (2017)
N catching effect	X			Breland (1996b); Finney et al. (2016); Lyngstad and Børresen (1996); Norberg and Aronsson (2020); Schipanski et al. (2014); Tonitto et al. (2006); White et al. (2017)
N availability			x	Breland (1996b); Finney et al. (2016)
Regulating				
Weed challenges	X			Finney et al. (2016); Florence et al. (2019); Holmes et al. (2017); Schipanski et al. (2014); Sjursen et al. (2012); Smith et al. (2014)
Weed suppression	X			Dorn et al. (2015); Finney et al. (2016); Schipanski et al. (2014)
Pest suppression	x			Reddy (2017)
Increased pollinators	X			Mallinger et al. (2019)
Wildlife	X			Goławski et al. (2013); Wilcoxen et al. (2018)
Challenge with snails/slugs	X			Douglas and Tooker (2012); Raudenbush et al. (2021)
Carbon sequestration	X	X		Amsili and Kaye (2020); Blanco-Canqui et al. (2013); Blanco-Canqui et al. (2011); Poeplau and Don (2015); Schipanski et al. (2014)
Soil erosion	x			Blanco-Canqui et al. (2013); Schipanski et al. (2014)

Higher leaching of P			X	Blanco-Canqui et al. (2013); Liu et al. (2019); Norberg and Aronsson (2020)
N_2O emission			X	Basche et al. (2014)

Ecosystem services in the categories of provisioning and supporting are all in agreement with literature (see Table 4). Unsurprisingly, instead of having nothing (with a conventional system) versus an added product (with the integration of cover crops), various ecosystem services enhance the bio-physical properties of the farm.

Almost none of the participants mentioned concerns of N availability for cash crops, regardless of the cover crop species used. It is in opposition to studies who showed reduced N availability in the soil in presence of a high C/N ratio cover crops, which limited the main crop growth (Breland, 1996b; Finney et al., 2016). This concern might not have been experienced by farmers on their farm. Also, some of them found alternatives to counter-act on the potential N availability challenge. For example, all farmers displayed careful consideration on how they planned and managed their crop rotation. They used a variety of species both for cover crops and for cash crops (e.g., using legumes as a fertilizer or using old varieties requiring less N) based on their desired outcomes.

In the category of regulating, some participants' opinions and observations clashed with research (i.e., carbon sequestration, P leaching and N_2O emissions).

A minority of farmers refuted the idea that cover crops sequestered carbon to help mitigate climate change. Farmers may lack a sense of closeness compared to other ecosystem services. For instance, if one sees the soil structure improving after using cover crops, it may be easier to claim an improved soil structure, because it is a tangible result. Clay et al. (2020) suggested a similar conclusion where farmers didn't associate their farming practices with environmental issues observed far from their farm and through an extended period of time. Besides, sequestering carbon in the soil isn't easily measurable outside of the research world. Also, it usually takes a number of years before seeing a noticeable change (Acuna and Villamil, 2014;

Blanco-Canqui et al., 2014, as cited in Blanco-Canqui et al., 2015). Additionally, participants might have dissociated the collection of atmospheric CO_2 and its role in the photosynthesis reaction, since they talked about the production of biomass for additional months.

Farmers didn't mention P leaching and N_2O emissions. It might be because participants didn't consider those two factors to have a direct impact on the farm (as opposed to other ecosystem services). Similarly to the carbon sequestration topic, P leaching and N_2O emissions cannot be easily measured outside the realm of academic research. Also, they expressed their worries about climate change, but did not mention the link associated with N_2O emissions. Maybe they didn't know the potential offsets of P leaching and N_2O emissions when using cover crops. Additionally, their positive bias might have restrained them to talk about the disadvantages during the interview. Because the direction of the interview wasn't geared toward these specific topics, they might have overlooked them, as we discussed an array of other related subjects.

Overall, farmers' positive biases might have influenced their answers. They might have embellished the reality, because of their conviction toward the benefits of cover cropping. Moreover, I showed an enthusiastic point of view and I didn't challenge the participants over what they said. Nevertheless, the general agreement between farmers' perceptions and the existing literature show that the participants were trustworthy in their recollection of facts and events about cover crops.

Furthermore, interviewees nuanced their thoughts. Often, they indicated that not everything worked as desired and some seasons were more successful than others. Also, they spoke about various challenges encountered with the use of cover crops, either on a practical and management side or on the economic side.

Since cover crops are multifunctional, the results showed many levels of satisfaction and from time to time, contradicting opinions. I also observed the same contradicting discourse while

researching other scientific work. Cover crops serve different needs, different purposes and the farming system will influence their efficiency.

4.2 RESEARCH QUESTION 2

First, participants' will to change their farming practices due to environmental concerns complies with other research studies (Arbuckle & Roesch-McNally, 2015; Clay et al., 2020; Ranjan et al., 2019).

Farmers mentioned potential ecosystem service benefits, availability of educational and technological resources as motivations to adopt cover crops which is in agreement with literature (Arbuckle & Roesch-McNally, 2015; Ranjan et al., 2019; Roesch-McNally et al., 2018). For example, participants found it important to have available knowledge when they started researching on the topic. When newcomers need guidance, they can turn to extension services. Farmers less likely to try new practices can refer to a local source of information that they know and trust. As a good example, the on-going pilot project Karbon Agro from NLR influenced some farmers interviewed in this thesis. Furthermore, creating a larger network in the spirit of Foreningen for Reduceret Jordbearbejdning i Danmark (the association for reduced tillage in Denmark) would help promote alternative farming practices such as cover crops in Norway.

Additionally, participants reached out to a successful practitioner (e.g., a neighbour using cover crops) and saw a good example, which helped them in their decision process to adopt the practice. Ranjan et al. (2019) found similar results. Moreover, farmers referred to the growing popularity of cover cropping in the country, which compares with a study by Roesch-McNally et al. (2018) where the sense of collectivity played a role in trying new practices.

Furthermore, benefiting from governmental subsidies was seen by participants as a way to share the risk of using cover crops and as potential appeal to non-practitioners, which is in agreement with findings in the literature (Arbuckle & Roesch-McNally, 2015; Ranjan et al., 2019). For instance, practitioners interviewed indicated that increasing governmental subsidies would help

engage more reluctant farmers, even if they didn't use money as a long-lasting incentive. Also, once non-practitioners start using cover crops and seek more information, nowadays they have the opportunity to access more resources (i.e., peers, professionals, research) with valuable experience, as the practice is becoming more popular. Having current practitioners who farm with different models (e.g., different types of production, variety of farm sizes) will be beneficial for those who want concrete examples and for those looking for practical advice.

Second, problems with the availability of seeds or equipment were not experienced by the interviewees, as opposed to other research experiments (Arbuckle & Roesch-McNally, 2015; Clay et al., 2020; O'Connell et al., 2015). Since the participants represented a minority of farmers using cover crops in Norway, it might be the reason why they didn't experience any trouble in buying seeds. Then, with the growing cover crop popularity, a growing demand could be expected in future years. If seed suppliers can't offer the amounts necessary to meet the demand, supplying all farmers could become challenging. Additionally, as explained in the results section (see Stage 3 - Persuasion), when needed, farmers found ways to make up for their lack of equipment.

Moreover, even though they initially spent more money when they started, participants didn't perceive expenses as constraints to start cover cropping, which is in accordance with O'Connell et al. (2015), but somewhat inconsistent with other research studies (Clay et al., 2020; Roesch-McNally et al., 2018; Snapp et al., 2005). Practitioners in this study observed tangible results (e.g., physical soil improvements), which became a return on the initial investment or they rationalized the idea of expected results in the future. Most of them valued cover crops for a desired future and they could disregard the initial costs. As such, this may be the reason why participants didn't see spending money as a barrier.

Furthermore, a common challenge found in the literature and expressed by the participants was the time management to sow and manage cover crops (e.g., taking care of crop residues) (Arbuckle & Roesch-McNally, 2015; O'Connell et al., 2015; Ranjan et al., 2019; Roesch-McNally et

al., 2018; Snapp et al., 2005). Farmers continuously experience time constraints. The management of what can be done to improve a sub-system of a farming system is part of the decision process. Producers have to assess what should prioritize, both for short-term and long-term vision based on their needs and beliefs.

Also, farmers didn't mention worrying about assessing the nitrogen input and disease transferability with legumes cover crops as opposed to findings from Snapp et al. (2005). They didn't experience soil moisture competition between crops, but some of them had difficulties with cover crop weed emergence the following year, as seen in other studies (Arbuckle & Roesch-McNally, 2015; Blanco-Canqui et al., 2015).

Besides, when the Norwegian government introduced cover cropping in the early 2000s, some participants didn't feel concerned about it. They didn't experience problems of soil erosion and nitrate leaching, therefore they believed they didn't need them and a review from Ranjan et al. (2019) explained the same reasoning.

Other research studies investigated participants who were both practitioners and non-practitioners (Arbuckle & Roesch-McNally, 2015; Clay et al., 2020; O'Connell et al., 2015; Ranjan et al., 2019), which could explain the higher number of negative factors found compared to the research I conducted. I purposely chose participants who adopted cover crops (or who were in the process of) because I was interested in learning how those progressive farmers viewed cover cropping and how they experienced adopting them in their farming system to promote a scaling-up of the practice in the country. However, the common results found in the literature and from the participants interviewed show that the data collected were not unfit due to their positive attitude and their title as practitioners.

In this research thesis, I demonstrated how the adoption and the use of cover crops was inefficient by simply handing out money to farmers. Individual factors motivated interviewees to integrate cover crops. From a governmental and policy standpoint, it could be difficult to

encourage more farmers to start using cover crops, but governments and extension services can be catalysts in using their authority to establish the path to follow (Weber & Khademian, 2008).

4.3 RESEARCH QUESTION 3

Farmers and research studies agreed on the benefits provided by cover crops (Arbuckle & Roesch-McNally, 2015; Clay et al., 2020; O'Connell et al., 2015; Snapp et al., 2005). Practitioners and non-practitioners perceived cover crops positively, yet so little area of farmland is under cover crops. Barriers in integrating a new practice is potentially related to the current learning approach prevailing in the agricultural sector, as research studies and participants in this thesis showed their favourable views on the benefits cover crops provide.

Also, Roesch-McNally et al. (2018) found that American farmers felt challenged by using cover crops, they changed their management style and subsequently their farming system. It relates similarly to experiences of participants interviewed about integrating cover crops in their farming system, but one noticeable difference is the timeline of events. In this study interviewees added cover crops after or while changing their system and it could be attributed to a different social context. Farmers evolve among a community, they comply with agricultural policies in place and they obtain knowledge via their local extension services, so different stakeholders may have a different agenda when diffusing desired farming practices.

Furthermore, farmers demonstrated their personal connection when using cover crops and managing their land in a more environmental way. They enjoyed the learning process, but also the outcomes where cover crops changed their soil and their landscape and Roesch-McNally et al. (2018) observed the same results.

Besides, interviewees talked about how cover cropping make sense for their farming system with a long-term mindset and it is conformed with other farmers' views on integrating conservation practices (Kennedy et al., 2016; O'Connell et al., 2015).

A key aspect related to the farming system is the production of livestock. Whether farmers grazed animals on cover crop fields or whether they used cover crops as animal feed, they believed the integration of both makes a better and a stronger farming system. It is supported by literature (Arbuckle & Roesch-McNally, 2015; Gliessman, 2015). Moreover, during the channeling policy era in Norway, many farmers located in the South-East abandoned livestock production because it wasn't economically interesting anymore (Arnoldussen et al., 2014; Lundekvam et al., 2003). However, participants in this research study demonstrated the value in producing both livestock and small grains. For instance, farms with a higher diversity (e.g., types of production, plant species, integration of organic manure) means reducing potential cover crops disadvantages. They also expressed a personal interest in producing both. Ultimately, an additional tool in the toolbox consolidates the farming system if something goes unexpected. Furthermore, the production of both has implications on a larger scale. Borgen, Grønlund, et al. (2012) propose to re-integrate producing livestock and small grains together to reduce CO_2 emissions on a national level in the agricultural sector.

Every participant showed how a system approach positively impacted their success in integrating cover crops. They were the aftermath of modifying their farming system. Research showed that system thinkers are more likely to adopt such practice (Church et al., 2020; Roesch-McNally et al., 2018).

Farmers' accounts of the integration and successful use of cover crops are in agreement with literature. According to the data collected, participants understood well how cover crops play a role in different sub-systems embedded in their farming system and how, in a broader sense, they evolve in a complex environment.

4.4 THE WAY FORWARD

Based on the current trend, where conventional farming predominates in Norway (and the rest of the world), promoting a faster cover crop scale-up will require a different approach to the mainstream method (i.e., client-based, with few collaborations between stakeholders). For example, when the Norwegian government first introduced cover crops in the early 2000s, they shaped the agricultural policy based on research done with a reductionist approach (Lundekvam et al., 2003). The policy presented cover crops as if they dealt with a limited number of ecosystem services (i.e., soil and P erosion and N leaching) (Aronsson et al., 2016) If farmers weren't concerned or engaged by these issues, they had rightfully less interest to adopt cover crops (Ranjan et al., 2019; Weber & Khademian, 2008). The long-term adoption failed, because cover crops are embedded in a farming system, where practitioners have to account for a variety of other components and sub-systems within their farming system. It is in agreement with Huesemann (2001), who declares that the current scientific-technological research paradigm is unlikely to succeed at finding sustainable solutions for environmental issues.

Throughout the research questions investigated, farmers demonstrated their system thinking mindset. They expressed how cover crops play a role and how they influence their farming system with the goal of a more resilient environment to farm and live on. Therefore, logically, to scale-up the use of cover crops, the process should be done in a systemic way, where stakeholders such as practitioners, future-practitioners, advisors, researchers, seed suppliers, governmental instances, work together rather than individually. The collaboration between persons with different backgrounds, providing a different point of view would provide a better overview and better chances to manage wicked problems (Batie, 2008; Weber & Khademian, 2008). Also, having a horizontal learning process rather than a vertical one would give a common goal to all stakeholders (Vaarst et al., 2007; Weber & Khademian, 2008). It would eliminate the unbalanced power dynamic and the outsider feeling that experts can have when they come in and out of the farming system without understanding its intricate components interacting among each other (Amsili & Kaye, 2020; Funtowicz & Ravetz, 1993; Vaarst et al., 2007). Overall, changing the current learning process to a more systemic approach would help tackle wicked problems

such as climate change and soil degradation (Batie, 2008; Bawden et al., 1984; Funtowicz & Ravetz, 1993; Weber & Khademian, 2008).

5. CONCLUSION

For RQ1, farmers interviewed viewed cover crops as a multi-functional tool that fit well into their operation. They also recognised different trade-offs, which impede on other components of their farm, but they considered advantages to outweigh the disadvantages. Additionally, for RQ2, the adoption process was rooted in the duality between individual factors and collective-contextual factors, where both influenced one another. Participants gathered knowledge and resources from their own initiative. However, the current re-emerging popularity of the practice increased those key individual factors. Then, for RQ3, farmers expressed that cover cropping was easily integrated into their farming system. Various factors favoured this; working with cover crops as a dynamic process rather than a static one, having a diversified farming system and having a system thinking mindset. Participants defined the term success with the concept of sustainability, where the purpose of using cover crops is to harvest the fruit of their work in the future with a healthier and a more robust farming system. Therefore, farmers had to accept and manage the uncertainty associated with cover cropping.

Findings in this thesis showed that increasing the use of cover crops did not work on a long-term basis in the early 2000s, because the agricultural policy put in place used a reductionist approach. The goals were too narrow and ill-fitted for a complex system like a farm, but participants showed how cover cropping can be used to improve it. They talked about how cover crops are an integral part of their farming system and the practice is intertwined with all other components. Based on these results, scaling-up the practice suggests taking a different approach to generate knowledge and share it among practitioners and other stakeholders. When dealing with wicked problems such as climate change and soil degradation, a systemic-horizontal learning approach could be a path forward.

REFERENCES

Amsili, J. P., & Kaye, J. P. (2020). Root traits of cover crops and carbon inputs in an organic grain rotation. *Renewable agriculture and food systems, 36*(2), 182-191. https://doi.org/10.1017/S1742170520000216

Arbuckle, J. G., Jr., & Roesch-McNally, G. (2015). Cover crop adoption in Iowa: The role of perceived practice characteristics. *Journal of Soil and Water Conservation, 70*(6), 418-429. https://doi.org/10.2489/jswc.70.6.418

Arnoldussen, A. H., Forbord, M., Grønlund, A., Hillestad, M. E., Mittenzwei, K., Pettersen, I., & Tufte, T. (2014). *Økt matproduksjon på norske arealer*. https://www.agrianalyse.no/getfile.php/13898-1513669775/Dokumenter/Dokumenter%202014/R6%20%C3%98kt%20matproduksjon%20p%C3%A5%20norske%20arealer.pdf

Aronsson, H., Hansen, E. M., Thomsen, I. K., Liu, J., Øgaard, A. F., Känkänen, H., & Ulén, B. (2016). The ability of cover crops to reduce nitrogen and phosphorus losses from arable land in southern Scandinavia and Finland. *Journal of Soil and Water Conservation, 71*(1), 41-55. https://doi.org/10.2489/jswc.71.1.41

Basche, A. D., Miguez, F. E., Kaspar, T. C., & Castellano, M. J. (2014). Do cover crops increase or decrease nitrous oxide emissions? A meta-analysis. *Journal of Soil and Water Conservation 69*(6), 471-482. https://doi.org/10.2489/jswc.69.6.471

Batie, S. S. (2008). Wicked Problems and Applied Economics. *American Journal of Agricultural Economics, 90*(5), 1176-1191. https://doi.org/10.1111/j.1467-8276.2008.01202.x

Bawden, R. J., Macadam, R. D., Packham, R. J., & Valentine, I. (1984). Systems Thinking and Practices in the Education of Agriculturalists. *Agricultural systems, 13*(4), 205-225.

Bernard, H. R. (2017). *Research methods in anthropology: Qualitative and quantitative approaches* (6th ed.). Rowman & Littlefield.

Blanco-Canqui, H., Holman, J. D., Schlegel, A. J., Tatarko, J., & Shaver, T. M. (2013). Replacing Fallow with Cover Crops in a Semiarid Soil: Effects on Soil Properties. *Soil Science Society of America journal, 77*(3), 1026-1034. https://doi.org/10.2136/sssaj2013.01.0006

Blanco-Canqui, H., Mikha, M. M., Presley, D. R., & Claassen, M. M. (2011). Addition of Cover Crops Enhances No-Till Potential for Improving Soil Physical Properties. *Soil Science Society of America journal, 75*(4), 1471-1482. https://doi.org/10.2136/sssaj2010.0430

Blanco-Canqui, H., Shaver, T. M., Lindquist, J. L., Shapiro, C. A., Elmore, R. W., Francis, C. A., & Hergert, G. W. (2015). Cover Crops and Ecosystem Services: Insights from Studies in Temperate Soils. *Agronomy journal, 107*(6), 2449-2474. https://doi.org/10.2134/agronj15.0086

Blanco-Canqui, H., Drewnoski, M. E., MacDonald, J. C., Redfearn, D. D., Parsons, J., Lesoing, G. W., & Williams, T. (2020). Does cover crop grazing damage soils and reduce crop yields? *Agrosystems, geosciences & environment, 3*(1), e20102. https://doi.org/10.1002/agg2.20102

Borgen, S. K., Grønlund, A., Andrén, O., Kätterer, T., Tveito, O. E., Bakken, L. R., & Paustian, K. (2012). CO2 emissions from cropland in Norway estimated by IPCC default and Tier 2 methods. *Greenhouse gas measurement & management, 2*(1), 5-21. https://doi.org/10.1080/20430779.2012.672306

Borgen, S. K., Lunde, H. W., Bakken, L. R., Bleken, M. A., & Breland, T. A. (2012). Nitrogen dynamics in stockless organic clover–grass and cereal rotations. *Nutrient cycling in agroecosystems, 92*(3), 363-378. https://doi.org/10.1007/s10705-012-9495-z

Børresen, T. (1993). The effect on soil physical properties of undersown cover crops in cereal production in southeastern Norway. *Norwegian Journal of Agricultural Sciences, 7*, 369-379.

Bossange, A. V., Knudson, K. M., Shrestha, A., Harben, R., & Mitchell, J. P. (2016). The Potential for Conservation Tillage Adoption in the San Joaquin Valley, California: A Qualitative Study of Farmer Perspectives and Opportunities for Extension. *PLoS One, 11*(12), e0167612. https://doi.org/10.1371/journal.pone.0167612

Breland, T. A. (1994). Measured and predicted mineralization of clover green manure at low temperatures at different depths in two soils. *Plant and soil, 166*(1), 13-20. https://doi.org/10.1007/BF02185476

Breland, T. A. (1995). Green manuring with clover and ryegrass catch crops undersown in spring wheat: effects on soil structure. *Soil use and management, 11*(4), 163-167. https://doi.org/https://doi.org/10.1111/j.1475-2743.1995.tb00950.x

Breland, T. A. (1996a). Green Manuring with Clover and Ryegrass Catch Crops Undersown in Small Grains: Crop Development and Yields. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 46*(1), 30-40. https://doi.org/10.1080/09064719609410944

Breland, T. A. (1996b). Green Manuring with Clover and Ryegrass Catch Crops Undersown in Small Grains: Effects on Soil Mineral Nitrogen in Field and Laboratory Experiments. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 46*(3), 178-185. https://doi.org/10.1080/09064719609413131

Bryman, A. (2012). *Social research methods* (4th ed.). Oxford University Press.

Bye, A. S., Aarstad, P. A., Løvberget, A. I., Rognstad, O., & Storbråten, B. (2020). Jordbruk og miljø 2019. Tilstand og utvikling. *Statistisk sentralbyrå*.

Carlson, S., & Stockwell, R. (2013). Research Priorities for Advancing Adoption of Cover Crops in Agriculture-intensive Regions. *Journal of agriculture, food systems, and community development, 3*(4), 125-129. https://doi.org/10.5304/jafscd.2013.034.017

Checkland, P., & Poulter, J. (2006). *Learning for action : a short definitive account of soft systems methodology and its use for practitioners, teachers, and students*. Wiley.

Chen, G., & Weil, R., R. (2010). Penetration of cover crop roots through compacted soils. *Plant and soil, 331*(1/2), 31-43. https://doi.org/10.1007/s11104-009-0223-7

Chu, M., Jagadamma, S., Walker, F. R., Eash, N. S., Buschermohle, M. J., & Duncan, L. A. (2017). Effect of Multispecies Cover Crop Mixture on Soil Properties and Crop Yield. *Agricultural & environmental letters, 2*(1), 1-5. https://doi.org/10.2134/ael2017.09.0030

Church, S. P., Lu, J., Ranjan, P., Reimer, A. P., & Prokopy, L. S. (2020). The role of systems thinking in cover crop adoption: Implications for conservation communication. *Land use policy, 94*, 104508. https://doi.org/10.1016/j.landusepol.2020.104508

Clay, L., Perkins, K., Motallebi, M., Plastina, A., & Farmaha, B. S. (2020). The Perceived Benefits, Challenges, and Environmental Effects of Cover Crop Implementation in South Carolina. *Agriculture 10*(9), 372. https://doi.org/10.3390/agriculture10090372

Darnhofer, I., Gibbon, D., & Dedieu, B. (2012). *Farming Systems Research into the 21st Century: The New Dynamic* (1st ed.). Springer.

Dorn, B., Jossi, W., & van der Heijden, M. G. A. (2015). Weed suppression by cover crops: comparative on-farm experiments under integrated and organic conservation tillage. *Weed Research, 55*(6), 586-597. https://doi.org/10.1111/wre.12175

Douglas, M. R., & Tooker, J. F. (2012). Slug (Mollusca: Agriolimacidae, Arionidae) Ecology and Management in No-Till Field Crops, With an Emphasis on the mid-Atlantic Region. *Journal of integrated pest management, 3*(1), C1-C9. https://doi.org/10.1603/IPM11023

FAO. (2014). *Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks*. http://www.fao.org/3/i3671e/i3671e.pdf

Finney, D. M., White, C. M., & Kaye, J. P. (2016). Biomass Production and Carbon/Nitrogen Ratio Influence Ecosystem Services from Cover Crop Mixtures. *Agronomy journal, 108*(1), 39-52. https://doi.org/10.2134/agronj15.0182

Florence, A. M., Higley, L. G., Drijber, R. A., Francis, C. A., & Lindquist, J. L. (2019). Cover crop mixture diversity, biomass productivity, weed suppression, and stability. *PLoS One, 14*(3), e0206195. https://doi.org/10.1371/journal.pone.0206195

Fuglestad, E. M., & Palmer, E. (2019). Land ownership and distribution: Modeling the relationship to property law in the Norwegian case. *Journal of rural studies, 72*, 11-22. https://doi.org/10.1016/j.jrurstud.2019.09.009

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the Post-Normal Age. *Futures 25*(7), 739-755. https://doi.org/10.1016/0016-3287(93)90022-L

Giller, K. E. (2013). Can We Define the Term 'Farming Systems'? A Question of Scale. *Outlook on agriculture, 42*(3), 149-153. https://doi.org/10.5367/oa.2013.0139

Gliessman, S. R. (2015). *Agroecology: The Ecology of Sustainable Food Systems* (3rd ed.). CRC Press.

Goławski, A., Kasprzykowski, Z., Jobda, M., & Duer, I. (2013). The importance of winter catch crops compared with other farmland habitats to birds wintering in Poland. *Pol. J. Ecol, 61*(2), 357-364.

Goodale, M. R. G., & Sky, P. K. (2001). A comparative study of land tenure, property boundaries, and dispute resolution: case studies from Bolivia and Norway. *Journal of rural studies, 17*(2), 183-200. https://doi.org/10.1016/S0743-0167(00)00041-3

Graneheim, U. H., & Lundman, B. (2004). Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. *Nurse Education Today, 24*(2), 105-112. https://doi.org/10.1016/j.nedt.2003.10.001

Groff, S. (2015). The past, present, and future of the cover crop industry. *Journal of Soil and Water Conservation, 70*(6), 130A-133A. https://doi.org/10.2489/jswc.70.6.130A

Holmes, A. A., Thompson, A. A., & Wortman, S. E. (2017). Species-Specific Contributions to Productivity and Weed Suppression in Cover Crop Mixtures. *Agronomy journal, 109*(6), 2808-2819. https://doi.org/10.2134/agronj2017.06.0309

Huesemann, M. H. (2001). Can pollution problems be effectively solved by environmental science and technology? An analysis of critical limitations. *Ecological economics, 37*(2), 271-287. https://doi.org/10.1016/S0921-8009(00)00283-4

IPCC. (2020). *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystem*. https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

Kennedy, S. M., Burbach, M. E., & Sliwinski, M. S. (2016). Sustainable Grassland Management: An Exploratory Study of Progressive Ranchers in Nebraska. *Sustainable Agriculture Research, 5*(2), 103-113. https://doi.org/10.5539/sar.v5n2p103

Kim, N., Zabaloy, M. C., Guan, K., & Villamil, M. B. (2020). Do cover crops benefit soil microbiome? A meta-analysis of current research. *Soil biology & biochemistry, 142*, 107701. https://doi.org/10.1016/j.soilbio.2019.107701

Knutsen, H. (2020). Norwegian Agriculture Status and Trends 2019. *NIBIO POP, 6*(8). http://hdl.handle.net/11250/2643268

Kvale, S. (1996). *Interviews : an introduction to qualitative research interviewing*. Sage.

Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability, 7*(5), 5875-5895. https://doi.org/10.3390/su7055875

Liu, J., Macrae, M. L., Elliott, J. A., Baulch, H. M., Wilson, H. F., & Kleinman, P. J. (2019). Impacts of cover crops and crop residues on phosphorus losses in cold climates: A review. *Journal of Environmental Quality, 48*(4), 850-868.

Lundekvam, H. E., Romstad, E., & Øygarden, L. (2003). Agricultural policies in Norway and effects on soil erosion. *Environmental science & policy, 6*(1), 57-67. https://doi.org/10.1016/S1462-9011(02)00118-1

Lyngstad, I., & Børresen, T. (1996). Effects of undersown cover crops on yields and soil mineral nitrogen in cereal production in southeast Norway. *Norwegian Journal of Agricultural Sciences 10*(1), 55-70.

Mahama, G. Y., Prasad, P. V. V., Roozeboom, K. L., Nippert, J. B., & Rice, C. W. (2020). Reduction of Nitrogen Fertilizer Requirements and Nitrous Oxide Emissions Using Legume Cover Crops in a No-Tillage Sorghum Production System. *Sustainability 12*(11), 4403. https://doi.org/10.3390/su12114403

Mallinger, R. E., Franco, J. G., Prischmann-Voldseth, D. A., & Prasifka, J. R. (2019). Annual cover crops for managed and wild bees: Optimal plant mixtures depend on pollinator enhancement goals.

Agriculture, ecosystems & environment, 273, 107-116. https://doi.org/10.1016/j.agee.2018.12.006

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being* (Vol. 5). Island press United States of America. http://www.bioquest.org/wp-content/blogs.dir/files/2009/06/ecosystems-and-health.pdf

NIBIO. (2019). *Jord- og Plantekultur 2019. Forsøk i korn, olje- og proteinvekster, engfrøavl og potet 2018*. http://hdl.handle.net/11250/2597429

NIBIO. (2020). *Totalkalkylen for jordbruket. Jordbrukets totalregnskap 2018 og 2019. Budsjett 2020*. https://hdl.handle.net/11250/2682380

Norberg, L., & Aronsson, H. (2020). Effects of cover crops sown in autumn on N and P leaching. *Soil use and management, 36*(2), 200-211. https://doi.org/10.1111/sum.12565

O'Connell, S., Grossman, J. M., Hoyt, G. D., Shi, W., Bowen, S., Marticorena, D. C., Fager, K. L., & Creamer, N. G. (2015). A survey of cover crop practices and perceptions of sustainable farmers in North Carolina and the surrounding region. *Renewable agriculture and food systems, 30*(6), 550-562. https://doi.org/10.1017/S1742170514000398

Patton, M. Q. (2002). Two Decades of Developments in Qualitative Inquiry: A Personal, Experiential Perspective. *Qualitative Social Work, 1*(3), 261-283. https://doi.org/10.1177/1473325002001003636

Poeplau, C., Aronsson, H., Myrbeck, Å., & Kätterer, T. (2015). Effect of perennial ryegrass cover crop on soil organic carbon stocks in southern Sweden. *Geoderma Regional, 4*, 126-133. https://doi.org/10.1016/j.geodrs.2015.01.004

Poeplau, C., & Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. *Agriculture, ecosystems & environment, 200*, 33-41. https://doi.org/10.1016/j.agee.2014.10.024

Ranjan, P., Church, S. P., Floress, K., & Prokopy, L. S. (2019). Synthesizing Conservation Motivations and Barriers: What Have We Learned from Qualitative Studies of Farmers' Behaviors in the United States? *Society & natural resources, 32*(11), 1171-1199. https://doi.org/10.1080/08941920.2019.1648710

Raudenbush, A. L., Pekarcik, A. J., Haden, V. R., & Tilmon, K. J. (2021). Evaluation of Slug Refuge Traps in a Soybean Reduced-Tillage Cover Crop System. *Insects, 12*(1), 62. https://doi.org/10.3390/insects12010062

Reddy, P. P. (2017). *Agro-ecological Approaches to Pest Management for Sustainable Agriculture* (1st ed.). Springer Singapore. https://doi.org/https://doi.org/10.1007/978-981-10-4325-3

Roarty, S., Hackett, R. A., & Schmidt, O. (2017). Earthworm populations in twelve cover crop and weed management combinations. *Applied Soil Ecology, 114*, 142-151. https://doi.org/10.1016/j.apsoil.2017.02.001

Roesch-McNally, G. E., Basche, A. D., Arbuckle, J. G., Tyndall, J. C., Miguez, F. E., Bowman, T., & Clay, R. (2018). The trouble with cover crops: Farmers' experiences with overcoming barriers to adoption. *Renewable agriculture and food systems, 33*(4), 322-333. https://doi.org/10.1017/S1742170517000096

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Rosner, K., Bodner, G., Hage-Ahmed, K., & Steinkellner, S. (2018). Long-term Soil Tillage and Cover Cropping Affected Arbuscular Mycorrhizal Fungi, Nutrient Concentrations, and Yield in Sunflower. *Agronomy journal, 110*(6), 2664-2672. https://doi.org/10.2134/agronj2018.03.0177

Schipanski, M. E., Barbercheck, M., Douglas, M. R., Finney, D. M., Haider, K., Kaye, J. P., Kemanian, A. R., Mortensen, D. A., Ryan, M. R., Tooker, J., & White, C. (2014). A framework for evaluating ecosystem services provided by cover crops in agroecosystems. *Agricultural systems, 125*, 12-22. https://doi.org/10.1016/j.agsy.2013.11.004

Sjursen, H., Brandsæter, L. O., & Netland, J. (2012). Effects of repeated clover undersowing, green manure ley and weed harrowing on weeds and yields in organic cereals. *Acta agriculturae Scandinavica. Section B, Soil and plant science, 62*(2), 138-150. https://doi.org/10.1080/09064710.2011.584550

Smith, R. G., Atwood, L. W., & Warren, N. D. (2014). Increased Productivity of a Cover Crop Mixture is Not Associated with Enhanced Agroecosystem Services. *PLoS One, 9*(5), e97351. https://doi.org/10.1371/journal.pone.0097351

Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., Nyiraneza, J., & O'Neil, K. (2005). Evaluating Cover Crops for Benefits, Costs and Performance within Cropping System Niches. *Agronomy journal, 97*(1), 322-332. https://doi.org/10.2134/agronj2005.0322a

Sustainable Food Trust. (2015). *Soil Degradation: A Major Threat to Humanity*. http://sustainablefoodtrust.org/wp-content/uploads/2013/04/Soil-degradation.pdf

Tonitto, C., David, M. B., & Drinkwater, L. E. (2006). Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. *Agriculture, ecosystems & environment, 112*(1), 58-72. https://doi.org/10.1016/j.agee.2005.07.003

Tzanakakis, V., Sturite, I., & Dörsch, P. (2017). Biological nitrogen fixation and transfer in a high latitude grass-clover grassland under different management practices. *Plant and soil, 421*(1), 107-122. https://doi.org/10.1007/s11104-017-3435-2

UNCCD. (2014). *Desertification the Invisible Frontline* https://www.unccd.int/sites/default/files/documents/12112014_Invisible%20frontline_ENG.pdf

Vaarst, M., Nissen, T. B., Østergaard, S., Klaas, I. C., Bennedsgaard, T. W., & Christensen, J. (2007). Danish Stable Schools for Experiential Common Learning in Groups of Organic Dairy Farmers. *Journal of Dairy Science, 90*(5), 2543-2554. https://doi.org/10.3168/jds.2006-607

Weber, E. P., & Khademian, A. M. (2008). Wicked Problems, Knowledge Challenges, and Collaborative Capacity Builders in Network Settings. *Public administration review, 68*(2), 334-349. https://doi.org/10.1111/j.1540-6210.2007.00866.x

White, C. M., DuPont, S. T., Hautau, M., Hartman, D., Finney, D. M., Bradley, B., LaChance, J. C., & Kaye, J. P. (2017). Managing the trade off between nitrogen supply and retention with cover crop mixtures. *Agriculture, ecosystems & environment, 237*, 121-133. https://doi.org/10.1016/j.agee.2016.12.016

Wilcoxen, C. A., Walk, J. W., & Ward, M. P. (2018). Use of cover crop fields by migratory and resident birds. *Agriculture, ecosystems & environment, 252*, 42-50. https://doi.org/10.1016/j.agee.2017.09.039

Wortman, S. E., Francis, C. A., & Lindquist, J. L. (2012). Cover Crop Mixtures for the Western Corn Belt: Opportunities for Increased Productivity and Stability. *Agronomy journal, 104*(3), 699-705. https://doi.org/10.2134/agronj2011.0422

Zahl-Thanem, A., Fuglestad, E. M., & Vik, J. (2018). *Trender i norsk landbruk 2018. Et landbruk i endring*. https://ruralis.no/wp-content/uploads/2018/10/r7_18-trender-i-norsk-landbruk-2018--et-landbruk-i-endring-a--zahl-thanem-e-m--fuglestad-og-j--vik-.pdf

APPENDIX I – CURRENT SCOPE OF NORWEGIAN AGRICULTURE

Farming in Norway is a family affair. The organisational structure is based on "odelsrett" (allodial right) or family privilege, where the farms in the country are handed within the immediate and extended family (Goodale & Sky, 2001). It is a right as old as the country stating that the eldest child has the priority to buy the agricultural property following the parents' retirement (previously discriminatory toward women, the law changed in 1974) (Fuglestad & Palmer, 2019; Goodale & Sky, 2001). From the survey *Trender i norsk landbruk 2018. Et landbruk i endring* (Zahl-Thanem et al., 2018), assessing the current trends in agriculture in Norway, the majority (72%) of farmers took over the farm based on "odelsrett". Additionally, the current Norwegian agricultural landscape is a result of the natural environmental conditions.

In its native state, livestock production suits the country better, as the weather and sunlight conditions make it difficult to grow crops (Arnoldussen et al., 2014). For example, compared to the majority of other European countries, sugar crops cannot be produced in Norway (Knutsen, 2020). From the annual statistical report *Jordbruk og miljø 2019. Tilstand og utvikling* (agriculture and environment) (Bye et al., 2020), in 2018, 3,2% (0,328 million of hectares) represented the total area cultivated for agriculture in Norway. The report mentions that the principal agricultural sectors were cropland like cereals and oilseeds, cattle, sheep and smaller productions such as horticulture and various grazing livestock. Additionally, 28,7% represented the total area of cereals and oilseeds production of the total agricultural land in use (Bye et al., 2020). The vast majority (80%) of cereal crops was aimed for animal feed (Bye et al., 2020; Knutsen, 2020). Furthermore, the most common cereal crops grown in the country were oat, rye, barley, wheat, oilseeds and peas (NIBIO, 2020).

Overall, the agricultural sector represented a very small portion of the national gross product (0,6%) and the employment level (1,7%), whereas most of the food produced was intended for national sales (Knutsen, 2020). Furthermore, the Norwegian agricultural land use decreased by 5% between 1999 and 2018 and the number of holdings declined by 44% for the same period (representing a total of 40 000 holdings in 2018) (Bye et al., 2020).

APPENDIX II – INTERVIEW GUIDE

Category	Interview question	Follow-up question
Background info	How old are you?	
	Are you a part-farmer or a full-time farmer?	
	Did you attend any agricultural school either at the high school level or higher education level?	
	How long have you been a farmer?	
	What made you decide to become a farmer/take over the family farm?	
	Where is your farm located?	
	Can you describe your farm?	
		Organic or conventional
		Number of decare (breakdown of the land)
		Main farming activity (ies) on the farm
		Other activities not related to farming
		Main cash crops/market to sell cash crops
		Main cover crops species used
		Autumn/Spring cover crops
		Methods of sowing
		Termination methods
Implementation phase	If you remember, can you tell me how you discovered cover cropping?	
	What impacted your decision to start cover cropping?	What was the turning point to take the decision to start cover cropping on your farm?
	What was your first impression (feeling) about this farming practice?	
	How did you build your knowledge about cover crops?	
	How long did it take you from learning about cover crops to start using them on the farm?	What were the steps you took to make this change, and what information was needed?
	Tell me about the process to implement cover crops during the first season you used them?	Was there any economic investment (equipment) to do before starting using cover crops?
		Did you do a trial season?
Current use	Today, what is the decision process when it comes to choosing the type of cover crops to be used?	How did you develop this process of making a decision?

		What decisions have you made about diversifying your cover crop species, and why?
	What are the most critical steps when using cover crops? (If a farmer asks you, what are the..)	
	If you have any questions today, where are you asking them?	
System inquiry	Can you tell me what sort of fertilizers you are currently using?	
	Have the use of cover crops impacted your use of fertilizers on your cash crops?	How would you describe the interaction between cover crops and fertilizers for your cash crops (natural or synthetic or both)?
	Can you describe what soil health means to you?	
	How would you describe the overall health of your fields?	Has it changed since you started using cover crops?
	Tell me about the effects of cover crops (if there are any) on your cash crops?	What adjustments have you made to minimize negative impacts and maximize benefits of cover crops?
	(if the farm produces any) How would you describe the interaction between the livestock production and the cover crop production?	Do you have potential for grazing cover crops? Would cover crop use influence your decision to add grazing ruminants to your system?
	What are cover crops being used for once they are terminated?	
	How would you describe the financial impact of using cover crops?	Would you continue using cover crops if the government was reducing or stopping the subsidies program?
	How are you managing the risks associated with using cover crops?	What would you say to a farmer who would be hesitant to start using cover crops about the risks that is associated with using them?
Future use	In the coming years how are you seeing your use of cover crops evolving on your farm?	
	Why do you think it is important to continue using cover crops in the future?	
	What would you like to learn more about cover crops?	(i.e., species, methods of sowing, termination methods, effect on the soil, etc.)
	Anything else to share about cover crops?	Do you know any other farmers using CCs?

APPENDIX III – SAMPLE OF CODING

Meaning unit	Condensed meaning unit (Description close to the text)	Code (Condensed meaning unit Interpretation of the underlying meaning)	Sub-category	Category	RQ
I've also add a lot of other machines you know when you are experimenting and so on, but I'm not sure if I get to use of it again, but this can be sold of course.	I've also purchased other machines to experiment and if I don't use them I can sell them after.	Purchased other machines to experiment	Bought equipment	Equipment	FS
I interseeded the, the clover and the grass and different types of grasses and and two types, the red clover and the white clover and then I harvested the oat in the normal way, but the undercover, the the, the under-seeded, the seeds.. They started to establish, to grow quite good in the autumn and then I cut it and let it stay and, so it was, it was quite okay to do it like this.	They started to establish, to grow quite good in the autumn, so it was, it was quite okay to do it like this.	Grew quite good in the autumn	Good first experience	Decision	KF
Yeah my mother and father has used cover crops for, yeah since 2000 with white clover 15% and then ryegrass... So, we used cover crops for like 20 years at this farm...	My parents have used CCs (rygrass-clover mix) for 20 yrs on the farm.	My parents used CCs for 20 yrs	CCs as a status quo	Knowledge	KF
And then the last couple of years, I've tried some other combinations of cover crops as well, not just white clover and ryegrass yeah.	And then the last couple of years, I've tried some other combinations of cover crops as well, not just white clover and ryegrass yeah.	Last couple of years, tried different combination of CCs	Work in progress		FS
when I discovered that you can have different mixes like nitrogen and soil, to loosen up the soil and everything it becomes really fascinating..	when I discovered that you can have different mixes like nitrogen and soil, to loosen up the soil and everything it becomes really fascinating..	Became fascinating when discovered the different uses of mixes	Positive attitude	Personnal connection to CCs	FS
Yeah, I think so in the beginning yes, I think so yeah, but now it's, we bought a new seed drill in 2018, which allows us to fetch in between the rows of the grains and then it's given us a possibility to drill cover crops in different ways, so now we tried with a bit different varieties and mix	We bought a new seed drill and it's given us a possibility to drill CCs in different ways.	Bought a seed drill, to drill CCs in different ways	Bought equipment	Equipment	FS
Yeah it was a lot from my father and I just used their mix for the first year and then I, I did some, I put my fields for this, for a scientist at NIBIO, so I talked to him a bit about it and also the Norwegian farmer counsel (NLR).. Talked to them a lot and and farmers around, like neighbors and yeah, talked to	A lot from my father, scientist from NIBIO, NLR and neighbor farmers.	My father, NIBIO, NLR and neighbor farmers	Seeking knowledge	Persuasion	AD
The cover crops has really here in Norway, if I can say, kicked-off, started the last couple of three four years maybe.. So, the Felleskjøpet and other shops have started to sell cover crop mixes yeah. Mmm yeah.	The CCs in Norway have kicked-off, started the last couple of 3-4 yrs, so Felleskjøpet and other shops have started to sell cover crop mixes.	CCs in Norwat have kicked-off in the last 3-4 yrs	Growing popularity in Norway	Other factors	KF
	The CCs in Norway have kicked-off, started the last couple of 3-4 yrs, so Felleskjøpet and other shops have started to sell cover crop mixes.	Suppliers started to sell CCs mixes	Growing popularity in Norway	Other factors	KF
we're interested and curious on this Karbon agriculture which I've been reading from the NLR, Norwegian you know this yeah.. And I read a lot of English articles and also some Danish research that were published	We're interested and curious about this Karbon agriculture from NLR and I read a lot of English and Danish publications.	Interested and curious about Karbon project	Positive attitude	Personnal connection to CCs	FS
	We took a chance and made a full-scale test and it helps to have the grant covering the cost of the seeds.	Helps to have grant covering the seeds	Subsidies pay for the cost of the seeds	Other	AD
yeah so do you you think it was euh the establishment of the cover crops was well done eum, are you satisfied with how much you've achieved? - Yes yes	do you you think it was euh the establishment of the cover crops was well done eum, are you satisfied with how much you've achieved? - Yes yes	Satisfied with establishment first season	Good first experience	Decision	KF
It works very well by the way and it's a general discussion you know in the newspapers and I also have two teenage daughters that is pushing me and my wife to farm more environmental friendly, so it it's a number of impulses that kind of led us to, to make this test..	it's a general discussion you know in the newspapers and I also have two teenage daughters that is pushing me and my wife to farm more environmental friendly, so it it's a number of impulses that kind of led us to, to make this test	General discussion about farming more environmental friendly	Environmental awareness	Knowledge	KF

* Green boxes indicate two different ideas or explanations, which are further broken down.

** The column to the right refers the research question (RQ):

- AD for RQ1
- KF for RQ2
- FS for RQ3

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway