Assessing the Adoption of Soil Health Beneficial Management Practices by Ontario Farmers

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Ananka Shah

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ABSTRACT

ASSESSING THE ADOPTION OF SOIL HEALTH BENEFICIAL MANAGEMENT PRACTICES BY ONTARIO FARMERS

Ananka Shah
University of Guelph, 2022

Advisor:
Dr. Alfons Weersink

Healthy soils are fundamental to building prosperous and resilient farms, to reduce GHG emissions and enhance overall environmental impacts from agriculture. Drawing from a survey of farmers (n = 247), the variation in adoption for 6 soil health BMPs: cover crops, crop rotations, no till, soil testing, conservation buffers and organic amendments is explored. The purpose of this study is to examine and analyze farmer adoption of and complementarity between soil BMPs using Ontario as a case study. Through univariate and multivariate models, the linkages between adoption of different conservation practices and the socioeconomic factors that affect the likelihood of adopting these practices are estimated. Furthermore, the motivations and barriers driving various farmer segments to adopt or not adopt these practices are analysed. The results can help guide policy and outreach efforts to promote the wider adoption of soil health practices amongst farmers.

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1 Introduction

1.1 Background

A key challenge of the 21st century is to feed a growing global population while combating climate change and environmental degradation (Bowles et al., 2020). Agroecosystems are increasingly threatened by extreme weather events and changing climates (Gaudin et al., 2015). Climate change impacts such as heavy rainfall, drought or changing pest conditions directly affect productivity which leads to social and economic repercussions that impact livelihoods. Thus, in order to ensure food security, and sustain the economic and social capacity of agricultural systems, action is urgently needed to build more resilient food systems.

Healthy soils are a key element in enhancing agricultural production, environmental sustainability, and food system resilience (Rejesus et al., 2021). The USDA Natural Resources Conservation Service (NRCS) defines soil health as “the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans” (Pankhurst et al., 1997). Well- managed soils capture and store soil organic carbon (SOC) through a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool (Ontl and Schulte, 2012). Healthy soil also stores and supplies nutrients, thus reducing the need for farm inputs, such as mineral fertilizers, whose production and volatilization contribute to greenhouse gas (GHG) emissions (CRSC, 2020). Studies suggest soil may be the most valuable single natural commodity, worth nearly US$4 trillion in 2012 alone (Amundson et al., 2015).

No matter how it is defined, soil health is vital to long-term, sustainable crop production in Canada. Soil delivers water and nutrients to crops and physically supports plants. It is one of the greatest reservoirs of biodiversity (Wallet al., 2010). It provides an environment for bacteria, fungi, nematodes and other biota, that are responsible for a myriad of beneficial functions. The abundance of these living organisms contributes to a healthy soil which in turn regulates water (water flow and retention), sustains soil biodiversity (plant and animal life), filters and buffers potential pollutants, retains and cycles nutrients (carbon, nitrogen, phosphorus and other nutrients) and provides physical stability and support.

Once degraded, it takes an extensive amount of time (up to 100 years) to rebuild an inch of topsoil. Canadian soils show promising results as soil cover has been increasing, though there is still much action needed to be undertaken. The national average increased from 268.5 soil cover days in 1981, to an average of 288.8 soil cover days in 2011, with the largest increases occurring in the Prairie Provinces especially Saskatchewan (Huffmand & Jiu, 2016). This improvement can mainly be attributed to a reduction in summerfallow – a practice of leaving fields bare, along with a shift to reduced tillage and no-till practices in this region. OMAFFRA (2021) reported that 68 percent of Ontario's farmland is estimated to be in an unsustainable erosion risk category, and 53 percent of Ontario's cropland is estimated to have low or very low soil cover, covered less than 275 days or 75 per cent of the year. Data from 2011 indicated that soil cover days for southern Ontario were classified as very low (less than 250 days); while Central Ontario was classified as having low soil cover days (between 250 and 275) and Northern Ontario had moderate soil cover (275-299 days). Soil health best management practices (BMPs) are a solution to regenerate soils.

Employing agricultural beneficial management practices (BMPs) can potentially mitigate the negative impacts of agriculture on the environment and promote the conservation of soil and water health without forgoing productivity relative to existing cropping practices. Natural climate solutions, including diversified crop rotation, conservation tillage, and restoration (conservation buffers), can significantly reduce net annual GHG emissions for Canada (Drever et al. 2021) and the United States (Fagione et al. 2021) while also offering other environmental co-benefits. For example, crop rotations with cover crops can sequester carbon and conservation tillage, reduce soil erosion, prevent nutrient leaching, and provide habitat for beneficial insects and pollinators (Sharma et al., 2018; Carlisle, 2016). The ability of BMPs to improve soil health specifically has been recently assessed by Groupe Agéco (2020). The extent to which any of the BMPs can mitigate GHGs and improve soil health varies depending on several factors such as geography and the BMP selected (Drever et al. 2021).

These practices—such as cover cropping, crop rotation, and conservation tillage—potentially provide synergistic environmental and economic benefits, both on and beyond the farms where these practices are adopted. For example, cover crops—non-harvested crops planted in the offseason to improve soil health—offer large-scale environmental benefits by sequestering carbon, reducing soil erosion, preventing nutrient leaching, and providing habitat for beneficial insects and pollinators, but they can also benefit farmers by boosting soil productivity and subsequent crop yields, suppressing weeds, reducing fertilizer needs, and improving nutrient cycling (Bergtold et al., 2012; Carlisle, 2016). Similarly, conservation tillage—any method of tillage that leaves residue from the previous crop on the field—reduces erosion, while also boosting soil productivity and often lowering farmers' labour and diesel costs (Fuglie 1999; Uri 1999). Given the potential financial and sustainability benefits of BMPs, governments are seeking to policies and programs that promote healthy soil practices and mobilize capacity and awareness around their adoption and implementation (Pretty, 2008; Van der werf & Petit, 2002). However, enhancing adoption requires understanding the perceived benefits and limitations of the BMPs (Shah et al., 2022).

In addition to enhancing environmental quality including soil health, BMPs can increase profit and are thus often promoted as win-win technologies. Yanni et al. (2021) provide a comprehensive review of the environmental (public) and economic (private) effects of 10 BMPs for mitigating soil related GHG emissions for Ontario corn farms. Seven of the tent are win-win but the extent of the gains varies depending upon the geographic location and financial situation of the farmer. Another factor is the time frame of analysis. Rejesus et al. (2021) find in their review that often the short-term, private benefits of BMPs are less than the implementation cost and note the lack of long-term economic studies on the relationships between BMPs, soil health indicators, and economic outcomes. Examples of such studies are Chahal et al. (2021), Janovicek et al. (2021) and Congreves et al. (2017) who determine that the long-run use of cover crops in a diversified crop rotation with reduced tillage in Ontario enhances soil health and improve both the average and resiliency of yields. This was also seen in the United States, where Bowles et al., (2020) found that long term diverse crop rotations improved not only the yields of corn, but also their resiliency to extreme weather events.

1.2 Economic Problem

The potential environmental benefits associated with BMPs have prompted governments to develop policies and programs that promote their adoption and implementation (Norris et al, 2020). However, enhancing adoption requires understanding the current level of uptake and the perceived benefits and limitations of the BMPs. Utility maximization forms the basis upon which a farmer chooses to adopt a certain practice over another. Most models are at the micro scale, where researchers often assume individual farmers are economically rational and maximize utility (Liu et al., 2018). A farmer presumably compares all potential benefits from alternative practices and then makes a decision about adoption. Since environmental benefits accrue to the public while economic profits accrue only to the farmer, the financial implications of BMP adoption decisions may largely influence the adoption decision. This helps explain why conservation practices are most often under-provided. Technologies that are deemed to have high relative advantages will be preferred over those that supersede them. Moreover, adoption is often dependent on the ease of testing and trialing before full implementation (Weersink and Fulton, 2020). When farmers adopt more than would be economically rational, other motivations besides profits need to be considered (Weersink and Fulton, 2020). Thus, understanding the farm level economic drivers that influence adoption is key. Farmers may not respond in predictable and rational ways, so using economics to understand their adoption behaviour provides insights to trends and tendencies that may be observed across farmer populations and can be useful in assessing which BMPs have potential for wide adoption.

Non-adoption or low adoption of a number of practices is readily explicable in terms of their failure to provide a relative advantage (particularly in economic terms) or a range of difficulties that landholders may have in trialing them. Moreover, heterogeneity in farm, farmer and BMP characteristics may drive the gap in adoption further. Other barriers to implementation involve the awareness and access to information. The lack of understanding regarding how to optimize the practice, the lack of regionally specific information on the practice, the costs associated with implementation, and the lack of time and labour are also obstacles to adoption.

People, places and specific situations determine the economic outcomes of BMP adoption (Pannell, 2013). This can be attributed to the spatial heterogeneity in the efficacy of BMPs depending on farm location and characteristics (Pannell, 2013; Liu et al., 2018, Prokopy et al., 2019, Carlisle, 2016). To determine how certain BMPs or groups of BMPs will perform, the farm and farmer context needs to be understood first. Every farmer has their own unique combination of demographic factors, personality, previous experiences, routines, and goals, as well as economic, cultural, family influences and perceptions of soil health (Ghazalian et al., 2009). The differences also lead to variations in the perception on the level of soil health and the role technologies can play in altering its quality (Mann 2021). This heterogeneity in farmer characteristics has led to inconsistencies in determining the factors that influence the adoption of BMPs (Prokopy et al., 2019; Baumgart-Getz et al., 2012; Knowler & Bradshaw, 2007). Heterogeneity may also operate within a farm where soil types may result in farmers choosing to adopt BMPs on some parts of their farm but not others (e.g. Baudron et al., 2012) and different cropping systems suiting some crops and not others (e.g. Erkossa et al., 2006). There may also be heterogeneity in how adoption proceeds. In some cases, it may involve step-wise adoption, starting with the component of a 'package' that provides the best returns to the farmer's limiting resources rather than adoption of the full BMP package (Pannell et al.,2013).

Identifying and understanding the key factors influencing adoption of soil health BMPs among farmers is critical for two reasons. First, it is necessary to develop the right tools to better communicate to farmers the effectiveness and necessity of adopting soil health BMPs. Second, once farmers decide to move forward with the adoption of BMPs to improve soil health, it is essential to design appropriate policies to support their successful implementation (Napier et al., 2000). To encourage wider adoption of BMPs at the farm level, policy proposals need to build a strong business case that provides the right support and signals (De Laporte et al., 2022).

Across Canada and worldwide, a number of public policy approaches are utilized to encourage and incentivize system improvements and farmer adoption of diverse practices. These often include assessment and planning tools such as the Environmental Farm Plan, grants to farmers, tools to manage risks, cost-share and offset programs, peer-to-peer learning and workshops. Encouraging sustainable agriculture is a shared responsibility between federal and provincial-territorial governments. Currently, one of the major federal-provincial programs that funds and regulates agriculture and environment is the Canadian Agricultural Policy (CAP). This initiative has been running since 2018 and has been funded with $3 billion over five years. The CAP comprises federal activities and programs, as well as cost-shared programs between the federal, provincial and territorial governments. In addition, producers continue to have access to a suite of Business Risk Management (BRM) programs designed to help them manage specific business risks on the farm and stabilize income. Another the major federal-provincial program introduced by Agri & Agri-Food Canada is the Agricultural Climate Solutions (ACS). This multi-stream program aims to help develop and implement farming practices to tackle climate change. One component is the Living Labs, a $185 million, 10-year program, which is an integrated approach to agricultural innovation that brings farmers, scientists, and other partners together to co-develop, test, and monitor new BMPs and technologies in a real-life context.

Outside of the federal and provincial context, there are also other organizations such as the Greenbelt Foundation and Farmers for Climate Solutions who are working at the forefront of agricultural sustainability and resiliency. Farmers for Climate Solutions (FCS) have assembled a range of policy recommendations for the next Agricultural Policy Framework (a five year funding agreement that will govern agriculture spending across Canada until 2028). Through a farmer led task force of experts, FCS have identified the most cost-effective ways to reduce GHG emissions rapidly through scaling up the adoption of climate friendly BMPs. The Greenbelt Foundation has emphasized the importance of soil health and the need for increased adoption of management practices through working alongside farmers, academics, government and other sectors to inform and develop programs. In 2020, the foundation released a report geared towards building an understanding of how and why Canadian farmers adopt soil health practices. Most recently, they developed a report advocating for soil health through building a practical business case. This no only helped encourage and influence decisions, but also provided critical information for Ontario farmers on how to manage risks associated with various practices.

Despite the policies, programs and research in place, Canada’s resources devoted to agri-environmental incentives remain low compared to United States and Europe (Groupe AGECO, 2020). Canadian farmers are willing to adopt sustainable practices, however, environmental initiatives are consistently overcrowded with demand greatly outstripping available financing. The insights provided from this study can offer a foundation for rethinking some of Canada’s agricultural and climate change policies and programs. Designing region-specific policies and programs that offer long-term support, rather than one-off interventions, is likely to be more effective in supporting farmers through the adoption process.

1.3 Research Problem

In Canada, most research focuses on particular areas or watersheds. Ghazalian et al. (2009) discovered, for instance, that farmers with greater cultivated fields or larger animal production systems are more likely to apply crop rotation and riparian buffers. They did this using survey data from a watershed in Quebec collected in 2007. The size of the farm is the sole factor that is statistically significant and positively correlated with the level of BMP adoption, according to a different study by Filson et al. (2009) that looked at the adoption of BMPs in five southern Ontario watersheds in 2006. Additionally, Lamba et al. (2009) discovered that financial incentives had a significant role in the choice to use BMPs in watersheds in southern Ontario. In the Grand River watershed in southern Ontario, between 1998 and 2004, Dupont (2010) examined farmers' decisions to engage in BMP programs and the participation rate (measured as the number of BMP projects per farm). She discovered that a farmer's decision to participate as well as their rate of participation are both positively correlated with the maximum grant amount available to them. Additionally, she discovered that the likelihood that a farmer will adopt BMPs is also positively correlated with the maximum grant percentage of costs covered. Finally, Weber (2017) conducted a review of factors affecting the adoption of BMPs amongst Canadian farmers. Weber (2017) discovered just a small number of relevant variables that were reliable predictors of BMP uptake, similar to Prokopy et al. (2019). She suggests that researchers and decision-makers create a framework for segmenting farms depending on agricultural practices and offer more extension services to boost participation rates.

Frequently, studied variables include producer age, producer farming experience, level of education, and producer attitude towards the environment. From the literature, age has been seen to have a consistent positive relationship with BMP adoption, however, its effect has been documented to be both significant and insignificant. Usually, age in years has a positive significant effect on the adoption of BMPs (Baumgart-Getz et al., 2012; Prokopy et al., 2008). Though, other studies have found that it may be an insignificant predictor of adoption behaviour (Knowler & Bradshaw, 2007; Liu et al., 2018). Another example is the effect of farmer experience on BMP adoption. It has been ambiguous on the adoption (Baumgart-Getz et al., 2012; Boyer et al., 2018; Ervin & Ervin, 1982; Knowler & Bradshaw, 2007; Liu et al., 2018; Prokopy et al., 2008). Education and income have a positive correlation with the adoption of BMP’s and their influence is significant (Knowler & Bradshaw, 2007; Mishra et al., 2018; Traxler & Li, 2020). These inconsistencies have made it difficult to design programs and policy interventions that achieve widespread BMP adoption.

These drivers of adoption are conditionally dependent on the suite of practices a farmer currently uses or plans to use. Farmers may get their “foot-in-the-door” with a practice or two, before adopting further practices. Previous research finds farmers who use one conservation practice are more likely to engage in others (Bergtold et al. 2012; Lichtenberg 2004; Ryan, Erickson, and Raymond 2003; Singer, Nusser, and Alf 2007; Upadhyay et al. 2003; Wilson, Howard, and Burnett 2014). This step-wise adoption may allow farmers to learn which provides the best returns to the farmer's limiting resources rather than adoption of the full BMP package (Pannell et al.,2013).

Interdependency between practices occurs biologically and psychologically. Biologically, soil health changes from different management practices can stack in synergistic, independent, or competitive manners. Practices including cover cropping, crop rotation, and conservation tillage, provide synergistic environmental and economic benefits. For example, in Ontario, cover crops such as winter wheat are incorporated into corn- soy rotations. Including winter wheat in rotations can provide several major soil health benefits, including increases in soil organic matter and resilience to environmental stresses, such as drought, while also increasing overall yields of corn and soy (Janovicek et al., 2021)

Psychologically, farmer preferences are likely to change once they successfully adopt a practice (Bergtold et al. 2012; Lichtenberg 2004; Ryan, Erickson, and Raymond 2003; Singer, Nusser, and Alf 2007; Upadhyay et al. 2003; Wilson, Howard, and Burnett 2014). For example, farmers who practice crop rotation typically practice other conservation practices (Vitale et al. 2011; Wu and Babcock 1998). Farmers who have a positive attitude about a BMP are often more likely to embrace other practices (Prokopy et al., 2019). Moreover, risk tolerance would increase once a farmer has observed the benefits of a BMP and would be more willing to adopt other complementary practices (Prokopy et al., 2019; Dessart et al., 2019).

Though there has been extensive research done on the drivers influencing the adoption of BMPs, growing evidence of the importance of simultaneous implementation of multiple BMPs has yet to be widely reflected in the conservation practice adoption literature. To date, little economic research has studied the drivers of farmers' simultaneous adoption of multiple soil health BMPs, though recent work suggests the importance of considering novel measures of BMP adoption (Ulrich-Schad et al.,2017). The gains in environmental quality improvement through the implementation of multiple BMPs indicate a need to better understand what motivates farmers to concurrently adopt multiple practices. To contribute to this understanding, we build on past research exploring the adoption of multiple soil health practices by focusing on how farm and farmer variables influence current adoption of multiple BMPs and the likelihood of future use.

1.4 Purpose and Objectives

The purpose of this paper is to analyze the determinants that contribute to the adoption of BMPs for Ontario farmers, as well as understand the constraints that inhibit adoption. This research focuses on the interrelated adoption of six soil health BMPs: cover crops, crop rotations, reduced tillage, soil testing, windbreaks, buffer strips and organic amendments. Each of these practices offers varying amounts of private and public benefits based on farmer perception, spatial differences and practice characteristics. Using a multivariate probit model which controls for interdependency between practices, the differences in adoption behaviour given current soil health practices can be contextualized. The objectives include:

1) To build a picture of the current rates of adoption of soil health BMPs amongst Ontario farmers and the demographics of adopters and nonadopters
2) To assess the socio-economic factors driving adoption of individual and multiple soil health practices.
3) To understand what motivates or hinders various farmer segments from adopting these soil health practices

1.5 Outline

The rest of this thesis is organized as follows. Chapter Two presents a summary of the survey design and distribution, as well as an overview of the summary statistics. Chapter 3 delves into the barriers and incentives driving adoption and sums them up using factor analysis. Chapter 4 outlines the empirical framework used to determine the factors influencing adoption, introduces the variables of interest and presents the main findings. Chapter 5 uses probit analysis to better understand who adopts these practices and why. The last chapter, Chapter 6, provides a brief summary, outlines policy implications of the results, and identifies areas for future research.

2 Data

2.1 Introduction

This chapter provides an overview of the data used for this study. It presents a description of the methods of data collection and the survey design. The second section outlines the descriptive statistics from the survey data, presenting farm and farmer characteristics, as well as the barriers and motivations to implementing the six soil health practices.

2.2 Survey Design and Distribution

The data used in this study is from an online survey conducted from January to April of 2020. The purpose of the survey, funded by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), was to gain a better understanding of the reasons behind the seemingly low adoption levels among Ontario farmers for several soil health BMPs and to elicit information on strategies and policy tools that have the most potential to improve adoption rates amongst Ontario farmers. A link to the survey was emailed to members of the Ontario Federation of Agriculture (OFA) through their newsletter. The survey was also advertised at the Southwest Agricultural Conference in January 2020 at Ridgetown, Ontario, where cards containing the survey link were handed out. In addition, a signup sheet was set up for participants, who preferred to participate by phone. To encourage participation, respondents who completed the survey were eligible to participate in a draw consisting of various prizes ranging from $20 to $100. There was a total of 249 respondents, of which 246 responses were through the online survey and 3 responses were through the phone survey. Of the 249 respondents, 2 (0.8%) of the responses were incomplete, lowering the total number of complete responses to 247.

The survey was constructed using Qualtrics and was designed to be completed in 10 to 30 minutes depending mostly on how many BMPs a farmer had adopted. The survey was split into eight distinct sections, each with a unique set of questions which were developed by a team consisting of members from the University of Guelph, OMAFRA and OFA. The first section of the survey posed questions related to general farm characteristics such as the location of the farm, types of primary commodity crops produced, and a general understanding of farmers' perceptions of BMPs. The next six sections focused on individual BMPs: (1) cover crops, (2) crop rotations (more than 2 crops in rotation), (3) no-till, (4) soil testing, (5) conservation buffers (i.e. windbreaks, buffer strips, naturalized areas) and (6) organic amendments (i.e. manure, biosolids, compost). For each BMP, farmers were asked about their use of the BMP and the reasons for adoption or non-adoption, as well as reasons that would increase the likelihood of adoption of a given BMP. The final section gathered socioeconomic data on the respondents, such as age, gender, and education level.

2.3 Characteristics of Respondents

Demographic characteristics for all participants (n=247) are presented in Table 2.1. The results are compared where applicable with the 2016 Census of Agriculture (Statistics Canada, 2016). Of the 247 participants, 63% reported working over 30 hours a week on average on the farm. Thus, the survey contained more full-time farmers compared to the 2016 Census in which 34% of farm operators in Ontario worked more than 40 hours a week on average on farm operations and 46.3% of farm operators had an off-farm job. The respondents to the survey were primarily male (89.9 %) with only 10.2% of female respondents, which is lower than the approximately 30% of farm operators that are female as reported in the Census. The difference between the survey and Census may be due to the nature of the question. The survey asked for the gender of the person answering the survey whereas the Census asks for the gender of all farm operators.

The average age of an Ontario farmer according to the Census is 55, with 9.1% of farmers being under 35 years, 36.3% between 35 to 54 years and the majority (54.5%) are over 55. Survey respondents were slightly younger farmers, with 11.3% under 35 years and 38.1% between 35 and 45 years. 50.6% of the sample was over 55 years. Producers in the sample also had more formal education than the average Ontario farmer. Over two-thirds of the sample had a college diploma or higher while only 15% of all Census farmers have a university degree or diploma at the bachelor's level or above, and 14% hold a post-secondary certificate or diploma. Similarly, less than one-fifth of the survey respondents had finished high school or less, compared to 29% of all Ontario farmers.

The location of the farmer is grouped into 5 geographical regions in Table 2.1. Over 70% of the respondents were located in the southwestern portion of the province. Of the remaining farms, 38 respondents were in Eastern Ontario, 25 were from the Central region, and 7 were from the North. The geographic distribution of the sample across the province is similar to the distribution for the location of Census farms (Neptis, 2003). The farms operated by the respondents tend to be larger than the average farm. The mean acreage of total land area of respondents' farm operation was 517 acres, of which two-thirds was owned and one-third was leased. Approximately one-quarter of respondents had farm cash receipts of less than $100,000, which is significantly smaller than the 62% of Census farms with sales of less than $100,000 (Table 2.1). The survey respondents were also twice as likely to have sales greater than $1 million annually (12.7%) than the average farm in the Census (6.5%). Grains and oilseed crops are the primary commodity produced by 60% of respondents, and about 20% of respondents are primarily livestock producers.

Table 2.1: Socio-economic Characteristics of Respondents

Characteristics	No. of observations	Frequency (%)	Census (%)
Farmer			
Full time farmer (Yes=1)	244	63.1	34.0
Gender (Male =1)	245	89.9	70.3
Age	239		
Less than 40	27	11.3	9.1
40-49 years	21	8.8	36.3
50-59 years	70	29.3	9.1
60-69 years	86	36.0	54.5
70 and over	35	14.6	36.3
Education	245		
High school or less	48	19.6	29.0
Some HS	33	13.5	42.0
College diploma	92	97.6	14.0
University degree	72	29.4	15.0
Farm			
Location	244		
South	98	40.2	34.3
West	76	31.1	32.7
Central	25	10.2	14.4
North	7	2.9	4.0
East	38	15.6	14.6
Acreage Operated)		517.1	249.0

Farm Cash Receipts	229		
< $100,000	82	36.2	63.5
$100,000-$249,999	51	22.3	11.4
$250,000-$499,999	35	15.3	11.8
$500,000-$999,999	31	13.5	13.4
> $1,000,000	29	12.7	7.1
Primary Commodity	232		
Grains & oilseeds	149	64.2	
Livestock	52	22.4	
Other	31	13.3	

2.4 Overall Adoption Rates of BMPs

Soil-testing was the most employed BMP by respondents (86%) while the least adopted was conservation buffers (53%) (Table 2.2). The difference may be attributed to the relative costs of adoption. Approximately three-quarters of the respondents used a crop rotation involving more than two crops. Nearly 70% of producers reported incorporating cover crops within their practices, which is significantly higher than current 30% adoption rate reported by the 2017 Farm Management Survey.

Respondents were likely to use more than one of the BMPs. Only 4% of the farmers used only one of the six BMPs (Table 2.3). In contrast, approximately one-third (71) adopted 5 of the practices and one-fifth (42) used all six. If multiple BMPs are adopted, the practices that are adopted together are indicated by the correlations given in Table 2.4. The adoption of cover crops is positively correlated with a diverse crop rotation (r=0.36), no-till (r=0.17) and organic amendments (r=0.25). The most likely combination of BMPs is the use of more than two crops in a rotation and no-till (r=0.42). The correlation is expected since those that include a third crop (winter wheat) into a corn-soybean rotation tend to plant it directly without tillage in the fall after soybean harvest and a cover crop is planted into the wheat. Soil testing is also likely to be correlated with cover crop, crop rotation, and tillage BMPs. In contrast, the adoption of conservation buffers tends not to be correlated with any of the other five BMPs.

Table 2.2: Adoption Rate of BMPs in Sample

BMP	Percentage of Farmers
Cover Crop	69.5
Rotation (> 2 crops)	75.9
No-Till	55.8
Soil Testing	86.3
Conservation Buffers	53.0
Organic Amendment	62.8

Table 2.3: Number of Farmers Adopting Multiple BMPs

Number of BMPs Adopted	Number of Farmers (%)
1	9 (4.1%)
2	20 (9.1%)
3	28 (12.8%)
4	47 (21.5%)
5	71 (32.4%)
6	42 (19.2%)
Total	**219 (100%)**

Table 2.4: Correlation among Adoption of BMPs

	Cover Crop	Crop Rotation	No-Till	Soil Test	Buffers	Organic Amendments
Cover Crop	1	0.3913*	0.1996*	0.2686*	0.0697	0.2546*
Crop Rotation	---	1	0.4177*	0.1985*	0.0487	0.1546*
No-Till	---	---	1	0.1963*	-0.0227	0.0522
Soil Test	---	---	---	1	-0.0703	0.0568
Buffers	---	---	---	---	1	0.0699
Organic Amendments	---	---	---	---	---	1

*Indicates significance at 5% level

2.4.1 Cover Crop Adoption

The majority of respondents (70%) used cover crops in their operation and 93% reported that they plan on continuing their use of cover crops. A small percentage (7%) said cover crops were not applicable to their farm operation. The mean acreage of land planted with cover crops is 169 acres, of which 66% (112 acres) is owned and 33% (57 acres) is rented.

The differences in demographic characteristics of adopters and non-adopters for cover crops are listed in Table 2.5. Of the farmers who adopt cover crops, 68% work full-time on the farm and the majority are male (90%), which is similar to the overall numbers (see Table 2.1). Of the female respondents, 17 (68%) adopt cover crops while 3 do not use cover crops. Producers from both adopter and non-adopter groups display no relative differences in education levels nor age (i.e. they are aged between 50-69 and hold college diplomas).

Farms adopting cover crops tend to be larger than farms not using cover crops (see Table 2.6). The mean acreage of adopters is higher (590 acres) than that of non-adopters (439 acres). Respondents from both groups have sales under $100,000, but the relative share in the low sales categories is higher for non-adopters. Non-adopters of cover crops represent 35% of respondents with sales less than $100,000 but around 20% of those with sales greater than $100,000. Of the non-adopter group, crop producers make up the majority (80%) while livestock producers make up 14%. This differs from the adopter group where 60% are crop producers and a third are livestock producers (35%).

2.4.2 Crop Rotation Adoption

Three-quarters of the respondents employ more than 2 crops in their rotations, which are predominantly soybeans, corn, and winter wheat. The respondents who adopt more complex crop rotations tend to be younger and have higher levels of education than non-adopters (Table 2.5). The adopters also have significantly larger farms both in terms of area operated and revenue generated compared to non-adopters of diverse crop rotations. Both groups have similar proportions of livestock and crop producers.

2.4.3 Tillage Adoption

The adoption rates across different tillage approaches (conventional, no-till, strip till and reduced till) suggest that many of the respondents use multiple tillage techniques depending on the crop in the rotation. For example, 56% use no-till, with the majority using it in soybean and winter wheat crops. Similarly, the one-third of the respondents that use conventional tillage will do so largely on a corn field. The 55% of respondents using reduced tillage tend to do so across the range of crops grown. Only 6% of the farmers used strip tillage. Adopters of no-till are more likely to be full-time operators but there is little difference in age and education levels with non-adopters (Table 2.5). As with crop rotations, adopters of no-till tend to operate larger farms but there is no difference in the primary commodity produced by the operation (Table 2.6).

2.4.4 Soil Testing Adoption

84% of the respondents test their soils, with less than 20% taking the actual soil sample themselves. Instead, the majority rely on a soil lab (42%), an input supplier (32%), or a consultant (8%) to obtain the sample, which is then evaluated by a testing facility. Approximately half test their soil every 3 years, with around one-fifth testing every other year and another one-fifth testing every 4 to 5 years. 10% test their soil every year. The frequency of soil testing does not vary significantly between owned and rented land. Like adopters of other BMPs, soil test adopters tend to be full-time farmers. There is little difference in age and education levels of soil test adopters and non-adopters (Table 2.5). However, respondents who adopt soil testing have larger farms (580 versus 232 acres) and report higher farm cash receipts (half of them earn $250,000 and over versus 13%) (Table 2.6).

2.4.5 Conservation Buffers Adoption

Approximately half (53%) of respondents have retired unprofitable or fragile cropland to establish conservation buffers, and of these respondents, more than half (56%) have established more than one type of buffer. The most common conservation buffer is a windbreak (32%), followed by a buffer strip (20%) and the least common is wind strip (5%). The difference in the use of these three buffers is likely due to the productivity impacts as buffer strips are usually planted on the edges of the field whereas wind strips maybe within the field. Approximately 15% of the respondents use either afforestation, perennial forage crops, or other naturalization such as establishing wetlands. In contrast to the other BMPs, non-adopters of conservation buffers tend to be younger than adopters but are similar in other demographic (Table 2.5) and farm characteristics (Table 2.6).

2.4.6 Organic Amendments Adoption

More than half the responders include organic amendments into their cropping practices. Soil manure is the most common amendment and is used by 64% of producers, followed by liquid manure (28%) and compost (26%). Approximately 40% of respondents apply organic amendments annually which is similar to the percentage of farmers applying manure or other amendments annually according to the 2016 Census of Agriculture. Comparable to many of the other BMP adopters, those who implement organic amendments are mostly fulltime producers and tend to be younger than non-adopters. While adopters tend to farm a larger land base (612 acres versus 383 acres), there is little difference in the distribution of farm cash receipts between adopters and non-adopters. As expected, given the availability of manure from their home operation, farms using organic amendments are much more likely to be livestock producers as compared to non-adopters (Table 2.6).

Table 2.5: Demographic Characteristics of Adopters and Non-Adopters of BMPs*

Demographic Characteristics (% in each category)	BMP											
	Cover Crops		Crop Rotations		No till		Soil test		Buffers		Organic Amendment	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Fulltime	**68%**	**54%**	**70%**	**44%**	**70%**	**50%**	**66%**	**44%**	**64%**	**62%**	**71%**	**49%**
Gender (Male)	90%	95%	89%	93%	88%	93%	91%	91%	90%	89%	90%	93%
Age												
Less than 40	13%	7%	13%	7%	13%	8%	11%	12%	7%	16%	12%	9%
40-49 years	10%	7%	10%	3%	9%	8%	9%	6%	8%	10%	9%	8%
50-59 years	26%	40%	27%	38%	28%	33%	31%	30%	32%	29%	29%	35%
60-69 years	38%	30%	37%	29%	35%	37%	35%	33%	42%	28%	38%	32%
70 and over	14%	16%	12%	22%	15%	13%	21%	18%	12%	18%	13%	16%
Education												
< High school	20%	19%	20%	19%	19%	21%	18%	27%	15%	25%	19%	23%
Some post HS	11%	23%	11%	21%	14%	13%	14%	12%	15%	11%	13%	15%
College diploma	41%	33%	39%	31%	38%	36%	39%	30%	35%	40%	38%	33%
University degree	28%	25%	30%	29%	29%	29%	29%	30%	34%	24%	31%	30%
Total	**170**	**57**	**185**	**58**	**160**	**85**	**206**	**33**	**131**	**114**	**154**	**80**

* Yes indicates the % of adopters, No indicates % of non-adopter

Table 2.6: Farm Characteristics of Adopters and Non-Adopters of BMPs

BMP	Farm Characteristic (% in each category)								
	Farm Area (Acres)	Farm Cash Receipts ($000s)					Primary Commodity		
		< 100	$100-$249	$250-$499	$500-$999	>$1,000	Crop	Livestock	Other
All	517.1	36.2%	22.3%	15.3%	13.5%	12.7%	64.2%	22.4%	13.3%
Cover Crop									
Adopter	580.9	31%	22%	17%	14%	16%	62%	35%	4%
Non-Adopter	438.6	43%	24%	13%	13%	7%	81%	14%	5%
Rotation									
Adopter	567.2	8%	26%	18%	15%	14%	68%	29%	3%
Non-Adopter	391.8	60%	13%	7%	11%	9%	68%	23%	9%
No-Till									
Adopter	587.6	24%	27%	20%	16%	13%	70%	26%	4%
Non-Adopter	388.1	59%	14%	8%	9%	11%	63%	31%	6%
Soil Test									
Adopter	579.9	30%	23%	18%	16%	14%	69%	27%	4%
Non-Adopter	232.4	67%	21%	3%	0%	9%	60%	35%	4%
Buffers									
Adopter	546.2	35%	22%	21%	9%	14%	64%	30%	5%
Non-Adopter	484.1	38%	23%	9%	19%	11%	71%	26%	3%
Organic Amend.									
Adopter	611.8	31%	22%	17%	14%	16%	62%	35%	4%
Non-Adopter	383.3	44%	24%	13%	13%	7%	81%	14%	5%

2.4.7 Reasons for Implementation

For each BMP adopted, the survey provided a list of reasons to better understand the motivations driving respondents towards implementation. These included economic reasons such as to increase profits or yields, environmental reasons related to improving soil health or reducing run-off and erosion, and social reasons linked to managerial decisions. Respondents could select up to 3 reasons, and results are presented in Table 2.7. “To improve soil health” was the most frequently selected reason for many of the BMPs adopted while nutrient optimization was the least frequently selected reason across all BMPs. The valuation of soil health as the primary driver for BMP adoption may have been related to response bias where the participants choose more socially accepted options, like the environmentally conscious option to improve soil health, as opposed to being economically driven.

Environmental reasons, specifically related to soil health, were the driver for adoption of all BMPs with the exception of conservation buffers, when compared to economic or social reasons. For example, all 147 respondents using cover crops noted improving soil health as one of the three reasons for implementation, except for buffers (Table 2.7). Cover crop adopters widely selected environmental reasons over economic or social reasons. After soil health, reducing run-off and reducing erosion, with each selected by more than half of the respondents, were the main driving forces pushing adopters to use cover crops. Environmental reasons were also a major driver for the adoption of no-till and conservation buffers. For no-till, 44% gave reducing run-off as a primary reason for implementation but surprisingly none cited reducing erosion. In contrast, reducing erosion was the primary reason for implementation of conservation buffers (77%), while 32% noted reducing run-off. Reducing run-off and/or erosion were not major reasons for implementation among the other three BMPs.

Economic factors were a driver in adoption for all BMPs except for conservation buffers. Improving yield was a reason for using cover crops given by two-thirds of the adopters. Similarly, half of the adopters of soil testing gave higher yields as a factor for adoption. The other major financial reason for using crop rotations was the reduction in weeds, pests and diseases, which was also noted by two-thirds of the adopters. Lowering the threat of pests was not cited as a reason for the use of any of the other BMPs. However, reducing other input costs, such as fuel and fertilizer, was a reason for adoption of several BMPs. As expected, this was the dominant reason for the use of organic amendments as manure could substitute for inorganic fertilizer. Over half of adopters of no-till cited reducing input costs as a reason, as this BMP could reduce fuel costs and machinery repairs. These financial reasons influence profitability, and an increase in net returns was given as a reason by two-thirds of the adopters of no-till. It was also a reason given by nearly half of the adopters of soil testing and organic amendments.

The remaining reasons played little role in the adoption decision of the BMPs apart from management for crop rotations and organic amendments. In the former, 27% of adopters used cover crops as means to spread out labour and machinery demands through the growing season. In the latter, 30% apply organic amendments as a necessary means to empty out waste from livestock barns.

Table 2.7: Percentage of Total Respondents by Motivations for Implementation for using BMP

Reasons for Use	Beneficial Management Practice					
	Cover Crops	**Crop Rotation**	**No-till**	**Soil Testing**	**Buffers**	**Organic Amendment**
Improve soil health	100%	80%	90%	89%	14%	84%
Reduce run-off	56%	1%	44%	11%	32%	
Reduce erosion	56%				70%	7%
Improve yields	37%	67%	18%	49%		
Increase returns	13%	28%	63%	45%	20%	44%
Reduce input costs	3%	24%	53%	28%		97%
Reduce pests	2%	64%	1%			
Management		27%	8%		3%	30%
Optimize nutrients	1%					1%
Other	5%	7%	2%	2%	60%	1%
Total	**147**	**169**	**153**	**188**	**125**	**154**

*Respondents could give up to 3 reasons for using an individual BMP

2.4.8 Barriers to Implementation

As with the reasons for implementation, the respondents were asked to select up to 3 reasons why they chose not to implement specific BMPs. Barriers to adoption include cost of implementation, low profits, additional resources required such as equipment, time and labour, land management issues related to tenured land, pre-existing structures, and fragile land. In contrast to the reasons for implementation, there is no consistent reason selected for all BMPs (see Table 2.8).

The first three barriers to implementation listed in Table 2.8 influence the bottom line of the farmer. The need for additional resources was cited as a reason by 82% of the 37 non-adopters of cover crops. It was also a major barrier to the adoption of crop rotations (63%) and soil testing (58%) but did not play a role in the non-use of the three other BMPs. In the case of soil testing, additional costs were the primary reason (87%) given for those not determining the fertility of their soil. More than half of non-adopters of cover crops and crop rotations also cited additional costs as a barrier to their implementation. While additional resources and/or costs were a primary barrier to adoption of several BMPs, the lack of returns played a less significant role. Approximately one-third of the non-adopters of cover crops, crop rotations and conservation buffers gave insufficient benefits as a reason for their non-use. Non-adopters of soil testing and organic amendments do not seem to question the existence of potential benefits of these BMPs but 70% of the respondents note the uncertainty of these returns as a barrier to implementation. Uncertainty of benefits is also a barrier to adoption of cover crops for 37% of the non-adopters.

There are other non-financial reasons that can prevent the adoption of the BMPs. For example, 79% of the non-adopters of cover crops note the complexity of the management for this BMP as a barrier. Lack of knowledge to effectively implement was also cited by approximately 30% of the non-adopters of no-till and soil testing. A similar percentage of non-adopters also pointed to land management issues as reasons for not implementing no-till and conservation buffers. Land management issues include poor soil drainage, soil types or delays in planting due to slow soil warming and/or drying. The effectiveness of no-till in influencing soil carbon levels and consequently its adoption depends on the soil type and region (Angers et al., 2017). Similarly, land management issues related to not owning land or conservation zones already being installed on the farm before purchasing the land were cited as a barrier by 27% of non-adopters of conservation buffers. Conservation buffers were viewed to be non-applicable by 70% of its non-adopters. The only other BMP viewed to be not applicable to their operation was crop rotations. A significant number of other barriers were cited as reasons for non-adoption across the BMPs, which highlights the need to understand the heterogeneity of farmers to encourage the adoption of BMPs related to soil health.

Table 2.8: Percentage of Total Respondents by Barrier to Implementation for using BMP

	Beneficial Management Practice					
Barrier for Not Using	**Cover Crops**	**Crop Rotation**	**No-till**	**Soil Testing**	**Buffers**	**Organic Amend.**
Additional resources	82%	63%	1%	58%	1%	
Additional costs	55%	4%	52%	87%	13%	32%
Lack of return	39%	28%	7%		38%	12%
Uncertainty of benefits	37%	11%	11%	71%	13%	71%
Management reasons	79%	2%	31%	32%	11%	1%
Land management	8%	9%	32%	6%	27%	3%
Nutrient management	11%	4%	1%			
Nobody else uses it	11%		4%	16%	1%	
Not applicable		39%	2%		70%	1%
Other	24%	13%	7%	26%	5%	22%
Total	**38**	**46**	**111**	**31**	**96**	**78**

*Respondents could give up to 3 barriers for not using an individual BMP

2.4.9 Likelihood of Implementation

For majority of the BMPs discussed, save for organic amendments, financial incentives are the most popular measure that would increase the likelihood of implementing a given BMP (Table 2.9). Cost-share programs or rebates would be particularly effective to increase the adoption of soil testing and cover crops according to the non-adopters of these BMPs. The role of financial incentives is lowest among the BMPs for no-till.

Better knowledge of benefits is widely selected as the main reason that would motivate organic amendment non-adopters towards implementation and is the second largest reason selected by non-adopters of other BMP groups. One-on-one advice or assistance from a professional agronomist is ranked as the third reason that would encourage adoption of the six BMPs, which is closely followed by workshops or demonstrations. While the role of professional assistance and demonstration plots suggest that producers may not have the knowledge to implement these BMPs, recommendations from other farmers have a limited influence on increasing the likelihood of adoption of these BMPs. Across all BMPs, but especially for cover crops, other factors aside from the stated measures can increase the likelihood of adoption.

Measure	Beneficial Management Practice					
	Cover Crops	**Crop Rotation**	**No-till**	**Soil Testing**	**Buffers**	**Organic Amend.**
Financial incentives	88%	63%	35%	100%	52%	42%
Better knowledge of benefits	33%	56%	21%	57%	30%	44%
Professional assistance	35%	20%	14%	57%	17%	27%
Workshops or demonstrations	35%	15%	10%	57%	6%	29%
Other farmers recommending	0%	12%	5%	7%	2%	8%
Other	90%	24%	7%	30%	10%	14%
Total	**40**	**41**	**111**	**30**	**101**	**78**

*Respondents could give up to 3 measures that would increase likelihood for using an individual BMP

2.5 Summary

The majority of the respondents implement more than one BMP in tandem, with soil testing being the most employed among the six soil health BMPs, and conservation buffers being the least. The difference can be attributed to the relative costs of implementation. The fee required to sample and conduct a soil test is relatively small and can result in lower overall input costs by determining the appropriate fertilizer rate. In contrast, conservation buffers involve taking land out of production and require significant costs to plant, establish, and maintain. Nearly three-quarters of the farmers surveyed implemented four or more BMPs as the use of practices such as a rotation with winter wheat, cover cropping and no-till tend to be positively correlated.

Across BMPs, adopters tend to be more likely female, have larger farms, and report higher farm cash receipts than non-adopters. Both members of each group have similar age and education levels.

Improving soil health was the most widely selected motivation for adoption across all six BMPs. The most effective interventions to enhance adoption among non-adopters include financial incentives, easily accessible information and advice, and farmer-to-farmer learning. Results suggest that farmers that adopt BMPs do so primarily to enhance soil health rather than solely economic considerations. Encouraging use among non-adopters may require monitoring and promoting the benefits of soil health. The results should aid in the development of strategic frameworks that facilitate innovations in policy to enhance soil health.

3 Factor Analysis

3.1 Introduction

The survey data on adoption of soil BMPs used in this study is differentiated by most previous studies by the direct questioning regarding the motivations and barriers for adoption. As described in the previous chapter, adopters identified the three primary reasons among a list of 18 for using each of the six BMPs while non-adopters indicated the three major reasons among a list of 10 for not using each of the six BMPs. The large number of reasons makes it difficult to provide useful summaries on the heterogeneity in adoption behaviour.

The purpose of this chapter is to reduce the large number of motivations for adopting and not adopting into a smaller number of common drivers using factor analysis. The chapter begins with a discussion on the method of factor analysis with the next section discussing how it will be employed using the data from this study. The results of the factor analysis are then presented followed by implications.

3.2 Factor Analysis Framework

Farmers' choice for adopting or not adopting a certain or group of BMPs is an individual one and is significantly influenced by underlying behavioural and psychological factors. Profitability is generally assumed to be the primary driver of BMP adoption (Dessart et al., 2019; Prokopy et al., 2019; Liu et al., 2018). The lack of profitability can hinder adoption as highlighted in a recent report conducted by AAFC (2020), where the most important barriers focused on economic issues such as upfront and maintenance costs, as well as costs related to additional resources. However, non-financial factors can also influence the adoption decision, and these include environmental factors such as perceptions of soil health, and concerns over nutrient run off or soil erosion. Social factors also impact adoption. For example, if a farmer sees their neighbour's success with BMPs, this will likely encourage them to adopt similar practices.

The survey described in the previous chapter contained questions on a variety of incentives and barriers to the adoption of beneficial management practices for soil health. The range of questions recognizes the heterogeneities driving the adoption decision. Factor analysis is a method that can group the number of factors influencing adoption into a smaller set of key drivers.

Factor analysis is a dimensionality reduction method often used to uncover the latent structure (dimensions) of a set of variables. The purpose of factor analysis is to describe, if possible, the covariance relationships among many variables by a few underlying but unobservable quantities called "factors" (Rolfe & Harvey, 2017). Factor analysis is often used to simplify large complex datasets by reducing correlated variables into few significant factors. In essence, factor analysis develops a variable which is a linear combination of the observable variables and is a proxy variable for the unobservable "factors", $f_1, f_2, \ldots\ldots f_m,$ with an accompanying error term to account for that part of the variable that is unique (i.e., not in common with the other variables. For $y_1, y_2, \ldots, y_p$ in any observation vector y, the model is as follows:

$$\begin{cases} y_1 - \mu_1 = \lambda_{11} f_1 + \lambda_{12} f_2 + \cdots + \lambda_{1m} f_m + \varepsilon_1 \\ y_2 - \mu_2 = \lambda_{21} f_1 + \lambda_{22} f_2 + \cdots + \lambda_{2m} f_m + \varepsilon_2 \\ y_p - \mu_p = \lambda_{p1} f_1 + \lambda_{p2} f_2 + \cdots + \lambda_{pm} f_m + \varepsilon_p \end{cases} \qquad [1]$$

In relation to the factor analysis model given by equation [1], the reasons selected by the farmers are represented by the y's i.e. the observable variables, while the f's represent factors including economic, environmental and social reasons. Ideally, *m* should be less than p in order to achieve a parsimonious description of the variables as functions of few underlying factors i.e., the observed measures are interrelated and the unobservable variable accounts for the correlations among these observed variables. The factors are represented by the *f*'s which engender the variables as functions of a few underlying factors

We might regard the *f*'s as random variables that calculate the y's or variables. The λ_{ij} are called factor loadings and serve as optimal weights, indicating how each y_i individually depends on the factors (Watkins, 2018) I.e. the variables having heavier loadings in a factor are considered to be strongly correlated to that particular "factor". The error terms represented by ε_i represent the variance in each y that is unexplained by the factor. Factor analysis retains most of the information contained in the original data and reduces the size of the operational data substantially.

Prior to extraction of the factors, it is pertinent to assess whether the data would be suitable to undergo factor analysis i.e. the data should be somewhat correlated and have a shared variance. Typically, there are two tests for this namely, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity. The KMO index ranges from 0 to 1 with values 0.5 and greater considered suitable for factor analysis i.e. the variables and the model meet the sampling adequacy. The Bartlett's Test of Sphericity should be significant ($p<0.05$) for factor analysis to be fit.

In order to extract the common factor, an additional dimension reduction process is undergone known as Principal Component Analysis (PCA). PCA analyses the entire correlational matrix and is intended to reduce data while preserving as much information from the original data set as possible. To do this PCA computes linear combination of the original measured variables that explain as much information as possible about those original variables. The new variables are components which are parsimonious but are not latent constructs (Watkins, 2018). The first component often tends to contain the maximum variation while the last contains the least amount of variation. Assuming that the measured variables are correlated because they are influenced by the same underlying latent construct, factor analysis attempts to separate the total variance of the measured variables into the variance that is common to the measured variables (Watkins, 2018). Both PCA and factor analysis produce estimates of the communality, but only common factor analysis produces the uniqueness of each measured variable. In PCA, there is one fixed outcome that orders the components from the highest explanatory value to the lowest explanatory value (Watkins, 2018).

The aim of the data extraction is to reduce a large number of items into factors. In order to produce scale unidimensionality and simplify the factor solutions, several extraction approaches are used. This Includes the cumulative percent of variance extracted, and parallel analysis, Kaiser's criteria (eigenvalue > 1 rule) and the Scree test. The threshold of the cumulative percent of variance extracted method has received much disagreement especially across different disciplines (Williams et al., 2010). According to Hair et al. (1995), in the natural sciences, factors should be stopped when at least 95% of the variance is explained. In the humanities, the explained variance is commonly as low as 50-60%. This method is paired with the Scree Test where a line is graphs through smaller eigenvalues. The point is highlighted where there is a break and indicates the number of factors to be retained. The factors retained tend to meet all these criteria including those that have eigenvalues greater than 1 (Williams et al., 2010). In the analysis, 6 factors were retained based on the scree test where eigenvalues to the left of the “elbow” (before the eigenvalues level off) were selected. Furthermore, any eigenvalues above 1 were taken, and for those models where there were no eigenvalues greater than 1 present, the cumulative percent of variance was employed to select factors that accounted for variance of 60% or greater.

The six factors were examined using varimax and oblimin rotations of the factor loading matrix. The rotations minimize the complexity of factor loadings making interpretation of the factors easier by reducing cross loading of variables and ensuring they load onto single factors. Varimax rotation was employed. This rotation applied a clockwise rotation of ninety degrees and aims to minimise the number of variables that have high loadings on each factor (see Table 3.2). Once all the factors have been rotated and all the above steps have been undergone, the final step includes interpretation. Factor models often do not have one concrete solution, it is often left to the researcher to develop an appropriate answer. To define the factors, I looked at the variables with the highest loadings on the factor i.e. 0.32 or greater, and used those to define the factor. The factor is then given a name or theme, for example, a factor may have included five variables which all related to costs and profits may be themed as “economic reasons”.

Factor analysis can be used to identify hidden dimensions or constraints that may not be apparent from direct analysis, though this process may have certain limitations. One such limitation is if important attributes are missed, the value of procedure is reduced accordingly. Moreover, naming or theming some factors can be difficult as multiple variables may be highly correlated with no apparent reasons, and further theoretical research would be needed to fully understand what the latent factors actually represent. For factory analysis to be valid, the observed variables need to be somewhat correlated so as to produce meaningful patterns (Williams et al., 2010).

3.3 Data for Factor Analysis

The data used for the factor analysis stems from the qualitative questions posed under each BMP, asking respondents to select up to 3 reasons for adopting or not adopting the given BMP. The reasons behind adoption and non-adoption varied across BMPs, since each BMP may have unique attributes that could encourage or discourage its implementation. For example, no-till practices may not work for all crops, or soil testing may be employed "to determine variable rate requirements for fertiliser use". Though the reasons were unique, they had overarching themes or "factors" that were similar across each BMP. These factors include economic, environmental, or social. Thus, to reduce data dimensionality, exploratory factor analysis is used to condense these attitudinal questions into latent perception factors. There were a total of 249 observations with 938 parameters and 47 variables. The number of observations refers to the total number of respondents i.e. adopters and non-adopters of the BMP. The parameters indicate the total number of reasons selected by respondents across all 6 BMPs while the variables represent all the motivations for adoption or non-adoption.

3.4 Results of Factor analysis

Below I present two set of results, factor analysis of the motivations and barriers driving the adoption of each individual BMP, and a cumulative factor analysis on all the motivations and barriers to adoption across the BMPs. Though the Cronbach alpha values for many of the factors are lower than 0.7, the 0.5 values represent that the factors do share covariances and can still measure the underlying construct. This further explained by the KMO values and bartlett's test of sphericity which suggest there is substantial correlation in the data making the factors suitable for use.

3.4.1 Individual Factor Analysis

The results of the individual factor analysis are summarized in three tables. The motivations for adoption are given in Table 3.1 for each of the 6 BMPs. The first column lists the estimated factor and the values inside the table are the loadings. The corresponding results for the barriers to adoption are given in Table 3.2. A summary of the major grouped reasons for both motivation and adoption across all BMPs are given in Table 3.3. The values highlighted in red represent the loadings onto a second factor while those in green represent the loadings onto factor 3.

Table 3.1: Results of factor analysis of individual BMP motivations.

Reasons For Use	Cover Crops	Crop Rotation	No Till	Soil Testing	Buffers	Organic Amend.
	Beneficial Management Practice Factor Loadings					
To improve soil health (e.g., retain moisture, reduce compaction, retain nutrients)	0.6803	0.5879	0.7687	0.3476		0.7913
To increase economic returns			0.3566	0.5024		0.4071
Reduce input costs e.g. fertilizer, feed, fuel			0.3966			0.3059
Reduce runoff	0.497		0.4661		0.538	
To improve yields		0.4349		0.5716		
Management reasons (e.g., to spread out the workload over time, reduce use of synthetic fertilisers)						0.5395
Reduce Erosion	0.5014				0.65	-0.322
Reduce weeds, pests and diseases		0.4532				
Optimize Nutrients				0.5732		0.3281
Other					0.4505	0.306

*Values in red represent loadings onto factor 2 while those in green represent values loaded onto factor 3

Table 3.2: Results of factor analysis of individual BMP barriers.

Barriers to use	Cover Crops	Crop Rotation	No Till	Soil Testing	Buffers	Organic Amend.
	Beneficial Management Practice Factor Loadings					
Additional Cost (inputs)	0.5677		0.7099	0.4929	0.4616	0.407
Lack of Return	0.3023	0.3979			0.5429	
Additional Resources (time, machinery, labour)	0.3862, 0.4639	0.6127	0.8228	0.5035		
Management Reasons (complexity, knowledge)			0.6769		0.4964	

Uncertainty of benefits	0.5274	0.3979	0.8169		0.4539	0.4299
Land Management issues			0.7483		0.3369	
Nutrient Management						
Not applicable					0.3715	
Nobody else around me uses it				0.3202		
Other			0.7134			0.3661

* Values in red represent loadings onto factor 2 while those in green represent values loaded onto factor 3

The motivations for adoption of cover crops were simplified into one factor that had KMO values greater than 0.5 and passed the Bartletts test of sphericity (Table 3.1). This factor is themed “Environmental” as it represented by the response to reasons such as improving water retention and infiltration, improving soil health and reducing erosion. In contrast, the variables that had the highest loadings on the barriers to adoption of cover crops were related to economic reasons such as additional cost, lack of return, additional time requirements (Table 3.2). The themes represented by each factor are presented in Table 3.3.

The factor analysis model representing the motivations to adopting crop rotations did not meet the KMO requirement of 0.5 and had a value of 0.462. The variables that had the highest loading on the factor were related to economic and environmental with soil health being the highest, thus theming the factor as “Environmental and Economic” (Table 3.3). The highest loadings on the factor representing barriers to crop rotation adoption represented the need for additional reasons. Unlike the motivations for adoption, the factor for barriers to adoption met KMO requirements.

Like the motivations for crop rotations, no-till model for motivations also did not meet the KMO test and noted a value of 0.472, however it did pass the bartletts test of sphericity. Both the barriers and motivations for no till adoption were simplified into two factors. Looking at table 8, the variables loading onto factor 1 under motivations represent a mix of environmental and economic, with the highest loading being “to improve soil health” with a value of 0.7671 (Table 3.1). The barriers to adoption of no -till were represented by two factors. Factor 1 represents economic and environmental barriers to no till adoption, while factor 2 represents complexity in implementing and using no-till practices (Table 3.2).

The motivations for adopting soil testing were represented by two factors. Factor 1 was represented by economic reasons for adoption such as improving yields, optimizing nutrient use and increasing economic returns. While factor 2 had one environmental variable i.e. to improve soil health and organic matter, load onto it. The barriers to adopting regular soil testing are represented by 1 factor which is highly loaded with 3 economic reasons such as cost, time and nobody else regularly conducting testing.

Conservation buffers are mostly employed for environmental reasons as shown by the analysis. These included reducing erosion, nutrient run-off and increasing biodiversity, and are represented by 1 factor. The barriers are represented by three factors. Factor 1 was represented by economic reasons: cost of establishment, taking land out of production leading to reduced profits, lack of unprofitable land, uncertainty of environmental benefits and no soil erosion present. Factor 2 was represented by environmental reasons (Table 3.3), and the third factor had only one variable load onto it that included management reasons.

The motivations driving adoption of organic amendments were simplified into 3 factors (Table 3.1). Factor 2 consisted of one variable, reducing erosion, indicating that it is negatively related to factor 2. Factor 1 was themed “Environmental and Economic” while factor 3 had one variable named other load onto it and was thus named “Other”. The barriers were represented by one factor (Table 3.2) that related to economic barriers (Table 3.3).

Table 3.3: Factor themes representing motivations and barriers for individual BMPs

BMP	Factor Themes	
	Motivations	**Barriers**
Cover Crops	Environmental	Economic
Crop Rotations	Environmental	Uncertainty
No-Till	Economic	Economic & environmental
Soil Testing	Economic	Economic
Organic Amendments	Environmental	Management complexity
Buffers	Environmental & Economic	Economic

3.4.2 Cumulative Factor Analysis on Motivations

The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.557, above the commonly recommended of 0.5 and Bartlett's test of sphericity was significant ($\chi 2 = 2271.435$, $p < .05$). Six factors were generated as their eigenvalues were greater than 1 and explained 65.2% of the variance and occurred before the "levelling off" of eigen values on the scree plot (Table 3.6). A Cronbach alpha test was used to determine the consistency of each of the individual factors and their ability to determine the underlying construct. The higher the α coefficient, the more the variables have a common covariance and are grouped under the same latent factor. The Cronbach alpha values of the first 4 factors were greater than the minimum coefficient of 0.5 and were thus retained (Table 3.6).

From Table 3.4, the four factors that represent the motivations to adoption of the 6 BMPs include: Environmental, Input use, Economic and Other. Looking at factor 1, the variables with the highest loadings onto it are environmental motivations such as "To improve soil health", "To optimize nutrient usage" and "To reduce erosion and run-off", thus we can label factor 1 as environmental motivations. Many of the variables that load onto factor 2 include "To reduce use of synthetic fertilizers", "To reduce input costs", "To increase economic returns" which can be attributed to economic motivations. The variables that load onto the second factor are mostly associated with inputs and their application e.g. "To reduce use of synthetic fertilizers", "to get rid of manure", "to reduce input costs". Thus, the factor is themed "Input use". Factor 3 is themed "Economic" as the 3 variables that are positively correlated to it and have the highest loadings are associated to economic reasons. Many of the other variables are correlated to the last factor and thus deriving the label "Other".

Comparing the individual FA to the cumulative, the variables that had the highest loadings on Factor 1 in the individual FA are similar to those that loaded onto the "Environmental" factor in the cumulative FA (Table 3.5). Majority of the variables within the "Environmental" came from 3 practices i.e. cover crops, crop rotations and no-till. This could be attributed to the fact that these three practices are highly correlated. Looking at "Input Use", majority of the variables that loaded onto it were from organic amendment motivations which were the same variables from Factor 1 in the individual FA. The results indicate that the latent structures driving the loadings are based on correlation of practices rather than the social, economic or environmental themes.

Table 3.3: Relevance of variables representing motivations in each factor. CC = cover crops; CR= Crop rotations; NT= No-till, ST= Soil Testing; CB= Conservation buffers; OA=Organic amendments

BMP	Variable	Environmental	Input use	Economic	Other
NT	To improve soil health (e.g., increase organic matter, reduce soil compaction)	0.6373			
CC	To improve soil health (e.g., increase organic matter, reduce soil compaction)	0.5475			
CR	To maintain or improve soil health	0.5469			
NT	To reduce run-off	0.4746			
CC	To reduce erosion and run-off	0.4598			
CR	To improve yields	0.4438			
NT	To increase economic returns	0.3802			
CC	To improve water retention and infiltration	0.3756			
CR	To reduce disease and pest risk	0.361			
OA	To improve soil health (e.g., increase organic matter, reduce soil compaction)		0.5801		
OA	To reduce use of synthetic fertilizers		0.4045		
OA	We need to get rid of our manure		0.3782		
OA	To increase economic returns		0.3239		
CC	Other		0.3105		
OA	To reduce input costs		0.3051		
CB	Other		0.3048		
ST	To optimize nutrient usage			0.5026	
ST	To increase economic returns			0.4418	
ST	To improve yields			0.388	
CR	Because this is how we've always done it			-0.3635	
CC	To attract pollinators			-0.4895	
CC	Peer pressure (e.g., because neighbours are using them)				0.6035
ST	Other				0.5318
CR	Other				0.3918
CB	To improve soil health (e.g., increase organic matter, reduce soil compaction)				0.3439

3.4.3 Cumulative Factor Analysis on Barriers

The Kaiser-Meyer-Olkin measure of sampling adequacy for the barriers was 0.52, above the commonly recommended of 0.5 and Bartlett's test of sphericity was significant ($\chi 2 = 1842.3$, $p < .05$). Like the motivations for adoption, six factors were generated as the initial eigenvalues of the first 6 factors were greater than 1, explained 71.9% of the variance and occurred before the "levelling off" of eigen values on the scree plot (Table 3.6). However, Cronbach alpha values of the last two were lower than 0.5 and were dropped, leaving 4 factors.

Table 3.5 presents the variables and their respective loadings onto each factor after varimax rotation. The four factors derived include: Economic, Cost, Complexity and Management. Factor 1 has high loadings of variables associated with economic barriers such as "Uncertainty of economic benefits", "lower profits". The variables with the highest loadings on factor 2 are associated with high costs and thus generates this theme. Factor 3 is themed as "Complexity" as the variables that loaded onto this factor all represent the complexities related to BMP implementation such as "Additional machinery", "management complexity". The last factor represents the barriers associated with managing the BMP such as the knowledge needed to successfully implement it along with the costs, as well as perceptions of whether it is needed on the farm.

Similar to the cumulative motivations, the cumulative barriers grouped based on the correlation of the practices rather than the initially perceived factors. "Economic" has variable related to cover crops, crop rotation and buffers, while cost consists of cover crop barriers, and management has solely no till barriers loaded onto it.

Table 3.4: Relevance of variables representing barriers in each factor. CC = cover crops; CR= Crop rotations; NT= No-till, ST= Soil Testing; CB= Conservation buffers; OA=Organic amendments

BMP	Variable	Economic	Cost	Complexity	Management
CR	Lack of evidence on economic benefits of diverse crop rotations	0.6726			
CR	Uncertainty about economic benefits of more diverse crop rotations	0.5803			

CB	It takes land out of production which I believe reduces my profits	0.4893			
CR	Lower profits	0.3947			
CC	Other	0.3698			
CC	Lack of return	0.3558			
CR	To reduce fertilizer requirements	0.3109			
CC	Additional cost		0.5903		
CC	Uncertainty/risk		0.4905		
CC	Potential reduction in BRM program payments		0.418		
OA	Other		0.3343		
OA	Uncertainty about the benefits of organic amendments			0.5163	
CC	Additional machinery requirements			0.4595	
CR	Nobody else around me uses diverse crop rotations			0.4244	
CC	Management complexity			0.3279	
CC	Additional machinery requirements			0.3237	
OA	Cost			0.3015	
NT	Lack of knowledge about no-till techniques				0.5771
NT	Cost of equipment				0.535
NT	There is no soil erosion issue on my farm				0.3492

Table 3.5: Sampling adequacy values

		Eigenvalues	Cronbach α	KMO
Motivations	Factor 1	3.27799	0.723	0.5569
	Factor 2	1.82769	0.5668	
	Factor 3	1.40553	0.5501	
	Factor 4	1.2433	0.5294	
Barriers	Factor 1	2.29734	0.6045	0.5281
	Factor 2	1.71043	0.5668	
	Factor 3	1.50326	0.5501	
	Factor 4	1.37049	0.5294	

3.5 Conclusion

Factor analysis was preformed to examine and help clarify relationships between the various motivations and barriers, and latent traits depicted by responses and combine correlated variables into factor sets. Looking at the individual factor analysis (Table 3.2 & Table 3.3), many of the adopters of the six practices mainly adopt due to environmental reasons such as improving soil health or reducing erosion and runoff, save for soil tests where adopters mainly prioritised agronomic reasons related to optimising nutrients and increasing yields. Economic reasons, for example high costs, low costs, uncertainty of economic benefits, were the main barriers preventing adopters from implementing all six of the soil health BMPs.

The latent structures that were driving the correlation between the various variables representing barriers and motivations were thought to be driven by underlying behavioural and psychological factors, however, the results from the factor analysis proved that the variables were being grouped based on the type of practices. Looking at Table 3.4, the variables that loaded highly onto the first factor represented the motivations of adopting cover crops, crop rotations and no till. These three practices, seen in the previous chapter, were highly correlated with one another. This was also the case for the barriers to adoption, as in Table 3.5, the last factor had only No-Till variables load onto it. A reason why the variables loaded in this way as opposed to the initially thought latent structures is due to the fact that the barriers and motivations for adopting the practices were somewhat unique to each practice. The results from this factor analysis allowed us to understand the various BMP bundles that farmers tend to adopt together providing useful insights which can then be further analysed in the next chapter.

4 Probit and Multivariate Probit Models

4.1 Introduction

This chapter introduces the empirical frameworks used to understand the factors that affect a farmer's decision to adopt a BMP. It also introduces the multivariate probit model used to analyze and examine farmers' joint and conditional adoption decisions. A description of the variables of interested is presented, along with their summary statistics. The chapter is concluded by presenting the results derived from the analysis.

4.2 Theoretical Model

4.2.1 Probit Model

Developing and implementing BMP policies requires a thorough understanding of the factors affecting the adoption decision. The decision of whether to adopt BMPs depends on the utility the farmer expects to derive from the technology. The producer may have subjective beliefs about the expected gains, whether economic or environmental, that may be driven by the adoption of a certain practice. For example, Mitchell, Weersink and Erickson (2017) note that innovations in agriculture can improve farm productivity through reduced input use, and Yanni et al. (2020) found that certain BMPs proved to be both economically and environmentally beneficial.

Utility maximization models a farmer's subjective beliefs of the expected gains derived from the adoption of a BMP. I assume that farmers maximize their expected utility with respect to the adoption of a BMP. Since farmers are given the choice to adopt a BMP or not, the decision takes a binary choice situation, making the dependent variable discrete. The decision to adopt a certain BMP is modelled as a function of the difference in utility from moving between two states of technology, $t = 0, 1$, where $t=0$ is a state in which a farmer chooses not to adopt a practice, while $t = 1$ is a state where a farmer chooses to adopt the practice. Using the factors derived in Chapter 3, alongside the attributes of the decision maker, and the socio-economic context, a probit regression is used to estimate the likelihood of a farmer choosing to adopt a given BMP.

The utility model of a producer i that adopts a technology t is denoted $U(R_{ti}, A_{ti})$, where R_t represents a vector of moments describing the distribution of net returns and costs of adoption for technology; and A_t represent a vector of other attributes associated with the technology. Rahm and Huffman (1984) hypothesise that although the variables R_{ti} and A_{ti} are unobserved and unavailable, a linear relationship is assumed for the ith firm between the utility derived from the t^{th} technology and a vector of observed farm and farmer characteristics X_i (such as farm size, age, gender and type of primary commodity produced), and e_i^{bmp} is a zero mean disturbance term.

$$U_{ti} = \beta_t X_i + e_i^{bmp} \qquad (4.1)$$

Farmers will only adopt a given practice if expected utility of adoption (U_{1i}) is greater than non-adoption (U_{0i}), i.e., $U_{1i} - U_{0i} > 0$. The adoption decision of a farmer can be represented by the variable Y_i such that:

$$Y_i = \begin{cases} 1 \; if \; U_{1i} \geq U_{0i}, & BMP \; is \; adopted \\ 0 \; if \; U_{1i} < U_{0i}, & BMP \; is \; not \; adopted \end{cases} \qquad (4.2)$$

Equation 4.3 describes how the probit regression is used to model the effect of a covariate, X, on a farmer's decision to adopt a given BMP:

$$P(Y = 1|X = x) = \phi(\beta_i x_i) = -\int_{\infty}^{\beta_0 + x_i\beta_i} \frac{1}{\sqrt{2\pi}} e^{-1/2 t^2} \, dt$$

Where each farmer's utility is related to X by:

$$U_0|X = \beta_0 X + \varepsilon_0$$
$$U_1|X = \beta_1 X + \varepsilon_1$$

Where, $\beta_i X$ represents the observed utility of option D = i (i = 0,1), and ε_i term embodies the random fluctuation of the utility of the choice. The error terms, ε_0 and ε_1, are independent identically distributed random variables. The Equation 4.5 shows how the utility of each of the choice options is normally distributed.

$$P(Y=1|X=x) = P(U_1 > U_0|X=x)$$

$$= P(X_i\beta_1 + \varepsilon_1 > X_i\beta_0 x + \varepsilon_0)$$

$$= P\big((\beta_1 - \beta_0)X_i > (\varepsilon_0 - \varepsilon_1)\big)$$

$$= P(X_i\beta > \mu_i) = F(X_i\beta)$$

Where $P(\cdot)$ is a probability function, $\mu_i = \varepsilon_0 - \varepsilon_1$ is a random disturbance term, $\beta = \beta_1 - \beta_0$ is a coefficient vector, and $F(X_i\beta)$ is a cumulative function for μ_i evaluated at $X_i\beta$. Therefore, the probability of farmer i adopting a practice is equal to the utility associated with adoption, U_1 is larger than the utility of not adopting, U_0 or the cumulative distribution function F evaluated at $X_i\beta$.

Supposing that the error terms are independent and normally distributed with:

$$Var\big(\varepsilon_{ij}\big|X_{1i}, X_{0i}\big) = \tau_j^2$$

$$\varepsilon_1 - \varepsilon_0 \sim N(0, \tau^2)$$

$$F(y) = \phi\left(\frac{y}{\tau}\right)$$

$$h(X_{1i}, X_{i0}, \beta) = \phi(x_i\beta') \; where \; \beta' = \frac{\beta}{\tau} \qquad (4.5)$$

The coefficients of the probit regression give an indication of the direction in which a characteristic will likely affect adoption. In order to determine the magnitude of the impact an attribute has on the likelihood of adoption; marginal effects need to be calculated and is given by:

$$Marginal\ effect\ of\ X_i = \frac{\partial Pr(Y_i=1)}{\partial X_i} = \frac{\partial \phi(X_i\beta)}{\partial X_i} \quad (4.6)$$

A farmer's decision to adopt a practice is highly dependent on individual farm and farmer characteristics. Understanding human behaviour is complicated in nature, compiled with the wide range of internal and external factors that influence their decisions. Thus, understanding individual motivations and barriers to implement practices is important to develop effective policies.

4.2.2 Multivariate Probit

Often farmers tend to adopt more than one soil conservation practice at a time as they are not mutually exclusive. For example, certain types of cover crops can be incorporated into rotations and can be used as organic amendments. Therefore, the decision to implement one practice may impact the decision to implement another. To model this interdependence of adopting multiple practices simultaneously, a multivariate probit (MVP) is used. Though univariate probits provide information on what factors significantly impact the adoption of a practice, an MVP provides crucial information on unobserved characteristics that could influence the adoption of different and correlated practices. The adoption of one BMP may be conditioned by the adoption of another supplementary practice which is indicated through the positive correlation between the error terms of the two equation. Theoretically, the MVP model is characterized by a set of binary dependent variables (y_{ik}^*), in this case the six soil health BMPs, which are determined by observed characteristics and the error term (Abay et al., 2018):

$$y_{ik}^* = \beta_i X_{ik} + U_{ik} \qquad [4.7]$$

Where y_{ik}^* is the latent variable that takes a value of 1 if an i^{th} producer adopts a BMP k (k = 1, 2,…….6) and zero otherwise. β_i is a vector of the estimated parameters of X_{ik}, while U_{ik} is the error term. In the MVP, the error terms jointly follow a multivariate normal distribution with zero conditional mean and variance normalized to unity (0, Ω) and the covariance matrix (Ω) is given by:

$$\Omega = \begin{bmatrix} 1 & \rho cr, cc & \rho nt, cc & \rho st, cc & \rho cb, cc & \rho oa, cc \\ \rho cc, cr & 1 & \rho nt, cr & \rho st, cr & \rho cb, cr & \rho oa, cr \\ \rho cc, nt & \rho cr, nt & 1 & \rho st, nt & \rho cb, nt & \rho oa, nt \\ \rho cc, st & \rho cr, st & \rho nt, st & 1 & \rho cb, st & \rho oa, st \\ \rho cc, cb & \rho cr, cb & \rho nt, cb & \rho st, cb & 1 & \rho oa, cb \\ \rho cc, oa & \rho cr, oa & \rho nt, oa & \rho st, oa & \rho cb, oa & 1 \end{bmatrix} \qquad [4.8]$$

where the correlation of the error terms is represented by ρ (rho). A positive correlation between error terms indicates that the practices are complements to one another while a negative correlation between the error terms indicates that the practices are substitutes for one another (see Table 4.1).

Table 4.1: Correlation among Adoption of BMPs

	Cover Crop	Crop Rotation	No-Till	Soil Test	Buffers	Organic Amendments
Cover Crop	1	0.3913*	0.1996*	0.2686*	0.0697	0.2546*
Crop Rotation	---	1	0.4177*	0.1985*	0.0487	0.1546*
No-Till	---	---	1	0.1963*	-0.0227	0.0522
Soil Test	---	---	---	1	-0.0703	0.0568
Buffers	---	---	---	---	1	0.0699
Organic Amendments	---	---	---	---	---	1

*Indicates significance at 5% level

4.3 Variables of Interest

4.3.1 Dependent Variables

The data on adoption of the soil health BMPs is from an online survey conducted in the winter of 2020. A link to the survey was sent to members of the Ontario Federation of Agriculture (OFA). In addition to characteristics of the farm and the operator, the survey asked respondents about their use of six individual BMP's and the reasons for adoption or non-adoption, as well as reasons that would increase the likelihood of adoption of a given BMP. The six BMPs examined were: (1) cover crops, (2) crop rotations (more than 2 crops in rotation), (3) no-till, (4) soil testing, (5) conservation buffers (i.e. windbreaks, buffer strips, naturalized areas) and (6) organic amendments (i.e. manure, biosolids, compost).

The adoption rates for the individual BMP's are listed in the bottom row of Table 1. Soil-testing was the most employed BMP by respondents (86%) while the least adopted was conservation buffers (53%) Approximately three-quarters of the respondents used a crop rotation involving more than two crops. Table 1 also indicates the number (and share) of farmers using multiple sets of practices. One-fifth (42) of the respondents used all six BMP's while only 5% of the farmers used none (1%) or only one (4%) of the six BMPs. If multiple BMPs are adopted, the practices that are adopted together are indicated by the correlations also listed in Table 1. The adoption of cover crops is positively correlated with a diverse crop rotation (r=0.36), no-till (r=0.17) and organic amendments (r=0.25). The most likely combination of BMPs is the use of more than two crops in a rotation and no-till (r=0.42).

The main dependent variables used in this analysis are the six-soil health BMPs included in the survey. Many of the BMPs tend to be interconnected and while they can be considered individually, understanding how they are interrelated within the broader production system is crucial, as farmers tend to adopt more than one BMP at a time.

Cover crops take the value of 1 if adopted and 0 if non-adopted. Cover crops tend to be a secondary crop grown after or between rows of a primary crop to provide a permanent surface cover between growing seasons of main crops. The top growth covers the soil surface while the roots bind and stabilize the soil particles. Cover crop residues may be left on the soil surface after harvest to protect the soil from erosion and can be also incorporated as organic amendments. Other potential companion practices for cover crops include no-till and diverse cropping systems.

Crop rotations consist of growing different types of crops (e.g., alternating forage or cereal crops with row crops) in the same field in sequenced growing seasons. A diverse crop rotation involves growing two crops or more in a sequence. The most common crop rotation sequence in Ontario is a corn-soybean-wheat rotation which usually lasts 3-4 years. Crop rotations can be adopted alongside no till and cover crops, for example winter wheat is a common cover crop that is incorporated into many rotations and no till tends to lead to a reduction in input costs and increase in organic matter (Drever et al., 2021).

No-till was defined as where only a no-till drill or no-till planter is used. This is commonly practiced in Ontario alongside crop rotations such as wheat/clover-soy-corn, cover crops and organic amendments.

Soil testing is often used to determine the variability of fertility, organic matter and overall soil health on a farm. It is often done by the farmer, soil labs and/or third parties such as retailers or seed suppliers. Soil tests provide necessary information that can identify areas in need of actions that can be addressed using other BMPs, as well as monitor and track the progress of these BMPs.

Conservation buffers are small areas or strips of land that are taken out of production and are permanently covered in vegetation. They include buffer strips, windbreaks, riparian areas and areas of reforestation. Trees can be intercropped in between crops as well as be integrated as silvopasture to manage simultaneously for tree crops, livestock grazing, and forage.

Organic amendments are materials of plant or animal origin, such as manure, compost, anaerobic digestive and biosolids, that are added to the soil to add nutrients and organic matter and improve its physical and biological properties. Organic amendments, a food source for soil microbes, can increase soil organic matter content, which can improve soil aeration, water retention, and drainage. They optimise nutrient performance, reduce inputs and minimize environmental impacts. Cover crops, crop rotations are also forms of organic amendments.

Out of the 246 participants there are a wide number of possible combinations of practices that a producer may adopt as seen in the table below. Over 15% of the respondents adopt all six of the practices while 2% of the respondents only adopt one practice (Table 4.2).

Table 4.2: Number of farmers adopting practices

Cover Crops	Crop Rotations	No Till	Soil Test	Buffers	Organic Amendments	**Frequency**
1	1	1	1	1	1	**42**
1	1	1	1	0	1	**36**
1	1	1	1	1	0	**16**
1	1	1	1	0	0	**15**
1	1	0	1	1	1	**14**
0	1	1	1	1	0	**7**
0	0	0	1	0	1	**6**
0	1	1	1	0	1	**5**
0	1	1	1	0	0	**5**
1	1	0	1	0	1	**5**
0	1	1	1	1	1	**5**
1	0	0	1	1	1	**5**
0	0	0	1	0	0	**5**

4.3.2 Independent Variables

The selection of independent variables included in this analysis is guided by the BMP adoption literature. This section provides a brief description of the variables included, how they are calculated, and their proposed effects based on previous literature. Their summary statistics are presented in Table 4.3.

Age has been a variable that has had inconsistent effects on adoption according to literature, reporting positive, negative significant and insignificant effect on adoption. In some studies, older producers have been seen to be less likely to adopt BMPs (has been seen to have a negative impact on adoption (Prokopy et al., 2019; Boyer et al., 2018, Gillespie et al., 2007. Older farmers tend to have a shorter planning horizon than younger farmers (Baumgart-Getz et al., 2012). Also, they tend to be less concerned by environment and less inclined to change their practices (Dessart et al., 2019). In contrast, other results suggest that age may positively influence adoption, especially for livestock producers, since these producers often raise livestock as a hobby in retirement and consider maintaining their health of their land as a priority (Kim et al., 2005; Paudel et al., 2016; Savage & Ribaudo, 2013). However, this positive relationship has also been documented in the literature as insignificant (Holley et al., 2020; Hyland et al., 2018), suggesting that BMPs have been developed and promoted for decades allowing older producers to be more familiar with BMPs and have various opportunities to adopt.

Education is another farmer characteristic measured on a scale of a high school diploma to a bachelor’s, Master’s degree or PhD. Education has been seen to have a positive influence on BMP adoption in the literature, with both significant and insignificant effects. Educated producers are significantly more likely to implement BMPs (Knowler & Bradshaw, 2007; Gillespie et al., 2007; Prokopy et al., 2008; Hyland et al., 2018; Kim et al., 2005; Paudel et al., 2008; Savage & Ribaudo, 2013; Liu et al., 2018). Often, a farmer’s ability to understand BMPs and make educated adoption decisions can often be reflected by their level of education. This is often because higher-educated livestock producers have better access to and processing of information, and they are more aware of the negative consequences of unsustainable livestock production, which leads to increased BMP adoption. Though, other studies have also reported the relationship as insignificant (Holley et al., 2020; Baumgart-Getz et al. 2012).

Gender is coded as a dummy variable taking 0 if the producer is male and 1 if female There is a persistent positive link between being a male producer and BMP adoption in the literature, with both significant and insignificant results. Liu et al. (2018) reported that in certain developing nations where women are in charge of farming, being female may enhance the likelihood of adoption. Females exhibited much lower levels of knowledge of BMPs but significantly more favourable attitudes about BMPs and collaboration than men. Male farmers are much more likely than female farmers to adopt BMPs (Gillespie et al., 2007; Hadrich & Van Winkle, 2013), because male producers have more experience with BMPs, which increases the chance of adoption. Other studies have found that this positive link is minor (Hyland et al., 2018), implying that while the majority of producers are male, gender is not a reliable predictor of BMP adoption.

Number of off farm hours plays an important role in the adoption of BMPs. Fulltime producers are likely to be more involved in managing the farm and are driven to increase profits as their farms are their sole source of income. Therefore, if a BMP is seen to be more profitable, they will have incentive to adopt the given practice. (Paudel et al., 2009). Moreover, BMP implementation may be time consuming and intensive, so the more time spent on the farm, the higher the probability that a producer will choose to adopt (Gillespie et al., 2007).

Farm cash receipts has been consistently seen to have a positive effect on BMP adoption (Baumgart-Getz et al., 2012; Boyer et al., 2018; Cooper, 1997; Knowler & Bradshaw, 2007; Liu et al., 2018; Rosenberg & Margerum, 2008). Producers that earn more money from their farms are more likely to adopt because they can afford to invest in BMPs and reap the benefits. The adoption of BMPs requires sufficient financial well-being, especially if new equipment is required. Prokopy et al. (2008), on the other hand, discover insignificant findings, suggesting that a producer's capacity to afford BMPs is not a predictor of their propensity to use them.

Farm Size has been seen to have a considerable favourable influence on BMP uptake (Lamba et al., 2009; Baumgart-Getz et al., 2012; Liu et al., 2018; Prokopy et al., 2008; Soule et al., 2000). Larger farms are more likely to profit from BMP adoption due to economies of scale. Farmers that manage larger farms are more likely to use BMPs because they are more environmentally conscious and have a better understanding of BMPs. They also have more equipment, more income, and more resources to invest in new technology (Liu et al., 2018).

Land tenure plays a role on the adoption of BMPs. From previous literature, it has been seen that **renters** who operate the land for a shorter period of time are less likely to adopt practices that have longer term benefits (Parker et al., 2007; Liu et al., 2017; Deaton et al., 2018). However, it is important to note that the impact of land tenure ownership depends on the length of the tenure (Deaton et al., 2018) as well as, whether the operators are cash renters or share renter. Results found that farmers are less likely to adopt specific conservation practices e.g., cover crops on rented land, however, this relationship diminishes as the length of the contract increases (Deaton et al., 2018). Moreover, Soule et al. (2000) found that share-renters and owner- operators are equally likely to adopt BMPs while cash-renters are significantly less likely to adopt BMPs.

The type of primary product plays a role in the adoption of certain soil health BMPs as different types of BMPs may be more complementary to certain farm types. **Crop producers** are likely to adopt more soil health BMPs as opposed to livestock producers. This is because more of these BMPs may be more applicable to crop production e.g., crop rotations. **Livestock producers** are more likely to adopt BMPs related to manure management and soil compaction (Traxler & Li, 2020). However, literature has suggested that the likelihood of adopting BMPs increases with more diverse production systems (Liu et al., 2018; Prokopy et al., 2008).

Table 4.3: Variable Description and Summary Statistics

Variable	Specification	N. Obs	Mean	SD
Farm Characteristics				
Rent	Proportion of land rented	246	0.25	0.3
Size	Acres (x100)	246	0.52	0.94
Type	0 = Grain & Oilseed	93		
	1 = Livestock	42		
	2 = Other (Hay, fruit, vegetable, greenhouse, sheep)	111		
Location	0 = South & Western Ontario	205		
	1 = Eastern & Central Ontario	41		
Farmer Characteristics				
Female	0 = Male	221		
	1 = Female	25		

Age	0 = 50 years and under	52
	1 = Over 50 years	194
Education	0 = No post-secondary education	84
	1 = post-secondary education	162
Number of hours worked on farm	0 = 0 hours employed off-farm	109
	1 = 1-30 hours employed off-farm	62
	2 = 31 and over hours	75

4.4 Results

4.4.1 Univariate Probit Results

Table 4.4 represents the marginal effects derived from the individual probit analyses of the six-soil health BMPs. Looking at the log likelihood values and the Akaike Information Criterion, of the six probit models, the one analysing soil test adoption had higher values of both, indicating that compared to the other models, it had a better fit to the data. While the model predicting conservation buffer adoption had lower values of both, indicating that compared to the other models it fit the data less than the other models. However, these values did not vary significantly across the other models.

Looking at characteristics impacting **cover crop adoption** and **crop rotations adoption,** female farmers and farmers who had higher levels of education had no significant impact on the adoption of both the BMPs. This finding aligns with certain literature that has documented education to have an insignificant impact on adoption (Baumgart-Getz et al., 2012; Liu et al., 2018). The likelihood of adopting cover crops and crop rotations decreased with every farmer aged over 50 by 0.47 units and 0.764 units respectively. This could be attributed to the fact that these practices provide longer term benefits which may not be realised by older farmers. Size has an insignificant but positive impact on the adoption of both the BMPs while rented land has a negative but insignificant influence on adoption. For every farmer located in Eastern or Central Ontario, the likelihood of adopting cover crops decreases by 0.804 and crop rotations decreases by 0.77 units compared to farmers located in Southern Ontario. This could be due to the shorter growing seasons in Eastern and Central Ontario. Moreover, prime agricultural land in is located south of the Canadian Shield, along the Lake Ontario shoreline, and down into western Ontario. Soils analyses done for southern Ontario have confirmed that over 50% of the land in the central zone qualifies as prime agricultural land (Hoffman & Noble, 1975) as compared to soils in East and Central Ontario. The number of hours worked off the farm and the type of production system had no significant impact on the adoption of either cover crops or crop rotations.

Similar to crop rotation and cover crops adoption, gender and education have no significant influence on **no-till adoption,** while age plays an important role in the adoption decision of no-till. From Table 4.3, for every farmer aged over 50, the likelihood of adopting no-till decreases compared to farmers aged under 50. Land that was rented was seen to have an overall negative influence on the adoption of BMPs, but this was only significant in the adoption of no-till practices. This may be due to the length of the contract and the type of contract. Farmers with longer contracts may be more likely to adopt these practices as they have time to reap benefits. Since no-till practices may involve initial upfront costs, farmers with shorter rental agreements may be disincentivised to adopt these practices (Deaton et al., 2018). However, for every acre increase in rented land, the likelihood of adopting no-till practices increased by 1.3 units. There are economies of scale from using expanding the area of no-till even if the land is rented. Similar to cover crops and crop rotations, farmers in Eastern and Central Ontario are less likely to adopt no till as compared to Southern Ontario farmers. For every farmer who works 31+ hours off the farm, the likelihood of adopting no-till practices decreases by 0.45 units. Though no-till may provide some short-term economic benefits (Sidhu et al., 2010), reduced tillage can also lead to an increase in weed outbreaks leading to and increase in labour needs (Rockstrom et al., 2009). The type of producer is seen to have a significant influence on the adoption of no-till practices, specifically those within the “other” category which consists of vegetable, greenhouse, sheep, fruit crop and tree producers. When compared to grain and oilseed producers, for every increase in “other” producer, the likelihood of no till adoption decreases by 0.52 units. Often a times, the benefits of no-till are highly dependent on the type of crop produced. For example, certain vegetable producers have been seen to produce higher yields under conventional tilling systems, as opposed to no -till. This is particularly true for short seasons crops like broccoli and snap beans (Hoyt, 1999).

Size of the farm had a positive and significant impact on the **adoption of soil tests.** Of the six soil practices, soil testing has the higher upfront costs associated with its adoption. The per unit savings on fertilizer obtained from knowledge of the soil fertility can justify the cost of collection and analysis if summed over a larger area. Livestock and “other” are seen to have a negative influence on the adoption of soil testing as compared to crop producers. Annual soil testing tends to be associated more with crop production while the inorganic and organic fertilizer application rates for livestock producers are often based on nutrient management plans that do not change annually.

For every farmer older than 50, the likelihood of **adopting conservation buffers** increases by 0.5 units. The former set of BMPs enhance soil health and thus the long-term productivity of the land and are thus more likely to be adopted by younger producers. In contrast, the benefits of buffer strips are in terms of reduced off-farm impacts from soil erosion and excess nutrient loading. These benefits to others may be more important to older farmers who are more concerned about a lasting legacy and may not be under the same immediate financial focus as younger producers. Similarly, to the other practices, farmers in central and eastern Ontario are less likely to adopt buffers. Livestock and Other farmers have a significantly positive influence on the adoption of conservation buffers. This can be attributed to the fact that fruit and maple producers rear trees which are also considered to be buffers. Additionally, livestock farmers often use windbreaks and buffers to protect their animals from cold winds and to provide shade so there is an additional reason for their adoption by farmers with animals as opposed to strictly crop producers (Smith et al., 2021).

Location, like the other practices, had an impact on the **adoption of organic amendment adoption.** For every farmer that worked 31 and over hours off the farm, the likelihood of implementing organic amendments decreased by 0.47 units as compared to fulltime farmers. This is because the application of organic amendments is highly labour intensive, and thus these group of farmers may have less time to implement amendments. Moreover, they require more planning and knowledge of use than chemical fertilisers making it more time consuming and less lucrative for farmers compared to their off-farm activities. Livestock and other producers have a significant and positive influence on the adoption of organic amendments. Since manure is an organic amendment, the significant positive impact on organic amendments adoption can be anticipated. This is because the processing and re-suing nutrients from organic wastes from livestock avoids the long-distance transport of these nutrients and reduces barriers to its implementation. The higher use of organic amendments amongst “other” producers may be attributed to the fact that a large proportion of these producers included sheep, vegetable, and fruit producers. Given the growing awareness of local consumers of the dangers of pesticide and chemical residues may favour these producers to adopt more natural and organic forms of fertilisers (Pannell et al., 2014).

Table 4.4: Individual Probits for Adoption of BMPs

	Dependent Variable: Adoption of Soil Health Practice					
	Cover Crop	Crop Rotation	No Till	Soil Test	Buffers	Organic Amendments
Female	-0.073	0.340	0.357	-0.301	-0.020	-0.079
	(0.304)	(0.352)	(0.318)	(0.324)	(0.28)	(0.291)
Postsecondary	0.246	0.281	0.042	0.208	0.192	0.116
	(0.192)	(0.203)	(0.19)	(0.229)	(0.184)	(0.191)
Over 50 years	**-0.469***	**-0.764*****	**-0.551****	-0.234	**0.500****	-0.261
	(0.248)	**(0.291)**	**(0.244)**	(0.287)	**(0.221)**	(0.292)
Size	0.086	0.032	-0.061	**1.526****	-0.215	0.761
	(0.321)	(0.34)	(0.314)	**(0.697)**	(0.293)	(0.522)
Size2	0.003	0.005	0.014	-0.107	0.024	-0.032
	(0.033)	(0.033)	(0.029)	(0.073)	(0.03)	(0.247)
Prop. Rented	-0.169	-0.050	**-0.784***	-0.174	-0.063	-0.162
	(0.423)	(0.458)	**(0.415)**	(0.543)	(0.381)	(0.41)
Size*Rented	1.046	0.998	**1.278****	0.569	0.332	-0.565
	(0.683)	(0.806)	**(0.629)**	(1.573)	(0.455)	(0.578)
East & Central	**-0.804*****	**-0.767*****	**-0.516*****	-0.399	**-0.399***	**-0.587****
	(0.24)	**(0.253)**	**(0.238)**	(0.285)	**(0.233)**	**(0.24)**
1-30 Hours	0.232	-0.350	0.197	0.106	-0.001	-0.0.15
	(0.231)	(0.237)	(0.229)	(0.265)	(0.214)	(0.227)
31+ Hours	-0.176	-0.326	**-0.451****	0.249	-0.084	**-0.469****
	(0.22)	(0.239)	**(0.217)**	(0.272)	(0.209)	**(0.222)**
Livestock	-0.169	0.322	-0.238	**-0.559***	**0.485****	**1.180*****
	(0.262)	(0.305)	(0.264)	**(0.317)**	**(0.244)**	**(0.292)**
Other	0.031	-0.104	**-0.52*****	**-0.395***	**0.716*****	**0.516*****
	(0.195)	(0.202)	**(0.194)**	**(0.238)**	**(0.187)**	**(0.188)**
Constant	0.755**	1.330***	1.272***	0.851**	-0.665**	0.139
	-(0.352)	(0.392)	(0.355)	(0.427)	(0.329)	(0.366)
Observations	246	246	246	246	246	246
Log Likelihood	-137.893	-120.407	-142.368	-93.415	-156.884	-142.398
Akaike Inf. Crit.	301.786	266.814	310.736	212.83	339.768	310.796
Note:						**p<0.1; **p<0.05; ***p<0.01*

4.4.2 Multivariate Probit Results

A multivariate probit analysis was conducted on the 4 highly correlated practices i.e. cover crops, crop rotations, no till and soil testing. These practices were selected due to their positive correlation with one another, indicating that the practices are complimentary rather than substitutes. Results of the full information maximum likelihood estimation of the multivariate probit model are presented in Table 4.5. The farm and farmer characteristics that impact the adoption of multiple BMPs are similar to those of the univariate models. Contrary to previous literature, farmers who were more educated did not seem to have a significant impact on the likelihood of adopting any of the four BMPs. Of the four practices farmers who rented land were less likely to adopt no-till practices. However, this changes, for every acre increase in rental acreage the likelihood of adopting no-till increases by 1.29 units. Farmers living in Eastern and Central Ontario are less likely to adopt three of the four practices as compared to those living in Southern Ontario. For every farmer working more that 31+ hours off the farm, the likelihood of adopting no-till decreases by 0.43 units. "Other" producers such as vegetable producer, fruit and tree producers are less likely to adopt no till practices as compared to grain and oilseed farmers.

Looking at Table 4.6, the results from the multivariate probit analysis are compared with the marginal effects from the individual probits. Based on these, the marginal effects do not vary significantly from the univariate models indicating that the univariate approach suffers minimal bias. This can be attributed to limited unobserved factors which effect the adoption or non-adoption of the four practices. The values of the MVP fall within the ranges of the highest and lowest values of the individual probits.

Table 4.5: Multivariate Probit of Four Interdependent Soil Health Practices

	Cover Crop	Crop Rotation	No Till	Soil Test
Female	-0.07	0.31	0.35	-0.29
	(0.36)	(0.45)	(0.34)	(0.44)
Postsecondary	0.25	0.28	0.04	0.24
	(0.25)	(0.25)	(0.25)	(0.31)
Over 50 years	**-0.46***	**-0.69***	**-0.59****	-0.21
	(0.28)	**(0.35)**	**(0.29)**	(0.44)
Size	0.08	0.04	-0.04	1.31

	(0.72)	(0.97)	(0.59)	(1.29)
Size^2	0.01	-0.01	0.01	-0.11
	(0.34)	(0.74)	(0.24)	(0.82)
Prop. Rented	-0.18	-0.05	**-0.88***	-0.19
	(0.54)	(0.69)	**(0.51)**	(0.94)
Size*Rented	1.01	0.92	**1.29****	0.53
	(1.12)	(1.46)	**(0.61)**	(2.90)
East & Central	**-0.88*****	**-0.89*****	**-0.46***	-0.33
	(0.27)	**(0.29)**	**(0.28)**	(0.34)
1-30 Hours	0.20	-0.41	0.19	0.12
	(0.26)	(0.28)	(0.30)	(0.34)
31+ Hours	-0.16	-0.35	**-0.43***	0.26
	(0.25)	(0.27)	**(0.25)**	(0.40)
Livestock	-0.2	0.28	-0.21	-0.59
	(0.30)	(0.38)	(0.32)	(0.41)
Other	0.03	0.10	**-0.52****	-0.47
	(0.22)	(0.25)	**(0.23)**	(0.32)
Constant	0.65	1.07*	1.46**	0.85
	(0.46)	(0.55)	(0.45)	(0.61)
Observations	246	246	246	246
Log Likelihood		-472.97		
Note:				**p<0.1; **p<0.05; ***p<0.01*

Table 4.6: Marginal Effects of independent probit and MVP

	CC	CR	NT	ST	Buffers	OA	MVP
Farmer Characteristics							
Female	-0.03	0.09	0.12	-0.06	-0.01	-0.03	0.02
Postsecondary	0.08	0.08	0.01	0.04	0.08	0.04	0.06
Over 50 years	-0.14	-0.18	-0.18	-0.04	0.20	-0.09	-0.14
Farm Characteristics							
Size	0.03	0.01	-0.02	0.27	-0.09	0.28	0.08
Size^2	0.00	0.00	0.00	-0.02	0.01	-0.01	-0.01
Prop. Rented	-0.06	-0.01	-0.28	-0.03	-0.03	-0.06	-0.10
Size*Rented	0.35	0.28	0.46	0.10	0.13	-0.21	0.29
East & Central	-0.30	-0.26	-0.20	-0.08	-0.16	-0.23	-0.21
1-30 Hours	0.08	-0.11	0.07	0.02	-0.04	-0.01	0.00
31+ Hours	-0.06	-0.10	-0.17	0.04	-0.03	-0.18	0.06
Farm Type							
Livestock	-0.06	0.08	-0.09	-0.12	0.19	0.33	-0.05

Other	0.01	-0.03	-0.19	-0.07	0.28	0.19	-0.07

4.5 Conclusion

The aim of this chapter was to jointly identify the determinants of BMP adoption through a multivariate probit model. The model diagnostic revealed jointness in four of the six practices i.e., cover crops, crop rotation, no till and soil testing. This is because the decisions to adopt BMPs are significantly positively correlated. In other words, the probability of adopting one BMP increases the probability of adoption of other BMPs. The implication is that there is significant synergy in decision to adopt modern technologies in multiple crops. Policymakers must take practice complementarities into account if they want to strengthen programs and policy to encourage broader adoption of conservation practices,

Among the host of socio-economic factors, location had the largest impact on the adoption of the practices. Larger farms positively influence the adoption of soil testing. Older farmers are less likely to adopt majority practices save for conservation buffers. Livestock producers are more likely to adopt conservation buffers and organic amendments, but less likely to adopt soil testing when compared to crop producers. The influence of these variables did not vary significantly across the univariate and multivariate probit models. Older farmers, renters, operating in Eastern and Central Ontario, working more than 31 hours off the farm and being an “other” producer have a negative influence on the adoption of the joint practices.

5 Barriers and Motivations

5.1 Introduction

Understanding which motivations or barriers drive various groups of farmers to adopt certain practices is critical for guiding policies and programs to enhance their adoption rates. This chapter delves into this by employing probit analysis to determine which motivations and barriers are significant to what groups of producers. The reasons for adopting and not adopting a given practice are broken up into four main groups i.e. economic, environmental, agronomic, social and other. Economic reasons pertain to those that increase or decrease productivity such as reducing inputs, higher costs etc. Environmental reasons pertaining to resilience such as increasing soil health, uncertainty about environmental benefits. While agronomic reasons include factors that directly influences yield e.g. reduced pest disease, increased fertilizer requirements. Social reasons are those related to peer pressure, or recommendations by advisers while other includes those that selected "other" as reasons. Tables 1 and 2 show the variables and their frequencies under each of the groupings

Table 5.1: Variable groupings of motivations

Motivations		Environmental	Economic	Agronomic	Social	Other
CC	To improve water retention and infiltration	52				
CC	To reduce erosion and run-off	82				
CC	To improve soil health (e.g., increase organic matter, reduce soil compaction)	128				
CC	To attract pollinators	5				
CR	To maintain or improve soil health	135				
NT	To improve soil health (e.g., retain moisture, reduce erosion, reduce compaction)	132				
NT	To reduce run-off	66				
ST	To improve soil health and organic matter	62				
ST	To reduce nutrient run-off	20				
CB	To improve soil health	18				
CB	To reduce soil erosion	88				
CB	To reduce nutrient run-off	40				
CB	To increase biodiversity and habitat (e.g., pollinators, beneficial predators)	69				
OA	To improve soil health	128				
OA	To reduce soil erosion	11				
		1036				
CC	To increase economic returns		19			
CR	To increase profits		47			
NT	To reduce fuel costs		76			
NT	To increase economic returns		95			
ST	To increase economic returns		84			
CB	To increase economic returns		24			
OA	To reduce input costs		64			
OA	To increase economic returns		67			
			476			

CC	To improve weed control	30		
CC	To reduce diseases	2		
CC	To reduce fertilizer requirements and input costs for the following year	36		
CC	To improve yields	55		
CR	To reduce disease and pest risk	107		
CR	To reduce fertilizer requirements	35		
CR	To improve yields	113		
CR	Management reasons (e.g., to spread out the workload over time)	45		
CR	Because this is how we've always done it	5		
NT	To improve yields	28		
ST	To improve yields	93		
ST	To determine variable rate requirements for fertilizer application	52		
ST	To optimize nutrient usage	106		
OA	We need to get rid of our manure	43		
OA	To reduce use of synthetic fertilizers	86		
		836		
CC	Peer pressure (e.g., because neighbours are using them)		1	
CR	Peer pressure (e.g., because neighbours use diverse crop rotations)		1	
CR	Recommended by advisors		3	
			5	
CC	Other			8
CR	Other			12
NT	Other			20
ST	Other			4
CB	Other			7
OA	Other			6
				57

Table 5.2: Variable groupings of barriers

Barriers		Economic	Environmental	Agronomic	Social	Other
CC	Additional cost	21				
CC	Uncertainty/risk	14				
CR	Lower profits	13				
CR	Lack of evidence on economic benefits of diverse crop rotations	5				
CR	Uncertainty about economic benefits of more diverse crop rotations	11				
NT	Cost of equipment	38				
NT	Lower profits relative to conventional tillage	8				
NT	Uncertainty about economic benefits of these practices	9				
ST	Cost of soil testing	12				
CB	The cost of establishing these areas	12				
OA	Cost	25				
OA	No economic benefit	9				
		177				
NT	Delays in planting due to slow soil warming and/or drying		22			
NT	Land on your farm is poorly drained		10			
CB	Uncertainty about environmental benefits of these areas		12			
CB	There is no soil erosion issue on my farm		21			
OA	Uncertainty about the trace metals and other potential contaminants		26			
			91			
CC	Lack of return			15		
CC	Lack of knowledge about cover crops and their potential benefits			6		
CC	Additional time requirements			15		
CC	Additional machinery requirements			16		
CC	Management complexity			17		
CR	I don’t have the equipment needed to manage other crops in the rotation			27		
CR	Increased herbicide use			2		

NT	Lack of knowledge about no-till and strip till techniques and practices	11		
NT	Increased disease risk	4		
NT	Increased herbicide use	16		
NT	Too complex to manage	9		
NT	Because we've always used conventional tillage	9		
ST	Uncertainty about benefits of regular soil testing	5		
ST	Time requirements	11		
ST	Inconvenience	4		
CB	It takes land out of production which I believe reduces my profits	36		
CB	There is no unprofitable or fragile land on my farm	39		
CB	They were already installed before I brought my farm	27		
OA	Uncertainty about the benefits of organic amendments	29		
		298		
CC	Nobody else around me uses cover crops		4	
CR	Nobody else around me uses diverse crop rotations		0	
NT	Nobody else around me uses no-till or strip till		4	
ST	Nobody else around me regularly conducts soil testing		2	
CB	Nobody else around me regularly conducts soil testing		2	
			12	
CC	Other			17
CR	Other			12
NT	Other			15
ST	Other			8
CB	Other			8
OA	Other			20
				80

5.2 Probit results of individual Motivations and Barriers

5.2.1 Cover Crops

Agronomic motivations such as improving weed control are less likely to motivate older farmers to adopt cover crops as compared to younger farmers (Table 5.3), but more likely to motivate farmers who work less hours on the farm. These farmers are also more likely to adopt cover crops to reduce their input and fertilizer costs as opposed to fulltime farmers. This may be because they may be more profit driven than fulltime farmers. Farmers who fall within the “Other” producer type are less likely to use cover crops to increase their yields as grain farmers because many of these farmers could be greenhouse producers who may not rely on cover crops to increase their yields.

Environmental motivations such as improving water retention and infiltration are more likely to motivate males than females, larger farm as opposed to smaller farms, and grain producers over livestock producers. This may be because larger farms may need to use more water to irrigate their crops, thus may employ cover crops to reduce irrigation needs and increase water retention. Livestock farmers depend less on irrigation needs as compared to grain and oilseed farmers. Soil health was a motivation that was selected by all cover crop farmers indicating that it was an important motivation for adopting cover crops across all farmer segments. Economic motivations did not play a significant role to any group of farmers.

Table 5.3: Cover Crop Motivations

	Agronomic			*Environmental*		*Economic*
VARIABLES	Improve Yields	Reduce input & fert cost	Improve Weed control	Improve water retention & infiltration	Reduce erosion and run-off	Increase economic returns
Female	-0.492	0.558	0.283	**-0.786***	0.251	0.357
	(0.412)	(0.367)	(0.407)	**(0.456)**	(0.352)	(0.436)
Postsecondary	-0.314	-0.078	-0.291	0.076	0.033	0.422
	(0.240)	(0.257)	(0.293)	(0.247)	(0.228)	(0.375)
Over 50	0.403	0.415	**-0.595***	-0.184	-0.444	-0.217
	(0.304)	(0.319)	**(0.356)**	(0.302)	(0.271)	(0.388)
Size	-0.744	-0.320	-0.462	**0.498***	0.123	0.333
	(0.645)	(0.318)	(1.481)	**(0.292)**	(0.264)	(0.365)
Prop. Rented	-0.532	-0.059	0.458	-0.342	0.295	-0.391
	(0.410)	(0.433)	(0.476)	(0.415)	(0.376)	(0.583)
East & Central	0.294	0.261	-0.308	0.279	-0.173	-0.592
	(0.344)	(0.360)	(0.436)	(0.349)	(0.324)	(0.527)

1-30 Hours	-0.421	0.020	**0.838****	-0.101	-0.017	0.451
	(0.290)	(0.307)	**(0.327)**	(0.283)	(0.266)	(0.334)
31+ Hours	-0.026	**0.481***	-0.285	-0.343	-0.102	-0.441
	(0.282)	**(0.292)**	(0.388)	(0.290)	(0.262)	(0.419)
Livestock	-0.331	0.224	0.324	**-0.605***	0.089	0.150
	(0.322)	(0.345)	(0.423)	**(0.366)**	(0.309)	(0.429)
Other	**-0.618****	-0.020	0.164	-0.093	0.126	0.082
	(0.241)	(0.259)	(0.291)	(0.240)	(0.228)	(0.322)
Constant	0.208	-1.171***	-0.421	-0.343	0.045	-1.535***
	(0.447)	(0.450)	(0.577)	(0.426)	(0.394)	(0.579)
Observations	**160**	**160**	**160**	**160**	**160**	**160**

Looking at barriers to adopting cover crops (Table 5.4), females are more likely to not adopt cover crops due to lack of return as compared to males. Higher educated farmers are more likely to not adopt cover crops due to their complexity and costs as opposed to less educated farmers. Lack of return and additional time play significant barriers for large farms, while costs were a significant barrier to renters. This may be expected as renters may prioritise making profits thus would reduce their costs as much possible. Larger farms may have more land and crops to manage as compared to smaller farms, they may be constrained by resources such as time.

Table 5.4: Cover crop barriers

	Economic			*Agronomic*		
VARIABLES	Additional costs	Uncertainty / risk	Lack of return	Additional time requirements	Additional machine requirements	Management complexity
Female	-	0.519	**2.433***	-0.019	0.595	-
		(0.803)	**(1.424)**	(0.839)	(0.826)	
Postsecondary	**0.908***	0.481	0.168	-0.018	-0.251	**0.924***
	(0.548)	(0.557)	(0.808)	(0.491)	(0.512)	**(0.533)**
Over 50	-0.982	0.937	-	-	-0.401	-0.534
	(0.732)	(0.804)			(0.840)	(0.751)
Size	-1.311	-0.450	**11.515***	**7.503****	-1.242	-2.173
	(1.204)	(1.146)	**(6.184)**	**(3.597)**	(1.675)	(1.800)
Prop. Rented	**2.523****	1.692*	0.562	-3.191	-1.605	0.598
	(1.074)	(1.016)	(1.394)	(2.056)	(1.060)	(0.918)
East & Central	-0.183	0.327	-1.836	-0.383	0.574	-0.426
	(0.612)	(0.578)	(1.556)	(0.699)	(0.602)	(0.619)
1-30 Hours	-0.298	-1.238	0.144	0.096	0.146	0.157
	(0.616)	(0.831)	(1.156)	(0.724)	(0.615)	(0.600)
31+ Hours	-0.394	-0.002	0.846	0.481	-0.123	-0.742
	(0.580)	(0.548)	(1.266)	(0.649)	(0.579)	(0.596)
Livestock	0.115	0.529	-1.167	-0.766	-0.388	0.282
	(0.582)	(0.610)	(1.442)	(0.788)	(0.643)	(0.587)
Other	0.131	-0.589	-0.743	0.231	-0.659	0.441

	(0.532)	(0.542)	(0.918)	(0.536)	(0.523)	(0.509)
Constant	-0.311	-2.038*	-3.982**	-1.684**	0.373	-0.439
	(1.088)	(1.152)	(1.962)	(0.819)	(1.207)	(1.124)
Observations	49	52	45	45	52	49

5.2.2 Crop Rotations

High yields were a significant motivation selected by male farmers, larger farms and more educated farmers, but less likely chosen as a motivation by farmers located in eastern and central Ontario (Table 5.5). Reducing fertilizer requirements was significant for less educated farmers and farmers in eastern and central Ontario. Management reasons such as to spread the workload over time was significant motivation for younger farmers, larger farms and livestock and "other" farmers. Livestock farmers may be motivated to incorporate crop rotations in order to diversify their operations. Improving soil health played a big role in motivating larger farmers while increasing profits was significant motivator for farmer who worked 1-30 hours on the farm.

Table 5.5: Crop rotation motivations

	Agronomic				*Environmental*	*Economic*
VARIABLES	Reduce disease and pest	Improve yields	Reduce fertiliser	Management reasons	Improve Soil Health	Increase profits
Female	0.280	**-0.896*** **	-0.932	0.236	-0.107	-0.654
	(0.310)	**(0.346)**	(0.628)	(0.335)	(0.323)	(0.426)
Postsecondary	-0.145	**0.452***	**-0.589*** **	0.006	0.013	0.338
	(0.225)	**(0.237)**	**(0.271)**	(0.258)	(0.244)	(0.274)
Over 50	-0.060	-0.329	0.473	**-0.515***	0.399	-0.285
	(0.262)	(0.288)	(0.381)	**(0.273)**	(0.271)	(0.291)
Size	-0.395	**0.846*** **	-0.482	**1.329*** **	**1.264*** **	0.590*
	(0.268)	**(0.307)**	(0.413)	**(0.657)**	**(0.630)**	(0.312)
Prop. Rented	0.106	-0.677*	-0.628	0.137	-0.480	0.025
	(0.370)	(0.405)	(0.522)	(0.420)	(0.395)	(0.419)
East & Central	0.211	**-1.003*** **	**1.076*** **	-0.529	0.460	0.083
	(0.300)	**(0.330)**	**(0.373)**	(0.341)	(0.335)	(0.324)
1-30 Hours	0.136	-0.360	-0.293	0.053	-0.054	**0.670*** **
	(0.263)	(0.278)	(0.376)	(0.309)	(0.284)	**(0.300)**
31+ Hours	0.042	-0.219	0.045	0.095	-0.295	0.288
	(0.245)	(0.260)	(0.313)	(0.285)	(0.259)	(0.286)
Livestock	-0.180	-0.160	0.412	**0.689*** **	0.208	-0.397
	(0.278)	(0.299)	(0.359)	**(0.304)**	(0.295)	(0.335)
Other	0.045	-0.165	0.192	**0.440***	0.133	0.017
	(0.221)	(0.234)	(0.299)	**(0.265)**	(0.236)	(0.254)
Constant	0.284	0.453	-0.927*	-1.154**	-0.088	-1.263***

	(0.392)	(0.417)	(0.510)	(0.468)	(0.438)	(0.466)
Observations	172	172	172	172	172	172

Larger farmers were less likely to select lower profits as a barrier compared to smaller farms (Table 5.6). This maybe because they already experience economies of scale to spread across the cost of implementation while smaller farmers may be more focused on growing their profits. This was also a significant barrier for farmers who are "other" producer. Farmer who work more hours off the farm were less likely to select "lack of evidence of economic benefits" as a barrier compared to full time farmers. This may be because they may be less invested in their farms as fulltime farmers who depend on their farms for income and would care more about increasing their revenues. Social reasons were a significant barrier for farmer who work more off-farm hours but were less likely to be a barrier for "other farmers". Part time farmers may have less time to experiment and trial practices, and thus may rely on their neighbours' experiences.

Table 5.6: Crop Rotation Barriers

	Economic		*Social*	*Other*
VARIABLES	Lower profits	Lack of evidence of economic benefits	Nobody else around me uses them	Other
Female	-1.030	-	-	1.695
	(0.988)			(1.103)
Postsecondary	0.977	0.124	-0.043	-1.003
	(0.653)	(0.799)	(0.445)	(0.684)
Over 50	0.679	-0.903	-0.460	-1.130
	(0.900)	(1.189)	(0.755)	(0.938)
Size	**-5.802****	-1.596	-0.943	2.099
	(2.522)	(1.906)	(1.084)	(1.391)
Prop. Rented	0.552	0.927	-1.001	0.641
	(1.030)	(1.326)	(0.814)	(1.040)
East & Central	-0.688	-0.049	0.241	0.732
	(0.822)	(0.802)	(0.503)	(0.718)
1-30 Hours	-0.464	**-2.177*****	**0.947***	-0.514
	(0.728)	**(0.834)**	**(0.539)**	(0.687)
31+ Hours	-0.344	**-1.673****	0.013	-1.291
	(0.683)	**(0.840)**	(0.548)	(0.855)
Livestock	1.080	-1.426	-0.165	0.703
	(1.119)	(0.947)	(0.717)	(0.856)
Other	**1.725****	-3.938	**-0.734***	-0.728
	(0.681)	(2.617)	**(0.442)**	(0.731)
Constant	-1.793	1.761	0.362	-0.162
	(1.298)	(1.738)	(0.945)	(1.224)

Observations	55	51	51	55

5.2.3 No Till

Livestock farmers and no-till farmers were less likely to select "improving yields" as a motivation for adopting no-till (Table 5.7). Environmental reasons such as reducing run-off were significant motivators for farmers older than 50 and who worked 1-30 hours off the Highly educated farmers were less likely to choose reducing fuel costs as a motivation but were more incentivized by increasing their economic returns. This may be because reducing costs may not necessarily mean that they are generating revenues, but increasing returns shows a net positive benefit. Whilst female farmers were less likely to select economic returns as motivations for adopting no till practice, larger farmers were more motivated by this.

Table 5.7: No-till Motivations

	Agronomic	*Environmental*		*Economic*	
VARIABLES	Improve Yields	Improve soil health	Reduce run-off	Reduce fuel costs	Increase economic returns
Female	0.351	0.152	-0.144	-0.029	**-1.289*** **
	(0.389)	(0.375)	(0.347)	(0.329)	**(0.376)**
Postsecondary	0.063	-0.050	0.331	**-0.568** **	**0.621** **
	(0.311)	(0.270)	(0.251)	**(0.242)**	**(0.254)**
Over 50	-0.351	0.290	**0.863*** **	-0.057	0.050
	(0.360)	(0.300)	**(0.318)**	(0.286)	(0.320)
Size	0.209	0.024	0.226	0.088	**0.688***
	(0.850)	(0.343)	(0.322)	(0.304)	**(0.356)**
Prop. Rented	0.441	0.368	-0.233	0.376	0.284
	(0.517)	(0.513)	(0.460)	(0.437)	(0.470)
East & Central	**-0.986***	-0.208	-0.262	0.350	-0.231
	(0.563)	(0.335)	(0.346)	(0.317)	(0.350)
1-30 Hours	0.403	0.390	**0.573** **	0.274	-0.176
	(0.348)	(0.316)	**(0.279)**	(0.272)	(0.282)
31+ Hours	0.515	-0.014	0.324	-0.154	-0.050
	(0.349)	(0.292)	(0.288)	(0.281)	(0.299)
Livestock	**-1.063** **	-0.450	0.341	-0.006	0.109
	(0.517)	(0.314)	(0.302)	(0.294)	(0.314)
Other	-0.149	-0.160	0.093	-0.223	-0.283
	(0.282)	(0.273)	(0.247)	(0.242)	(0.252)
Constant	-0.942	0.550	-1.600***	0.090	-0.237
	(0.592)	(0.457)	(0.458)	(0.419)	(0.455)
Observations	149	149	149	149	149

Female farmers and part time farmers are more likely to not adopt no-till due to the uncertainty of benefits. Whilst, economic reasons such as cost play a significant barrier to "other" producers (Table 5.8).

Table 5.8: No Till Barriers

VARIABLES	*Economic*		*Agronomic*
	Cost	No economic benefit	Uncertainty about benefits
Female	-	-	**1.404****
			(0.668)
Postsecondary	0.127	-0.415	-0.160
	(0.405)	(0.536)	(0.394)
Over 50	0.021	0.632	0.411
	(0.615)	(0.939)	(0.531)
Size	1.916	0.230	2.206
	(1.683)	(2.128)	(1.382)
Prop. Rented	-0.446	0.754	0.133
	(0.717)	(0.877)	(0.652)
East & Central	-0.697	1.006	-0.157
	(0.509)	(0.655)	(0.423)
1-30 Hours	0.346	-0.982	**0.904***
	(0.507)	(0.681)	**(0.466)**
31+ Hours	0.547	-0.519	**0.872****
	(0.455)	(0.579)	**(0.445)**
Livestock	0.205	0.809	0.500
	(0.820)	(0.882)	(0.748)
Other	**0.680***	0.735	0.147
	(0.354)	(0.482)	(0.341)
Constant	-1.275	-1.905	-1.935**
	(0.910)	(1.225)	(0.842)
Observations	67	67	73

5.2.4 Soil Testing

Female farmers are more likely to soil test to determine variable rate requirements but less likely to soil test to increase returns (Table 5.9). Higher educated farmers are less likely to use soil tests to reduce run-off. While larger farmers are more likely to employ soil tests to optimize their nutrient usage. Renters are motivated to use soil tests to determine their nutrient rates as they are motivated to optimize their production, while part time farmers are less incentivized to use soil test to improve yields.

Table 5.9: Soil test Motivations

VARIABLES	*Agronomic* Improve Yields	Determine variable rate req.	Optimise nutrient usage	*Environmental* Improve soil health	Reduce run-off	*Economic* Increase returns
Female	-0.454	**0.548***	-0.093	-0.179	0.307	**-1.098*****
	(0.338)	**(0.329)**	(0.322)	(0.342)	(0.425)	**(0.402)**
Postsecondary	-0.185	-0.009	-0.261	-0.295	**-0.784*****	-0.189
	(0.207)	(0.227)	(0.215)	(0.216)	**(0.282)**	(0.211)
Over50	0.131	0.228	-0.263	-0.318	-0.049	-0.259
	(0.250)	(0.282)	(0.253)	(0.255)	(0.378)	(0.259)
Size	0.043	-0.377	**1.465*****	-0.186	-0.035	0.514
	(0.229)	(0.261)	**(0.512)**	(0.257)	(0.372)	(0.507)
Prop. Rented	-0.169	**0.703***	-0.308	-0.066	-0.143	0.008
	(0.334)	**(0.359)**	(0.343)	(0.345)	(0.500)	(0.345)
East & Central	0.139	-0.121	-0.221	0.206	0.102	0.003
	(0.266)	(0.303)	(0.267)	(0.272)	(0.387)	(0.271)
1-30 Hours	**-0.447***	-0.048	0.173	0.194	-0.175	0.041
	(0.245)	(0.266)	(0.250)	(0.260)	(0.343)	(0.251)
31+ Hours	-0.198	-0.014	0.073	0.299	-0.516	-0.213
	(0.229)	(0.252)	(0.238)	(0.239)	(0.366)	(0.239)
Livestock	-0.105	-0.223	0.435	0.009	0.167	0.301
	(0.272)	(0.301)	(0.285)	(0.282)	(0.395)	(0.280)
Other	-0.173	-0.220	-0.191	-0.255	0.309	0.183
	(0.207)	(0.225)	(0.209)	(0.218)	(0.303)	(0.212)
Constant	0.205	-0.757*	-0.021	-0.017	-0.775	-0.050
	(0.367)	(0.412)	(0.399)	(0.374)	(0.527)	(0.403)
Observations	191	191	191	191	191	191

From table 5.10, there was only one barrier that had a significant influence on soil testing non-adopters. More educated farmers were less likely to choose inconvenience as a reason for why they chose not to adopt soil tests, as they may understand the benefits for using soil tests.

Table 5.10: Soil Test Barriers

VARIABLES	*Economic* Cost	*Agronomic* Uncertainty of benefits	Inconvenience
Female	-0.365	1.672	-
	(1.005)	(1.184)	
Postsecondary	1.173	-1.329	**-2.175***
	(0.748)	(0.823)	**(1.170)**
Over 50	-0.213	-2.134	5.239

	(1.277)	(1.580)	(5.264)
Size	0.225	1.528	0.741
	(3.870)	(4.626)	(5.457)
Prop. Rented	-1.154	1.710	1.206
	(1.283)	(1.358)	(2.039)
East & Central	-0.584	-0.741	1.451
	(0.818)	(1.008)	(1.772)
1-30 Hours	-0.703	-0.228	-0.624
	(0.792)	(0.850)	(1.599)
31+ Hours	**-1.999****	0.095	-0.414
	(0.890)	(0.789)	(0.959)
Livestock	0.817	-0.382	-2.001
	(0.903)	(1.003)	(3.808)
Other	0.475	1.125	1.510
	(0.621)	(0.823)	(1.076)
Constant	0.232	1.466	-7.023
	(1.596)	(1.710)	(5.587)
Observations	32	32	29

5.2.5 Conservation Buffers

Looking at Table 5.11, higher educated farmers are less likely to choose environmental motivations to explain their adoption decision. Farmers older than 50 are less likely to use buffers to increase their returns, while farmers located in eastern and central Ontario are more likely to be motivated to use buffers to reduce runoff.

Table 5.11: Conservation Buffer Motivations

	Environmental				*Economic*
VARIABLES	Improve soil health	Reduce erosion	Reduce run-off	Biodiversity & Habitat	Increase economic returns
Female	-	**-0.677***	-0.181	0.262	0.052
		(0.412)	(0.482)	(0.410)	(0.488)
Postsecondary	**-0.645***	0.006	**-0.678****	0.324	-0.483
	(0.345)	(0.283)	**(0.283)**	(0.268)	(0.316)
Over 50	-0.730	-0.116	0.411	0.352	**-0.762***
	(0.532)	(0.426)	(0.459)	(0.408)	**(0.446)**
Size	1.059	0.635	0.600	-0.362	0.538
	(1.051)	(0.788)	(0.372)	(0.776)	(0.420)
Prop. Rented	-0.651	-0.202	0.076	0.837*	-0.492
	(0.681)	(0.469)	(0.492)	(0.480)	(0.565)
East & Central	0.060	-0.007	**0.743****	0.441	-0.022
	(0.434)	(0.322)	**(0.329)**	(0.308)	(0.389)
1-30 Hours	0.333	-0.247	0.445	0.262	0.313
	(0.401)	(0.329)	(0.340)	(0.313)	(0.364)
31+ Hours	0.175	0.178	0.491	0.527	-0.442

	(0.513)	(0.399)	(0.407)	(0.393)	(0.483)
Livestock	-0.628	0.234	0.047	-0.346	-0.189
	(0.721)	(0.404)	(0.394)	(0.379)	(0.466)
Other	0.457	-0.152	-0.067	0.044	0.119
	(0.368)	(0.282)	(0.289)	(0.276)	(0.330)
Constant	-0.570	0.628	-1.053*	-0.737	-0.189
	(0.737)	(0.610)	(0.594)	(0.590)	(0.612)
Observations	112	125	125	125	125

The barrier "no unprofitable land was significant and negative across many farmer groups i.e. renters, farmers who worked more that 30 hours off their farm, livestock and other producers (Table 5.12). Farmers in eastern and central Ontario are likely to adopt buffers as they believe there is no soil erosion on their farms.

Table 5.12: Conservation Buffer Barriers

	Agronomic		*Environmental*	*Economic*
VARIABLES	Takes land out of production	Already installed	No soil erosion	No unprofitable land
Female	-0.676	0.191	0.312	-0.335
	(0.486)	(0.452)	(0.427)	(0.479)
Postsecondary	0.025	0.382	-0.414	-0.371
	(0.293)	(0.341)	(0.318)	(0.303)
Over 50	-0.017	0.119	-0.532	-0.269
	(0.326)	(0.365)	(0.333)	(0.347)
Size	0.041	0.657	0.716	0.635
	(0.706)	(0.926)	(0.911)	(0.690)
Prop. Rented	-0.583	0.398	-0.294	**-0.880***
	(0.490)	(0.524)	(0.547)	**(0.521)**
East & Central	-0.060	-0.185	**0.553***	0.114
	(0.334)	(0.380)	**(0.336)**	(0.358)
1-30 Hours	0.071	-0.012	-0.244	-0.219
	(0.352)	(0.393)	(0.396)	(0.367)
31+ Hours	-0.279	0.196	-0.109	**-0.581***
	(0.331)	(0.365)	(0.348)	**(0.339)**
Livestock	0.024	-0.513	-0.037	**-0.708***
	(0.382)	(0.462)	(0.380)	**(0.398)**
Other	0.284	-0.059	-0.357	**-0.840****
	(0.313)	(0.333)	(0.340)	**(0.341)**
Constant	-0.357	-1.324**	-0.047	0.532
	(0.550)	(0.638)	(0.576)	(0.567)
Observations	104	104	104	104

5.2.6 Organic Amendments

Female producers are more likely to adopt organic amendments to get rid of manure but less likely to adopt them to reduce their fertilizer use (Table 5.13). Farmers over 50 and livestock producers are less likely to be motivated by economic reasons such as increasing economic returns, while renters prioritize these reasons. Livestock and other producers are more likely to adopt organic amendments to get rid of their manure.

Table 5.13: Organic Amendment Motivations

VARIABLES	*Environmental*	*Economic*		*Agronomic*	
	Improve soil health	Reduce input cost	Increase economic returns	Reduce fertiliser use	Get rid of manure
Female	-0.327	0.180	-0.001	**-0.650***	**0.684***
	(0.395)	(0.351)	(0.358)	**(0.362)**	**(0.388)**
Postsecondary	-0.181	-0.078	0.030	-0.012	-0.332
	(0.296)	(0.241)	(0.243)	(0.239)	(0.273)
Over 50	0.185	0.175	**-0.509***	-0.258	0.295
	(0.316)	(0.289)	**(0.289)**	(0.283)	(0.324)
Size	-0.248	-0.355	0.671	-0.082	0.857
	(0.280)	(0.271)	(0.570)	(0.584)	(0.693)
Prop. Rented	0.381	**0.809***	0.561	-0.570	-0.464
	(0.517)	**(0.417)**	(0.431)	(0.430)	(0.524)
East & Central	0.120	-0.344	-0.333	0.269	0.506
	(0.387)	(0.356)	(0.361)	(0.336)	(0.356)
1-30 Hours	0.306	0.013	-0.129	0.043	-0.554
	(0.351)	(0.278)	(0.288)	(0.280)	(0.343)
31+ Hours	-0.098	0.193	-0.349	0.001	-0.174
	(0.316)	(0.281)	(0.290)	(0.283)	(0.321)
Livestock	-0.438	-0.120	**-0.662****	-0.385	**1.495*****
	(0.363)	(0.305)	**(0.315)**	(0.304)	**(0.376)**
Other	-0.193	-0.353	-0.276	-0.328	**0.732****
	(0.325)	(0.263)	(0.262)	(0.262)	**(0.350)**
Constant	1.197**	-0.192	0.260	0.786*	-1.566***
	(0.499)	(0.424)	(0.459)	(0.456)	(0.545)
Observations	145	145	145	145	145

Females and farmers who work more hours off the farm are more likely to choose “uncertainty about benefits” as barrier, while “other “producers are more likely to not adopt organic amendments due to additional costs they may accrue.

Table 5.14: Organic Amendment Barriers

	Economic		*Agronomic*
VARIABLES	Cost	No economic benefit	Uncertainty about benefits
Female	-	-	**1.404****
			(0.668)
Postsecondary	0.127	-0.415	-0.160
	(0.405)	(0.536)	(0.394)
Over 50	0.021	0.632	0.411
	(0.615)	(0.939)	(0.531)
Size	1.916	0.230	2.206
	(1.683)	(2.128)	(1.382)
Prop. Rented	-0.446	0.754	0.133
	(0.717)	(0.877)	(0.652)
East & Central	-0.697	1.006	-0.157
	(0.509)	(0.655)	(0.423)
1-30 Hours	0.346	-0.982	
	(0.507)	(0.681)	**(0.466)**
31+ Hours	0.547	-0.519	**0.872****
	(0.455)	(0.579)	**(0.445)**
Livestock	0.205	0.809	0.500
	(0.820)	(0.882)	(0.748)
Other	**0.680***	0.735	0.147
	(0.354)	(0.482)	(0.341)
Constant	-1.275	-1.905	-1.935**
	(0.910)	(1.225)	(0.842)
Observations	67	67	73

5.3 Summary of significant motivations and barriers across farmer groups

Looking at the farmer characteristics, results found that female farmers were less likely to be motivated by economic reasons as compared to males, specifically those that adopted crop rotations, no till and soil tests. Of the barriers, “uncertainty about benefits” was significant for female no till and organic amendment non-adopters. Highly educated farmers were more likely to choose improving yields and returns as motivations for adopting a practice, but less likely to be motivated by environmental reasons such as reducing run-off and improving soil health. Of the six practices, only two i.e. cover crops and soil tests had results that were significant for higher educated non-adopters. For cover crops, the barriers included additional costs and complexity. Educated soil test non-adopters were less likely to choose “inconvenience” as a barrier. This may be because they understand the benefits of soil testing but may not be able to afford implementing the practice. There were no barriers that were significant for farmers older than 50. However, of the motivations, older farmers were less likely to choose increasing economic returns as opposed to younger farmers. Older farmers that adopted no -till did so to reduce run-off. Older farmers may prioritize environmental over economic reasons, as they may value leaving behind a more sustainable planet, as opposed to younger farmers.

Many of the motivations that were significant for large farms were related to increasing returns and optimizing on farm productivity. For example, larger farms that incorporated crop rotations did so to improve yields, management reasons e.g. spreading the workload over time, and improving soil health. Barriers followed similar patterns, larger farms who chose not to adopt cover crops did so due to lack of returns and additional time requirements. Since large farms have more crops and land to manage, they may be very focused on generating more economies of scale i.e. producing more with fewer resources. Renters had no significant barriers but were motivated to adopt practices to make the most of the land they rented (motivations included reducing costs and optimizing nutrients). Farmers located in Eastern and Central Ontario were less likely to be motivated by improving yields. Interestingly, these farmers that adopted conservation buffers were motivated to reduce soil erosion, while those that did not believed that they had no soil erosion issues on their farms. Farmers in these regions used conservation buffers to mitigate the impacts of erosion. Farmers who work more hours off the farm or are part-time are more likely to choose practices to optimize their returns while many of the barriers that hindered adoption were related to the uncertainty of benefits that practices provided.

Of the motivations, there were only 3 practices that derived significant results for livestock producers. Livestock producers adopted crop rotations due to management reasons such as spreading workload over time, organic amendments to get rid of manure and no till to improve yields. This was similar for “other producer” (those that produce vegetable and fruit crops, operate greenhouses and rear sheep). However, barriers preventing “other” producers from adopting practices were mainly economic e.g. reduced profits, increased costs.

5.4 Conclusion

A farmer's choice of whether or not to adopt a BMP is a personal one that is greatly impacted by their own behavioural traits. It is essential to have an understanding of what motivates a farmer to select practices, and what barriers hinder their adoption to design policies and programs that can target different famer segments. From the above results, to enhance adoption rates amongst female and part time producers, policies could invest more in education and information awareness among these groups. Building stronger business cases for the BMPs could be effective in encouraging fruit, greenhouse and tree producers to adopt practices which also rings true for higher educated and larger farms. From the results, it is clear that policies and programs cannot be one-size fit all, rather need to be tailored to each farmer and account for heterogeneity between farming segments.

6 Conclusion

6.1 Introduction

This chapter reviews the motivation and contribution of the study, summarizes the methods used and provides an overview of the main findings. The policy implications, limitations of the study, and suggestions for future research are also presented.

6.2 Review of Motivation

As climate change and food security pressures rise, healthy soils are critical to build prosperous and resilient farms and communities. Beneficial management practices (BMPs) are perceived as measures to enhance environmental quality, including the improvement of soil health, and consequently are being promoted by government efforts such as through the new Agricultural Policy Framework, Living Labs, Canadian Agricultural Policy. The effective design and implementation of programs to enhance BMP adoption requires assessing current levels of use as well as understanding the factors affecting both the uptake by adopters, and the barriers by non-adopters.

Although the adoption literature is growing, there is limited research on the specific barriers and incentives driving the implementation of soil health practices in Ontario. Previous research on BMP adoption has focused on the role farm-level characteristics have with the respect to the rate of adoption. While these studies often account for the effects of readily measurable farm characteristics (such as farm size or managerial experience) on innovation, few have focused on assessing qualitative motivations and barriers to adoption. Moreover, much of the published research focused on BMP adoption is either carried out in developing countries, Europe, United States and a few conducted in China. While those that have been conducted in Canada are often conducted in localized areas such as watersheds as opposed to looking at the province as a whole (Liu & Brouwer, 2022).

The aim of this research is to understand farmers' preferences for certain BMPs, as well as the variables that influence them, and compare them to previous experiences. The novelty of this study, as compared to others conducted in Canada, is that there is a focus on the interrelatedness of the soil health practices. Relatively few studies have focused on the adoption of multiple soil BMPs at a given time. This research therefore aims to provide contextual richness to current knowledge and adds to the understanding of BMP adoption for Ontario farmers and improve policies and programs to support the adoption of BMPs in Canada. It does this by:

1) To build a picture of the current rates of adoption of soil health BMPs amongst Ontario farmers and the demographics of adopters and non-adopters
2) To assess the socio-economic factors driving adoption of individual and multiple soil health practices.
3) To understand what motivates or hinders various farmer segments from adopting these soil health practices

6.3 Main Findings

This research focuses on the inter-related adoption of six soil health BMPs: cover crops, crop rotations, reduced tillage, soil testing, windbreaks, buffer strips and organic amendments. Of the six soil health BMPs, soil testing had the highest rate of adoption while conservation buffers had the least. The majority of farmers (73%) implemented 4 or more BMPs as the use of practices such as a rotation with winter wheat, cover cropping and no-till tend to be positively correlated.

Using a multivariate probit model to control for interdependency, the results show that the conditional marginal effects influencing adoption are influenced combination of practices. Of the six practices, four were significantly positively correlated i.e. cover crops, crop rotation, no till and soil testing. This joint adoption is particularly important in the context of multi-practice programs which incentivize farmers to change their behaviour. However, looking at the individual probits and the multivariate probit, the farm and farmer characteristics influencing the adoption of the practices did not vary significantly.

The location of the farm, type of production system and the age of the farmer were seen to have a significant impact on the adoption of many of the BMPs. Variables such as size of the farm, whether the farmer rented the land, and the number of hours worked off the farm significantly influenced the adoption decision of some of the practices while had insignificant influences on others. Contrary to literature, variable such as education had a positive but insignificant impact on the likelihood of adopting any of the six BMPs. This heterogeneity in characteristics is essential to the implementation of policies aimed at enhancing adoption. By understanding the variations of preferences across farmer groups or segments may enable policies to effectively target groups. Moreover, groups who have already adopted certain practices may be targeted by promoting the complementarities between practices that have not been adopted, thus enhancing overall environmental benefits of conservation programs.

Environmental reasons, specifically related to soil health, were the driver for adoption of five of the six soil health BMPs except for conservation buffers. The result suggests adopting farmers understand the need for preserving their soils and place more importance on soil health than economic or social reasons. However, the biggest barriers indicated by non-adopters include the additional costs of BMP implementation, the knowledge required to use the BMP, and the uncertainty of how certain BMPs benefit farmers and soils. Encouraging use among non-adopters may require monitoring and promoting the benefits of soil health along with understanding the heterogeneity that influences the relative net advantage of a BMP for a given farmer.

Looking at the motivations and barriers across farming groups, results found that females are less motivated by economic reasons and their biggest barriers tend to be uncertainty of benefits. Highly educated farmers are more driven by economic reasons and tend to select costs and complexity as barriers to adopting the practices. Older farmers had no significant barriers, but prioritized environmental motivations for adoption as opposed to economic. Large farmers are concerned about efficiency and using the least resources to generate the most yields and returns, thus many of the motivations and barriers for adopting the six practices were centered around this. Renters tended to prioritize reducing costs and increasing returns. This was also true for part time farmers who also selected uncertainty as reasons that hindered their adoption.

6.4 Policy Implications

The findings from this thesis indicate that broad targeting policies to promote the adoption of soil health practices are unlikely to be successful. The findings are aimed at supporting program level recommendations that are tactfully target farmers and take their preferences as individual producers into account when determining adoption incentives.

The adoption of BMPs have been seen to be an effective solution in the sustainability of Canada's agricultural sector, making it an important exercise for academics and policymakers to understand the elements that promote the uptake of new technology (AAFC, 2017; Statistics Canada, 2016). Additionally, industry stakeholders around the nation are constantly looking for information about fresh developments in agriculture that might boost agribusinesses' production, profitability, and competitiveness (Mitchell, Weersink and Erickson, 2017). Therefore, knowledge of the factors that influence farmers' decisions to adopt new practices may be useful in developing and putting into practice policies and strategies that will promote the general adoption of BMPs.

According to Canales et al. (2020), farmers will probably embrace conservation strategies over time at a faster rate if they take use of the complementarities between activities. Canales et al. (2020) discovered that for farmers who had already embraced no-tillage, the time to adopt cover crops was decreased by up to 70%, boosting the environmental effects of this practice over time. Adoption of various conservation strategies is influenced by a variety of variables, including geography and involvement in conservation programs. The possibility of farmers adopting numerous conservation measures is increased when they take part in incentive-based conservation programs like the ACS Living Laboratories and APF.

In order to increase the additionality of programs and promote greater adoption of conservation practices and environmental stewardship across the landscape, it is crucial that policymakers take practice complementarities into consideration (Pannell and Classen 2020). Estimates of additionality from studies of cover crop incentive programs range up to 98 percent (Fleming et al. 2018). By creating programs that build on the sequential adoption of practices that have complementarities, policymakers and agencies, like the Agri and Agri-Food Canada, may be able to take use of practice complementarities to have greater environmental benefits and involvement. Policymaking, extension, and outreach initiatives that encourage conservation adoption by leveraging practice complementarities must also take into consideration geography and the environment in which adoption is occurring. For instance, extension and outreach specialists should concentrate their outreach and programming efforts on integrating livestock producers and regions with a high concentration of livestock production in order to encourage the adoption and use of manure usage and technology (e.g., feedlots).

By identifying adoption incentives that are most likely to motivate Ontario farmers to adopt BMPs, federal and provincial organizations may be prepared to establish programs and strategies targeted at supporting the spread of soil health practices across the Canadian agricultural sector. More specifically, institutions such as AAFC, Greenbelt foundation and Farmers for Climate Solutions, may use the findings to introduce effective interventions to increase the uptake of BMPs. Policymakers are given extra information that can not only enhance uptake but may also increase the net benefits associated with adoption by pinpointing the precise incentives that induce farmers to embrace and employ new practices on the farm. For instance, policymakers may minimize the cost of adoption while also sending signals to potential adopters about the need for a particular BMP by offering subsidies to farmers wishing to use new practice on the farm.

The insights from this study can help guide Canada's range of policy and programming tools used to promote soil health which include EFPs and assessment and planning tools, private sector assessment and certification schemes, grants, education and extension services; business risk management tools and market based mechanisms. Planning and assessment tools such as the EFP provide detailed assessments of soil health and prescription to improve fields. Private sector tools such as Fertiliser Canada's 4R Nutrient Stewardship program emphasize principles of right source, right rate, right timing, right place to optimize nutrient performance, reduce inputs and to minimize environmental impacts. Grants and cost-share programs are principal mechanisms through which the federal and provincial governments of Canada encourage resolving environmental concerns in agriculture are grants to farmers. Extension and education play an important role in increasing adoption of BMPs. With the overall shrinking of government services over the last few decades, government extension services have been significantly decreased. With growing involvement of industry-led groups and private firms, the usage of provincial extension agents and researcher publications has ceased to be the primary extension tool. BRM programs are designed for the important purpose of farm income stabilization. In order to protect the environment, some methods, such as retiring farmland to permanent cover as grassland, marsh, or forest, entail removing land from agricultural production. The Ecological Goods and Services (EGS) method, which is based on the idea of natural capital, aims to value the "services" provided by ecosystems. For these tools and programs to be effective they need to offer the appropriate support and signals to improve BMP adoption rate and foster system changes at the production level.

In order for Canadians to meet the challenge and opportunity before them, major policy change is required. Through a systems approach that encourages the interconnection of required policies and initiatives, climate and agriculture policy must assist many more farmers in making soil health their own priority. No one activity will result in the necessary transformation. The pieces of the solution are awareness, readily available information, guidance, farmer-to-farmer learning, technology, and improved financial incentives. Governmental strategic planning and collaboration with business and other stakeholders are also important. To do this, soil health needs to be prioritised in the next APF, and key stakeholders need to collaborate to develop a soil health strategy. To enhance and share soil health knowledge amongst stakeholders, a key network can be formulated through which information, resources and knowledge can be shared. The results from this research build on developing the understanding of socio-economic characteristics and their impacts on BMP uptake, as well as, farmer segments and their needs. This then allows policies to provide individualised support to farmers and help them choose practices for their specific production systems, regions, climate and soil characteristics. From the findings, there is a need to enhance farmer to farmer learning opportunities, and improve communications focused on the benefits. This can be done through extension services provided by impartial representatives who are acquainted with the community. Field demonstrations and self-testing opportunities are also relevant, as are workshops and short seminars on BMPs. Numerous studies have found that sharing information with peers is one of the most effective strategies to encourage farmers to embrace new techniques or technologies (Ontario Cover Crop Strategy, 2019). One of the most effective methods for changing farmer behaviour was found as discussions with a producer who employs BMP and farm visits, especially one-on-one visits (Gagné et al., 2018).

6.5 Limitations of the Study and Areas for Future Research

First, the use of cross-sectional data constrained the study that was done. It offered a comprehensive study for a single point in time, but ideal future research in this field would use a panel dataset that spans several years. The possible sequential character and temporal dynamics of the adoption process throughout time cannot be fully understood by the methodologies in use today. Producers must often spend up to many years evaluating, testing, overcoming obstacles, and effectively integrating conservation methods into their present cropping system. While this framework offers a way to utilize cross-sectional adoption studies more effectively, more dynamic longitudinal approaches are required to fully comprehend the complexities and intricacies of the adoption process itself, including the complementarities between conservation practices in different agricultural systems.

A second limitation of this study stems from the choice of questioning used to capture producers' barriers and incentives. The survey was designed such that farmers who adopted a practice were only asked about their motivations for adopting, while only non-adopters provided reasons for their non-adoption. By asking adopters to provide insights to any barriers they may have faced when adopting may provide critical information for policy makers and extension officers to address these barriers and ease the adoption process for adopters. Likewise, had non-adopters answered questions related to motivations for adopting a certain practice would help programs in targeting these groups and increase adoption rates. By doing so, further methods such as propensity score matching could have been utilized to match adopter and non-adopters based on their farm and farmer characteristics, then determine which barriers and incentives played more significant roles in adoption for different farmer groups.

Thirdly, there could be the potential of omitted variable bias. Although this study controls for many factors of adoption, there are variables that are not included in this research that may have influenced the adoption decision. For example, there were no variables that captured producers' risk attitudes. This has been seen to be a critical variable in past literature for predicting BMP adoption (Prokopy et al., 2019; Dessart et al., 2019; Liu et al., 2018; Knowler & Bradshaw, 2007). Farmers that are more risk-tolerant typically use more BMPs (Prokopy et al., 2019; Dessart et al., 2019). Farmers' risk tolerance affects their actions because they may be concerned about yield loss or believe they lack the essential abilities for BMP success (Liu et al., 2018). Dessart et al. (2019) found that risk-seeking farmers tend to perceive lower financial risk on BMP adoption than risk-averse farmers. Moreover, other variables such as social interaction effects, time preferences, and prior adoption experience to explain producers' adoption decision may be included. Incorporating these factors into this research may allow future researchers to improve the accuracy of the results.

Fourthly, some groups of Ontario farmers might not have access to the internet, which would make them less likely (or unable) to reply to online surveys (Hambly and Chowdury, 2018). As a result, since only producers with internet connection are able to take the survey, there may be self-selection bias in the results. This analysis may also be subject to self-selection bias since producers who often interact with agri-food sector information sources may be more likely to learn about the study's online poll. However, O'Chieng (2015) observes that as internet use grows more pervasive among Canadians, restrictions linked to possible bias in internet-based surveys are becoming less of a worry. Another potential of self-selection bias may arise when farmers were asked why they chose to adopt certain practices. For example, in chapter 2, all 147 respondents using cover crops noted improving soil health as one of the three reasons for implementation. This may be due to the fact that some farmers may perceive themselves to care more for the environment and social good, but often at times when tasked with real life choices may prioritize economic gains over environmental stewardship.

The limits listed above serve as an example of how crucial it is to recognize any limitations that can limit the application of academic research. The concerns raised imply that when drawing general conclusions from this thesis's findings, care should be used. The main problem with the sample of farmers chosen for this study is that generalizing statistical findings to bigger groups may be challenging. According to Kraemer and Blasey (2016), greater sample sizes often boost the efficacy of significance testing by narrowing the distribution of test statistics. Nguyen and Landais (2017) go on to say that if a sample size is too small, it could be challenging to generate results that are useful and can be extrapolated to bigger populations. Furthermore, the results of this study may not be totally representative of Ontario's agriculture industry, according to probable bias in the data. To overcome this, researchers could target larger populations and farmers from other parts of Canada. While Ontario makes a major contribution to Canada's agricultural sector, incorporating farmers from other provinces might help researchers determine whether adoption rates, preferences for adoption, and barriers and incentives vary among farmers in various parts of the nation.

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Appendices

Appendix A: Survey Questions

General Farm Questions

1. Do you have a farm business registration number?
   - Yes
   - No
2. In which region, county or district is your farm operation located? (If more than one, select the one in which the majority of your operation is located.)
   - *[Dropdown: list of census divisions]*
3. What is the total land area (in acres) of your farm operation? Please enter the approximate number of acres, broken down between owned land and rented/leased land:
   - *[Three text boxes with labels "Owned", "Rented/Leased", and "Total"]*
4. What are the primary commodity types produced on your farm? Select up to three commodity types, ranking them based on the share of farm cash receipts that they generate for your farm (e.g., select '1' for the commodity type that generates the highest amount of farm cash receipts).
   - Grain and oilseed crops (e.g., corn, soybeans, wheat, edible beans)
   - Field grown vegetable crops (e.g., carrots, onions, tomatoes)
   - Fruit crops (e.g., berries, orchard crops such as apples or peaches)
   - Greenhouse crops (e.g., vegetables, flowers)
   - Hay or other perennial forage crops
   - Other crops: *[Text box where answer can be entered]*
   - Beef cattle (e.g., cow-calf, feedlot)
   - Pigs (e.g., farrow-to-finish, farrow-to-wean, finishing)
   - Poultry
   - Dairy
   - Other livestock: *[Text box where answer can be entered]*
   - Other: *[Text box where answer can be entered]*
5. What do you think of when you hear the phrase "Best Management Practice"?
   - Science-based recommended practices
   - Government trying to influence farmers
   - Practical, economical practices
   - "City people trying to tell farmers what to do"
   - Other
     - *[Text box where answer can be entered]*

Cover Crops

1. In the past five years have you used cover crops?
   - Yes

- No
- Not applicable to my farm operation (e.g., I only grow hay or other perennial crops)

[If Yes, go to next question. If No, go to question 5. If not applicable, go to next section.]

2. Do you plan to continue to use cover crops?
    - Yes
    - No
    - Uncertain

[If 'Yes', go to next question. If 'No' or 'Uncertain', go to question 5.]

3. On approximately how many acres do you typically use cover crops? Please provide acreage amounts for both owned land and rented/leased land:
    - *[Two text boxes with labels "Owned" and "Rented/Leased"]*
4. Which of the following are the main reasons that you use cover crops? Please rank up to three reasons.
    - *[For each of the options below, use a dropdown list with the numbers 1-3]*
    - To improve yields
    - To improve weed control
    - To improve water retention and infiltration
    - To reduce erosion and run-off
    - To reduce fertilizer requirements and input costs for the following year
    - To improve soil health (e.g., increase organic matter, reduce soil compaction)
    - To reduce diseases
    - To attract pollinators
    - To increase economic returns
    - Peer pressure (e.g., because neighbours are using them)
    - Recommended by advisors
    - Other

[Go to next section.]

o*[Text box where answer can be entered]*

[The remainder of questions are for respondents that answered 'No' to the first question and 'No' or 'Uncertain' to the second question.]

5. Which of the following are the main reasons that you do not use (or are no longer using) cover crops? Please rank up to three reasons.
    - *[For each of the options below, use a dropdown list with the numbers 1-3]*
    - Additional cost
    - Lack of return
    - Additional time requirements

- Additional machinery requirements
- Management complexity
- Lack of knowledge about cover crops and their potential benefits
- Uncertainty/risk (related to economics, impacts on current rotation or farm practices)
- Potential reduction in BRM program payments
- Nobody else around me uses cover crops
- Other
    - *[Text box where answer can be entered*

6. which of the following would increase the likelihood of using cover crops on your farm? Please rank up to three options.
    - Workshops or demonstrations on how to use cover crops
    - One-on-one advice or assistance from a professional agronomist
    - Better knowledge of agronomic and environmental benefits of cover crops
    - More evidence of long-term benefits, such as increased yields
    - Financial incentives, such as government cost-share program
    - Other
        - o*[Text box where answer can be entered]*

[If financial incentives option was selected in the previous question, go to next question. Otherwise, go to next section.]

7. What is the government cost-share amount (percentage of costs) you would need to start using cover crops?
    - *[Box where number can be entered]*

Diverse Crop Rotations

1. Do you use diverse crop rotations (i.e., more than 2 crops in your main rotation)?
    - Yes
    - No
2. Which crops do you regularly include in your main rotation (i.e., those that you always or almost always include in the rotation)? Select all that apply.

- Grains, oilseeds, edible beans
    - Corn
    - Soybeans
    - Winter wheat
    - Spring wheat
    - Barley
    - Oats
    - Rye
    - Mixed grain
    - Canola
    - White beans
    - Coloured beans
    - Other grains, oilseeds, edible beans: *[Text box]*
    - Hay
    - Other forage crop: *[Text box]*
- Vegetables
    - Potatoes
    - Sweet corn
    - Peas
    - Tomatoes
    - Green beans
    - Carrots
    - Pumpkins, squash
    - Onions
    - Peppers
    - Cabbage
    - Cucumbers
    - Asparagus
    - Broccoli
    - Other: *[Text box]*

[If answer to question 1 was ‘Yes’, go to next question; if ‘No’, go to question 4.]

3. Which of the following are the main reasons that you use diverse crop rotations? Please rank up to three reasons.
    - *[For each of the options below, use a dropdown list with the numbers 1-3]*
    - To reduce disease and pest risk
    - To improve yields
    - To maintain or improve soil health
    - To reduce fertilizer requirements
    - To increase profits
    - Management reasons (e.g., to spread out the workload over time)
    - Peer pressure (e.g., because neighbours use diverse crop rotations)
    - Recommended by advisors
    - Because this is how we’ve always done it
    - Other
        - [Text box where answer can be entered]
        -
    - Other
        - [Text box where answer can be entered]

[The following questions are for respondents that selected two or fewer crops in the first question.]

4. Which of the following are the main reasons that you do not include more crops in your rotation? Please rank up to three reasons.
    - Lower profits
    - Lack of evidence on economic benefits of diverse crop rotations
    - Increased herbicide use
    - Uncertainty about economic benefits of more diverse crop rotations
    - I don’t have the equipment needed to manage other crops in the rotation
    - Nobody else around me uses diverse crop rotations
    - I don’t grow annual crops
    - Other
        - *[Text box where answer can be entered]*
5. Which of the following would increase the likelihood of including more crops in your rotation? Please rank up to three options.
    - Workshops or demonstrations on crop rotations
    - One-on-one advice or assistance from a professional agronomist
    - Better evidence of economic benefits of diverse crop rotations
    - Other farmers recommending the practice
    - Financial incentives
    - Other
        - *[Text box where answer can be entered]*

Reduced Tillage / Residue Management

1. What types of tillage and planting equipment do you typically use? For each crop in the table below, please provide approximate percentages of acres for which you typically use each
equipment category (for example, if you grow corn and you typically use conventional tillage for half your corn acres and reduced tillage for the other half, enter ‘50%’ in the ‘Conventional tillage’ column and 50% in the ‘Reduced tillage’ column):
    - *[Create matrix of text boxes with crops by tillage equipment category. Crops included in the matrix are those selected from the list in the first question from the diverse crop rotation section (will vary for each participant depending on their selections). Tillage equipment categories include: 1. Conventional tillage (mouldboard plow, chisel plow, ripper, heavy disc); 2. Reduced tillage (all acres worked but fewer passes or lighter equipment used, such as cultivator or light disc); 3. Strip till (not all surface is worked); 4. No-till (only no-till drill or no-till planter is used). Respondent will enter percentages for the categories that apply for each of their crops.]*

[If no-till is selected for at least one crop, go to question 2. If no-till is not selected but strip-till is selected for at least one crop, go to question 4. Otherwise, go to question 7.]

2. Which of the following are the main reasons that you use no-till practices? Please rank up to three reasons.
    - *[For each of the options below, use a dropdown list with the numbers 1-3]*
    - To improve yields
    - To improve soil health (e.g., retain moisture, reduce erosion, reduce compaction)
    - To reduce run-off
    - To reduce fuel costs
    - To increase economic returns
    - Other (e.g., because neighbours or other farmers use no-till practices)
        - *[Text box where answer can be entered]*

[If other tillage categories were selected in question 1 (in addition to no-till), go to next question. Otherwise, go to next section.]

3. Which of the following are the main reasons that you do not use no-till on more of your crop land? Please rank up to three reasons.
    - Doesn’t work well for all my crops
    - My land needs to be tilled occasionally
    - Delays in planting due to slow soil warming and/or drying
    - Some land on your farm is poorly drained
    - Increased disease risk

- Uncertainty about economic benefits of using only no-till
- Other
    - *[Text box where answer can be entered]*

Go to next section.]

]Which of the following are the main reasons that you use strip till practices? Please rank up to three reasons.

- *[For each of the options below, use a dropdown list with the numbers 1-3]*
- To improve yields
- To improve soil health (e.g., retain moisture, reduce erosion, reduce compaction)
- To reduce run-off
- To reduce fuel costs
- To increase economic returns
- Other (e.g., because neighbours or other farmers use strip till practices)
    - *[Text box where answer can be entered]*

4. Which of the following are the main reasons that you do not use no-till practices? Please rank up to three reasons.
    - Cost of equipment
    - Lower profits relative to conventional tillage
    - Lack of knowledge about no-till techniques and practices
    - Increased herbicide use
    - Delays in planting due to slow soil warming and/or drying
    - Land on your farm is poorly drained
    - Increased disease risk
    - Uncertainty about economic benefits of these practices
    - Too complex to manage
    - Nobody else around me uses no-till
    - Because we've always used conventional tillage
    - Other
        - *[Text box where answer can be entered]*
5. Which of the following would increase the likelihood of using no-till on your farm? Please rank up to three options.
    - Workshops or demonstrations on no-till techniques
    - One-on-one advice or assistance from a professional agronomist
    - Better evidence of economic benefits of no-till
    - Other farmers recommending the practice
    - Financial incentives, such as rebates for no-till planters
    - Other
        - *[Text box where answer can be entered]*

[The following questions are for respondents that did not select no-till or strip till for any crops in the first question.]

6. Which of the following are the main reasons that you do not use no-till or strip till? Please rank up to three reasons.
    - Cost of equipment
    - Lower profits relative to conventional tillage
    - Lack of knowledge about no-till and strip till techniques and practices
    - Increased herbicide use
    - Delays in planting due to slow soil warming and/or drying
    - Land on your farm is poorly drained
    - Increased disease risk
    - Uncertainty about economic benefits of these practices
    - Too complex to manage
    - Nobody else around me uses no-till or strip till
    - Because we've always used conventional tillage
    - Other
        - *[Text box where answer can be entered]*
7. Which of the following would increase the likelihood of using no-till or strip till on your farm? Please rank up to three options.
    - Workshops or demonstrations on no-till and strip till techniques
    - One-on-one advice or assistance from a professional agronomist
    - Better evidence of economic benefits of no-till and strip till
    - Other farmers recommending the practice
    - Financial incentives, such as rebates for no-till planters
    - Other
        - *[Text box where answer can be entered]*

Soil Testing

1. Do you conduct laboratory soil testing?
    - Yes
    - No
    - Not applicable to my farm operation

[If Yes, go to next question. If No, go to question 8. If not applicable, go to next section.]

2. Who does the soil sampling?
    - You (or another owner or employee of your farm)
    - Retailer (local seed or fertilizer suppliers who provide this as a paid or in-kind service)

- Consultant (someone contracted financially to soil sample, either as a standalone service or part of a complete soil testing service)
- Soil lab (the lab you pay for soil testing also provides sampling services for a fee)

3. What do you test for? Select all that apply.
    - Soil fertility
    - Soil organic matter
    - Soil health
4. On average, how frequently do you conduct soil testing on land that you own?
    - Every year
    - Every other year
    - Every 3 years
    - Every 4-5 years
    - Less than once every 5 years
5. On average, how frequently do you conduct soil testing on land that you rent or lease?
    - Every year
    - Every other year
    - Every 3 years
    - Every 4-5 years
    - Less than once every 5 years

[If answers to either 4 or 5 are three years or less, go to question 6, otherwise go to question 7.]

6. Which of the following are the main reasons that you regularly conduct soil testing? Please rank up to three reasons.
    - *[For each of the options below, use a dropdown list with the numbers 1-3]*
    - To improve yields
    - To improve soil health and organic matter
    - To determine variable rate requirements for fertilizer application
    - To optimize nutrient usage
    - To reduce nutrient run-off
    - To increase economic returns
    - Other (e.g., because neighbours or other farmers conduct soil testing)
        - *[Text box where answer can be entered]*

[Go to next section.]

7. Which of the following are the main reasons that you do not regularly conduct soil testing? Please rank up to three reasons.
    - Cost of soil testing
    - Time requirement
    - Uncertainty about benefits of regular soil testing
    - Inconvenience
    - Nobody else around me regularly conducts soil testing

- Other

a*[Go to question 9.]*

[The following questions are for respondents that answered ‘No’ to the first question.]

8. Which of the following are the main reasons that you do not conduct soil testing? Please rank up to three reasons.
    - Cost of soil testing
    - Time requirement
    - Uncertainty about benefits of regular soil testing
    - Inconvenience
    - Nobody else around me conducts soil testing
    - Other
        - *[Text box where answer can be entered]*
9. Which of the following would increase the likelihood of regularly conducting soil testing on your farm? Please rank up to three options.
    - Workshops or demonstrations on soil testing
    - One-on-one advice or assistance from a professional agronomist
    - Better evidence of economic benefits of soil testing
    - Other farmers recommending the practice
    - Financial incentives
    - Other
        - *[Text box where answer can be entered]*
10. If a cost-share program for soil testing was implemented, what is the minimum cost-share percentage (e.g., 20%, 50%) you would need to conduct soil testing?
    - *[Box where number can be entered]*

Windbreaks / Buffer Strips / Afforestation (other tree planting) / Naturalized Areas

1. Have you retired any non-profitable or fragile cropland or changed the use of land within individual fields by establishing a windbreak, buffer strip, wind strip, other treed area, perennial forage crop or naturalized area (e.g., wetland or grassland)? Please select all that apply.
    - Windbreak
    - Buffer strip
    - Wind strip
    - Afforestation (other tree planting)
    - Perennial forage crop
    - Other naturalization (e.g., restoring or establishing wetlands or grasslands)
    - None of the above

[If any of the first six options is selected, go to next question. If 'None of the above' is selected, go to question 3.]

2. Which of the following are the main reasons for retiring your cropland and establishing these areas? Please rank up to three reasons.
   - *[For each of the options below, use a dropdown list with the numbers 1-3]*
   - To improve soil health
   - To reduce soil erosion
   - To reduce nutrient run-off
   - To increase biodiversity and habitat (e.g. pollinators, beneficial predators)
   - To increase economic returns
   - Other (e.g., because neighbours or other farmers did so)
     - *[Text box where answer can be entered]*

[Go to next section.]

[The following questions are for respondents that answered 'None of the above' to the first question.]

3. Which of the following are the main reasons that you have not retired any non-profitable or fragile cropland by establishing such areas? Please rank up to three reasons.
   - The cost of establishing these areas
   - It takes land out of production which I believe reduces my profits

- They were already installed before I bought my farm
- There is no soil erosion issue on my farm
- There is no unprofitable or fragile land on my farm
- Uncertainty about environmental benefits of these areas
- Nobody else around me has established these areas
- I don't own any land
- Other
    - *[Text box where answer can be entered]*

4. Which of the following would increase the likelihood of putting in a windbreak, buffer strip, wind strip, trees or other naturalized area on your farm? Please rank up to three options.
    - Workshops or demonstrations on these practices
    - One-on-one advice or assistance from a professional agronomist
    - Better evidence of economic benefits of these practices
    - Other farmers recommending these practices
    - Financial incentives, such as government cost-share programs
    - Other
        - *[Text box where answer can be entered]*

5. If you selected financial incentives in the previous question, what is the minimum cost-share percentage (e.g., 20%, 50%) you would need from the government to consider retiring your unprofitable or fragile cropland through establishing one of these areas?
    - *[Box where number can be entered]*

Organic Amendments

Organic amendments are materials of plant or animal origin, such as manure, compost, anaerobic digestate and biosolids, that are added to the soil to add nutrients and organic matter and improve its physical and biological properties. Organic amendments, a food source for soil microbes, can increase soil organic matter content, which can improve soil aeration, water retention, and drainage.

1. Do you add organic amendments to your soil?
    - Yes
    - No
    - Not applicable to my farm operation

[If Yes, go to next question. If No, go to question 6. If not applicable, go to next section.]

2. Which organic amendments do you typically add to your soil? Select all that apply.
    - Liquid manure

- Solid manure
- Compost
- Biosolids
- Processed biosolids
- Liquid anaerobic digestate
- Solid anaerobic digestate
- Other
    - *[Text box where answer can be entered]*

3. How frequently do you add organic amendments to your soil?
    - Every year
    - Every other year
    - Every 3 years
    - Every 4-5 years
    - Less than once every 5 years
4. On approximately what percent of your land do you add amendments? Please provide figures in percentages for both owned land and rented/leased land:
    - *[Two text boxes with labels "Owned" and "Rented/Leased"]*
5. Which of the following are the main reasons for adding organic amendments? Please rank up to three reasons.
    - *[For each of the options below, use a dropdown list with the numbers 1-3]*
    - To improve soil health
    - To reduce soil erosion
    - To reduce use of synthetic fertilizers
    - To reduce input costs
    - To increase economic returns
    - We need to get rid of our manure
    - Other (e.g., because neighbours or other farmers add organic amendments)
        - *[Text box where answer can be entered]*

[Go to next section.]

[The following questions are for respondents that answered 'No' to the first question.]

6. Which of the following are the main reasons that you do not add organic amendments? Please rank up to three reasons.
    - Cost
    - No economic benefit
    - Uncertainty about benefits of organic amendments
    - Uncertainty about the trace metals and other potential contaminants
    - Other
        - *[Text box where answer can be entered]*
7. Which of the following would increase the likelihood of adding organic amendments to your soil? Please rank up to three options.
    - Workshops or demonstrations on organic amendments

- One-on-one advice or assistance from a professional agronomist
- Better evidence of economic benefits of organic amendments
- Other farmers recommend the practice
- Financial incentives
- Other
    - *[Text box where answer can be entered]*

Additional General Farm Questions

1. Do you classify yourself as a full-time farmer?
    - Yes
    - No
2. How many hours per week (on average) do you work off the farm?
    - 0 hours
    - 1-10 hours
    - 11-30 hours
    - Over 30 hours
3. What is your gender?
    - Male
    - Female
    - Other
4. What is your age?
    - Under 20 years
    - 20-29 years
    - 30-39 years
    - 40-49 years
    - 50-59 years
    - 60-69 years
    - 70-79 years
    - 80 years and older
5. What is your highest level of education?
    - Did not finish high school
    - Graduated from high school
    - Some post-secondary education (did not complete diploma/degree)
    - Completed college diploma or certificate
    - Completed university degree (e.g., B.A., B.Sc.)
    - Completed graduate degree (e.g., M.A., M.Sc., Ph.D.)
6. How long have you been a decision maker on your farm?
    - Less than 5 years
    - 5-9 years
    - 10-19 years

- 20-29 years
- 30-39 years
- 40-49 years
- 50 years or more

7. Within which of the following ranges are your average annual total gross farm cash receipts?
    - Under $10,000
    - $10,000 - $24,999
    - $25,000 - $49,999
    - $50,000 - $99,999
    - $100,000 - $249,999
    - $250,000 - $499,999
    - $500,000 - $999,999
    - $1,000,000 - $1,999,999
    - $2,000,000 and over
8. When you make changes in farm production practices, what is generally the primary source of information you use to make these decisions? Please select up to 3 sources.
    - *[For each of the options below, use a dropdown list with the numbers 1-3]*
    - Neighbours
    - Relatives or friends
    - Respected local farmers
    - Input suppliers
    - Seed companies
    - Implement dealers
    - Certified crop advisors
    - Academics (university researchers)
    - OMAFRA staff
    - OMAFRA publications
    - Research publications
    - Social media
    - Other
        - o*[Text box where answer can be entered]*