The Impacts of Non-Legume Cover Crop Use on Crop Yields and Profit Margins in Ontario

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ABSTRACT

THE IMPACTS OF NON-LEGUME COVER CROP USE ON CROP YIELDS AND PROFIT MARGINS IN ONTARIO

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Cover crops are widely discussed in academic literature prompting the use of government payments to increase their use. However, without knowledge of the private net benefits of cover crops on yield and profits, the policy tools used may be ineffective and create barriers to adoption. Knowledge about the private net benefits justifies government incentives and can inform adoption decisions. This thesis addresses this gap by evaluating the impacts of four non-legume cover crops on yield and profit margin ratios in Ontario using data from a long-term cover crop experiment. ANOVA and regression analyses were used to isolate the effect of the tested cover crops. The results demonstrated significant heterogeneity in the cover crop effects depending on the cash crop type, i.e. distinguishing the effects on grain and oilseed crops compared to vegetable crops. The heterogeneity found should be reflected in the policy options for increasing cover crop use.

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List of Abbreviations

AAFC	Agriculture and Agri-Food Canada
BMP	Beneficial Management Practice
CSP	Conservation Stewardship Program
ECO	Environmental Commissioner of Ontario
EQIP	Environmental Quality Incentive Program
IISD	International Institute for Sustainable Development
IPES-Food	International Panel of Experts on Sustainable Food Systems
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
OPVG	Ontario Processing Vegetable Growers
osr	Oilseed Radish
osr+rye	Cover Crop Mixture of Oilseed Radish and Rye
no-cc	No cover crop
UoG	University of Guelph

Chapter 1 Introduction

This introductory chapter outlines the motivation, background, purpose and objectives of this thesis. Cover crops are a widely discussed agricultural beneficial management practice (BMP) and many scientists and government policy makers are interested in promoting the use of this strategy in Ontario. This chapter explains why cover crops have received so much attention in recent years, as well as why knowledge about private net benefits of cover crop use is crucial to achieving the goal of increased covered acres in Ontario. This chapter identifies the knowledge gap that this research fills, the value of filling that gap and the policy implications of that knowledge.

> Public concern about contamination of the environment by agricultural chemicals, soil erosion, depletion of natural resources, and pesticide residues on foods have prompted shifts to sustainable production systems, [such as] crop rotation, reduced tillage and cover crops. (Lu et al., 2000, 122)

The concerns raised by Lu et al. (2000) explain the rationale behind the use of BMPs such as cover crops. The need to reduce the environmental footprint of the agricultural sector is made more urgent by the changing precipitation and temperature patterns that agriculture must contend with due to the threat of climate change. At the same time, agricultural productivity must continue to thrive to meet growing domestic and international food demand. The uncertainty of climate change and growing concern about the environmental costs of agriculture are the foundations of the movement towards environmentally sustainable production through increased use of BMPs such as cover crops.

According to the 2016 Census of Agriculture, approximately 18 percent of farmers in Ontario use cover crops, although total covered acreage is not reported (Statistics Canada, 2016; OMAFRA, 2017). Government stakeholders at both the provincial and federal levels advocated the use of financial incentives to increase cover crop use in the province. However, a "market failure" (Wolf Jr, 1979, 107) should be identified before government, or non-market intervention is justified, i.e. are cover crops providing public benefits at the expense of private land-owners or is mitigating the environmental costs of agriculture a government responsibility.

Academic literature identifies many environmental gains from cover crop use. Additionally, many of those gains are public benefits that reduce the environmental costs of agriculture contributing to the province's commitments with respect to environmental sustainability, and thus underpinning the desire to increase cover crop use (ECO, 2016). On the other hand, the rationale for promoting cover crops could be an example of Pannell's (2008) criticism that policy-makers over-estimate the significance of public benefits to encourage land-use change on private land. Policy-makers, Pannell (2008) argues, have several tools at their disposal to encourage private land-owners to change their land-use practices for environmental gain. Nonetheless, they are too reliant on payments/sanctions (positive/negative incentives) ignoring the potential for other policy options. To choose the best policy mechanism for increasing cover crop usage in Ontario, policy-makers need an evaluation of the public and private net benefits associated with this strategy. The evaluation results with respect to private net benefits will help policy-makers decide whether financial incentives are necessary. To date, studies on the private, economic benefits of cover crop use had mixed results and few studies have examined the impacts on profits in the long-term (>2/3 growing seasons). As such, providing financial incentives is unjustified without knowledge of the private benefits, and the lack of knowledge could explain the limited cover crop use in the province. Therefore, an evaluation of the net benefits of cover crops could prevent the government agencies funding cover crop implementation from incurring "redundant and rising costs" (Wolf Jr, 1979, 124) because the use of public funds to incentivise cover crops would be validated.

1.1 Purpose and Objectives

This research examined the private, economic impacts that Ontario farmers can expect in terms of yield and profit from cover crop use. The objectives were to provide clarity to farmers about the impacts of cover crop use on their farms and facilitate their decision to implement this BMP. Additionally, the findings will give policy-makers the necessary information to guide decisions about the best policy tool to increase cover crop usage in the province and reduce the barriers to adoption. This research used data from a cover crop experiment at the University of Guelph (UoG) Ridgetown Campus. The experiment collected data on the effects of four different cover crops on a variety of environmental parameters, including the wide-ranging yields of eight different vegetable and field crops. The analysis was conducted on the yield data and constructed profit margins to estimate the effect of cover crops on both parameters. The results demonstrated a positive and significant effect for each of the cover crops on yields, compared to no cover crop (no-cc). However, for profits only one type of cover crop (oilseed radish) presented a positive and significant effect; all other cover crops had no effect on profits despite the additional cost of using cover crops. The results also looked at the interaction effects between the cover crop treatments and the main crops and found that sweet corn and tomato were both positively impacted by some cover crops in both yield and profits. This suggested that some cover crop-main crop pairings may be of interest to farmers in Ontario.

1.2 Background

> In changing climate, resilience is extremely important. Resilient agricultural systems could allow Ontario to maintain, or even exceed current levels of agricultural productivity in the face of significant change (ECO, 2016, 9)

The quote from Lu et al. (2000) indicates the paradigm shift towards looking at agricultural production as a system. Therefore, to enhance the productivity and resilience of this system, increased use of BMPs in agricultural production are needed. In 2016, the Environmental Commissioner of Ontario (ECO) published a report called "Putting Soil Health First." The report itemised the productivity gains that commercial agriculture has made since the Green Revolution. Simultaneously, the ECO (2016) report documented the environmental costs associated with the rise of modern, industrial agriculture. These costs include the degradation of soil resources through erosion, loss of soil organic matter, and interference with the chemical and biological processes that nourish crops. The environmental costs of agriculture extend beyond the farm gate, and include: nutrient run-off from fertilisers that cause algal blooms in surface water; chemicals from pesticides and herbicides that contaminate surface and ground water; and soil run-off (erosion) reducing the water storage capacity of the soil, increasing flood risk (IPES-Food, 2016; ECO, 2016; Smith and McDougal, 2017). The prominence of the environmental problems associated with industrial agricultural production led to the creation of a global movement that demands environmental sustainability i.e. production that conserves and enhances agricultural resources, and increasing productivity (ECO, 2016; IPES-Food, 2016).

This demand for environmentally sustainable agriculture led to increased support for the scientific community to investigate optimal intervention points in agricultural ecosystems resulting in the development of beneficial management practices (BMPs). BMPs, such as cover crops, simultaneously enhance and maintain the ecological functions of agricultural resources, thus improving productive capacity (Lu et al., 2000; Blanco-Canqui et al., 2015). Cover crops are defined by the Ontario Cover Crops Strategy as non-commodity plants seeded into agricultural fields typically after the regular growing season (Mervin and McLarty, 2017). However, the academic literature about cover crops demonstrates inconsistent results in terms of agricultural productivity improvements, i.e. direct gains in yield and profits. Additionally, Lu et al. (2000) and Blanco-Canqui et al. (2015) in their summaries of the cover crop literature both found that environmental and economic benefits of cover crops vary depending on specific, local, environmental characteristics such as soil type, precipitation, types of crops grown, and types of cover crops used. Therefore, to determine the specific environmental and economic gains that can be expected in Ontario, local cover crop research is needed.

Meanwhile, the ECO (2016) recommended financial incentives to increase cover crop use, and the federal and provincial governments currently provide some financial incentives for cover crops through Growing Forward 2. Growing Forward 2 was the policy framework for the agriculture and agri-food industry in Canada from 2013 to 2018. The framework prioritised innovation, competitiveness, adaptability and sustainability within the Canadian agricultural sector. The requirements for cost-sharing are that only non-commodity crops are used and only first time cover crop projects are funded. Additionally, each farmer using cover crops is eligible for 35% of their establishment costs up to $10,000 (AAFC, 2017). However, these government payments are given without adequate research into yield and profit gains that farmers may be receiving from cover crop use. Consequently, the use of financial incentives is perhaps premature until the local research advocated by Blanco-Canqui et al. (2015) and others starts producing evidence.

The Ontario Cover Crop Strategy (Mervin and McLarty, 2017) was developed in response to this call for local research and has articulated the need for more deliberative and informed policies that reduce barriers to adoption and increase cover crop use. The current research seeks to contribute to an evidence based policy to increase cover crop use in Ontario. The knowledge gap with respect to the private net benefits of cover crops that farmers can expect needs to be addressed to decide if financial incentives are necessary and how much public funds are warranted. Additionally, the findings can inform farmers about the effects of cover crops on yield and profits to identify the advantages of or the challenges to implementation.

The need to mitigate the environmental costs of agriculture and enhance agricultural productivity drive the movement towards environmentally sustainable production practices through increased use of BMPs, such as cover crops. However, to adequately promote increased use of cover crops, evidence based policy is required to identify the benefits that incentivise adoption and the challenges that create barriers to adoption. The lack of knowledge about the private impacts on yields and profits prevents some farmers from adopting cover crops.

The lack of knowledge also impedes the development of the best policy mechanisms for increasing cover crop use because the specific challenges and benefits are unknown. Therefore, policies and public spending may not be appropriately targeted. The next chapter will demonstrate in more detail the environmental gains from cover crop use, the lack of clarity with respect to the private, economic impacts of cover crops, and the reasons why the knowledge of private net benefits is necessary.

Chapter 2 Literature Review

The claims made in the previous chapter, about the environmental benefits of cover crops, the uncertainty of private benefits, and the reasons why knowledge about the private benefits is crucial to policy-makers, are elaborated here. This chapter will demonstrate why cover crops are considered a good strategy for reducing the environmental costs of agriculture, and explain the present uncertainty about the private, economic impacts of cover crops due to the inadequacies within the literature. Additionally, the chapter discusses why policy-makers and other cover crop advocates need the information about the private net benefits and concludes with considerations about incorporating environmental cost reduction into the cost-benefit analysis framework for cover crops. The purpose of this chapter is to demonstrate why the lack of clarity about the private benefits (yield and profit) of cover crops can thwart the increase of new cover crop users and covered acres, and how filling the knowledge gap can illuminate potential challenges and barriers that are obstructing efforts to increase cover crop use in Ontario.

2.1 Cover Crops Mitigating the Environmental Costs of Agriculture

Modern agriculture has continuously contributed to social and economic development through unprecedented levels of productivity. However, these achievements came at the expense of agricultural resources, soil in particular, and wider environmental harm especially with respect to surface water quality in North America (IPES-Food, 2016; ECO, 2016). The issue of agriculture's environmental cost has prompted stakeholders to seek better, cleaner ways of meeting the productivity needs of our societies while mitigating the environmental ills. As previously mentioned, the new paradigm for agricultural production focuses on the use of agri-environmental strategies that incorporate the ecosystem services already present within agricultural environments into field management practices (IPES-Food, 2016). Ecosystem services in this case refer to the naturally occurring, interconnected systems that manage fertility, pests, weeds, and biodiversity within agriculture ecosystems, among other things. Cover crops are one of those strategies and refer to non-commodity plants typically seeded into fields after main crops have been harvested (Mervin and McLarty, 2017). These crops cover the soil to reduce sediment run-off (erosion), and they also provide environmental benefits, such as nutrient retention, increased soil organic matter and other benefits depending on the type of cover crop (Blanco-Canqui et al., 2015; Lu et al., 2000; Roberts et al., 1998; Zhang et al., 2007; Dominati, Patterson, and Mackay, 2010). Compared to other strategies that reduce soil erosion and chemical run-off, cover crops have lower costs: lower opportunity cost of land and lower infrastructure costs (Roley et al., 2016). The lower cost makes the use of cover crops easier than other agri-environmental strategies that may require large capital investments, such as no till or two-stage ditches.

Cover crops are widely discussed in academic literature. The main drivers of this literature are disciplines within the natural sciences. Consequently, most of the academic work focuses on accounting for and quantifying the magnitude of the environmental benefits associated with cover crop use that mitigate the environmental costs of agriculture and enhance soil resources. Lu et al. (2000) in a summary of the cover crop literature found that cover crops reduce soil erosion, suppress weeds, improve nutrient retention and improve the physical, chemical and biological properties of soil. Similarly, Blanco-Canqui et al. (2015) collected and summarised the cover crop literature to date. Both studies found a variety of environmental benefits accruing from cover crop use. However, while the benefits of cover crops discussed in Lu et al. relate to enhancement of agricultural resources, Blanco-Canqui et al. added climate change mitigation and improved resilience to changing weather to the discussion of cover crop benefits. Blanco-Canqui et al. (2015) found that along with erosion reduction and the other benefits found by Lu et al., cover crops also sequester carbon, reduce fluctuations in soil temperature, conserve soil moisture, reduce soil compaction and improve the soil microbial environment. However, despite the wide variety of environmental benefits that can accumulate through cover crop use, Blanco-Canqui et al. (2015) confirm that the benefits of cover crops depend on local conditions and, therefore, cannot be generalised to all situations and geographies. While many studies report positive benefits, these results are site specific, complex, and dependent upon local circumstances, such as precipitation patterns, soil type, main and cover crop types, cropping and tillage systems (Blanco-Canqui et al., 2015). Similarly, since the negative impacts of agriculture are also site and region specific, the environmental goals prompting cover crop adoption vary. Consequently, Blanco-Canqui et al. (2015) conclude that local studies should be undertaken to discern the specific benefits cover crop use accrue in a specific location. Therefore, local studies are needed to determine what benefits we can expect from the use of cover crops in Ontario.

2.2 Cover Crops Mitigating the Environmental Costs of Agriculture In Ontario

The ECO (2016) report itemised some of the environmental costs of agriculture in Ontario. These costs are caused to some unknown extent by on-farm practices and the consequences are felt off-farm some distance away. Nutrient run-off from chemical fertilisers was identified as the primary cause of algal blooms in the Great Lakes and other surface water bodies throughout the province. Algal blooms in Canada have been estimated to cause millions of dollars in losses due to: clean up costs, loss of income, loss in property values, loss of recreational values (Bass, 2015; Smith and McDougal, 2017). Similarly, the ECO (2016) report discusses the role of poor soil quality in increasing flood risk. Good quality soil with high concentrations of organic matter can absorb more water than heavily eroded and degraded soil, thus preventing puddling and reducing run-off which can reduce flooding. Therefore, areas with poor quality soil have higher flood risk and when partnered with more frequent extreme weather events flood damage and clean up would also incur large losses and social costs. Consequently, the ability of cover crops to reduce nutrient run-off and improve soil organic matter and other soil quality parameters is of interest to many stakeholders in the province and throughout the country.

Several studies have taken place with the goal of evaluating the various environmental benefits associated with cover crop use in Ontario. The cover crop experiment at the UoG Ridgetown Campus has been ongoing since 2007 and has produced several studies accounting for the environmental benefits of cover crops in Ontario. The data analysed in this thesis comes from this same experiment. O'Reilly et al. (2011, 2012) sought to determine the effectiveness of cover crops on weed suppression, nutrient management and sweet corn yields. The results indicated that only one cover crop, oilseed radish (osr), presented weed suppression benefits, while all other treatment groups including no cover crop the effect on weeds was the same (O'Reilly et al., 2011). The O'Reilly et al. (2012) results indicated that cover crops retain nitrogen (N) in the soil during the fall and winter periods. However, the retained N was insufficient to meet the needs of the main crop planted the following spring, therefore, some fertiliser was needed for the next rotation. Belfry et al. (2017) sought to determine the effectiveness of cover crops on fruit quality, N availability and pest pressure for processing tomato. The results demonstrated that osr improved soil N content, however, pest pressure and quality were "not negatively affected" (Belfry et al., 2017, 13). This suggests that the results may have been the same for the cover crop treatments as the no cover crop treatments. The results from these studies do not provide powerful evidence about the environmental benefits of cover crops in Ontario. The lack of significance is probably due to the relatively short duration of cover crop use in these studies and a study period of only one or two growing seasons. The need for longer term examinations into the environmental benefits accumulating from cover crop use is necessary and has been called for in the literature (Blanco-Canqui et al., 2015; Lu et al., 2000; Snapp et al., 2005; Schipanski et al., 2014; Zhang et al., 2007).

These Ontario studies provided preliminary evidence about the nutrient retention benefits of cover crops and indicate the potential of cover crops with reduced fertiliser and cover crops with reduced herbicide cropping systems. However, the effect of cover crops to reduce the environmental costs is incremental and requires wide participation to demonstrate meaningful and tangible improvements. Furthermore, the research to date cannot speak to the direct impact of cover crops towards decreasing the presence of algae in lakes or reducing flood risk. The diffuse nature of the pollutants causing algal blooms and the need for large participation in agri-environmental solutions before progress can be seen make farmer buy-in to cover crop use difficult without the presence of direct, tangible, on-farm benefits. Therefore, the private net benefits of cover crops on-farm must be demonstrated before the public benefits from reducing the environmental costs of agriculture can be discussed.

An additional concern raised by Blanco-Canqui et al. (2015) is that cover crops "contribute to the multi-functionality of agricultural ecosystems meaning that many of the ecosystem services they enhance are interconnected, such as soil moisture and soil temperature, and yield and soil quality. Therefore, despite the many benefits attributed to cover crops, the time frame for these benefits to accumulate may not be limited to one growing season. The building up of soil resources and re-establishment of chemical and biological cycles both support more productive agricultural ecosystems and require repeated use of cover crops for multiple growing seasons in succession before some benefits can be seen (Schipanski et al., 2014; Zhang et al., 2007). Meanwhile, the annual cost of cover crop implementation is borne primarily by the farmers. Although many of the benefits discussed are occurring on farm, outcomes such as reduced nutrient run-off and increased water capacity are public benefits that do not contribute to offsetting the annual cost of cover crop use incurred by the farmer. Therefore, if policy-makers want to increase the use of cover crops in Ontario, they must demonstrate or generate tangible, private benefits for farmers.

2.3 On Farm Costs and Benefits of Cover crops

Despite a wide range of evidence demonstrating some environmental gains from cover crop use, the farmers' decision to use cover crops is an economic one based on the costs and benefits of implementation. The academic literature regarding profitability of cover crops is in the "beginning stages" (Lu et al., 2000, 131) in terms of economic or private benefits. In addition to greater discourse about economic benefits of cover crops Blanco-Canqui et al. (2015) call for more long-term evaluations of profit (>1-2 growing seasons). When discussing private benefits, this research focuses on yield and profit. Lu et al. (2000) demonstrated the variability in the literature with respect to improvements in yield from cover crop use. Bollero and Bullock (1994) and Shurley (1987) concluded that legume cover crops enhance yields for grain corn and sorghum. In terms of profitability Allison and Ott (1987) concluded that cover crops can improve profits, while Frye, Smith, and Williams (1985), Klonsky, Livingston et al. (1994) and Creamer et al. (1996) concluded that profits are varying, lower or the same, respectively. The inconsistency of the results presented in Lu et al. (2000) is made more complex when considering that most studies used different cover crop types and the effects refer to different main crops. These localised variations provide doubt that makes extension and promotion of cover crops to farmers more difficult.

Blanco-Canqui et al. (2015) encountered similar variability in their summary of the cover crop literature with respect to private benefits. They found that nine of the 17 studies indicated positive effects on yields due to cover crop use (Balkcom and Reeves, 2005; Maughan et al., 2009). However, six studies found no significant change or varying results between using cover crops and no cover (Acuña and Villamil, 2014; Reese et al., 2014), and two studies found that cover crops decrease yields (Nielsen and Vigil, 2005; Nielsen et al., 2015). The variability in yield outcomes is similar to the variability in other environmental benefits, and is likely due to local characteristics such as annual precipitation, types of cropping systems, types of crops and cover crops used, as well as the short time-frames of the studies. The profitability story described in Blanco-Canqui et al. (2015) also demonstrates varying results because profitability was discussed in two different ways, gross margins and cost reduction. Flower et al. (2012) evaluated cover crops in terms of their effect on gross margins. Conversely, Schomberg et al. (2014) and Ott and Hargrove (1989) looked at the usefulness of cover crops in offsetting costs through the effect of cover crop use on feed cost for livestock, and on fertiliser inputs, respectively. While the latter studies indicate an alternative mechanism for evaluating the private benefits of cover crops, the direct impact of cover crops on revenue may be more effective in changing behaviour to increase cover crop use.

Despite a growing literature demonstrating the potential of cover crops to facilitate environmental and economic gains, cover crops can cause unexpected costs to farmers that disincentivise use. Blanco-Canqui et al. (2015) identified that in cold climates, such as in Ontario, cover crops can delay soil warming in the spring that can negatively affect main crop establishment. Cover crops, according to Blanco-Canqui et al. (2015), keep soil cooler in the spring and warmer in the fall. As a result, slow soil warming can reduce seed germination, and may hinder growth of the main crop, potentially affecting yield, or prolonging time till harvest (Blanco-Canqui et al., 2015; Snapp et al., 2005). Conversely, Flower et al. (2012) and Nielsen and Vigil (2005); Nielsen et al. (2015) demonstrated that in semi-arid climates cover crops reduce the amount of water available in soils for the subsequent main crop, adversely affecting yields. The literature also discussed the potential of cover crops to become weeds due to excessive growth (Pratt et al., 2014; O'Reilly et al., 2011; Snapp et al., 2005). Excessive growth makes cover crops difficult to kill incurring higher termination costs because more time and more herbicide are required, thus increasing the cost of cover crop use (Snapp et al., 2005). Finally, effective management of a cover crop system incurs a high opportunity cost of management, i.e. the time needed for planning and execution to seed and terminate cover crops to maximise their benefits without adversely affecting the main crop planting schedule. The additional time, labour and machinery costs for cover crop establishment and termination may cause farmers to be unwilling to adopt (Snapp et al., 2005). These drawbacks of cover crop use increase farmers unwillingness to implement but information about the private benefits can encourage farmers to overlook these potential disincentives.

Once again, the literature demonstrates that similar to the environmental benefits discussed previously the economic costs and benefits of cover crops vary depending on specific, local, environmental characteristics such as soil type, precipitation, types of crops grown, and types of cover crops used. Consequently, to determine the economic costs and benefits available to Ontario farmers, the discussion returns to the cover crop experiment at the UoG Ridgetown Campus.

2.4 On Farm Costs and Benefits in Ontario

The papers demonstrating the environmental benefits of cover crops in Ontario also address the impacts on yield and profit margins. However, the results varied due to the relatively short time frames these studies evaluated: one to two growing seasons. In addition, due to the focus of these studies on the environmental benefits most of the statistically significant estimates with respect to profitability were not related to typical Ontario farm management practices. Consequently, farmers interested in how cover crops will affect their livelihoods under the typical management practices that they use may find the results from these studies unrelated. The Ontario studies discussed in this section came from the long-term cover crop experiment at the UoG Ridgetown Campus.

O'Reilly et al. (2011) evaluated profit margins for sweet corn production in both weeded (typical) and un-weeded fields. Cover crops in the weeded fields increased yields compared to weeded without cover crops. All other yields were the same with or without cover crops. With respect to profit margins, O'Reilly et al. (2011) found that in an un-weeded field an oat cover crop increased profits by approximately \$600/ha, osr increased profit by approximately \$1300/ha and osr+rye increased by approximately \$750/ha compared to no-cc on an un-weeded field. However, in one field, the profits in the weeded plots were higher than the un-weeded suggesting that although weed suppression benefits are occurring they may come at a loss to farmers. In contrast, in a different field, the profit margins for un-weeded plots were higher than the weeded plots but this result was attributed to the different conditions in the two fields before the experiment. In the weeded fields that represent typical Ontario production practices oat, osr and osr+rye cover crops were found to increase profit margins compared to no cover crops. In O'Reilly et al. (2012) the experiment looked at the effect of different fertiliser rates and cover crops on sweet corn yield and profit margins. The results from O'Reilly et al. (2012) indicated that cover crops and full fertiliser treatments have no effect on yield. However, oat and osr+rye cover crops with reduced fertiliser had higher yield than no cover crop with reduced fertiliser. All other yields were the same with or without cover crops. All profit margins were the same with or without cover crops, except for osr and osr+rye cover crops with reduced fertiliser that increased profit margins by about \$1300/ha and \$760/ha respectively. Finally, Belfry et al. (2017) also examined the effect of different fertiliser rates and cover crops but on processing tomato yields and profit margins in Ontario. Osr and rye cover crops demonstrated yield benefits compared to no cover crops, and all other yields were the same with or without cover crops. For profit margins, Belfry et al. (2017) found that oat, osr and osr+rye cover crops with reduced fertiliser increased profit margins compared to no-cc by approximately: \$960/ha for oat, \$2300/ha for osr, and \$1400/ha for osr+rye. However, with the full fertiliser treatment (typcial Ontario management) the profit margins were the same with or without cover crops, except for the osr cover crop which reduced profit margins by approximately \$1200/ha.

Collectively, these studies indicate that there are some private benefits to cover crop use. However, the results from the Ontario studies do not provide definitive proof about the private benefits of cover crops because many of the statistically significant outcomes were not related to typical Ontario farm practices, for example non-weeded fields or reduced fertiliser. Farmers would require evidence related to yield and profit gains under typical farm management practices to inform their decision to use cover crops on their land before they make decisions about other alternative management strategies.

2.5 The Knowledge Requirements for Government Intervention and Policy

The ECO (2016) suggested that financial incentives be used to increase cover crop acreage in the province. The ECO's justification for the use publicly funded incentives is based on the potential public benefits of cover crop use to achieve the province's environmental sustainability commitments with respect to reducing the environmental costs of agriculture and increasing adaptability to climate change. However, the push for financial incentives could be an example of policy-makers over-estimating the relevance of public benefits in changing the behaviour of private land-owners (Pannell, 2008). Without adequate private incentives, land-owners may not actively or adequately implement an agri-environmental strategy despite the availability of public funding. Pannell (2008) argues that an evaluation of net private benefits and net public benefits is necessary to choose the best strategy for incentivising land- use change for environmental gains, therefore maximising the "net benefits of intervening" (Pannell, 2008, 227).

Despite some cost-sharing available for cover crop use in Canada through Growing Forward 2, only 18 percent of farmers in the province use cover crops, according to the 2016 Census of Agriculture. While, 18 percent is an increase in cover crop users from nine percent in the 2011 census, the majority of farmers in the province are not using cover crops (Statistics Canada, 2016; OMAFRA, 2017). The limited uptake of cover crop use could be explained by the lack of evidence about the net private benefits. Wolf Jr (1979, 107) argued that "inadequate market outcomes" are a necessary but not sufficient reason to justify public intervention. Wolf Jr (1979, 107) warns that before public intervention can proceed, an analysis of the market inadequacies must be compared to the "potential inadequacies of a non-market, or policy, approach". Highly politicised issues such as the threat of climate change and environmental sustainability in agriculture can lead to "redundant and rising costs" non-market failure (Wolf Jr, 1979, 124). Public opinion leads to "misperceiving the cause [of the problem] as a market failure rather than something more intractable". Therefore, policy-makers and politicians are pressured to act and provide a "remedy" for a misdiagnosed problem. An evaluation of public and private net benefits is one way to ensure accurate problem identification, i.e. is the lack of financial resources the barrier preventing new users from implementing cover crops.

As such, before discussions about using financial incentives to increase cover crop use can occur, an evaluation of market inadequacies is necessary. The evaluation will determine if the private, economic benefits are insufficient to increase cover crop use in accordance with policy-makers wishes, then policy interventions can be formulated based on the public benefits accruing from this environmental strategy. Understanding the private and public net benefits associated with cover crop use ensures the appropriate incentivising tools are used. Pannell (2008) argued that choosing the best tool to increase environmental gains depends on whether the net benefits accumulate more towards public interests or private. Despite having different policy tools available, policy-makers tend to rely heavily on positive and negative incentives (payments/sanctions) to facilitate land-use change for environmental gains. The reliance on these tools without evidence about the net private benefits increases the chances of "inadequacies [in] non-market efforts" (Wolf Jr, 1979, 107). A good example of this can be seen in the United States (US) approach to increasing cover crop use. Lichtenberg, Wang, and Newburn (2018) and Plastina, Liu, and Sawadgo (2018) both looked at additionality in cover crop acreage generated by government financial incentive programs in Maryland and Iowa, respectively. In the US, cover crops are eligible for cost-sharing under the Environmental Quality Incentive Program (EQIP) and the Conservation Stewardship Program (CSP). Lichtenberg, Wang, and Newburn (2018) and Plastina, Liu, and Sawadgo (2018) both sought to estimate the increase in cover crop use that was due to the incentive programs. In other words, did the incentives bring new land under cover crops that would never have been without the subsidy. Both studies showed that acreage of cover crops was increasing due to these incentives. However, the increases in cover crop acreage demonstrated diminishing marginal returns, i.e. every additional dollar of incentive payment saw fewer increases in cover crop acreage. Additionally, Lichtenberg, Wang, and Newburn (2018) discovered that the increased acreage belonged to farmers who already used cover crops rather than farmers changing their behaviour and starting to use cover crops. Therefore, while the subsidies may be increasing acreage, new cover crop users were not increasing in the same way. The limited increase in cover crop users is caused by heterogeneity among farmers motivation with respect to land value and environmental stewardship (Lichtenberg, Wang, and Newburn, 2018). This indicates that perhaps different tools are necessary to increase cover crop use among the different types of farmers. Therefore, the barriers that different farmers face can be identified by understanding the advantages and challenges related to cover crop effects on yield and profit.

2.6 More Inclusive Cost-Benefit Accounting

This research seeks to estimate the private net benefits of cover crop usage in Ontario. However, as discussed earlier this is merely a first step to inform farmers about the private benefits they can expect and to inform policy-makers about the best strategy for increasing cover crop use in the province. As per Pannell (2008) and Wolf Jr (1979), before the best strategy can be deliberated on, an evaluation of the private and public net benefits is necessary to provide the full account of the usefulness of cover crops in Ontario. While this study is limited to the private net benefits, the fact that cover crops are a crucial BMP to reduce the public, environmental costs of agriculture necessitates the development of an evaluation framework that incorporates both the private and public net benefits, as the the next step for this research. Some literature has already surfaced using more inclusive methods of cost-benefit accounting with respect to cover crops.

These inclusive accounting methods are rooted in the idea of environmental stewardship. Cover crops as an agri-environmental strategy were not conceived for their yield and profit benefits, rather for cover crops ability to conserve and enhance agricultural resources without compromising productivity. Therefore, cover crops and other agri-environmental strategies have an environmental purpose, and their effectiveness in achieving that purpose should be accounted for. Furthermore, Blanco-Canqui et al. (2015); Schipanski et al. (2014); Zhang et al. (2007) discussed the multi-functionality of cover crops, i.e. cover crops enhance and accrue a variety of eco-system services that cannot be separated from each other. As such, provisioning ecosystem services, such as increased yields, are related to regulating and supporting ecosystem services such as nutrient retention, soil moisture and improved nutrient uptake by plants from soils. Furthermore, because of this interconnectedness, some benefits may be seen before yields and profitability benefits begin to show.

Consequently, accounting for environmental benefits may indicate to farmers the usefulness of cover crops in offsetting costs or increasing productive capacity to farmers and encourage the adoption of cover crops with the expectation of increased yield and profit in the future.

Roth et al. (2018) examined the cost effectiveness of cover crops to reduce nitrogen (N) load in tile drains, increase N retention in soil, and reduce erosion. The study monetised erosion reduction, N retained in soil (N mineralisation) and N removed from tile drains (N load). To determine how much of the cover crop costs were recovered through environmental gains, the N savings and erosion reduction values were subtracted from the cover crop costs including establishment, termination and yield change. The results estimated that in the 2014 cover crop - 2015 corn rotation 88% of the cover crop adoption costs and 86% of the total costs were recovered when a fall cover crop was used, while 66% of the cover crop adoption cost and 33% of the total costs were recovered using a spring cover crop. In the 2015 cover crop-2016 soybean rotation 84% of the cover crop adoption costs and 57% of the total costs were recovered when using a fall cover crop, while 91% of the cover crop adoption costs and 65% of the total costs were recovered using a spring cover crop.

Although the percentage of costs recovered vary dramatically with the season that the cover crops were planted and by main crop, these results do indicate the potential of the cost recovery approach in accounting for the usefulness of cover crops in reducing the environmental costs to farmers. As Blanco-Canqui et al. (2015) suggested there are different environmental challenges depending on location, therefore the cost recovery method can be tailored to account for the relevant benefits in different localities. However, the different time frames that these environmental benefits accumulate can cause the cost recovery estimates to reflect poorly on cover crops. Therefore, the framework for the evaluation of environmental benefits should not be negatively impacted by today's shortfalls when future gains are accumulating.

While Roth et al. (2018) attempted to quantify the usefulness of cover crops in offsetting the additional cast of use, Pratt et al. (2014) demonstrated the usefulness of cover crops in opening additional revenue opportunities. Similar to Schomberg et al. (2014) who investigated the use of cover crops to offset livestock feed costs, Pratt et al. (2014) examined whether the use of cover crops could increase opportunities for harvesting corn stover for use in the bio-fuel industry. Pratt et al. (2014) found that cover crops provide sufficient erosion protection and soil organic matter to allow a higher percentage of corn stover to be removed and sold as an input for bio-fuels. As such, the additional revenue gained from the corn stover offset the additional cost of cover crop use. Therefore, while cover crop use provides an additional expense to farmers, it may also open new opportunities for additional revenue streams or reduced management costs.

This chapter described the complex state of affairs with respect to increasing cover crop use in Ontario, i.e. the factors driving the desire of policy-makers and scientists to increase cover crop use in the province and the uncertainty of private benefits that has led to limited uptake of cover crops by farmers. The movement to reduce the environmental costs associated with agriculture, such as algal blooms in the Great Lakes provide support for policies that incentivise the use of agri-environmental strategies such as cover crops. However, the diffuse nature of the environmental costs associated with agriculture and the direct cost associated with annual cover crop use requires that direct on-farm benefits be demonstrated first to encourage farmers to use cover crops on their land. Additionally, although some cost-sharing is available for cover crop use the limited increase in users suggests that there are other barriers to usage that an evaluation of net private benefits to farmers may illuminate. The chapter also demonstrated that policy-makers need information about the net private benefits that farmers receive from cover crop use to determine if financial support is necessary and at what level. Finally, the chapter concludes with a discussion about the crucial next step of this research incorporating the cover crop benefits that reduce the environmental costs of agriculture into a cost-benefit framework to appropriately internalise the negative consequences associated with agriculture.

Chapter 3 Data and Analysis

This chapter discusses the UoG Ridgetown Campus cover crop experiment that generated much of the peer-reviewed literature on the effects of cover crops in Ontario. This research is the first to compile all the years of yield data to evaluate the effect of cover crops on yields and profit margins. The specific data and the methods used to carry out this evaluation are discussed here. The story within this chapter is of the variables created, the questions the analysis attempted to answer and an explanation of how those answers were found and what they mean.

The data for this research came from a cover crop experiment that was started in field 1 in 2007 and in field 2 in 2008 at the University of Guelph Ridgetown Campus. The experiment is ongoing and will continue until at least 2025. The experiment is carried out on two fields (field 1 and 2), each subdivided into 40 individual plots, for a total of 80 plots. Each field is arranged in a randomised complete block design with four replications i.e. each field is divided into four blocks of 10 plots each and the plots in each block are randomly assigned to a treatment group. The main plot factor is fall cover crop type and the randomly assigned treatment groups are: No cover crop control (no-cc), oat, rye, oilseed radish (osr) and oilseed radish + rye (osr+rye). After the main crops are harvested in preparation for the cover crop planting in the fall, the fields are disked and cultivated. The following spring in preparation for main crops, the fields are sprayed with glyphosate to kill rye cover crops and then are disked and cultivated incorporating the cover crop residues. The crop rotation was pea, sweet corn, spring wheat, tomato, grain corn, squash, soybean, winter wheat, and tomato, Table 3.1

shows the experiment rotation in fields 1 and 2. The fields are managed under typical Ontario production practices except when additional field management treatments were tested. This research paper examines main crop yields from 2008/09 sweet corn harvest to 2015/16 tomato harvest. Due to a harvesting error, the pea harvest (2016/17) was left out. The only deviations from the fall cover crop-spring main crop schedule occurred in fall 2011/12 when no cover crops were planted before squash (harvested 2012/13) and in 2014/15 when winter wheat was planted in the fall, not cover crops.

During the examined period (2008-2015/2009-2016) in fields 1 and 2, four additional field management treatments were tested. During the pea - cover crop - sweet corn portion of the rotation, a split-split plot design tested fertiliser rate applied to corn (0 or 140 kg of N per hectare) and the presence or absence of weeds during the corn season. During the spring wheat - cover crop - tomato portion of the rotation, a split-split plot design tested fertiliser rate applied to tomato (0 or 140 kg of N per hectare) and tomato cultivar (early or late). During the cover crop- grain corn - squash portion of the rotation, a split-plot design tested the presence or absence of corn stover. Finally, during the winter wheat - tomato portion of the rotation, a split-plot design tested the presence or removal of wheat straw. These additional treatments looked at the effectiveness of cover crops in providing environmental benefits specific to Ontario.

The goal of this cover crop experiment is to determine the impact of different cover crops on a variety of field and vegetable crops, in Ontario. It also seeks to determine how cover crops perform under different crop management strategies, in terms of the effectiveness of cover crops in accumulating environmental benefits and the subsequent impact on yields. This paper uses the data collected from the cover crop experiment to determine the effect of the four cover crop treatments compared with no-cc on yields and profit margins (more about profit margins in the 'Data' section). It seeks to determine specific effects on each main crop, and a more general effect of cover crops irrespective of environmental and experimental variation.

Table 3.1: Cover Crop Experiment Crop Rotation in Fields 1 and 2

Crop	Harvested Pea	Fall CC	Harvested Sweet Corn	Fall CC	Harvested Spring Wheat	Fall CC	Harvested Tomato	Fall CC	Harvested Grain Corn	Harvested Squash	Fall CC	Harvested Soybean	Harvested Winter Wheat	Fall CC	Harvested Tomato (2)
Field 1	2007	2007	2008	2008	2009	2009	2010	2010	2011	2012	2012	2013	2014	2014	2015
Field 2	2008	2008	2009	2009	2010	2010	2011	2011	2012	2013	2013	2014	2015	2015	2016

Note: For Main Crops year indicates when harvested.

For Cover Crops (CC) year indicates when seeded

3.1 The Data

The primary concern of this study is the effect of cover crops on yield and profit margins. The yield data in tonnes per hectare (t/ha) of all the main crops from sweet corn in 2008/09 to tomato (2) in 2015/16 were collected for analysis. Input costs and market price data was collected to construct partial profit margins. The input costs refer only to the additional cost of using cover crops, as well as the additional management treatments for fertiliser, stover and straw removal. All other costs are assumed to be constant across all treatments. The input costs for fertiliser and herbicide are average annual costs, taken from the Ontario Farm Input Monitoring Survey (Economics and Business Group, 2008-2016). Cover crop seed costs were based on the rates and seed prices in Table 3.2. All costs included custom application rates from the OMAFRA Custom Rate Survey (Molenhuis, 2015). These input costs were fixed because this study is not interested in variability due to input prices. This paper is only concerned with the returns from cover crop use.

Partial profit margins were constructed to determine whether the additional cost of cover crop implementation is offset by revenue. The profit margins were calculated as $revenue - additional\,costs$ in dollars per hectare ($/ha). The cost, as previously mentioned, only considers the additional costs incurred from the use of cover crops and the other management strategies. For each plot, these costs include the sum of the cover crop seed and application costs. For treatments including rye, a herbicide and application cost was also included. The costs associated with the additional management strategies include the cost of nitrogen (for sweet corn and tomato) and the cost of corn stover removal (squash) and wheat straw removal (tomato (2))[1]. All other costs were assumed equal among cover crop treatments and would not affect the decision to use cover crops. All costs are described in Table 3.2.

[1]tomato (2) refers to the second tomato crop in the rotation

Table 3.2: Costs Associated with Cover Crop Implementation

Seed Cost (including custom application)			
	Seeding rt (kg/ha)	Price($/kg)	Cost ($/ha)
Oat	81	0.3227	64.59
Rye	67	0.2727	45.15
OSR	16	2.1	83.03
OSR+Rye	9	2.1	69.61
	34	0.2727	
Termination Costs for Rye (including custom application)			
		$/ha	
Herbicide		55.41	
Fertiliser cost for Sweet Corn and Tomato (including custom application)			
		$/ha	
140 kg of N (Full N)		244.68	
Stover and Straw removal			
		$/ha	
Stover		0.31	
Straw		0.001	

Revenue is the product of each plot yield and the average market price for the harvesting year. Market prices for tomato, squash and sweet corn were obtained from the Ontario Processing Vegetable Growers, Seasonal Fruit and Vegetable Annual Summary Reports for the Fruit and Vegetable Survey[2]. The prices for winter wheat, soybean and grain corn were obtained from Statistics Canada, Field Crop Reporting Series, Ontario 2012-2018. Spring wheat prices were obtained from OMAFRA's Historical Provincial estimate by crop 1981-2017. A summary of the market prices can be found in Table 3.3 (OPVG, 2017; OMAFRA, 2018; Molenhuis, 2015).

[2] Average price for squash is bundled together with pumpkins and zucchini

Table 3.3: Market Prices for Main Crops in \$/tonne

Crop	Year	Market Price (\$/tonne)
Sweet Corn	2009	320.11
Spring Wheat	2010	213.00
Tomato	2011	154.10
Grain Corn	2012	260.25
Squash	2013	472.40
Soybean	2014	511.48
Winter Wheat	2015	291.38
Tomato (2)	2016	190.30

Note: Prices used for each main crop are the average annual price in the given year

3.2 Empirical Framework

3.2.1 Yield and Profit Margin Ratios

To combine and analyse all yield and profit data, the environmental and experimental variation within the raw data was removed. As the old adage claims "you cannot compare apples to oranges", so too you cannot compare corn yield to tomato, or soybean yield to squash. The differences among the main crops are quite distinctive since the rotation includes grain, oilseed, and vegetable crops, and the variation in average yield from crop to crop is quite significant. Therefore, to make corn yield and tomato yield comparable so the effects of cover crops can be estimated, this natural variation needed to be removed. Similarly, the additional management treatments within the experimental design also caused variation in the yield data that had to be removed. Therefore, to address this problem of comparability, a yield ratio was calculated for each yield data point.

To calculate the yield ratio, each plot yield was divided by the average of the four no cover crop control plots (no-cc) in each field. These no-cc averages were calculated for each main crop in each field and for each split plot. The yield ratio for the no-cc control plots would be approximately one ($\frac{no-cc\,yield}{average\,no-cc\,yield} \approx 1$) because the no-cc average in the denominator is the average of the no-cc plots. The crop variation and additional management effects would cancel out in the ratio because the different effects are included in both the individual plot yield (numerator) and the no-cc average yield (denominator). A profit margin ratio was created for the same reasons and using the same process as the yield ratios. The formulae below illustrate how the ratios work.

Yield Ratio Formula for any given crop:

$$\frac{plot\,yield\,osr\,tomato\,field2\,N}{no\,cover\,crop\,avg\,yield\,tomato\,field2\,N} \tag{3.1}$$

- Plot yield refers to each yield data point
- field 2 = variable name for the specific field each plot yield was taken from. Two no-cc averages were calculated one for each field (i.e. field 1 no-cc average and field 2 no-cc average)
- N = variable name identifying the presence of experimental variation testing fertiliser N rate (sweet corn, tomato). Other variables for additional management strategies include: weed control (sweet corn), stover removal (squash), early cultivar (tomato), straw removal (tomato 2)

Yield Ratio Formula: Removing variation

$$\frac{\textbf{plot yield osr}\,\cancel{tomato\ field2\ N}}{\textbf{no cover crop avg yield}\,\cancel{tomato\ field2\ N}}$$

Each ratio represents the proportional difference in yield or profit between the cover crop treatment and the no-cc average. Ratios equal to 1 (= 1) represent no difference in yield or profit between the plot data point and the no-cc average. Ratios greater than one (>1) represent yield or profit gains compared to no-cc average and ratios less than one (1<) represent yield or profit losses compared to no-cc average.

The yield and profit margin ratios were the dependent variables in an analysis of variance (ANOVA) and several regession analyses to determine the effects of cover crops. An ANOVA is an analytical tool that is frequently used in the agriculture science literature to demonstrate experimental treatment effects (Belfry et al., 2017; O'Reilly et al., 2011, 2012; Congreves, Vyn, and Van Eerd, 2013; Gaudin et al., 2015). The ANOVA output is an F-Test that determines whether the cover crop treatments demonstrate any effect on the yield or profit margin ratios. However, the ANOVA output does not provide information about the specific effect of each treatment group on the dependent variables. The regression analyses, on the other hand, allow for the estimation of parameters for each variable, i.e. each cover crop treatment. As such, the regression provides a parameter estimate (β) for each cover crop treatment on the yield and profit margin ratios, and through a T-test, the regression output indicates whether each $\beta = 0$, i.e. whether the parameter estimate for a cover crop has no effect (zero effect) on the yield or profit margin ratios. Consequently, while the ANOVA answers the question do any of the cover crop treatments have an effect, it provides no indication of the magnitude or direction of said effect. As such, the ANOVA results are combined with the mean yield or profit margin ratios for each cover crop treatment to show whether the mean values are higher or lower than the no-cc ratio means. The regression analyses estimate both magnitude and direction of each cover crop treatment effect on yield or profit margin ratios.

3.3 The Analysis

The models used to describe the yield and profit margin ratio data were mixed models, i.e. the data contains both random and fixed effects. Random effects refer to variables that may have an effect on the data but are not controlled for in the experiment. For this thesis, any environmental factors that could affect yields differently among the four blocks in each field were considered an uncontrolled (random) effect. Similarly, any variability in crop performance between field 1 and field 2 was another uncontrolled (random) effect. Consequently, two categorical variables were added to all models to account for any uncontrolled or random variation that may exist and that could affect the cover crop effect estimates or the standard errors: A "Field" variable accounting for potential variation between field 1 and field 2, and a "Block" variable accounting for any variation among the eight blocks of the randomised complete block design. The fixed effects refer to the cover crop treatments and main crop types that were intentionally manipulated. Since mixed models were necessary for the analysis, a linear mixed model package ("lmerTest") analysed the random effects and fixed effects, and estimated the degrees of freedom to reduce the probability that the parameter estimates for the cover crop treatments would present significant effect ($\beta \neq 0$) when there is no (zero) effect in reality (Type I error). All analyses were performed in R Studio.

3.3.1 Yield and Profit Margin Ratios for Each main Crop (ANOVA)

Due to the rotation used in the crop experiment, the data relates to a different main crop each year. The exception to this is tomato, which was grown twice between 2008/09 and 2015/16, but in non-consecutive years. Therefore, to determine if the cover crop treatments had a significant effect on each main crop in each year, the yield and profit margin ratios for each main crop were analysed individually with an ANOVA. The goal of the ANOVA was to determine whether the cover crop treatments demonstrated any significant effect on the yield or profit margin ratios for each crop. An ANOVA (F-Test) was performed on the linear mixed model specified for each main crop. The formula of the ANOVA and the linear mixed model is as follows.

$$ANOVA(Y \sim Block(r) + Field(r) + Cover\,Crop) \tag{3.2}$$

- Y: Vector of yield ratios or profit margin ratios for one main crop (sweet corn, spring wheat, tomato, grain corn, squash, soybean, winter wheat, tomato (2))
- Cover Crop: no-cc (reference), oat, rye, osr, osr+rye
- Field: Categorical variable distinguishing field 1 and field 2
- Block: Categorical variable distinguishing 4 blocks in field 1 (1-4) and 4 blocks in field 2 (5-8)
- r: Indicates random variables

The ANOVA was performed on the linear model to determine if the use of cover crops created a change in the yield or profit margin ratios of each main crop. However, the ANOVA does not indicate the magnitude of the effect (change) nor whether the effect is positive or negative. The regression of the linear model for each main crop, however, allowed for the identification of the specific cover crop treatments that drove the treatment effect in the ANOVA.

3.3.2 Cover Crop Effects on Yield and Profit Margin Ratios (Regression Analysis)

The analysis of each main crop provides a glimpse into the impacts of cover crops in each year of data collection. However, a general statement about cover crop use, on all crops, cannot be made because of the limited number of observations in each year and because those results only represent one main crop. Therefore, by combining the ratios from all years and all main crops, the parameter estimates for each cover crop should be more accurate due to more observations. Furthermore, with the variety of main crop types in the rotation, i.e. grains, oilseed and vegetable crops, farmers and policy-makers can make generalisations about the effect of cover crops on similar crop types or rotations based on the analysis of all crops.

The yield or profit ratios were regressed together to determine the effect of each cover crop type on all main crops. The ratios were analysed first for the average effect of each cover crop type on all yield and profit margin ratios (Equation 3.3). These average effects will demonstrate whether or not each cover crop affected yields or profits, unrelated to the crop type. However, if variability exists between certain cover crop-main crop interactions, the knowledge of those interactions would be valuable in planning cropping systems. Therefore, another model was specified to determine whether any significant interactions could be found between cover crop type and each main crop (Equation 3.4).

$$Y \sim Block(r) + Field(r) + Cover\,Crops \tag{3.3}$$

$$Y \sim Block(r) + Field(r) + Cover\,Crop * main\,Crop \tag{3.4}$$

- Y: Vector of all yield ratios or profit margin ratios
- Cover Crop: no-cc (reference), oat, rye, osr, osr+rye
- Main Crop: sweet corn (reference), spring wheat, tomato, grain corn, squash, soybean, winter wheat, tomato (2)
- Field: Categorical variable distinguishing field 1 and field 2
- Block: Categorical variable distinguishing 4 blocks in field 1 (1-4) and 4 blocks in field 2 (5-8)
- r: indicates random variables

The estimates from Equation 3.3 will demonstrate the proportional effect of each cover crop treatment on the yield or profit margin ratios, i.e. the percentage difference in yield or profit for each cover crop treatment compared to the no-cc average yield or profit. The null hypothesis for Equation 3.3 was that the cover crop treatments have no effect, i.e. the parameter estimates will be equal to zero ($\beta = 0$). Significant outcomes would reject the null hypothesis indicating that the yield or profit with the cover crop is different from yield or profit without cover crops. In terms of the ratio magnitudes, rejecting the null hypothesis would indicate that the ratios for the cover crop treatment are not equal to 1 ($\neq 1$), and therefore different from the no-cc control.

Meanwhile, the estimates from Equation 3.4 will demonstrate whether each cover crop has the same effect on each main crop. The null hypothesis in Equation 3.4 was that each cover crop-main crop interaction (interaction) has no effect, i.e. the parameter estimates for each interaction will be equal to zero ($\beta = 0$). The significant outcomes would reject the null hypothesis ($\beta \neq 0$) indicating that those interactions had different yield or profit ratios than the no-cc control. Therefore, the significant estimates would represent interactions that may be advantageous or disadvantageous in Southern Ontario. In terms of magnitudes, the yield and profit margin ratios for significant interactions reject the null hypothesis ($\beta \neq 0$) and the parameter estimates would represent the percentage difference in the yield or profit for the interaction compared to the no-cc average yield or profit.

3.3.3 Cover Crops, Grain and Oilseed Crops and Vegetable Crops

Grain and oilseed production, according to the 2016 Census of Agriculture, accounts for 68% of cropland in Ontario (OMAFRA, 2017), and therefore represents an integral part of the agricultural sector in the province. Consequently, when looking at the differential effects of agri-environmental BMPs such as cover crops, the impacts of these practices on this segment of the agricultural sector is crucial. To determine the effects of cover crops on these crop types, the yield and profit margin ratios were separated into two subsets grain and oilseed crops, and vegetable crops. These subsets were regressed separately on the cover crop treatments to determine the general effect of each cover crop treatment on the yield and profit margin ratios of each subset. The results from these analyses would determine the percentage difference in grain and oilseed yield and profit margin ratios with cover crops (Equation 3.5) and the percentage difference in vegetable yield and profit margin ratios with cover crops (Equation 3.6) compared to the no-cc average yield and profit. The null hypotheses for Equations 3.5 and 3.6 were that each cover crop treatment had no effect on the yield and profit margin ratios for grain and oilseed crops nor vegetable crops, i.e. the parameter estimates for each cover crop would be equal to zero ($\beta = 0$).

$$Y_{g+o} \sim Block(r) + Field(r) + Cover\,Crops \tag{3.5}$$

- Y_{g+o}: Vector of yield or profit margin ratios for all grain and oilseed crops: Spring Wheat, Grain Corn, Soybean, and Winter Wheat
- Cover Crop: no-cc (reference), oat, rye, osr, osr+rye
- Field: Categorical variable distinguishing field 1 and field 2
- Block: Categorical variable distinguishing 4 blocks in field 1 (1-4) and 4 blocks in field 2 (5-8)
- r: indicates random variables

$$Y_{veg} \sim Block(r) + Field(r) + Cover\,Crops \tag{3.6}$$

- Y_{veg}: Vector of yield or profit margin ratios for all vegetable crops: Sweet Corn, Tomato, Squash, Tomato (2)
- Cover Crop: no-cc (reference), oat, rye, osr, osr+rye
- Field: Categorical variable distinguishing field 1 and field 2
- Block: Categorical variable distinguishing 4 blocks in field 1 (1-4) and 4 blocks in field 2 (5-8)
- r: indicates random variables

Chapter 4 Results

The analysis identified heterogeneity between the different main crop types suggesting that economic success in a cover crop system depends not only on the cover crop type but also on the type of main crop. The discussion about the policy implications of the findings, described below, will be presented in the next chapter.

4.1 ANOVA Results: Cover Crop Effects on each Main Crop

In terms of yield ratios, the results from the ANOVA found significant cover crop treatment effects for sweet corn, tomato (2) and winter wheat* (* at the 10 % level). The cover crop treatment effects of all other main crops were insignificant (see Table 4.1). The significant results demonstrated that for those main crops there was a distinct difference between the yield ratios with cover crop treatments compared to the no-cc control. While the ANOVA found these significant treatment effects for sweet corn, tomato (2) and winter wheat, the linear model for each main crop indicated which cover crops had the strongest effects. From the linear models, the cover crops that demonstrated significant effects were: for sweet corn, rye, osr, and osr+rye; for tomato (2), oat, osr, and osr+rye; and for winter wheat, osr* (* at the 10 % level). However, in the linear model for tomato, osr had a significant effect but the ANOVA was insignificant. This inconsistency in the ANOVA results could be due to the experimental variation within the tomato system. Since, the tomato system was a split-split plot design testing the effects of different cover crop types, different fertiliser rates, and an early cultivar, the experimental variation could have concealed the cover crop treatment effects. This discrepancy demonstrated the benefits of combining the regression analysis with the ANOVA. All significant treatment effects identified in the ANOVA were found to be positive by the linear regressions. Therefore, the yields for sweet corn, tomato (2) and winter wheat improved because of the cover crop treatments. For all other main crops, the cover crops had no effect on the yield ratios. Table 4.1 displayed the mean yield ratios for each cover crop treatment by main crop demonstrating the direction of the significant outcomes.

In terms of profit margin ratios, the ANOVA found significant cover crop treatment effects for sweet corn, spring wheat, grain corn, tomato (2), soybean*, and winter wheat* (* at the 10% level). Tomato and squash were the only crops with insignificant treatment effects (see Table 4.2). As previously mentioned, the significant results from the ANOVA indicated that the cover crop treatments changed the profit margin ratios of the specified main crops. However, the linear regression of each main crop found that for spring wheat, grain corn and soybean the profit margin ratios were less than the no-cc control while the profit margin ratios for sweet corn, tomato(2), and winter wheat were higher than the no-cc control. While the rye, osr and osr+rye cover crops improved sweet corn profit margin ratios, they decreased the profit margin ratios for spring wheat. Furthermore, the linear model for grain corn suggests that all cover crop treatments negatively affect the profit margin ratios but oat was only significant at the 10% level. Soybean profit margin ratios with rye and osr+rye cover crops were negative while winter wheat profit margin ratios with osr were positive but only at the 10% level. For tomato (2), similar to its yield ratio model, oat, osr and osr+rye increased the profit margin ratios. Table 4.2 displayed the mean profit margin ratios for each cover crop treatment by main crop indicating the direction of the significant outcomes.

While these results indicated wide variability in the performance of cover crops on the yield and profits of the main crops, the number of observations underlying each linear model and ANOVA were relatively small, as such the significant effects may be over-estimated. By combining all the yield and profit ratios from all the main crops into one linear regression, the validity and accuracy of the parameter estimates for cover crops should improve.

Table 4.1: Mean Yield Ratios by Cover Crop and ANOVA results indicating cover crop treatment effects for each main crop

	Sweet Corn	Spring Wheat	Tomato	Grain Corn	Squash	Soybean	Winter Wheat	Tomato (2)
No CC	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Oat	1.0119	1.1545	1.0228	0.9954	1.0403	1.0151	1.0154	1.1490 **
Rye	1.2215 ***	0.9313	0.9981	0.9778	1.0524	0.9697	0.9780	1.0583
OSR	1.3440 ***	1.0186	1.0770 **	0.9913	1.0315	1.0157	1.0431 *	1.2361 ***
OSR+Rye	1.2736 ***	1.0380	1.0318	0.9963	1.0685	1.0200	0.9954	1.1528 ***
ANOVA								
Cover Crop	***						*	***
Random Effects								
Block	***	*	***	***				
Field								

Significance: 0.01 *** 0.05 ** 0.1 *

Table 4.2: Mean Profit Margin Ratios by Cover Crop and ANOVA results indicating cover crop treatment effects for each main crop

	Sweet Corn	Spring Wheat	Tomato	Grain Corn	Squash	Soybean	Winter Wheat	Tomato (2)
No CC	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Oat	0.990	0.950	1.016	0.970 *	1.041	0.954	1.015	1.142 **
Rye	1.201 ***	0.658 ***	0.989	0.944 ***	1.053	0.888 ***	0.978	1.049
OSR	1.331 ***	0.78 **	1.07 *	0.962 **	1.032	0.944	1.043 *	1.228 ***
OSR+Rye	1.251 ***	0.718 ***	1.021	0.957 ***	1.069	0.924 **	0.995	1.142 **
ANOVA								
Cover Crop	***	***		**		*	*	***
Random Effects								
Block	***	*	***	***				
Field								

Significance: 0.01 *** 0.05 ** 0.1 *

4.2 Regression Results: The Effect of Cover Crops

An explanation is provided here describing how the ratio magnitudes were interpreted to facilitate understanding of the results to come. The subsequent sections refer to the specific variables under evaluation and presents those results. The next chapter will present a more detailed discussion of the implications of the results presented here.

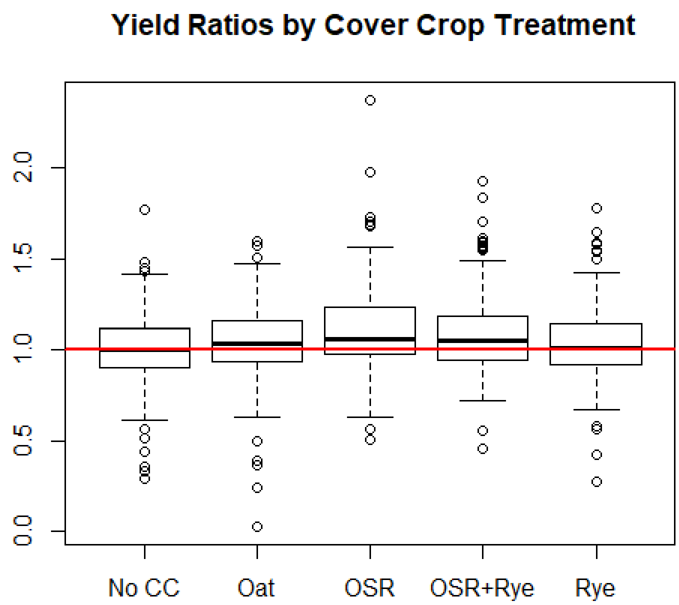
The yield or profit margin ratios provided a tool for analysing all the data from all the main crops. For all the linear models and for both the yield and profit margin ratios, the estimates for the no-cc control (intercept) were equal to one. This confirmed that the average ratio for all no-cc treatments was one, as expected from the empirical framework (1 = no cover crop effect). The ratios represent the proportional change in the yield or profit margins with a cover crop compared to the no-cc average yield or profit margins.Therefore, the parameter estimates (β) in each model indicate the percentage difference in the yield or profit with cover crops or the percentage difference due to the cover crop-main crop interaction compared to the no-cc average yield or profit.

Therefore, the null hypothesis ($\beta = 0$) represents zero difference between the yield or profit margins with cover crops and the no-cc average yield or profit. However, significant parameter estimates rejected the null hypothesis, i.e. the percentage difference in the yield or profit margin with cover crops is different than the no-cc average yield or profit ($\beta \neq 0$).

4.2.1 On Yield Ratios

The results of Equation 3.3, with respect to the yield ratios, demonstrated that all the cover crops have a positive and significant effect on the yield ratios compared to the no-cc average although oat and rye cover crops were only significant at the 10% level (see Table 4.3). According to the results osr and osr+rye cover crops improved yields, across all main crops, by approximately 11 and 9 percent compared to the no-cc average yield. Oat and rye cover crops improved yields, across all main crops, by approximately 4 percent compared to the no-cc average yield. However, despite these promising average estimates, the results from Equation 3.4 confirmed the variability seen in Table 4.1. While the results in Table 4.3 represent the average cover crop effect across all yield ratios, these effects are not distributed equally across all main crops. The results from Equation 3.4 demonstrated that some main crops are more affected by cover crops than others. The boxplot below (Figure 4.1) is a visual representation of the effect of cover crops on all yield ratios. The red line at 1 represents no effect, i.e. no difference in yield with cover crops and the no-cc average yield.

Figure 4.1: Boxplot of the Cover Crop Effects on All Main Crop Yield Ratios



Note: The boxplot presents the distribution of all yield ratios for each cover crop
Note: Red line indicates a yield ratio of 1, i.e. no difference between yield with cover crops and the no-cc average yield

Table 4.3: The Average Effect of each Cover Crop on All Main Crop Yield Ratios

Fixed Effects	Estimate	Std. Error	P-Value
Intercept (No-cc)	1.000	0.03616	0.006 ***
Oat	0.0436	0.02351	0.0641 *
Rye	0.0417	0.02351	0.0762 *
OSR	0.1099	0.02351	0.0000033***
OSR+Rye	0.0864	0.02351	0.00025 ***
Random Effects			
Block	***		
Field			

Significance: 0.01 *** 0.05 ** 0.1 *

Note: Estimates reflect the proportional difference in yield between the cover crop treatment and the no-cc average

The effects estimated in Equation 3.4, for yield ratios, were insignificant for most cover crop-main crop interactions indicating that the null hypothesis was not rejected ($\beta = 0$) demonstrating no difference in yield with cover crops compared to the no-cc average yield (see Table 4.4). However, some outcomes were significant, i.e. for these parameter estimates the null hypothesis was rejected ($\beta \neq 0$): Sweet corn yields with rye, osr and osr+rye cover crops were 22, 34 and 27 percent higher than the no-cc average yield, and tomato (2) yields with oat, osr and osr+rye cover crops were 15, 24 and 15 percent higher than the no-cc average yield. The Equation 3.4 results were somewhat consistent with the ANOVA results in Table 4.1, with some exceptions. The significant treatment effect found for winter wheat did not carry through from the ANOVA, similarly, the significant effect of osr on tomato from the linear model failed to remain significant. Meanwhile, the regression results for Equation 3.4 found that spring wheat yield with oat cover crops was 15% higher than the no-cc average yield. For all other cover crop-main crop interactions, the null hypothesis was not rejected signifying that the yields with cover crops were no different than the no-cc average yield. Ultimately, while cover crops presented a positive impact on yield ratios on average (see Figure 4.1), all main crops were not equally affected. Osr and osr+rye cover crop treatments had the highest yield gains and both seem to benefit tomato and sweet corn in particular indicating that these interactions may be ideal for Ontario.

Table 4.4: Effects of each Cover Crop on the Yield Ratios of Specific Main Crops, i.e. Interaction Effects (significant results shown)

	Estimate	Std. Error	*P*-Value
Intercept (No-cc)	1.000	0.0488	0.000007 ***
sweet corn*rye	0.222	0.0518	0.000021***
sweet corn*osr	0.344	0.0518	0.0000000 ***
sweet corn*osr+rye	0.274	0.0518	0.0000002***
springwheat*oat	0.155	0.0634	0.01506 **
tomato2*oat	0.149	0.0634	0.01902 **
tomato2*osr	0.236	0.0634	0.00021 ***
tomato2*osr+rye	0.153	0.0634	0.01621 **
Random Effects			
Block	***		
Field			

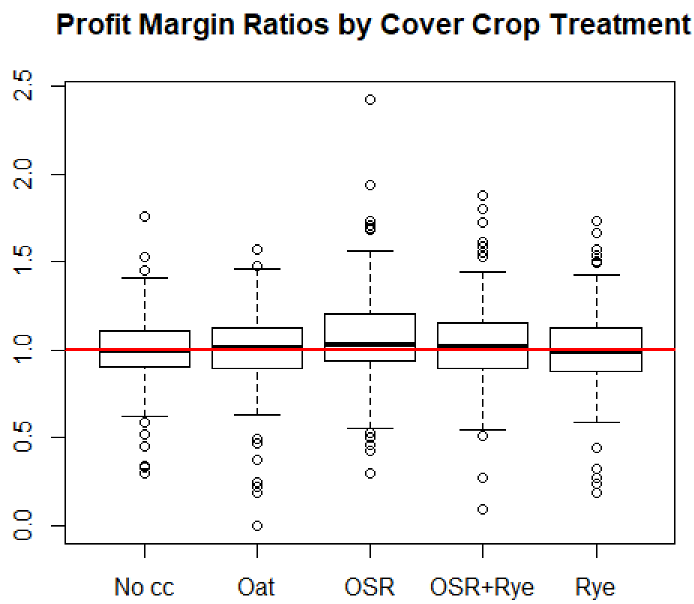
Significance: 0.01 *** 0.05 ** 0.1 *

Note: These results reflect the proportional difference in the yield of the specific main crop-cover crop interactions compared to the no-cc average for the same main crop.
Note: All interactions not displayed are insignificant. These interactions drive the general effects of cover crops on profits seen in Table 4.3

4.2.2 On Profit Margins

The results of Equation 3.3, for profit margin ratios (see Table 4.5), indicated that only osr cover crops had a positive and significant effect on all profit margin ratios, while all other cover crops were insignificant, i.e. the parameter estimates did not reject the null hypothesis ($\beta = 0$), the estimates were positive. Therefore, except for osr that increased profit margins by approximately 7 percent compared to the no-cc average profit, cover crops had no effect on profit margin ratios despite the additional costs associated with cover crop implementation. The boxplot below (see Figure 4.2) shows the results that were discussed above, i.e. the effect of cover crops on all profit margin ratios.

Figure 4.2: Boxplot of the Cover Crop Effects on All Main Crop Profit Margin Ratios



Note: The boxplot presents the distribution of all profit margin ratios for each cover crop

Note: Red line indicates a profit margin ratio of 1, i.e. no difference between profit with cover crops and no-cc average profit

Table 4.5: Average Effects of Each Cover Crop on All Main Crop Profit Margin Ratios

Fixed Effects	Estimate	Std. Error	*P*-Value
Intercept (No cc)	1.000	0.0341	0.0034 ***
Oat	0.01194	0.0249	0.632
Rye	0.0003	0.0249	0.9903
OSR	0.0748	0.0249	0.0028 ***
OSR+Rye	0.038	0.0249	0.128
Random Effects			
Block	***		
Field			

Significance: 0.01 *** 0.05 ** 0.1 *

Note: Estimates reflect the proportional difference in yield between the cover crop treatment and the no-cc average

Similar to Equation 3.4 for yield ratios, the results from Equation 3.4 for profit margin ratios found that some main crops were more affected by cover crops than others. The results (seen in Table 4.6) demonstrated that profit margin ratios for sweet corn with rye, osr and osr+rye cover crops and the tomato (2) crop with oat, osr and osr+rye were positive and significant, i.e. the null hypothesis was rejected ($\beta \neq 0$). Sweet corn profit margins with rye, osr and osr+rye were approximately 20, 33 and 25 percent higher than the no-cc average profit. Meanwhile, tomato (2) profit margins with oat, osr and osr+rye were approximately 14, 23 and 14 percent higher than the no-cc average profit. The estimates indicate that these interactions may be quite lucrative for Ontario farmers. However, not all the results demonstrated benefits. Spring wheat profit margin ratios with rye, osr and osr+rye rejected the null hypothesis ($\beta \neq 0$) estimating profit margins approximately 34, 22, and 28 percent less than the no-cc average profit. For all other main crops, the profit margin ratios were equal to one, i.e. the parameter estimates failed to reject the null hypothesis ($\beta = 0$). The regression results for cover crops and all main crop profit margins (Table 4.6) were more positive than the individual main crop results in Table 4.2. While the positive results remain for sweet corn and tomato (2), the negative effects for grain corn and soybean and the positive effect for winter wheat became insignificant. Once again, the results demonstrated that the choice of cover crop type has meaningful implications with respect to the profitability of the main crop. The cover crop types tested in this experiment had beneficial effects on sweet corn and tomato (2) profits, however they were not favourable for spring wheat profits. Ultimately, the story of profit margin ratios and cover crops was positive. While some profit margin ratios increased and a few decreased, the majority of parameter estimates failed to reject the null hypothesis ($\beta = 0$), indicating that profit margin ratios with cover crops were no different than to the no-cc average profit in spite of the additional costs associated with cover crop use.

Table 4.6: Effects of each Cover Crop on the Profit Margin Ratios of Specific Main Crops: Interaction Effects (significant results shown)

	Estimate	Std. Error	*P*-Value
(Intercept)	1.000	0.0468	0.000002 ***
sweet corn*rye	0.201	0.0515	0.00010 ***
sweet corn*osr	0.331	0.0515	0.00000 ***
sweet corn*osr+rye	0.251	0.0515	0.000001 ***
springwheat*rye	-0.342	0.0631	0.00000008 ***
springwheat*osr	-0.220	0.0631	0.000505 ***
springwheat*osr+rye	-0.283	0.0631	0.000008 ***
soybean*rye	-0.112	0.0631	0.075975 *
tomato2*oat	0.143	0.0631	0.024092 **
tomato2*osr	0.228	0.0631	0.00031 ***
tomato2*osr+rye	0.143	0.0631	0.024111 **
Random Effects			
Block	***		
Field			

Significance: 0.01 *** 0.05 ** 0.1 *

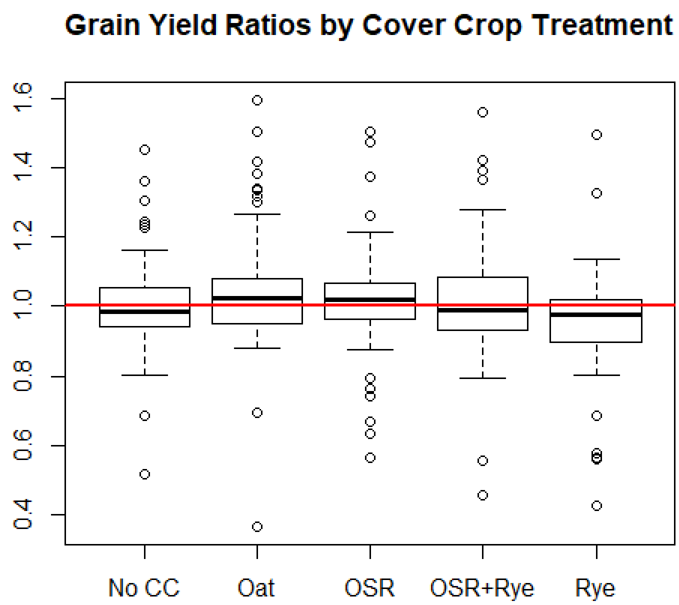
Note: These results reflect the proportional difference in the profit of specific main crop-cover crop interactions compared to the no-cc average for the same main crop.
Note: All interactions not displayed are insignificant. These interactions drive the general effects of cover crops on profits seen in Table 4.5

4.2.3 On Grain and Oilseed Crops and Vegetable Crops

Grain and oilseed crops cover 68% of Ontario cropland (OMAFRA, 2017; Statistics Canada, 2016), and therefore represent a large segment of the agricultural sector in the province. The impact of cover crops on this crop types is crucial to the bottom-line of many producers in the region, and will be the primary driver in a farmer's decision to adopt cover crops or not. As such, distinguishing the effect of cover crops on grain and oilseed crops and vegetable crops is necessary to provide policy-makers with more insight about the challenges that may affect different farmers' willingness to adopt cover crops.

In terms of grain and oilseed yield ratios, the parameter estimates for the regression analysis were not significant for any cover crop treatment (see Table 4.7). As such, the parameter estimates for each cover crop failed to reject the null hypothesis ($\beta = 0$) indicating that grain and oilseed yields with cover crops were no different than the no-cc average yield. The boxplot below (see Figure 4.3) demonstrates the results discussed above, i.e. the average effect of cover crops on the yield ratios of grain and oilseed crops.

Figure 4.3: Boxplot of the Cover Crop Effects on All Grain and Oilseed Yield Ratios



Note: The boxplot presents the distribution of grain and oilseed yield ratios for each cover crop
Note: Red line indicates a yield ratio of 1, i.e. no difference between yield with cover crops and no-cc average yield

Table 4.7: The Average Effect of each Cover Crop on All Grain and Oilseed Yield Ratios

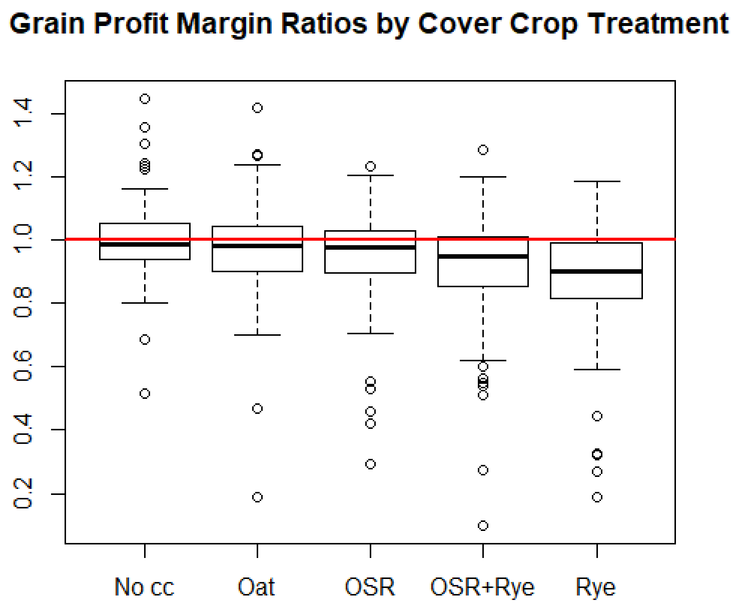
	Estimate	Std Err	P-Value
Intercept	1.000	0.041	0.005 ***
Oat	0.045	0.028	0.113
Rye	-0.036	0.028	0.208
OSR	0.017	0.028	0.546
OSR+Rye	0.012	0.028	0.661
ANOVA			
Cover Crop	*		
Random Effects			
Block	*		
Field			

Significance: 0.01 *** 0.05 ** 0.1 *

Note: The estimates express the change in grain and oilseed yield ratios due to cover crop use.
Note: The values represent the proportional change in yield with each cover crop compared to no-cc average

In terms of profit margin ratios for grain and oilseed crops (see Table 4.8), the regression analysis found that the parameter estimates for rye, osr and osr+rye rejected the null hypothesis ($\beta \neq 0$). This significant effect was negative, i.e. the grain and oilseed profit margins with rye, osr and osr+rye were approximately 13, 6 and 10 percent less than the no-cc average profit. These results seen in the boxplot below (see Figure 4.4) reaffirm that some main crops benefit more from different types of cover crops. Perhaps, grain and oilseed crops require a different type of cover crop to facilitate yield and profit benefits, for example legume cover crops were found to have positive yield benefits in the literature (Blanco-Canqui et al., 2015; Snapp et al., 2005; Lu et al., 2000; Roberts et al., 1998).

Figure 4.4: Boxplot of the Cover Crop Effects on All Grain and Oilseed Profit Margin Ratios



Note: The boxplot presents the distribution of grain and oilseed profit margin ratios for each cover crop
Note: Red line indicates a profit margin ratio of 1, i.e. no difference between profit with cover crops and no-cc average profit

Table 4.8: Regression Analysis Results: The Average Effect of each Cover Crop on Grain and Oilseed Profit Margin Ratios

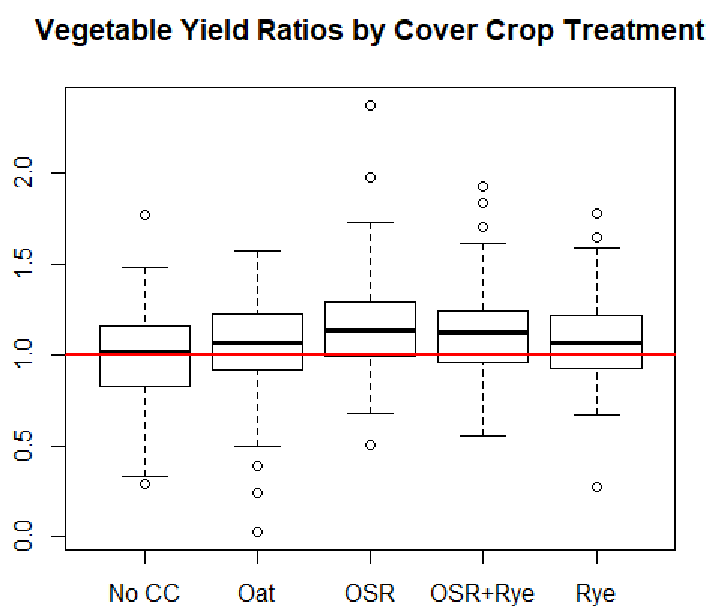
	Estimate	Std Err	P-Value
Intercept	1.000	0.035	0.0008 ***
Oat	-0.0271	0.031	0.386
Rye	-0.1328	0.031	0.000 ***
OSR	-0.0678	0.031	0.031 **
OSR+Rye	-0.1016	0.031	0.001 ***
ANOVA			
Cover Crop	***		
Random Effects			
Block			
Field			

Significance: 0.01 *** 0.05 ** 0.1 *

Note: The estimates express the change in grain and oilseed profit margin ratios due to cover crop use.
Note: The values represent the proportional change in grain profits with each cover crop compared to no-cc average

While the story of cover crops and grain and oilseed crops is not ideal, the story of cover crops and vegetable crops is quite exceptional. The results for vegetable yield ratio demonstrated that cover crops had a strong treatment effect on the vegetable subset (see Table 4.9). The regression analysis identified positive parameter estimates for rye, osr and osr+rye that rejected the null hypothesis ($\beta \neq 0$) indicating significant effects for those cover crop treatments. The average vegetable yield ratios with rye, osr and osr+rye were 9, 16 and 13 percent higher than the no-cc average yield, as seen in the boxplot below (see Figure 4.5) the median vegetable yield ratios are above the no effect line. Similarly, the profit margin ratios for vegetables also demonstrated positive and significant parameter estimates ($\beta \neq 0$) (see Table 4.10). The profit margins for vegetable crops with rye, osr and osr+rye were 8, 16 and 12 percent higher than the no-cc average profit. Additionally, the boxplot below (see Figure 4.6) illustrated the median vegetable profit margin ratios are above the no effect line indicating that vegetable crops in Ontario may benefit most from cover crop use.

Figure 4.5: Boxplot of the Cover Crop Effects on Vegetable Yield Ratios



Note: The boxplot presents the distribution of the vegetable yield ratios for each cover crop

Note: Red line indicates a yield ratio of 1, i.e. no difference between yield with cover crops and no-cc average yield

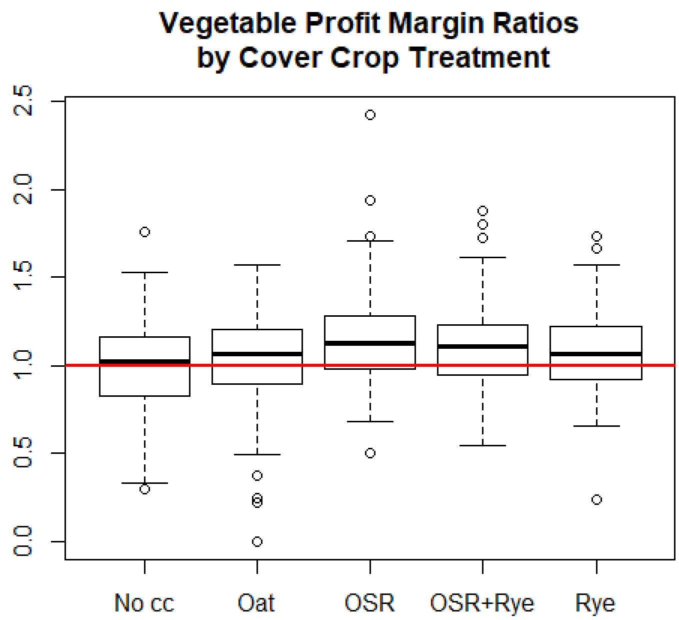
Table 4.9: Regression Analysis Results: The Average Effect of each Cover Crop on Vegetable Yield Ratios

	Estimate	Std Err	*P*-Value
Intercept	1.000	0.0370	0.001 ***
Oat	0.043	0.032	0.184
Rye	0.086	0.032	0.008 ***
OSR	0.163	0.032	0.000 ***
OSR+Rye	0.129	0.032	0.000 ***
ANOVA			
Cover Crop	***		
Random Effects			
Block	***		
Field			

Significance: 0.01 *** 0.05 ** 0.1 *

Note: The estimates express the change in vegetable yield ratios due to cover crop use.
Note: The values represent the proportional change in vegetable yield with each cover crop compared to no-cc average

Figure 4.6: Boxplot of the Cover Crop Effects on Vegetable Profit Margin Ratios



Note: The boxplot presents the distribution of vegetable profit margin ratios for each cover crop
Note: Red line indicates a profit margin ratio of 1, i.e. no difference between profit with cover crops and no-cc average profit

Table 4.10: Regression Analysis Results: The Average Effect of each Cover Crop on Vegetable Profit Margin Ratios

	Estimate	Std Err	*P*-Value
Intercept	1.000	0.0370	0.0013 ***
Oat	0.0342	0.032	0.284
Rye	0.0764	0.032	0.017 **
OSR	0.1562	0.032	0.000 ***
OSR+Rye	0.1177	0.032	0.000 ***
ANOVA			
Cover Crop	***		
Random Effects			
Block	***		
Field			

Significance: 0.01 *** 0.05 ** 0.1 *

Note: The estimates express the change in vegetable profit margin ratios due to cover crop use.
Note: The values represent the proportional change in vegetable profit with each cover crop compared to no-cc average

Chapter 5 Discussion and Conclusion

Agriculture in Canada has come under increased pressure, both domestically and internationally, to reduce its environmental footprint (IPES-Food, 2016; ECO, 2016). Threats to water quality and livelihoods around the Great Lakes due to agricultural run-off, and increased flood risk from heavily eroded and degraded soils are some of the driving factors for "cleaning up" the sector. Simultaneously, these environmental costs combined with the unpredictable and highly variable precipitation and temperature patterns due to climate change have caused alarm regarding the resilience of the agriculture sector and its ability to maintain productivity in the face of increasing domestic and international demand for food (IPES-Food, 2016; ECO, 2016). The use of agri-environmental strategies, such as cover crops, have been widely discussed in academic literature and by government policy-makers as a mechanism to address the environmental ills of agriculture without reducing the productivity essential to improving food security and economic development in Ontario.

While the environmental gains from cover crop use have been confirmed in the academic literature, the economic gains in terms of yield and profitability have not been definitively established (Blanco-Canqui et al., 2015; Lu et al., 2000; Snapp et al., 2005). Despite incomplete evidence about the private net benefits of cover crops, financial incentives have been provided to increase cover crop use in Ontario. However, without the knowledge about the private benefits cover crops can provide to farmers, financial (positive) incentives may be unjustified and may create barriers to implementation, preventing the change policy-makers are trying to achieve. This thesis sought to provide clarity on the private net benefits of cover crops to inform policy decisions about the best mechanism to increase cover crop use and to prevent unjustified government payments. Furthermore, the knowledge about the private benefits of cover crops can inform farmers' decisions to implement the agri-environmental strategy without policy intervention.

5.1 Summary of Findings

The results of this research suggest that the decisions about cover crop and main crop type are crucial to the profitability of the cropping system. Specifically, vegetable crops with cover crops demonstrated between 8 and 16 percent higher yield than the no-cc average yield and 7 to 16 percent higher profit than the no-cc average profit. Conversely, grain and oilseed crops with cover crops saw no change in yield compared to the no-cc average yield, and saw 6 to 13 percent lower profits than the no-cc average profit. This heterogeneity among the different main crop types drove the majority of the results from this analysis.

The disparity between grain and oilseed crops and vegetable crops is demonstrated when looking at the two best performing cover crop treatments, osr and osr+rye. Oilseed radish (osr) and the mixture of oilseed radish and rye demonstrated the greatest potential especially when combined with the vegetable crops sweet corn and tomato (2): sweet corn with osr and osr+rye had 34 and 27 percent higher yield and 33 and 25 percent higher profits than the no-cc average yield or profit, while tomato (2) with osr and osr+rye had 24 and 15 percent higher yield and 23 and 14 percent higher profits than the no-cc average yield or profit. Conversely, spring wheat with osr and osr+rye experienced lower profit margins, with 22 and 28 percent lower profit than the no-cc average profit.

Additionally rye with spring wheat was the lowest profit interaction, among all main crop types, with 34 percent lower profit than the no-cc average profit. These were the most notable interactions based on the analysis and may be of particular interest to Ontario farmers.

5.2 The Impacts of Cover Crops on Yield and Profit

To place the results of this thesis into the wider cover crop literature, this thesis provides a wider scope in terms of the different cover crops used as well as the variety of main crops. Typically in the literature, the main crops discussed are grain corn with some featuring soybean (Bollero and Bullock, 1994; Acuña and Villamil, 2014; Henry et al., 2010; Balkcom and Reeves, 2005; Plastina et al., 2018; Frye, Smith, and Williams, 1985). However, only two studies look at vegetable crops and both only feature processing tomato (Creamer et al., 1996; Klonsky, Livingston et al., 1994). In terms of cover crops discussed in the literature, many of the studies look at legume cover crops such as hairy vetch (Roberts et al., 1998; Bollero and Bullock, 1994; Acuña and Villamil, 2014; Frye, Smith, and Williams, 1985). This thesis, on the other hand, has no legume cover crops, provides evidence about cereal cover crops (oat and rye), and demonstrates the potential of oilseed radish cover crops.

The findings with respect to grain and oilseed crops are reflective of the literature in both yields and profitability. In most of the literature, grain corn yields are only positively affected by legume cover crops mainly, hairy vetch or red clover (Roberts et al., 1998; Bollero and Bullock, 1994; Acuña and Villamil, 2014; Henry et al., 2010; Frye, Smith, and Williams, 1985). Rye cover crops do not fair well in the literature.

Bollero and Bullock (1994) found that grain corn yield after rye was lower than fallow and hairy vetch, while Acuña and Villamil (2014) found that soybean yield following rye and a mixture of radish and rye were both lower than the no cover crop treatment. This thesis found that rye, in general, had no effect on grain and oilseed crop yields, unlike the negative effect shown in the literature. However when looking at profit margins, spring wheat following rye had 34 percent lower profit than the no-cc average profit, while, soybean following rye had 11 percent lower profit than the no-cc average profit. In general all cover crops except oat negatively impacted grain and oilseed profits and rye demonstrated the largest loss, with 13 percent lower profit than the no-cc average profit. Similar to this study, Plastina et al. (2018) looked at the impact of a variety of cover crops on grain corn and soybean yield and profit, and found that cover crops reduced corn and soybean returns by approximately $46/acre, without cost-sharing.

The results for vegetable crops are meaningful given the limited literature related to this main crop type. Additionally, the results from this thesis are fundamentally different from the other two studies. Creamer et al. (1996) and Klonsky, Livingston et al. (1994) both found that processing tomato yield in cover crop systems were lower than conventional no cover crop systems. Klonsky, Livingston et al. (1994) found that cover crops in an organic system were profitable due to the premium effect, but when prices were low, cover crops became unprofitable. On the other hand, Creamer et al. (1996) found that the conventional system had higher returns compared to a low input system with cover crops. In both studies, cover crops were tested as part of a lower input system where cover crops were used to compensate for reduced chemical inputs. However, in this thesis, the positive yield and profit impacts are attributed solely to cover crop use because the experimental manipulation was removed. Ultimately, this thesis demonstrated the potential of oilseed radish and radish and rye cover crops in vegetable crop rotations, especially for sweet corn and tomato.

5.3 Policy Implications for Ontario

The cropping system (grain-vegetable rotation with non-legume cover crops) tested in the UoG Ridgetown Campus cover crop experiment indicated favourable outcomes for vegetable crops in both yield and profitability. Meanwhile, the profitability of grain and oilseed crops was lower despite the yields being unaffected on average. Consequently, the policy interventions developed to promote the use of cover crops in Ontario should address this heterogeneity.

According to the 2016 Census of Agriculture, 31% of the total cropland in Ontario was planted with soybean, while approximately 37% was planted with grains (winter wheat, spring wheat and grain corn) (OMAFRA, 2017). Therefore, the policy mechanisms related to increasing cover crop use need to recognise that grain and oilseed profits with cover crops were around 6 to 13% lower than the no-cc average profit, since approximately 68% of all cropland in the province is covered by grain and oilseed crops. As such, financial incentives would be necessary to compensate producers for potential losses due to cover crop use. Unfortunately, under Growing Forward 2, cost-sharing for cover crops is only accessible "where cover crops of any kind have not been grown in [the] last five years" (AAFC, 2017). Additionally, whether the potential losses to grain and oilseed crops will persist with continuous cover crop use is unknown. Consequently, the restrictions to cost-sharing may make continuous cover crop use over multiple growing seasons problematic if grain and oilseed producers face potential losses every year.

Therefore, if cover crops are the chosen strategy to increase environmentally sustainable agricultural production by reducing the environmental costs of agriculture, then the current restrictions to cost-sharing need to be re-evaluated.

Evaluating the public environmental benefits from cover crop use is crucial due to the large share of Ontario cropland that may experience losses from cover crop use. Pannell (2008) discussed the different policy tools available to incentivise private landowners to change their land-use behaviour for environmental gains. However, that framework requires an understanding of both the private and public net benefits of the agri-environmental strategy. Knowledge of the public net benefits justifies the use of non-market, or policy, approaches such as government payments to promote a land-use change (Wolf Jr, 1979). Given the potential losses projected for grain and oilseed producers, i.e. negative private benefits, positive public benefits must be shown to justify the policy measures promoting cover crop use. The magnitude of public benefits can also help determine the level of public support that should be devoted to a particular agri-environmental strategy.

Alternatively, since the majority of public benefits from cover crop use address negative externalities from agricultural production, an argument should be made that the potential private losses due to cover crop use internalise some environmental costs. Nevertheless, since increasing cover crop use is the priority, relaxing the restrictions on cost-sharing that prevent using cover crops for revenue generation could reduce government expenditure by opening avenues for farmers to cover their own potential losses. Schomberg et al. (2014) and Pratt et al. (2014) identify the potential of some cover crop varieties to offset their cost through feed for livestock or by creating alternative revenue streams, such as harvesting corn stover for biofuels. Given the scale of grain and oilseed production in Ontario, increasing cover crop use will require compromise and a deliberative, informed approach to policy-making.

5.4 Recommendations

The potential losses to grain and oilseed farmers from cover crop use will make increasing the use of this BMP in Ontario quite challenging. Therefore, the policy tools that promote cover crop use must address this challenge. Cost-sharing for grain and oilseed producers would be required for multiple growing seasons, not just the first, if losses due to cover crop use accumulate every season. Conversely, to reduce the burden of cover crop support payments, policy makers should develop other mechanisms that allow cost offsetting opportunities. One potential opportunity would be to remove the "non-commodity" restriction on the types of cover crops that can be used. However, in addition to revenue earning offsets, extension programs would be necessary to ensure that the environmental benefits that the cover crops provide are not hindered. Finally, the use of cover crops in vegetable rotation should be actively encouraged through extension, especially oilseed radish or radish and rye. However unlike grain and oilseed crops, financial incentives for vegetable crops may not be required for multiple growing seasons.

5.5 Limitations and Further Research

Due to harvesting problems, the data for peas (harvested 2016/17) was removed from the analysis. Additionally, the diversity of main crops in the rotation made comparing yield improvements throughout the cover crop experiment challenging. Perhaps the use of a more typical crop rotation, such as an Ontario corn-soy-wheat rotation, could have allowed for a direct comparison between different rotations of the same crop. This type of design could demonstrate more pronounced cover crop effects and could facilitate the examination of benefit accumulation over time. Additionally, data with respect to the quality aspects of the main crops could also improve the economic analysis. Produce that meets certain processing specifications may garner a premium, therefore increasing the profitability of cover crops due to the quality enhancements of the main crops. Finally, further research is needed to develop an evaluation framework for agri-environmental strategies, such as cover crops. The framework required would need to incorporate all public and private costs and benefits, both environmental and economic, to determine the most cost-effective strategy to mitigate the environmental costs of agriculture, and enhance productivity of agricultural ecosystems through optimal levels of cover crop use.

5.6 Concluding remarks

Ultimately, grain and oilseed production represents the largest share of cropland in Ontario, and this research demonstrates losses to these producers in a cover crop system. Therefore, if the goal of government policy is to mitigate the negative consequences of agriculture and to improve the productive capacity of agricultural ecosystems through increased cover crop use, the priority should be to increase the use of this agri-environmental strategy by all available means. Since grain and oilseed farmers may experience losses, government payments are justified to facilitate the use of cover crops among this producer group. However, to defend the magnitude of public spending used to promote cover crops, research quantifying the public net benefits is needed. The inclusive accounting strategies discussed in Chapter 2 could demonstrate tangible environmental gains from government expenditure. Roth et al. (2018) estimated a monetary value for erosion reduction and nutrient retention in their study of the cost-effectiveness of cover crops. This method could be adapted and used to demonstrate the environmental returns from government spending on cover crops. In conclusion, this thesis demonstrates the potential of cover crops, oilseed radish in particular, in vegetable cropping systems and identifies potential losses to grain and oilseed producers, who represent a large segment of Ontario's agricultural sector. This heterogeneity uncovers potential barriers to the adoption of cover crops due to the restrictions identified in Growing Forward 2. The recommendations made, in this thesis, seek to address these potential barriers in order to facilitate increased cover crop use in Ontario.

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