EFFICIENT NITROGEN FERTILIZER MANAGEMENT

OPPORTUNITIES FOR PRINCE EDWARD ISLAND'S AND ONTARIO'S AGRICULTURE SECTOR

Smart Prosperity Institute

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KEY MESSAGES

The federal government has set a national target to reduce GHG emissions from nitrogen fertilizers by 4 megatonnes by 2030. Agriculture and Agri-Food Canada's February 2022 Discussion paper on the target recognizes that while current approaches are 'moving the needle,' new policies and programs will be needed to achieve this ambitious target.

N_2O emissions are one of the largest sources of greenhouse gas (GHG) emissions in Canada's agricultural sector - the time to act is now. In 2019, 44% of Ontario's and 60% of PEI's total agricultural sector GHG emissions were attributed to N_2O from agricultural soils.

The essential first step to solving the problem of GHG emissions from excess nitrogen fertilizer use is to identify the application practices that are scientifically proven to be effective. These include nutrient management planning and practices found in Fertilizer Canada's 4R program, such as enhanced efficiency fertilizers, split nitrogen application, and variable rate application with soil testing.

Efficient nitrogen fertilizer management needs to be embedded into a broader understanding of natural on-farm sources of nitrogen and the overall health of agricultural soils. To maximize the efficiency of nitrogen management we must also consider opportunities for complementing and synergizing with beneficial management practices (BMPs) to promote soil health.

There are several barriers farmers face when trying to adopt efficient nitrogen management and soil health practices. Some of the primary barriers include:

- Production risks or concerns about a trade-off between profit and risk
- Upfront and recurring costs of practice adoption
- Knowledge requirements of the practice
- Perceived efficacy of the practice
- Time constraints or inconvenience resulting from the change in management practices

There are several novel policy options that can mitigate these barriers and support farmers in adopting efficient nitrogen management practices. Through regionally-grounded workshops, our research has found that stakeholders in both provinces recognize the need for new policy tools and support testing new approaches.

Behavioral economics approaches were championed by workshop participants in both provinces, particularly leveraging the use of trusted messengers and collective adoption bonus payments. Both policy tools help increase the perceived effectiveness of BMPs and help farmers learn about new practices more efficiently.

BMP insurance schemes that encourage farmers to trial new practices while also protecting them against production risk associated with practice change were also high on the list of participants' priorities. This was due to the strong potential for de-risking existing BMPs and because a payout is only provided in the event of a loss.

Finally, participants supported reforming the suite of business risk management programs, such as AgriInvest and AgriInsurance, to encourage the use of new BMPs. Modifications that received support included offering increased matching under AgriInvest or offering lower insurance premiums through AgriInsurance, both contingent upon BMP adoption.

The next step is for policymakers and researchers to pilot these policies to gauge their effectiveness in motivating the use of efficient nitrogen management and soil health practices. By identifying the tools and policies with the highest degree of environmental and economic impact, Canada can advance its clean growth objectives and move one step closer to having a high-performing, efficient, and sustainable agriculture sector.

EXECUTIVE SUMMARY

Nitrous oxide (N_2O) emissions are one of the largest sources of greenhouse gas (GHG) emissions in Canada's agricultural sector, accounting for more than half of Ontario's (ON) and two-thirds of Prince Edward Island's (PEI) agricultural sector GHG emissions. Policymakers can support efforts to reduce agricultural GHG emissions within these two provinces by focusing on efficient nitrogen fertilizer management practices across farm operations. Beyond direct GHG emissions reductions, improving the efficiency of nitrogen fertilizer management can also bolster farmer incomes, enhance soil health, and improve water quality.

This study focuses on optimizing nitrogen fertilizer management in two production systems: corn-soybean-winter wheat systems in Ontario and potato systems in Prince Edward Island. Corn, soybean and winter wheat are Ontario's top three field crops; oilseeds and grain crops also made the largest contribution to gross domestic product (GDP) and employment in Ontario's agri-food sector in 2018. Similarly, potatoes are the largest agricultural commodity in PEI, accounting for nearly 50% of the agriculture industry's GDP in 2015 and nearly a quarter of Canada's potato production in 2021. These cropping systems therefore make substantial contributions to provincial agricultural output and employment, as well as GHG emissions.

Federal and provincial GHG emissions reduction commitments are providing a clear impetus for improving the sector's environmental performance. The federal government has committed to a 30% reduction (from 2020 levels) in greenhouse gas emissions from nitrogen fertilizers by 2030.[1] The federal government released a discussion paper on this target in February 2022 that provides early details on the forthcoming Green Agricultural Plan and some of the initial fertilizer management practices that will be necessary to reduce emissions by 4 Mt to meet the target by 2030. While the document notes that current initiatives are 'moving the needle,' it also emphasizes that new actions and programs will be required to meet the ambitious target.[2]

AAFC's February 2022 Discussion Paper on the nitrogen fertilizer emissions reduction target states that while current initiatives are 'moving the needle,' new policies and programs will be needed to meet the ambitious target.

Corporate sustainability commitments are also taking off. For instance, Kellogg's has committed to sustainably sourcing 100% of its ten key ingredients, with sustainable sourcing practices in place for 96% of its purchased corn and 89% of its purchased wheat as of 2019. These combined commitments have driven producers to see soil health, GHG emissions reductions, and other sustainability measures as an economic necessity to continue to meet evolving buyer needs.

The essential first step to solving the problem of GHG emissions from excess nitrogen fertilizer application is to identify the application practices that are scientifically proven to be effective. This report primarily focuses on **nutrient management planning** and related efforts such as certification under Fertilizer Canada's 4R™[3] Nutrient Stewardship program. Efficient nitrogen fertilizer management needs to be embedded into a broader understanding of on-farm nitrogen inputs (such as cover crops or manure) and the overall health of agricultural soils. As such, this report also focuses on complementarities and synergies between nitrogen fertilizer management and **soil health** beneficial management practices (BMPs) – such as cover cropping, more diverse crop rotations and conservation till/no-till agriculture.

To better understand nitrogen fertilizer management in their local contexts and develop policy solutions that can support emissions reductions, we co-convened two workshops with Équiterre in Guelph and Charlottetown. Workshop attendees included staff from federal and provincial governments, industry, environmental non-government organizations (ENGOs), as well as local producers. In addition to assessing the performance of current nutrient management and soil health programs in ON and PEI, we assessed five novel policy options that showed promise for improving nutrient management and soil health outcomes. These were: (1) Behavioral economics approaches (especially collective adoption bonus payments, and interventions that leverage trusted messengers); (2) BMP Insurance schemes; (3) Reforming federal-provincial-territorial (FPT) business risk management (BRM) programs such as AgriInvest, AgriInsurance and AgriStability; (4) Reverse auctions; (5) Carbon offsets.

Special attention was given to behavioral economics approaches in the workshops and research as they identify a valuable and distinctive set of features influencing BMP adoption, offering innovative perspectives on BMP adoption and policy design. In contrast to the traditional view of the economic agent as an expected utility maximizer (or 'rational profit maximizer'), behavioral research emphasizes the various cognitive biases and other psychological and social factors that shape peoples' decision-making, including that of farmers. By grounding policy design in a more realistic understanding of how producers act and behave, behavioral approaches have the potential to accelerate the adoption of BMPs that generate 'win-win' outcomes for farmers and the environment, and enhance the overall effectiveness of incentive programs for promoting the adoption of more costly BMPs.

When considering existing FPT programming in Canada, there was a general consensus among workshop participants that current programs play a crucial role in rewarding farmers for their stewardship measures, and in sensitizing farmers to new BMPs. On the other hand, participants also identified some shortcomings with these programs, especially the need to dramatically improve the research-policy interface, both on the 'front end' (in terms of governments' and affiliated associations' recommended nutrient application rates) and the 'back end' (rigorously evaluating current programs for cost-effectiveness and overall impact).

Our workshop participants and the broader literature review identified strengths of all five of the suggested policy options examined in the workshop. However, participants also recognized that some tools are better for solving certain kinds of problems than others, and some tools were considered less of a priority within the distinct ON and PEI contexts. BMP insurance was identified as one of the strongest policy candidates for encouraging efficient nutrient management in ON and PEI, due to its potential for de-risking the adoption of nitrogen-related BMPs and because it only provides a payout in the event of a loss - rather than an unconditional payment. Participants were also very receptive to the idea of reforming BRM programs so that they offer enhanced financial benefits in exchange for BMP adoption, especially reforming AgriInvest and lowering insurance premiums under AgriInsurance. Collective bonus payments were seen as another attractive option for encouraging both nutrient management planning and soil health measures in both provinces. Finally, workshop participants from all sectors emphasized the importance of trusted messengers (especially fellow farmers), which they argued should be considered an essential part of *any* agri-environmental policy in these jurisdictions.

The above policies were identified as having the highest potential for supporting the use of nutrient management and soil health BMPs within their local contexts. Designing and implementing pilot projects which test some of the policy options outlined in this report is an important next step for this work. Ideally, these pilots should harness quasi-experimental research designs (featuring treatment and control groups) to test some of the outstanding research questions identified in this report, such as the role that risk preferences (especially loss aversion and probability weighting) and social norms play in BMP adoption decisions. This approach would provide rich insights to help improve the design of new and existing agri-environmental programs, and foster continuous improvements and potential nitrogen-related emissions reductions in Ontario's and PEI's agriculture sectors.

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ABBREVIATIONS

AAFC	Agriculture and Agri-food Canada
ac	Acre
ADOPT	Adoption and Diffusion Outcome Prediction Tool
AES	EU's Agri-environmental schemes
AGGP	AAFC Agricultural Greenhouse Gases Program
AIM	Agronomy Initiative for Marketable Yield
ASP	PEI's Agriculture Stewardship Program
BMPs	Beneficial management practices
bu	Bushels
C	Carbon
CAGR	Compound annual growth rate
CAP	Canadian Agricultural Partnership
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CT	Conventional tillage
cwt	Hundredweight
EEF	Enhanced efficiency fertilizer
EFP	Environmental Farm Plan
ENGOs	Environmental non-government organizations
GDP	Gross domestic product
GHG	Greenhouse gas
kg	Kilogram
kt	Kiloton
Mg	Megagrams
Mt	Megatonnes
N	Nitrogen
N_2	Dinitrogen / nitrogen gas
N_2O	Nitrous Oxide
NERP	Nitrous Oxide Emission Reduction Protocol
NH_3+	Ammonia
NMP	Nutrient management planning
NO_3-	Nitrate
NPV	Net present value
NT	No Till
OMAFRA	Ontario Ministry of Agriculture, Food, and Rural Affairs
ON	Ontario
P	Phosphorous
PEI	Prince Edward Island
PEIFA	PEI Federation of Agriculture
PT	Tillage from a moldboard plow
RSN	Residual soil nitrogen
SOC	Soil organic carbon
SOM	Soil organic matter
TVP	Total value produced
UAN	Urea Ammonium Nitrate
USDA	US Department of Agriculture
ZT	Zone Till

1. INTRODUCTION

Nitrous oxide (N_2O) emissions are one of the largest sources of greenhouse gas (GHG) emissions in Canada's agricultural sector. More than half of Ontario's (ON) and two-thirds of Prince Edward Island's (PEI) agricultural sector GHG emissions stem from N_2O emissions, which are primarily from agricultural soils. Policymakers can help reduce agricultural GHG emissions within these two provinces by focusing on efficient nitrogen (N) fertilizer management practices across farm operations. In addition to mitigating GHG emissions, efficient N fertilizer management has the potential to boost producers' incomes, enhance the overall health of agricultural soils, and improve water quality. This is a special concern in ON and PEI, as both provinces have seen increased risks of surface and groundwater contamination by N in recent decades (see Section 2 for more information).

More than half of Ontario's and two-thirds of Prince Edward Island's agricultural sector GHG emissions stem from N_2O emissions, which are primarily from agricultural soils.

This study specifically focuses on optimizing N fertilizer management in two production systems: corn-soybean-winter wheat systems in southwestern ON and potato systems in PEI. These cropping systems were selected for three reasons:

1. They are the primary cropping systems within their respective provinces.

2. Some producers in these cropping systems are already feeling pressure from their downstream supply chain partners to adopt more sustainable practices, such as Kellogg's Canada and General Mills for cereal crops in ON, and McDonald's Canada and Cavendish Farms for potatoes in PEI. These combined pressures have driven producers to see soil health, GHG emissions reductions and other sustainability measures as an economic necessity to continue to meet evolving buyer needs.

3. Farmers are experiencing the impacts of climate change on their livelihoods first-hand, and are actively seeking viable climate change mitigation, adaptation and resilience strategies, such as nutrient stewardship, conservation cropping and improved livestock feeding strategies.

In light of these challenges, there is a vital need to better understand how nutrient management and soil health beneficial management practices (BMPs) can further mitigate climate change, while improving water quality, soil health, and farmers' livelihoods. Our research was informed by two expert workshops co-convened with Équiterre – one in Charlottetown, PEI and the other in Guelph, ON – which included staff from federal and provincial governments, industry, environmental non-government organizations (ENGOs), and local producers. Through expert presentations, question and answer sessions, and breakout group discussions, workshop participants assessed the performance of current policies and programs on nutrient management and soil health in ON and PEI and evaluated additional policy options that could support efficient nutrient management and soil health outcomes. The research design and workshop format were developed in close consultation with subject matter experts and informed by an in-depth literature review.

This report integrates these findings to assess the environmental impacts of nitrogen fertilizer application (especially for GHG emissions), analyze fertilizer overapplication and its causes, review promising BMPs to efficiently manage nitrogen fertilizer and improve soil health, highlight the role of current policies in promoting BMP adoption, and outline new policy options to support producers in reducing fertilizer-related emissions while supporting economic performance.

The report is structured as follows: section 2 of this report outlines the current state of play in the two cropping systems in terms of production characteristics, trends in fertilizer application, environmental impacts, and pressures to improve environmental performance.

Section 3 provides an overview of proven BMPs for each region and cropping system, as well as barriers to their adoption, with an emphasis on nutrient management planning (NMP) and related efforts such as retailer certification under Fertilizer Canada's 4R™ Nutrient Stewardship program as well as three soil health BMPs (cover cropping, more diverse crop rotations, conservation tillage). Further information on the economic and environmental benefits of nutrient management BMPs (improved N fertilizer source, timing, rate, and placement) are summarized in Appendix A.

Section 4 briefly reviews some of the policy considerations for optimal N fertilizer use, as it requires an understanding of both the privately and the socially optimal rates of N fertilizer application. The privately optimal rate of N application is described as the application rate which produces the maximum amount of benefit for producers based on the market price of N inputs and the expected yield; however, the social cost of N accounts for both the private costs to the producer and the monetization of a variety of non-market assets (i.e., human health, clean air, clean water) that are impacted by the producer's decisions.

Section 5 reviews Canada's current suite of programs to promote N fertilizer management, water quality and soil health, and highlights workshop participants' assessment of the strengths and shortcomings of these programs.

Section 6 outlines several policy options that show promise in promoting efficient N fertilizer management and overall soil health, taking into account current federal and provincial agricultural policy contexts as well as lessons learned from other jurisdictions. More specifically, it examines the five following policy options:

1. Behavioral economics approaches (especially collective bonus payments, and leveraging trusted messengers)

2. BMP Insurance schemes

3. Other risk management tools, namely reforming the joint federal, provincial, and territorial Business Risk Management (BRM) programs such as:

4. AgriInvest

5. AgriStability

6. AgriInsurance

7. Reverse auctions

8. Carbon offsets

Section 7 provides a synthesis of the strengths and weaknesses of the five proposed policy options, and highlights some cross-cutting policy considerations and next steps to support higher levels of adoption for efficient nutrient management and soil health practices in both provinces.

Section 8 concludes.

2. OVERVIEW OF PRODUCTION SYSTEMS

This section of the report provides the basic background information for understanding the production dynamics of Ontario corn-soybean-winter wheat and PEI potato production systems. It summarizes their economic importance, production characteristics (planting and harvest times, recommended fertilizer application rates), trends in fertilizer applications (both total fertilizer use and per-acre application rates), as well as the main environmental impacts in terms of GHGs, soil health, and water quality.

2.1 Ontario

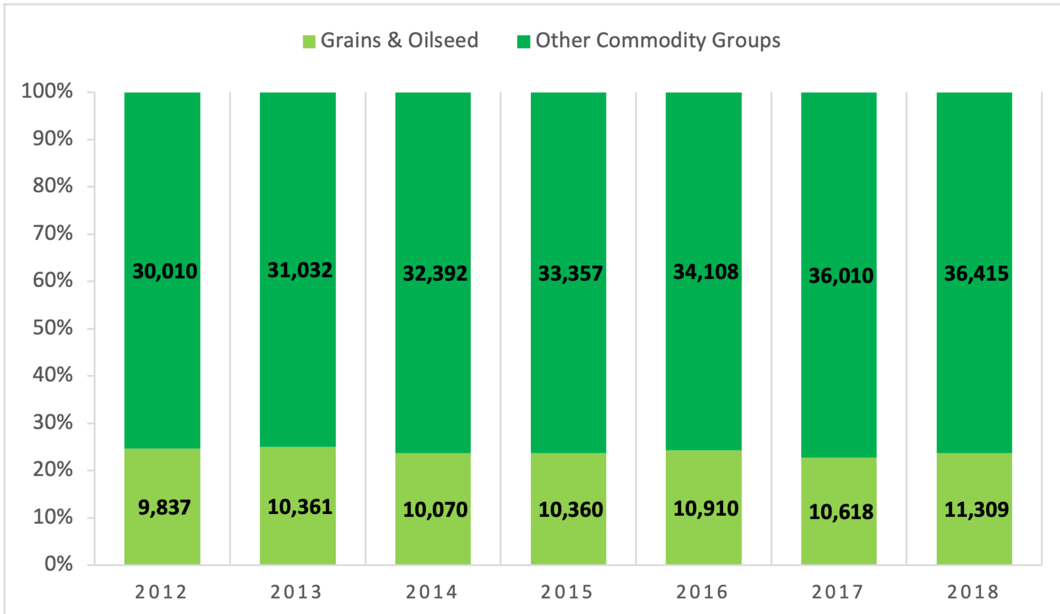
2.1.1 System Characteristics

Economic Importance

Over 8.6 million acres of land in Ontario is dedicated to cropland. Nearly two-thirds of that land is dedicated to growing soybeans, grain corn, and winter wheat. According to the 2017 estimates from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), the total winter wheat yield was equal to 87.3 bushels (bu) per acre (ac), grain corn yield was 167 bu/ac, and soybean yield was 45.6 bu/ac.

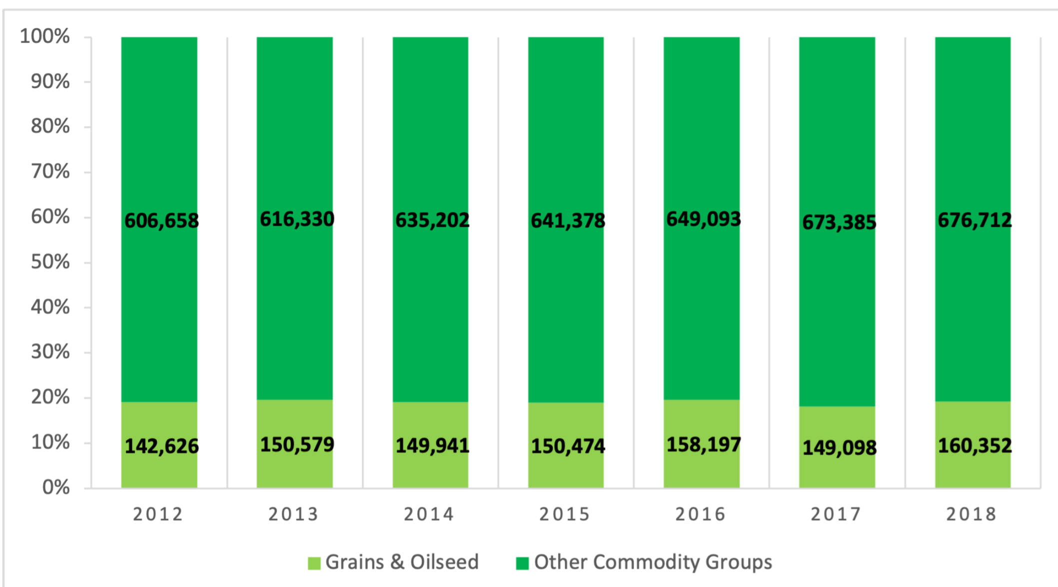
Oilseeds and grain crops also made the largest contribution to both gross domestic product (GDP) and employment in Ontario's agri-food[4] sector between 2012 and 2018, accounting

Figure 1. Ontario Gross Domestic Product From Agriculture and Grain & Oilseed Crops in Millions of Chained 2012 Dollars (2012-2018)



Source: OMAFRA (2019). Economic Impact Analysis of Ontario Agri-food Value Chain

Figure 2. Ontario's Employment in Agri-food and Grains & Oilseed (2012-2018)



Source: OMAFRA (2019). Economic Impact Analysis of Ontario Agri-food Value Chain

for around 25% of the agri-food industry's real GDP (as can be seen in Figure 1). The compound annual growth rate of GDP from oilseed and grain crops was 2% during this time, reaching $11.4 billion in 2018. Oilseed and grain crops also consistently accounted for around 20% of agri-food employment during this time, employing 160,352 people in 2018 (as shown in Figure 2).[5]

Production Characteristics

In Ontario corn-soybean-winter wheat rotations, corn is typically planted in late April or early May and is then harvested in the first few weeks of September. After the September harvest, farmers have the option to plant winter wheat. There is quite a large window for effectively planting winter wheat in Ontario, ranging from late August to early October. Winter wheat establishes itself in the soil prior to the winter season, then lies dormant in the soil over winter.

In spring of the following year, winter wheat resumes its growth phase and is typically assessed for harvest in early May. Soybeans are commonly planted between late April and early May in the second year, with earlier planting being recommended for any farmer intending to plant winter wheat again in the fall. Soybeans are generally harvested later in the growing season, around early October, which makes managing their seeding date an important consideration to maintain this rotation.

Although total yield and input expenses vary across similar crops, OMAFRA provides sample grain corn field budget guidelines based on an expected yield of 174 bu/ac, recommending N application rates of 68 kg/ac (or alternatively, 244 kg/ac of Urea Ammonium Nitrate [UAN]).[6] However, OMAFRA also notes that planting soybeans prior to corn in a rotation can reduce N requirements for corn by approximately 12 kg/ac.[7]

By contrast, the Manitoba Fertility Guide recommends applying 88 kg/ac of N to corn if existing N levels are 13.5 kg/ac (as revealed by a soil test), but this combination of application rate and level of soil N is only expected to yield approximately 130 bu/ac.[8] The University of Arkansas' Corn Production Handbook proposes as a general rule that 1-1.5 lbs of N are required to produce each bushel of corn, although N requirements increase as soils become siltier or highly clay-like.[9]

Other common Ontario crops in the rotation, such as winter wheat, require between 54.63 and 66.77 kg/ac of N in order to yield approximately 84.5 bu/ac.[10] While the total N requirement for a soybean yield over 70 bu/ac is between 90. 72kg/ac and 136.07 kg/ac. However, OMAFRA documents do not typically recommend N application to high yielding soybean crops, as N application has not demonstrated a significant contribution to increasing total yield. This is propounded to be a result of the soybean's ability to draw over 75% of its N requirement naturally from the environment.[11]

The range cited in these estimates alludes to the fact that determining the appropriate N application rate is very context-specific. Proper N prescriptions for crop production can be developed by examining the soil type, using a soil test, and adjusting based on the previous crop cultivated.

2.1.2 Trends in Fertilizer Use

Total Fertilizer Use

Although trends in total fertilizer use in Ontario have been volatile for the past decade and a half, overall fertilizer use increased by 13% from 2002 to 2018. From 2002 to 2008, fertilizer use declined by 43% (from 646 kilotons [kt] to 370 kt), reaching its lowest point in the time series by 2008. After a sharp 60% uptick in fertilizer use from 2008 to 2010 (which is explained in more detail below) fertilizer use generally increased from 2010-2015, returning to 2002 levels by 2013. Despite a slight dip from 2016-2017, fertilizer use nonetheless stood at 734 kt in 2018 – nearly double from 2008 levels.[12]

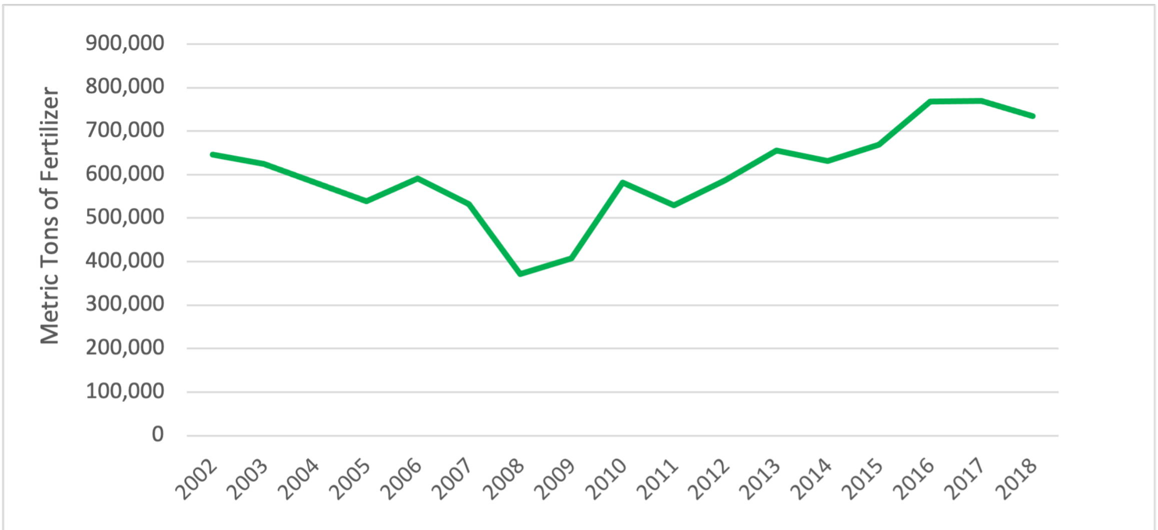
N fertilizer prices tend to be more variable than their potash- or phosphorous-based counterparts, due to the use of natural gas in the production of ammonia.[13] Ammonia is a prominent ingredient in nearly all N fertilizers and natural gas is responsible for upwards of 70% of the cost of ammonia production.[14] These factors help explain the significant uptick in fertilizer use in the 2009/2010 period and the visible year-over-year variability across other time periods shown in Figure 3.

For example, when fertilizer prices in Canada rose rapidly between 2007 and mid-2008, it was generally due to increased global demand for food, a limited supply of fertilizers, good crop prices, and higher energy costs;[15] however, one analysis by the USDA attributed the rise in N fertilizer prices in particular to a 65% increase in the cost of natural gas between June 2007 and June 2008 and a doubling of the price of ammonia in Tampa.[16,17] In Ontario, fertilizer prices were generally lower than in the Prairies in the spring and summer months of 2008, but, in contrast, were higher in the fall of 2008.[18] A more recent analysis has shown that both natural gas and ammonia prices remained significantly below the 2007/2008 peak until around 2013 when both inputs once again experienced a moderate increase in price.[19] While not shown in the timeseries below, ammonia and chemical fertilizer prices have once again skyrocketed (+132%) between November 2020 and 2021 in Canada. Increases in natural gas and coal prices have been identified as one factor, as well as global shortages brought on by trade restrictions in Russia and China.[20]

Fertilizer Application Rates

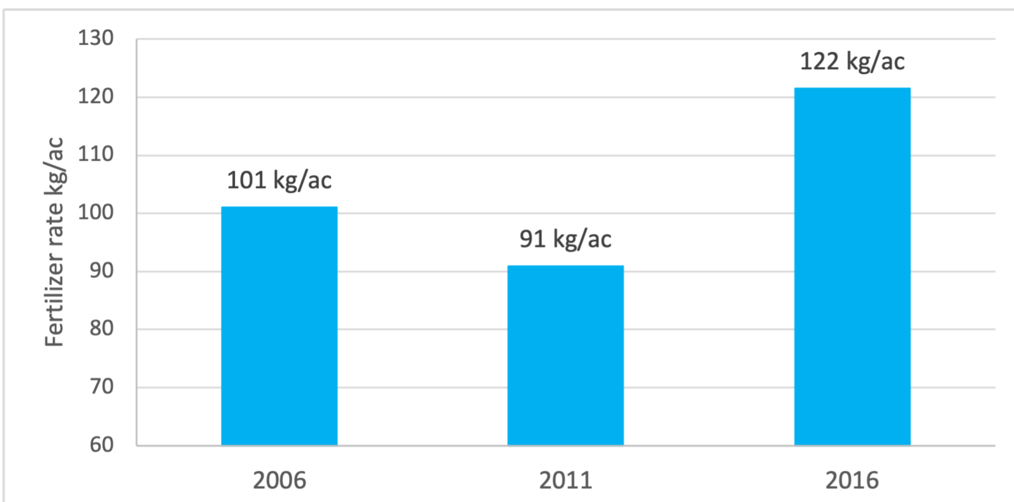
Although direct studies of farmers' reported nitrogen fertilizer application rates in Ontario are rare, a USDA study found that corn producers reported applying nitrogen fertilizers at higher levels than the agronomic benchmark rate (75 kg/ac) on 36 percent of corn acres, equivalent to nearly 18 kg/ac of extra fertilizer for these acres.[22] A study based on experimental field trials of corn in Ontario also found that a risk-neutral farmer would maximize their utility by applying 14% more N than OMAFRA's recommended rate at the time of publication.[23,24]

Figure 3. Estimated Total Fertilizer Use (Metric Tonnes) in Ontario From 2002 to 2018[21]



Source: Bannon, N. & Weersink, A. (2019a). Department of Food, Agricultural and Resource Economics, University of Guelph. Accessed through personal correspondence

Figure 4. Ontario Fertilizer Application Rates



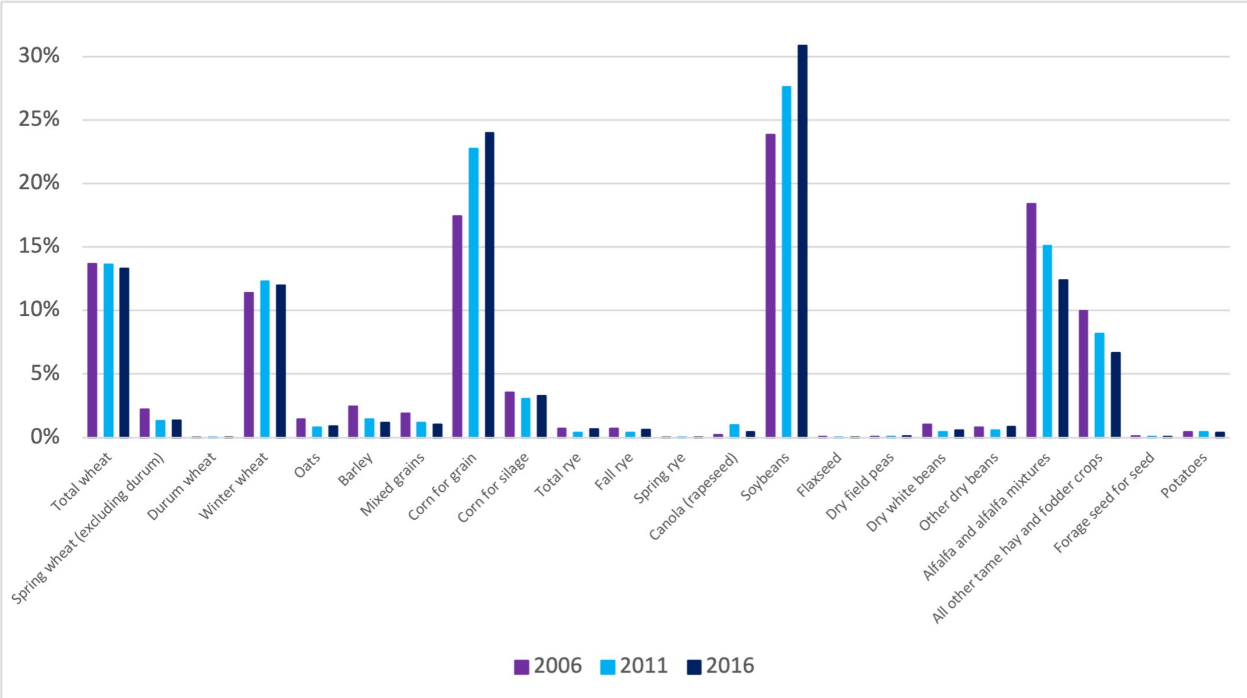
Source: Bannon, N. & Weersink, A. (2019c). "Canadian fertilizer application rates". Food Focus Guelph (54), Department of Food, Agricultural and Resource Economics, University of Guelph.

Time series data also lends indirect support for this hypothesis, as shown in Figure 4. Although the time series data are limited, per acre fertilizer application rates in Ontario have increased by 21% from 2006 to 2016, rising from 101 kg/ac to 122 kg/ac. However, this growth trajectory was inconsistent, with application rates falling to 91 kg/ac between 2006 and 2011, before climbing to 122 kg/ac in 2016.[25]

The application rate estimated here is an aggregate measure for all cropland. However, the amount of land receiving fertilizer has remained more or less constant since 1991.[26] Moreover, with the exception of some points in the 2001 series, the mix of crops grown in Ontario has not changed substantially in the past two decades — as can be seen in Figure 5, which are largely clustered around corn for grain and silage, soybeans, and wheat. While the mix of crops has not changed substantially, it is worth noting that grain corn production levels have increased significantly over this period.[27]

Corn and winter wheat both require intensive amounts of fertilizer, with both crops having the highest absolute N requirements within the OMAFRA field crop guidelines,[28] although their yield-scaled N requirements are relatively low – canola has the highest yield-scaled N requirements, whereas

Figure 5. Share of Each Crop in Total Area Under Crops in Ontario for 2006 to 2016 Census Years



Source: Authors' calculations based on Statistics Canada tables; Land in crops (excluding Christmas tree area) Ontario; Table: 32-10-0406-01: DOI: https://doi.org/10.25318/3210040601-eng (2011-2016 data) and Table 4.3-2 https://www150.statcan.gc.ca/n1/pub/95-629-x/2007000/4182415-eng.htm#crops (2001-2006 data); Hay and Field Crops Ontario ;Table: 32-10-0416-01 . DOI: https://doi.org/10.25318/3210041601-eng (2011-2016 data) and Table 5.1-1 -5.1-25 https://www150.statcan.gc.ca/n1/pub/95-629-x/2007000/4123849-eng.htm (2001-2006 data)

winter wheat ranked third and grain corn ranked seventh respectively.[29] Recall that OMAFRA recommends applying 68-88 kg/ac of N fertilizer application for corn (or approximately 56-76 kg/ac for corn after soy), little or no fertilizer for soybean, and between 55 and 67 kg/ac for winter wheat depending on the variety.[30] These recommended application rates are significantly lower than the range of N fertilizer application rates provided in Figure 4 (91 kg/ ac in 2011 to 122 kg/ac in 2016) – even if one grants for the sake of argument that some of OMAFRA's recommended application rates may be conservative.

As such, comparing the recommended N application rates for corn and winter wheat with the estimated aggregate application rate provides suggestive evidence that a sizable proportion of Ontario corn producers may be overapplying fertilizer.

2.1.3 Environmental Challenges – Ontario

GHG Emissions

In 2019, N_2O emissions accounted for approximately 53% of Ontario's agriculture sector GHG emissions, with 82% of N_2O emissions emanating from agricultural soils. Annual emissions from agricultural soils in Ontario have increased by 7.7% between 1990-2019, from 3.9 megatonnes (Mt) in 1990 to 4.2 Mt in 2016, respectively.[31] When scaled by the area of cultivated land, GHG emissions from soils have increased by 15% between 1990-2016, from 0.43 Megagrams (Mg) of carbon dioxide equivalent (CO_2e) per acre in 1990 to 0.49 Mg of CO_2e/ac in 2016. Synthetic N fertilizer was the top source of direct N_2O emissions from agricultural soils in Ontario in 2016, followed by N from crop residues and manure, respectively.[32] The greenhouse gas emission intensities of corn, soybean, and winter wheat grown in Ontario are 0.38, 0.36, and 0.48 kg CO_2e per kg of dry matter, respectively.[33]

Although emissions have been trending upward for primary agriculture (crop and animal production), so has the sector's GDP. Primary agriculture GDP has grown steadily since 2008, exhibiting a compound annual growth rate (CAGR) of 3.4% from 2013 to 2018.[34]

Soil Health

Soil organic carbon (SOC) is estimated to have decreased on much of Ontario's farmland from 1981-2011, and more than 55% of farmland has experienced large decreases in soil organic matter (SOM) (more than 36 kg/ac/year) over this period.[35] This has been corroborated by a more recent analysis of laboratory soil samples.[36] Similarly, Ontario's Soil Health Strategy estimates that 82% of Ontario's agricultural soils are losing more carbon dioxide (CO_2) to the atmosphere than they are increasing in SOC. The main drivers of this loss in carbon sequestration have been increased conversion of permanent pasture to cropland, increased tillage intensity, and comparatively less diverse crop rotations due to the increasing prevalence of annual cropping systems.[37] More recent soil trends show that 2018 SOM levels in Ontario have further declined since 2011, and over the last 15 years have experienced a cumulative average loss of 5000 lbs SOM/ac.[38]

Moreover, more than two-thirds of Ontario's farmland is at risk of soil erosion, and over half of Ontario cropland has either low or very low soil cover for the majority of the year. Additionally, over 60% of farmland in Ontario was classified as having a high risk of residual soil nitrogen (RSN) in 2011.[39] This emphasizes the need to increase soil health measures to reduce risks of fertilizer leaching and runoff, mitigate GHG emissions, and promote the long-term sustainability of crop production.

Water Quality

The risk of water contamination from N on Ontario farmlands has remained stable between 1981 and 2011. However, around 40% of farmland was classified as being at high contamination risk in 2011.[40] In 2018, the number of confirmed reports of blue-green algae in Ontario increased by over 20% when compared to 2017, with N and phosphorous runoff being named two of the main contributing factors.[41] The growing incidence of nutrient loading impacts underscores the need to motivate the adoption of BMPs that mitigate nutrient runoff and enhance water quality.

The Nitrogen Cycle

The nitrogen cycle is a process that accounts for the movement of nitrogen through its atmospheric and terrestrial stages. In its atmospheric stage, dinitrogen (N_2) composes 78% of the atmosphere. In this form, however, nitrogen is not available or useable by plants. Nitrogen is a key plant nutrient, as it is a required component for amino acids, proteins, nucleic acids and enzymes. Due to its essential nature, nitrogen is commonly the growth limiting factor for plants.

The nitrogen cycle proceeds with a few important processes: nitrogen fixation, mineralization nitrification, denitrification, volatilization, immobilization and leaching. Simplistically, nitrogen fixation converts nitrogen from its atmospheric stage into the terrestrial stage of the cycle. Mineralization, nitrification and immobilization are processes that change the molecular structure of the nitrogen in the soil. Denitrification and volatilization are processes that result in the loss of nitrogen from the soil into the atmosphere. Whereas, leaching is the loss of nitrogen from the targeted body of soil due to the saturation of soil with water.[42]

Nitrogen gas can be converted from the atmosphere in two ways: biological fixation and industrial fixation. Biological fixation is facilitated by legume plants and diazotrophs. Legume plants can fix atmospheric nitrogen in the absence of available nitrogen in the soil. Diazotrophs are nitrogen-fixing microorganisms that form symbiotic relationships with plants.[43] Both methods utilise the enzyme nitrogenase to break the triple bond that connects the two nitrogen atoms in a molecule of nitrogen gas (N_2). Once this bond is broken, the nitrogen atoms rapidly bond with available hydrogen forming ammonia (NH_3^+). This ammonia will be taken up by the associated plant and incorporated into the organic matter, which – if left in the field – will be returned to the soil as organic nitrogen upon decomposition.[44]

Organic nitrogen is not bioavailable to plants but can become bioavailable through mineralization, which transforms organic nitrogen to ammonium. This can be further converted by the process of nitrification which produces nitrate (NO_3^-), the most useable form of nitrogen for plants. This can also be reversed through immobilization which converts ammonium and nitrate back to organic nitrogen.

In the early 1900s, the honing of industrial fixation of nitrogen would change the equilibrium of the nitrogen cycle indefinitely. By 1913, the Haber-Bosch process for nitrogen fixation had been adapted for industrial use of the fixation of dinitrogen gas. The reaction proceeds through the use of a catalyst that nitrogen gas and hydrogen are exposed to at 500 degrees Celsius at a pressure of 200 atm.[45] The use of this method has shifted more nitrogen to bioavailable forms which can be distributed via inorganic fertilizers. This has been a significant discovery and has allowed for the growth of the agriculture industry to support the vast global population.

Loss of nitrogen from soil can occur in several ways including nitrogen leaching, denitrification and ammonia volatilization. Nitrogen leaching occurs primarily with nitrate because it is highly soluble and is not retained well by soil.[46] As water saturates soils then drains away it can wash nitrate out of the soil. Leaching can lead to the delivery of nitrogen to surface and groundwater, which can cause a host of environmental issues. Denitrification and ammonia volatilization will reintroduce nitrogen to the atmosphere, completing the cycle. In the process of denitrification, plants uptake the oxygen atoms from the nitrate molecules leaving gaseous forms of nitrogen. The main form of gaseous nitrogen resulting from this process in dinitrogen but can also take the form of nitrous oxide and nitric oxide, which have a detrimental effect on the environment. Ammonia volatilization occurs in acidic soils when ammonium is reduced to ammonia gas. In soil bodies with high ammonium, application leaching can also be an issue, although in most environments ammonium is quickly converted to nitrate and does not persist in high concentration in soil.[47]

2.2 Prince Edward Island

2.2.1 System Characteristics

Economic Importance

In PEI, potatoes are the largest agricultural commodity, accounting for nearly 50% of the provincial agriculture industry's GDP in 2015[48] and nearly a quarter of Canada's potato acreage in 2021.[49] They therefore make substantial contributions to provincial agricultural output, employment, and GHG emissions.

Production Characteristics

Potato production in PEI typically starts with planting in May and the main harvest begins in September.[50] After a few low-yielding seasons, PEI potato yields have reverted back to an average of 300 hundredweight (cwt) (e.g., approximately 15.2 tonnes) per harvested acre in 2019.[51] However, the 2021 harvest saw a 33% increase in average yield, resulting in a total of 334 cwt on average in PEI.[52] Historical data shows that potato production in PEI was relatively stable between 2011 and 2019, but experienced a significant drop in 2020. Potato production has since rebounded in 2021 and increased by approximately 16% relative to 2011 levels.[53]

Synthetic fertilizer is the primary input for potato production in this region.[54] According to PEI Analytical Laboratories Soil Testing, the recommended Potato N application rate is between 53 to 75 kg/ac depending on the potato variety.[55] By contrast, the Agronomy Initiative for Marketable Yield (AIM) recommends N application rates of approximately 84 kg/ac for Russet Burbank and 54-61 kg/ac for Prospect potatoes.[56]

2.2.2 Trends in fertilizer use

Fertilizer Use

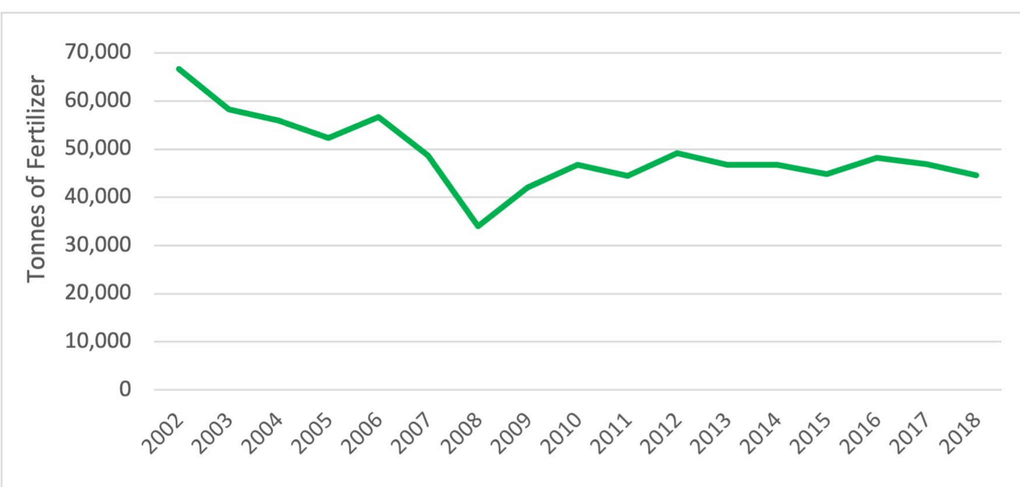
Fertilizer use in PEI has declined significantly relative to 2002 levels, and has stabilized in recent years, as shown in Figure 6. There was a pronounced decline in fertilizer application rates from 2002 to 2008, falling by 50% over this period. After a sharp increase between 2008-2010, fertilizer use has fluctuated between 44,000 and 49,000 tonnes from 2011-2018. Thus, although fertilizer use has been relatively constant over the past eight years in this series, at 44,000 metric tonnes in 2018, fertilizer use in PEI has nonetheless increased by 30% from 2008 levels.[57]

Fertilizer Application Rates

Between 2006-2011, fertilizer use decreased twice as fast as the amount of land under fertilizer, leading to a 12% reduction in fertilizer application rates over this period. However from 2011 and 2016, this trend was reversed. This is shown in Figure 7. Fertilizer use increased by 8% (from 247,409 tonnes in 2011 to 255,189 tonnes in 2016), while the amount of land under commercial fertilizer in PEI increased by 3% over that same period. Taken together, these trends lead to increased fertilizer application rates in recent years, climbing from 180 kg/ac in 2011 to 189 kg/ac in 2016.[58]

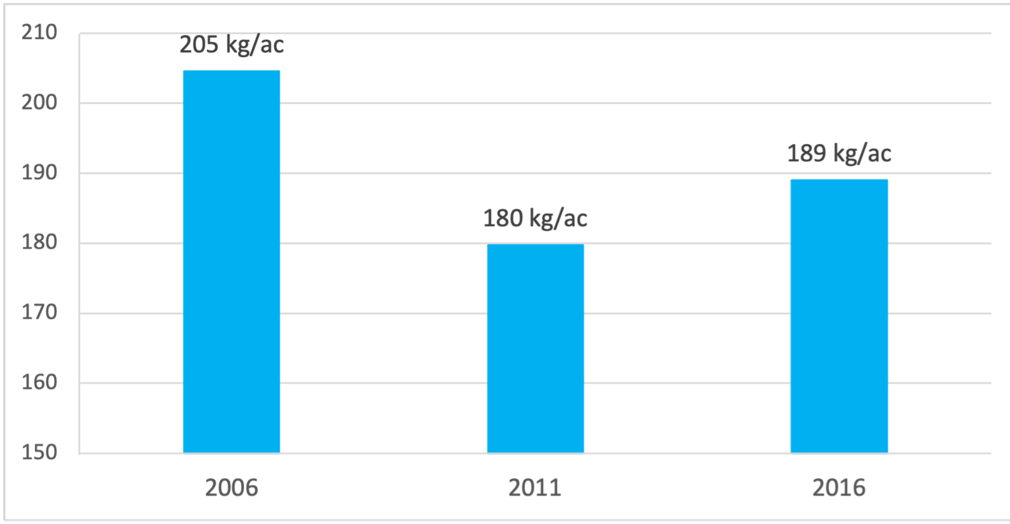
As mentioned previously, these are aggregate estimates of PEI N fertilizer application rates. However, comparing these figures against the overall crop composition in the region can potentially provide an understanding of N application dynamics in PEI potato cropping systems. Similarly to Ontario, PEI's crop mix has not changed substantially in the past two decades — except for the post-2011 increase in soybean production (Figure 8) — which made crop production in PEI mostly focused on potatoes, soybeans and barley. Production levels of potato and barley, have remained relatively stable, but production of corn

Figure 6. Estimated Fertilizer Use (Metric Tonnes) in PEI From 2002 to 2018



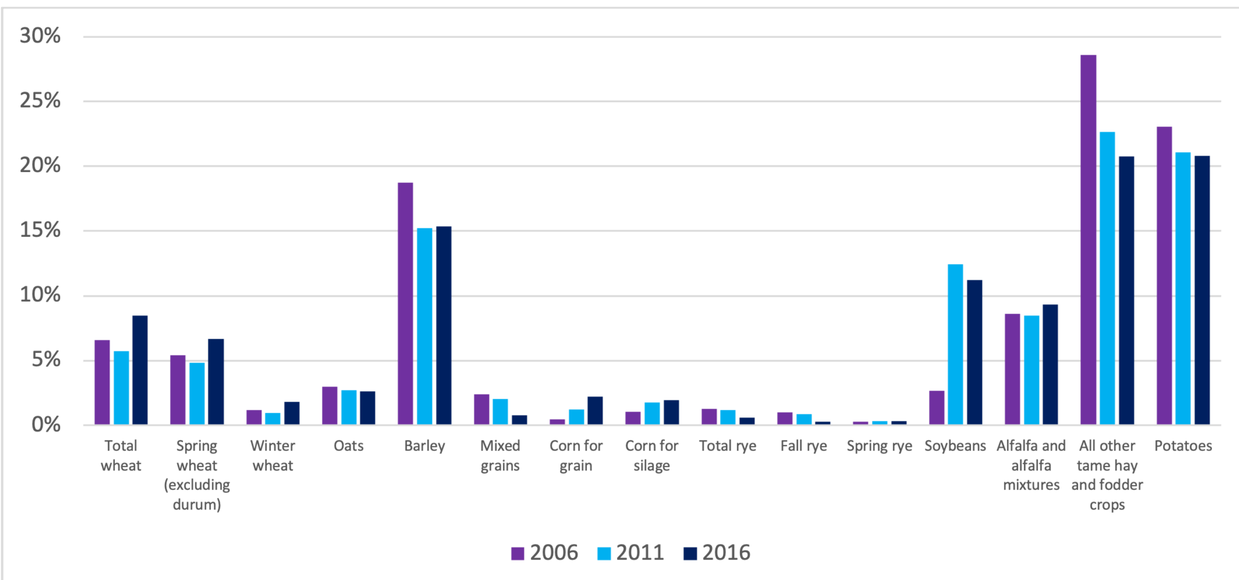
Source: Bannon, N. & Weersink, A. (2019a). "Canadian fertilizer application rates". Department of Food, Agricultural and Resource Economics, University of Guelph. Accessed through personal correspondence.

Figure 7. PEI Fertilizer Application Rates



Source: Bannon, N. & Weersink, A. (2019a). "Canadian fertilizer application rates". Department of Food, Agricultural and Resource Economics, University of Guelph. Accessed through personal correspondence.

Figure 8. Share of Each Crop in Total Area Under Crops in Prince Edward Island for 2006 to 2016 Census Years



Source: authors' calculations based on Statistics Canada tables; Land in crops (excluding Christmas tree area) Prince Edward Island; Table: 32-10-0406-01: DOI: https://doi.org/10.25318/3210040601-eng (2011-2016 data) and Table 4.3-2 https://www150.statcan.gc.ca/n1/pub/95-629-x/2007000/4182415-eng.htm#crops (2001-2006 data)); Hay and Field Crops Prince Edward Island ;Table: 32-10-0416-01 . DOI: https://doi.org/10.25318/3210041601-eng (2011-2016 data) and Table 5.1-1 -5.1-25 https://www150.statcan.gc.ca/n1/pub/95-629-x/2007000/4123849-eng.htm (2001-2006)

for silage, wheat, and soybeans increased significantly over this period. Potato, barley, and soybeans encompassed 47% of the cropland in PEI in 2016, whereas other N intensive crops such as wheat and corn encompassed only 12% of cropland in PEI.[59] This suggests that the trends in fertilizer application rates are not due to changes in associated crop N requirements, but instead mostly reflects farmers' decisions about fertilizer application rates for the same crops.

Potato is also a relatively N intensive crop, with some of the highest N requirements (in absolute terms) among PEI field crops. As was mentioned previously, depending on the potato variety the recommended N application rate ranges from 53 kg N/ac to 83 kg N/ac.[60] By contrast, the recommended application rate is only 20 kg/ac for barley.[61] Taking the information on N fertilizer application rates, the recommended N application rates for potatoes and other crops, and trends on crop composition together, this time series data suggests significant discrepancies between recommended and actual N fertilizer application rates for PEI agricultural land. This discrepancy likely includes potato production due to its substantial share of cropland in PEI.

2.2.3 Environmental Challenges

GHG Emissions

In 2019, N_2O emissions made up 65% of PEI's GHG emissions from agriculture, with 92% of these emissions coming from agricultural soils.[62] Synthetic fertilizer is the primary source of N input in potato production, so focusing on N fertilizer management in this cropping system is a key priority for reducing GHG emissions in PEI. The greenhouse gas emission intensity of potato grown in the Atlantic Provinces is 0.51 kg CO_2e per kg of dry matter.[63]

Soil Health

PEI soils have continued to lose SOM due to changes in farming practices over the last 40 years. Canada's Agri-Environmental Indicators Report series showed that SOC declined by more than 0.49 tonnes/ac over the 1981-2011 period for this region. Direct measures from the PEI Soil Quality Project confirm these findings — over 5 % of PEI's land base has suffered from a 1% decline in SOM, corresponding to a loss of 0.2 tonnes C/ac/year.[64] Additionally, studies have shown that over an 18-year period (1998-2015) the acreage with over 4% SOM has declined by 18% and the acreage with 3.1-4% SOM has decreased by 46%.[65] This decline is due to producers shifting from perennial cropping systems to annual ones, a reduction in livestock operations, and increasing tillage intensity.[66] One concerning trend for SOM is the recent increase in soybean acreage, which increased by almost 450% between 2005 and 2015. Soybeans are known as a particularly low residue crop that does not offer much opportunity to increase soil C stocks.[67] These trends in PEI's soil health likely contributed to the decline in potato yields over the past three decades.[68] RSN in PEI is also increasing, with nearly 60% of farmland classified as high risk in 2011 (the year for which most recent data is available).[69]

Water Quality

PEI suffers from numerous water contamination issues from years of over-applying synthetic fertilizers. PEI shows an increase in the risk of water contamination with N over the 1981-2011 period, as 45% of farmland was classified at high risk for water contamination by N in 2011.[70] Recent data from the PEI Water Quality Report Cards show that 46% of the 41 watersheds included in the evaluation have average groundwater nitrate concentrations over 3 Mg N/liter and an additional 12% have nitrate concentrations over 5 Mg N/liter.[71] For perspective, 3 Mg N/liter is the acceptable threshold before negative aquatic ecosystem impacts become a concern.[72] Some studies have shown that nitrate leaching potential is much higher following potato production, which places PEI at higher risk[73] — although some of this risk is an inherent feature of crop cultivation on a small island with sandy loam soils (like PEI), since these geographic features increase risks of erosion and nitrate leaching.[74]

Agricultural authorities understand that nutrient management issues are prevalent in PEI and have implemented measures to help counteract them. For instance, a mandatory regulation for farmers to maintain a 15-meter buffer zone for all watercourses and wetlands was introduced in 1999 (in accordance with the Environmental Protection Act of PEI), to address water quality issues and mitigate the negative impacts of farmland runoff.[75] Despite this requirement, fish kills continue to be a problem for the province (although most were suspected to be the result of pesticide contamination).[76]

2.3 Pressures to Improve Environmental Performance

There are a variety of pressures acting upon producers from both Ontario corn-soybean-winter wheat and PEI potato cropping systems to reduce the environmental impacts and increase the productivity of their farm operations. Two of these pressures include meeting new value-chain requirements and reducing the risk of exposure to climate change impacts.

2.3.1 Supply Chain Pressures

An increasing number of agri-business leaders such as Maple Leaf,[77] Wal-Mart Canada,[78] the Agropur Dairy Cooperative,[79] McDonald's Canada,[80] Loblaw, Nestlé and Unilever[81] are making commitments to reduce GHG emissions, protect biodiversity, and improve water quality along their supply chains. These commitments can help influence farmers' production practices.

Ontario

With regard to corn producers, Kellogg's has committed to 100% sustainable sourcing for a list of key ingredients, including wheat and corn. It is already sourcing 96% of its purchased corn and 89% of its wheat sustainably.[82] Kellogg's Supplier Code of Conduct accomplishes this by requiring that all suppliers make a commitment to continuous environmental improvements through optimizing energy, water and agricultural input use, reducing emissions, minimizing food and landfill waste, reducing water pollution, and working towards net-zero deforestation where applicable. Participating suppliers must submit at least one report per year outlining the continuous improvements they have made from their baseline levels; however, Kellogg's maintains the power to request a report at any time. For farm suppliers, Kellogg's relies on tools like the Fieldprint Calculator, the Cool Farm Tool or its own self-developed Kellogg Grower Survey to document the required continuous improvements.[83]

Kellogg's is not alone in this type of venture. General Mills is working to promote integrated pest management (IPM) practices for key crops in its supply chain[84] and is currently supporting a series of pilot projects to assess the sustainability of various cereal, soy, and lentil crops in Ontario and Western Canada as part of the Canadian Field Print Initiative.[85] With support from industry actors like General Mills, the Fieldprint Calculator has been piloted on over 180,000 acres in Canada since 2012. The goal of this initiative is to establish baseline levels of farm performance and then use these to document continuous practice improvements for four sustainability metrics across rotations and growing seasons. These metrics include: land use efficiency, energy use efficiency, GHG emissions, and soil erosion risk.[86] Results from the Southern Plains Wheat Fieldprint Project in the United States highlighted the potential economic and environmental implications of producers applying the Fieldprint Calculator. For instance, producers were empowered to identify fields where N inputs could be reduced without negatively impacting yields, or better understand how the use of cover cropping helps maintain SOM and reduce soil erosion.[87] Moreover, approximately 90% of the fields enrolled in this Fieldprint Project practice reduced tillage to increase SOC, soil moisture, and reduce field compaction, all without negatively impacting yield.[88]

PEI

Potato growers in PEI have also been directly affected by these changing market pressures. McDonald's Canada is helping farmers reduce pesticides, fertilizer, and water use through on-farm auditing,[89] while McCain is promoting the use of multispecies cover crops for potato systems[90] and mandating the creation of an Environmental Farm Plan (EFP) as a prerequisite to awarding potato contracts.[91]

The Annual Potato Sustainability Initiative Survey captures the impact that the pesticide reduction initiative, initially led by McDonald's, has had on farmer practices between 2010 and 2016. As of 2016, the number of farmers enrolled in the initiative had more than doubled, including over 540 farmers, and just under 50% (+10.6% from 2010) of all farmers were now exhibiting practices that earned them the 'Master Practice' designation.[92] Master Practice designations are bestowed upon farmers exhibiting sustainable practices that benefit both the environment and their workers. Farmers must also display documented resource-related improvements to their practices, and must be involved in pesticide education or resource conservation planning activities.[93] Despite the increase in the number of farmers performing 'Master Practices', the overall index score of the survey has remained relatively stable, increasing by about 2% over the six-year period.[94] These types of corporate pressures have driven producers to see soil health, GHG emissions reductions and other sustainability measures as an economic necessity to continue to meet evolving buyer needs.

2.3.2 Concern About Climate Change Impacts

Farmers in Ontario and PEI are also concerned about the risks posed by climate change to their production and communities, and are investigating measures that would increase their resilience to climate change. For instance, recent research on the effects of climate change on cereal production suggests that every 1-degree Celsius increase in average global temperatures would decrease US corn yields by approximately 10% and US wheat yields by 5.5%, respectively.[95]

Other studies predict that climate change in Southwestern Ontario, when considering only the influence of increased crop heat units, will increase corn yields by up to 24%. However, this increase comes with a caveat. Despite the favourable crop heat unit increase, moisture availability may decrease, and thus, producers will be required to adapt their irrigation systems or adopt drought-resistant cultivars in order to capitalize on the expected increase.[96]

Generally speaking, there are a number of climate change impacts that could increase the risk of nutrient management-related issues in Central Canada. Specifically, increased spring run-off resulting from climate change could increase soil erosion and nutrient loss, which contributes to the risk of water contamination discussed in sections 2.1.3 and 2.2.3. Springtime farm operations, such as seeding, might also be delayed by the increased soil water volume.[97] Other notable risks include increased or novel pest pressures to crop yields or damage to infrastructure resulting from extreme weather events.

For PEI, climate change is expected to manifest itself as an increase in the number of hot days, fewer cold days and an increase in the frost-free period, which will negatively affect crops that require cool growing season conditions, such as potato.[98] Moreover, changes in precipitation levels and average temperatures will begin causing permanent shifts in the current growing seasons. Such shifts will alter the ideal planting period, the timing of pathogen susceptibility and potentially exacerbate pest pressures. For instance, these changing temperature patterns may result in an earlier or later susceptibility period for potato late blight, which can decimate yields if not addressed quickly enough.[99]

The PEI Climate Action Plan 2018 to 2023 further emphasizes that the more frequent, heavy rainfall events that are predicted from future climate change will only further exacerbate issues of N runoff from agriculture activities.[100] The Government of PEI has committed to performing detailed research from 2018-2023 to improve knowledge of the agronomic and climate resilience benefits of agricultural BMPs, such as nutrient stewardship, conservation cropping and improved livestock feeding strategies, and how to mitigate the barriers preventing their widespread adoption.[101]

These trends make it clear that the status quo is no longer sustainable, whether for producers, supply chain partners, or the environment. Policymakers need to respond with innovative policies that help all of these actors adapt to this new era of climate uncertainty. Specifically for producers, this will mean policies that champion and motivate the adoption of new technologies and practices that enhance economic growth, climate resilience and greenhouse gas mitigation.

3. PROVEN AND EMERGING BENEFICIAL MANAGEMENT PRACTICES

Ontario and PEI farmers both face challenges brought about by market fluctuations, seasonal and changing weather conditions, environmental impacts and pressure to improve business margins. Fortunately, agronomic research is converging on a set of BMPs that will help safeguard or increase producers' profit margins, lower GHG emissions, and enhance soil health. These include: (1) nutrient management planning (NMP) and related to efforts such as retailer certification under Fertilizer Canada's 4R™ Nutrient Stewardship program –namely improving the timing, rate, source, and placement of nitrogen fertilizer application. The other priority BMPs consist of measures to enhance soil health (especially SOM) such as: (2) cover cropping,[102] (3) conservation tillage and (4) more diverse crop rotations.

This section reviews the agronomic, economic and environmental impacts of these BMPs for corn-soybean-winter wheat systems in Ontario and for potato production in PEI, respectively. It also provides a brief overview of the main barriers to BMP adoption identified in the literature for both production systems.

3.1 Ontario

3.1.1 Nutrient Management Planning

NMP attempts to optimize nutrient applications to a given area of land to increase both productivity and reduce environmental impacts.[103] It assesses the land's agronomic characteristics (including existing nutrient levels in the soil) and uses that information to devise a management plan. From an economic standpoint, these plans have the potential to significantly improve on-farm profitability. A study of the economic efficiency of the advanced Nitrous Oxide Emission Reduction Protocol (NERP) on Ontario corn farms found that net revenue (revenue minus agronomic and fertilizer costs) increased by over 10% (up to $70.65/ac). The advanced NERP requires the implementation of practices such as banded spring fertilizer applications, the use of urease inhibitors, soil testing, and the formulation of variable rate applications through zoning.[104]

Other studies have demonstrated that NMP (especially modifying the fertilizer source, timing and application rate) can significantly reduce GHG emissions, as demonstrated by a recent scenario analysis of fertilizer management practices for N_2O mitigation from corn systems in Canada. Applying side-dressed fertilizer – a method of placing fertilizer to the side of row crops in a shallow furrow to increase nutrient availability – can reduce yield-scaled N_2O emissions by 60% compared to fall fertilization, or by 30% compared to applying fertilizer at planting.[105] Further N_2O emissions reductions can be achieved by combining side-dressed fertilizer with nitrification inhibitors.[106]

Fertilizer Canada's 4R™,[107] Nutrient Stewardship Certification Program also contributes to nutrient management planning in Ontario.[108] It is a national program that has developed a set of standards which reflect the specific circumstances of Ontario's agriculture sector, and offers specific certification programs for crop advisors and retailers to communicate the value of implementing 4R™ practices to farmers (see section 5.1.3 for more information on the 4R™ program in Ontario).

Several scientific studies have experimentally tested 4R nutrient management practices in corn systems. A Minnesota study examined the impact of application timing (splitting N applications), application source (applying nitrification inhibitors to fertilizer), and application rate (decreasing the amount of fertilizer applied) on N use efficiency, N_2O emissions, and corn yield. The results found that none of the treatments impacted corn yield, and that application timing alone did not reduce N_2O emissions. However, when combining inhibitors with split application and reducing the application rate, N_2O emissions decreased by 20-53% and nitrogen use efficiency increased by over 15%. These results affirm that by optimizing application timing, source and rate, as prescribed by 4R™ practices – and nutrient management planning more broadly – reductions in N fertilizer inputs and N_2O emissions can be achieved without negatively impacting corn yield.[109]

3.1.2 Soil Health BMPs

Adopting soil health measures can also boost long-term productivity by increasing SOC and by supporting improved management of residual soil N. Farmers can further reduce N fertilizer application rates in Ontario corn-soybean-winter wheat systems without decreasing yields through BMPs such as cover cropping and diverse crop rotations, benefiting both the environment and the farmer's bottom line.[110] Soil health BMPs also have the potential to further mitigate by increasing soil organic carbon, although this needs to be carefully balanced against risks of risks of increasing N_2O emissions.

Relationship Between N_2O and Soil Organic Carbon

Canada has witnessed a decreasing trend in soil organic carbon (SOC) as well as concerning levels of N_2O emissions. Soils can be an important and productive carbon sink. When managed strategically, they can also help balance rising atmospheric carbon. To increase SOC, however, total soil organic matter (SOM) must be increased. Nitrogen additions are typically required to achieve a C:N ration that will promote the formation of SOM.[111] Nitrogen addition is required at an estimated ratio of 12:1 carbon to nitrogen.[112]

Increasing the application of nitrogen, however, can result in further emissions of N_2O due to denitrification.[113] Given that the warming potential of N_2O is 298 times greater than that of CO_2, this is an important concern. Even with nitrogen additions increasing carbon sequestration, the risk of emitting a more potent greenhouse gas increases.

The trade-off, however, is that increased organic carbon in the soil can reduce mineralization, which in turn reduces the emission of N_2O and CO_2.[114] Therefore, an ideal course of action implements nutrient management practices that limit N_2O emissions while building a stable stock of SOC. Research has identified that no-till systems, diverse crop rotations, and crop to pasture rotations are all beneficial management practices for regenerating SOC while minimizing N_2O emissions.[115]

It is vital to develop a management system that balances nitrogen availability to build organic matter in the soil and sequester carbon without increasing N_2O emissions.[116] Once the SOM is more stable and plentiful, it will contribute to preventing mineralization thereby reducing N_2O and CO_2 emissions.

Cover Cropping

Cover cropping remains of the most effective practices for capturing natural N sources in the soil and promoting overall soil health, with the potential to financially benefit farmers through increases in land productivity. Cover crops add organic matter to the soil, which provides N for later crops, increases the residual N levels in the soil, and decreases the need for additional commercial fertilizer. Additionally, cover crops can also reduce soil erosion on at-risk farmlands by replacing the bare fallow period over winter.

Terminating cover crops in the spring has the potential to sequester additional carbon in the soil and reduce N_2O emissions during winter and spring thaws, bringing emissions down to nearly negligible amounts.[117] By adding carbon content to the soil, cover cropping helps mitigate climate change, with a mean sequestration potential of 0.13 ± 0.03 Mg C/ac/year (averaged across all fertilization, tillage and cover crop types).[118] Cover crops also have a positive impact on indirect N_2O emissions through the reduction of NO_3. The total average GHG mitigation potential of using overwinter cover crops is estimated at 0.52 t CO2e/ac/year.[119]

The timing of cover crop termination can greatly impact the amount of RSN available before spring planting. Spring termination (as opposed to fall) is better for providing N for the following corn crop.[120] One two-year study examined the effects of spring terminated alfalfa and red clover cover crops on corn yields and plant-available N. Corn yield improved for the first two years with the crop. When compared to soil that had been commercially fertilized at 90.65 kg N/ac, alfalfa provided a 37-63% increase in plant available N, whereas red clover provided a 46-65% increase.[121]

Another study investigated N leaching in clay loam fields under controlled tile drainage and unrestricted tile drainage. Spring-terminated winter wheat was used as the cover crop over five years in corn-soybean rotations. Over a three-year average, soybean yield increased by 8-15%.[122] The planting of winter wheat as a cover crop also reduced NO_3 leaching by 21-38% and subsequently provided more available N for the following crop.[123] In addition, winter wheat presents a unique advantage to farmers as a cover crop as it can be sold as a commodity crop after serving its purpose over the winter period. OMAFRA estimates the farm value per bushel of winter wheat at $7.93.[124] Although cover crops are not typically grown to be harvested for profit, winter wheat's ability to grow quickly in the fall to protect the soil, survive the winter temperatures, and then resume growth in the spring, make it attractive as both a cover and commodity crop.

Cover cropping remains of the most effective practices for capturing natural N sources in the soil and promoting overall soil health, with the potential to financially benefit farmers through increases in land productivity.

More Diverse Crop Rotations

In combination with cover cropping, more diverse crop rotations can lead to greater yields, lower GHG emissions, and better water and soil health. For instance, winter wheat – which is the standard cover crop in Ontario corn-soybean rotations – improves the N use efficiency of these systems.[125] Adding winter wheat to a corn-soybean rotation can lead to profit increases of $143/ac, through a combination of input cost savings, increased corn and soybean yields, and wheat straw sales.[126] This provides further economic justification for wheat's incorporation into Ontario corn-soybean rotations.[127] Beyond increased yield and yield stability, adding wheat to a corn-soybean rotation provides a proper niche for cover crops, while enabling no-till or reduced till practices and benefits.

Studies also show that further diversifying the corn-soybean-winter wheat rotation can significantly improve yield per acre. The Agronomy Guide for Field Crops from OMAFRA suggests that underseeding red clover during the winter wheat phase of rotations can increase corn yields by an average of 12 bu/ac across tillage systems. This effect is less pronounced in soybean yields (only representing a 2bu/ac increase) and the effect is only apparent under conventional tillage practices. Additionally, underseeding with red clover can also slightly increase soil carbon content when compared to the same rotation without its inclusion.[128]

Another Ontario study examined a rotation of corn-oat-alfalfa-alfalfa compared to continuous corn over a period of 49-51 years. Yields under the corn-oat-alfalfa-alfalfa rotation averaged 4.05 t/ac, while continuous corn yielded an average of 2.23 t/ac.[129] The same study found that corn-in-rotation had lower GHG emissions than continuous corn, both in absolute terms (2.63 kg N_2O -N/ac vs 2.99kg N_2O -N/ac respectively) as well as in terms of yield-scaled emissions.[130] Similarly, the replacement of continuous corn with alfalfa rotations in southern Ontario increased SOC by 3.24 ± 1.62 Mg C/ac in 25 years.[131]

Conservation Tillage

Conservation tillage refers to a variety of practices that avoid mechanically breaking the soil, to keep soil in place and improve soil health.[132] Generally, conservation tillage can be broken down into reduced tillage practices and no-till practices. Corn and soybean yields under these two practices are typically lower compared to yields under conventional tillage practices.[133] On the other hand, farmers adopting conservation tillage can take advantage of the cost savings that result from fewer tractor passes over the field, which may help compensate for the foregone income from yield loss. OMAFRA (2018) proposes that on an annual basis, reduced tillage practices can save the average 500-acre Ontario farm up to $2,500 in machinery repairs and maintenance, 1,750 gallons of fuel, and 225 hours of their working time, compared to conventional tillage practices.[134]

In addition to the potential economic benefit, conservation tillage practices also positively impact the environment. Specifically, reduced tillage practices (such as zone-tillage) and no-till practices in Ontario corn systems have the ability to reduce N_2O emissions by up to 43% and 17%, respectively.[135] Furthermore, studies of reduced tillage practices also show a more than 65% reduction in sediment and N exports in soil runoff.[136] No-till practices in Ontario corn-soybean systems have also been shown to increase SOC levels by up to 36%.[137]

The environmental and economic impacts of NMP, 4R™ certification, and soil health BMPs are summarized in Table 1 below. Further information on the environmental and economic benefits of individual nutrient management BMPs (improved N fertilizer source, timing, rate, and placement) are summarized in Appendix A.

Table 1. Summary of Nutrient Management and Soil Health BMPs in Ontario

BMP	Productivity	Cost	GHGs	Water Quality	Soil Health
Nutrient Management Planning	**Ontario Corn** No significant yield difference when combining improved source, placement and reduced tillage (Drury et al. 2012) Yield loss for combining improved source and placement with No-till (11%) (Drury et al. 2012) NERP increases marginal value to a farmer by $70.65/acre compared to baseline (Mussell et al., 2015)	**Ontario Corn (Implementing Advanced NERP BMPs vs. Baseline)** Agronomy and fertilizer costs increase by 7% using advanced NERP (Mussell et al., 2015)	**Ontario Corn** Side Dressing reduces yield scaled N_2O emissions by 60% compared to fall fertilization (Abalos et al., 2016) Addition of nitrification inhibitors reduced N_2O an additional 10% (Abalos et al., 2016)	**Ontario Corn** Splitting N applications can reduce NO_3-N loading by 11% and 10% compared to single at-plant and side dress application, respectively (Ahmed et al., 2007)	**ND**
4R™ Nutrient Certification	**Ontario Corn (Improved placement + improved source)** Yield increase of up to 20% for injecting Urea Ammonium Nitrate (Fertilizer Canada, 2018) Estimated value of $70.65 per acre per season (Fertilizer Canada, 2017)	**Ontario Corn (Gross cost of implementing an NERP)** NERP basic protocol: $161.80/acre NERP Advanced protocol : $171.15/acre Without NERP (status quo practice): $159.55/acre (Mussell et al., 2015)	**Ontario Corn (improved source + improved timing)** Urea or UAN w/ inhibitors can reduce GHG emissions between 40 and 60% (weather dependent) (Fertilizer Canada, 2018)	**Ontario Corn (improved placement + improved timing)** Subsurface banding can reduce phosphorus (P) losses to runoff by 60% (Fertilizer Canada, 2018)	**ND**
Cover Crops	**Ontario Winter Wheat** Increase in the 3-year average of the soybean yield by 8 to 15% Ontario Corn-Soybean – Winter wheat as a CC in crop rotation, corn yield was improved by 16.6% and 18.8% (Yanni et al., 2018)	**Kansas Price of Various Cover Crops (Cost of Seeding, Planting, Fertilizing, Applying and Terminating in USD$ per acre)** Hairy vetch costs $51 to $67 Crimson clover costs $42 to $57 Rye costs $59 to $119 Oats cost $54 to $108 (Bergtold et al., 2017)	**Ontario Corn, Soy, Canola or Grass** Use of cover crops can make emissions overwinter almost completely negligible (Wagner-Riddle & Thurtell, 1998)	**Ontario Winter Wheat** Depending on the drainage system, up to 21 to 38% reduction in NO_3 leaching (Yanni et al., 2018)	**Ontario Corn** 37-63% (alfalfa) 46-65% (red clover) extra plant available N compared to soil that was fertilized at 90.65 kg N/ac (Yanni et al., 2018)
More Diverse Crop Rotations	**Ontario Corn/ Corn-Soybean/ Wheat** Net returns calculated at an average of $56.66 per acre per year across tillage systems (Meyer-Aurich et al., 2006b) **Ontario (Diversifying Rotations w/ Wheat)** Increase in subsequent corn and soybean yield of 4% and 11%, respectively (OMAFRA, 2017) **Ontario (Diversifying Rotations w/ Wheat)** Adding wheat into corn-soybean rotations is valued at approximately $115/acre (OMAFRA, 2017)	**Iowa Corn** Two-year (corn-soybean) production cost = $568.79/ac Three-year (corn-soybean-oat) production cost = $542.77/ac Four-year (corn-soybean-oats-alfalfa) production cost = $812.14/ac (Johanns et al., 2012)	**Ontario Corn** Compared with perennial hay (timothy grass and alfalfa mixture): N_2O emissions were approximately 6 times lower hay than in corn (Yanni et al., 2018)	**Ontario Corn-Soybean** Reducing corn in rotations by 33% (moving to a corn- soybean-soybean from a corn-soybean) reduces NO_3-N loading by up to 19% (Ahmed et al., 2007)	**Ontario Continuous Corn vs Corn-Oat- Alfalfa-Alfalfa** SOC was about 8.09 Mg C/ac greater in the rotation than the continuous corn. This translates to a rough estimate of C storage of 0.85 Mg CO_2e/ac/year under the diversified system that included alfalfa (Yanni et al., 2018)
Conservation Tillage	**Southern Quebec Corn-Soybean** Yield advantage using PT (Tillage from a moldboard plow) 10% and 13% for corn and soybean respectively (Pelster et al., 2011 ; Ziadi et al., 2014) **Ontario Corn** Yield was 4% lower under ZT and 11% lower under NT versus CT A 6% (2-10%) reduction in yield with conservation tillage versus CT (Yanni et al., 2018)	**Illinois Corn** Reduced till cost $53.31/acre No till cost $52.85/acre Conventional tillage (CT) cost $55.21/acre (ICF International, 2013)	**Ontario Corn** Compared to CT averaged over 3 years, N_2O emissions from No Till (NT) were 16.6% lower (ranging from 41% decrease to 5% increase in emissions) and Zone Till (ZT) were 43.9% lower (ranging from 36 to 54% lower emissions) compared to CT (Drury et al. 2012) Average reduction with ZT was 36% (range of -49 to -19%) (Yanni et al., 2018)	**Manitoba Experimental Site (general)** CT reduced sediment and N export by 65% and 69% per year, respectively, compared to conventional tillage Total P export was 12% greater using conservation tillage (AAFC, 2019)	**Ontario Corn-Soybean** NT had 36% more Soil Organic Carbon (SOC) content (and concentration) compared to chisel-plow in the top 0-5 cm profile, 26% in 0-10 cm, and 16% more 0-100 cm When perennial crops are included in a rotation there is automatically a reduction of tillage frequency compared to a continuous corn system (Yanni et al., 2018) Chisel plowing increases SOC in 0-10cm depth by 6.4%, but reduces SOC in 10-20cm by 7.8%, compared to moldboard plowing (Yang & Kay, 2001)

3.2 Prince Edward Island

3.2.1 Nutrient Management Planning

As mentioned in the previous section, NMP attempts to jointly optimize the source, rate, timing and placement of nutrient inputs based on local agronomic conditions. Demonstration plots using PEI potatoes have shown how NMP is vital to achieving both economic and environmental objectives. For instance, trials conducted by the PEI Soil and Crop Improvement Association show that adopting NMP generally has no negative impact on the yield of russet-type potatoes compared to conventional practices, and in some cases significantly increases yields. Furthermore, despite stable yields, average input costs declined across all trials. Based on these findings, the value of nutrient management plans, in terms of fertilizer savings, has been estimated to be between $10 and $110 per acre for PEI potato farmers.[138]

> ***The value of nutrient management plans, in terms of fertilizer savings, has been estimated to be between $10 and $110 per acre for PEI potato farmers.***

In addition to the economic benefits, NMP also shows significant potential for improving environmental outcomes. The PEI Federation of Agriculture estimates that implementing nutrient management plans, such as the Nitrogen Emissions Reduction Protocol (NERP),[139] can result in a 15% reduction in emissions for PEI farmers. The PEI NERP includes practices such as using digitized soil maps for application prescriptions, using split fertilizer application methods, and incorporating between 33% and 50% of enhanced efficiency fertilizer (EEF) products in fertilizer applications.[140] Other studies conducted in the Souris Watershed on potato and grain rotations, show how combining nutrient management BMPs — specifically reduced application and delaying plowing till spring — can reduce nitrate loading to groundwater and surface water by almost 12% compared to fields without a nutrient management plan. These results are especially important for PEI, where groundwater is a vital resource for agriculture and for drinking water.[141]

Fertilizer Canada's **4R™ nutrient stewardship program** in PEI also supports NMP. By changing practices, the program recommends reducing phosphorous application rates by 10-30% and N fertilizer rate by 10-20%, as these are the estimated levels of reduction that can be achieved without any loss in profit.[142] For example, through split applications of 60 kg and an additional 30 kg of N applied through multiple foliar urea applications, the Harrington Research Station in PEI was able to produce yields equivalent to applying 180 kg of fertilizer at planting. Additional findings suggest that implementing NMP in potato production in PEI can reduce nitrate leaching into the soil by as much as 32%.[143] This highlights the potential for 4R™ nutrient stewardship and NMP to simultaneously achieve economic and environmental objectives.

3.2.2 Soil Health BMPs

Making informed N fertilizer application recommendations requires considering all sources of N in the soil. Recent work has shown that there is considerable variation in the N supplying capacity of PEI soils, and that this N supplying capacity is directly correlated with SOM content. As such, soil health practices such as cover cropping or more diverse crop rotations can increase plant-available N while reducing N_2O emissions.

Cover Cropping

Cover cropping[144] provides numerous benefits to crop production and soil health. Cover crops in PEI help replenish soil nutrients and SOM, while increasing soil fertility and aggregate stability.[145] Farmers need to consider the trade-off between different cover crops, as some grasses produce a low-quality cover crop in a large quantity, whereas legumes are a cover crop that produces a high-quality marketable product,[146] but at nearly 10 times the initial start-up cost.[147,148]

The potential for economic gains is highly influenced by the initial input price and adoption costs associated with cover crop management practices.[149] As previously mentioned, using cover crops that double as commodity crops, such as winter wheat, can mitigate the initial costs through its value at harvest in the following year.[150] Fall rye has been another successful cover crop in PEI, as it quickly establishes strong roots at low temperatures after the October potato harvest and is relatively inexpensive to plant.[151]

Cover crops can also be utilized by PEI growers to manage crop diseases and sustainably maintain potato production, as potatoes are commonly susceptible to a variety of soilborne diseases. One study assessed seven different 2-year rotations – barley/clover, canola, green bean, millet/rapeseed, soybean, sweet corn, and potato, all followed by potato in the second year – over a period of 10 years (1997-2006).[152] This long-term trial examined the effects of spring-terminated cover crops and crop rotation on the development of soilborne potato diseases in the northeast.[153] The cover crops led to modest reductions in soilborne diseases (5-20%),[154] adding to the cost-saving benefits of this approach.

Introducing spring-terminated cover crop into commodity crop rotations can also have meaningful impacts. Planting winter rye as the cover crop in canola or rapeseed rotations can reduce black scurf and common scab by 25-41% relative to a continuous potato rotation.[155] Cover crops also provide a unique opportunity to decrease production costs, specifically those related to pesticide and fumigation application.[156] A study in Texas found that planting spring-terminated crimson clover and rye led to savings of $7.47/ac from weed suppression and pre-emergence herbicide costs.[157] Fall rye, the popular PEI cover crop, is also known for its weed suppressing abilities.[158]

One recent study reviewed the nutrient management implications that cover cropping, spring or fall-terminated with immediate incorporation, can have on PEI farms, and found maintaining SOM and reducing nutrient loss to be two prominent advantages presented by the practice. The study further emphasizes the potential for cover cropping to simultaneously provide economic and environmental benefits, specifically the potential for mustard and buckwheat cover crops to reduce yield loss and pesticide inputs by suppressing wireworms and weeds in the potato growing phase.[159]

More Diverse Crop Rotations

More diverse crop rotations are able to increase SOC levels dramatically compared to shorter, more potato-intensive rotations. For instance, studies of PEI potato production show that adding forages to diversify away from two year potato-grain rotations can increase SOC levels by 13% when switching to a three year rotation, and 32% when switching to a four year rotation. If approximately 74,100 acres in PEI were to switch from the two year rotation to a three year rotation diversified with forage, an additional 19.2kt of CO_2e per year could be sequestered by the soil.[160] In addition, the switch from a two year potato-grain rotation to a three year potato-grain-red clover rotation could decrease nitrate leaching between 15-22%.[161]

From an economic perspective, the aforementioned two year rotation was estimated to have approximately the same net return ($141.64/ac/yr) as the three year potato-grain-forage rotation. However, extending rotations isn't always in farmers' financial interest – the same report concluded that extending to a five year rotation could decrease net income by 40%.[162] The Eastern Canada Soil and Water Conservation Center estimates the value accrued to producers from the addition of grain and/or forage into potato rotations is approximately $72.84/ac/yr in Atlantic Canada.[163] Based on this financial assessment and the environmental benefits associated with diverse rotations, the three year potato-grain-forage rotation seems to offer the greatest combination of private economic benefits to producers and public environmental benefits in PEI – greater financial supports might be needed to support farmers' transitions to longer rotations (provided that the public environmental benefits outweigh the private economic costs).

Conservation Tillage

Contrary to findings in Ontario, applying **conservation tillage** practices to PEI potato crops did not have a significant yield penalty, implying that this could be a viable alternative to conventional tillage practices.[164] Economically, conservation tillage could reduce tillage costs by up to 9% per acre, and chisel plow equipment, which is commonly used in conservation tillage, costs about 45% less than some other conventional tillage equipment, such as the mouldboard plow.[165]

In terms of environmental benefits, conservation tillage has the ability to significantly reduce GHG emissions. Adoption of conservation tillage practices on one-third of the land going into potato production in PEI (10,000 hectares or ~24,700 acres) could eliminate 1.7kt of CO_2e annually.[166] Conservation tillage can also improve soil nutrients stocks in PEI, increasing SOC by 7%, and increasing other nutrients such as potassium and magnesium as well. Additionally, this BMP can increase microbial biomass in soil by up to 13%, which plays an important role in soil nutrient release and in maintaining soil structure.[167]

One conservation tillage practice showing a great deal of promise is postponing tillage until spring, which could decrease nitrate leaching losses by 20-61% during the forage phase of a PEI potato rotation (which is usually every second year).[168] However, a 7-year study conducted at Souris and Harrington in PEI found that compensation of between $92.67 and $338.32/ac per year would be needed to persuade potato-growers to adopt this practice, due to perceptions that conservation tillage would lead to a yield loss.[169]

The environmental and economic benefits of NMP, 4R certification and soil health BMPs are summarized in Table 2 below. For additional information on the effects of fertilizer rate, source, timing and placement, see the technical Appendix.

Table 2. Summary of Nutrient Management and Soil Health BMPs in PEI

BMP	Productivity	Cost	GHGs	Water Quality	Soil Health
Nutrient Management planning	**PEI Potatoes** Improved yield in some sites by 15- 25% compared to conventional practice (PEISCIA, 2006) Maintained at least stable yield at all sites (PEISCIA, 2006) NMP valued at $10 to $110 per acre (mainly due to input cost savings) over conventional practice (PEISCIA, 2006)	**Nova Scotia** NSDA offers 100% of the total costs ($1500) needed to develop a new NMP (Nova Scotia Institute of Agrologists 2014)	**Atlantic Canada** Implementing an intermediate or advanced NERP strategy that combines all NMP aspects can reduce emissions by 15% (PEIFA, 2019)	**PEI Potatoes** Combining reduced application and spring plow reduced nitrate loading to ground and surface water by 11.9% compared to non-nutrient managed scenarios (Cheverie, 2009)	**ND**
4R Nutrient Certification	**PEI Potatoes** Some plots under 4R increased yield per acre by 18 to 21% – other plots kept yield stable compared to general standard practice (GSP) (Watts, 2016) Overall offers between $200 – $300 improvement per acre compared to GSP (Watts, 2016)	**PEI Potatoes** Cost of implementing 4R ranges from savings of $60 per acre to additional costs of $50 per acre depending on existing growing strategy (Watts, 2016)	**PEI Potatoes** Splitting fertilizer applications (w/ in-season foliar application) cuts total N requirements in half compared to single application at planting (from 72.84kg N/ac down to 36.42kg N/ac) thereby reducing GHG emissions (Fertilizer Canada, 2018)	**PEI Potatoes** 32% decrease in nitrate leaching into the soil (4R Findings, 2020)	**PEI Potatoes** Soil Testing led to a 25% reduction in nitrogen input use (4R Findings, 2020)
Cover Crops	**PEI Potatoes** Potatoes following green manure legume cover crops produced approximately 36-38% higher tuber yields compared with potatoes following winter wheat when zero N was applied (Sincik et al 2008) Impact of cover crop management on gross margin ranges from $-20/acre (i.e., a net cost to producers) (Jatoe et al., 2012) to $104/acre (net gain to producers) (Barrett 2018)	**Kansas Price of Various Cover Crops (USD $/acre costs of Seeding, Planting, Fertilizing, Applying and Terminating in)** Hairy vetch costs $51 to $67 Crimson clover costs $42 to $57 Rye costs $59 to $119 Oats cost $54 to $108 (Bergtold et al., 2017)	**PEI Potatoes** Adoption of non-legume cover crop following fall tillage/forage results in GHG reduction of 12.6 kt CO_2e per year (24,710 ac scenario) (PEIFA, 2019)	**PEI Potatoes** Fall-seeded cereal crop reduced flow-weighted mean nitrate concentration of tile-drainage water by up to 30% compared with no cover crop (Zebarth et al., 2014) Fall incorporation of straw following early harvested potatoes in PEI reduced flow-weighted mean nitrate concentration of tile-drainage water by 15-30% in 2 years (Zebarth et al., 2014)	**PEI Potatoes** Adapting estimated benefits of general cover crop adoption to PEI growing season increased soil carbon by 40.47kg C/ac per year (PEIFA, 2019)
More Diverse Crop Rotations	PEI Potatoes- Grain-Forage 2 and 3 year rotations had comparable average net incomes (approximately $141.64/ac/year) (PEIFA, 2019) Switching from 2 or 3 year rotations to a 5 year rotation reduced net income by about 40%; whereas switching to continuous cropping reduced net incomes by 55% (PEIFA, 2019) Switching to a 2 or 3 year rotation is valued at approximately $72.84/ac, when compared to continuous cropping (ECSWCC, undated)	**PEI Potatoes- Grain-Forage** Average cost of production = $1294.99/ac of potatoes Switching to a two-year rotation can decrease cash cost by $60.70 (or approximately 5%) per acre Cost with rotation = $1234.29/ac (ECSWCC, undated)	**PEI Potatoes- Grain-Forage** Switching from a 2 year to 3 year rotation increases carbon storage by 19.8 kt CO_2e per year (74,130 ac scenario) Switching from 3 year to 4 year rotation increases carbon storage by 3.3 kt CO_2e per year (24,710 ac scenario) (PEIFA, 2019)	**PEI Potatoes** Increasing the length of the potato rotation (3-year / barley-red & clover-potato) resulted in 15%- 22% lower nitrate leaching (Zebarth et al., 2014)	**PEI Potatoes- Grain-Forage** Switching from a 2 year to 3 year rotation increased SOC by 13% Switching from 2 year to 4 year rotation increased SOC by 32% Switching from 2 year to 5 year rotation increased SOC by 23% (PEIFA, 2019)
Conservation Tillage	**PEI Potatoes (Conservation vs. Conventional Tillage)** No significant yield impacts – viable alternative (Carter et al., 2009a) Conservation tillage reduces tilling cost per acre by about 9% (-$2.03/ac) when compared to conventional tillage (Scott & Cooper, 2002)	**Atlantic Canada** Chisel plow equipment costs about 45% less than moldboard plow equipment Mouldboard plow costs $11,000; Chisel Plow costs $7,550 (Scott & Cooper, 2002)	**PEI Potatoes** Adopting a conservation tillage strategy (24,710 ac scenario) represents a reduction of 1.7kt CO_2e per year (PEIFA, 2019)	**PEI Potatoes** Delaying the termination of forage until spring reduces forage-phase nitrate leaching loss by 20% to 61% (Jiang et al., 2014)	**PEI Potatoes (Conservation vs. Conventional Tillage)** 7 to 16% increase in SOC content over 10 year period (19.3g SOC/kg to 23.7g SOC/kg) Increase in soil organic matter concentrations over 3 year period (Phosphorous +19% – 223mg P/kg to 265mg P/kg), (Potassium +18% – 93mg K/kg to 110mg K/kg), (Magnesium +18% – 103mg Mg/kg to 122mg Mg/kg) 13% increase in Microbial Biomass Carbon Quotient over 10 year period (264μg C/g to 299μg C/g) (Carter et al., 2009b)

3.3 Barriers to BMP Adoption

The workshop discussions and literature review identified five major barriers affecting the adoption of NMP and soil health BMPs in corn-soybean cropping systems in Ontario (and in the US),[170] and potato cropping systems in PEI. These are: (1) Concerns about profit (traded off against risk); (2) upfront and recurring costs associated with transitioning to new practices; (3) knowledge or complexity associated with transitioning to or maintaining these practices; (4) time constraints; and (5) the perceived effectiveness of NMP and soil health BMPs. These six barriers are analyzed using the Adoption and Diffusion Outcome Prediction Tool (ADOPT) as a conceptual framework, because ADOPT has proven to be a useful tool for analyzing and predicting the adoption potential of beneficial agricultural practices and technologies.[171]

Three additional adoption barriers unique to the PEI context were discussed in the Charlottetown workshop, namely: (6) limitations on farm size; (7) the moratorium on high-capacity wells for irrigation; and (8) lack of consumer demand for alternative potato varieties.

The impact of these barriers on adoption is heterogenous – some barriers are more likely to affect the peak adoption rate (i.e., maximum rate of adoption for the practice), whereas others primarily affect the timing to peak adoption (e.g., 10 vs. 15 years).[172] Moreover, farmers are a very diverse group of people, with different objectives, values, resources, knowledge, and capacities, so not all farmers will be equally affected by these barriers. Nevertheless, this section identifies some of the most important barriers that need to be considered when designing policies and programs to encourage adoption of these BMPs.

1. Concerns About Profit (Traded-off Against Risk)

Producers' profit orientation and risk preferences, as well as the actual profitability and riskiness of the new practices themselves, are all predicted to impact the peak adoption level and the amount of time it takes for the practice or technology to disseminate, or reach peak adoption.[173]

Workshop participants and the academic literature both emphasized that farmers who choose to overapply N fertilizer primarily do so to meet their economic objectives.[174] Explaining the tendency of some farmers to overapply nitrogen fertilizer requires accounting for several factors, such as whether nitrogen fertilizer and favorable weather conditions are complements or substitutes, whether nitrogen fertilizer application is a risk-increasing or risk-reducing input, producers' beliefs about the efficacy of nitrogen fertilizer application, as well as producers' risk preferences.[175] These topics are discussed in further detail in section 6.1.2. For now, it suffices to emphasize that most producers are generally profit-oriented, and that producers are reluctant to reduce nitrogen fertilizer application rates due to its potential impact on their profits. However, producers are slightly risk averse on average,[176] and are willing to trade off some profit to reduce production risk.[177]

The profitability and riskiness of improved nitrogen management practices are both indirectly affected by nitrogen fertilizer prices.[178] Low nitrogen fertilizer prices are generally a positive development, since it reduces the cost of inputs needed to grow food and fibre. However, low nitrogen fertilizer prices also increase the incentive to overapply fertilizer, contributing to greenhouse gas emissions and water pollution (these social costs are further discussed in section 4.1).

OMAFRA and the PEI Department of Agriculture and Land both provide a set of recommended N application rates, but they are not necessarily tailored to every producer's specific context. It is difficult for farmers to predict what the profit-maximizing rate of N application would be for their field in any given year. Since fertilizers are relatively inexpensive inputs, farmers have an incentive to overapply fertilizer since the cost of over-application is generally small in comparison to the potential opportunity cost (forgone income and yield) of applying too little.[179]

In terms of soil health BMPs, conservation tillage is another example where risk aversion is identified as a prominent barrier to adoption. A study primarily based on producers in ON and Quebec identified that the practice is perceived to result in yield loss and when this is coupled with the significant transition period, makes adopting conservation tillage appear quite risky. Diversifying crop rotations also tends to induce concerns about profitability, especially in the transition period.[180] Specific concerns for crop diversification in Atlantic Canada will be discussed later in this section.

2. Upfront and Recurring Costs

Upfront costs or investment costs are generally associated with a slower rate of adoption, but are not expected to directly impact the peak adoption level.[181] However, upfront and recurring costs can also indirectly affect the peak adoption level by impacting the profitability of a given practice.

N fertilizer management and soil health BMPs often require additional equipment, training, or labor costs, and farmers are unlikely to adopt the prescribed practices if they are not convinced that the private economic benefits will outweigh the costs. Farmers' learning, experimenting, assumption of risk, and management of labour and time all create real costs and barriers for adoption.[182] In some cases, the decision to adopt may depend on the magnitude of the initial equipment costs and labour adjustments during the trial period.[183]

For soil health BMPs, a study based primarily on ON and Quebec found that the cost of acquiring new equipment or modifying existing equipment was a barrier for conservation tillage, cover cropping, diversifying crop rotations, the use of organic amendments, and reducing soil compaction. The costs of management was also noted as a barrier for cover crops, as they require the farmer to incur additional planting, labour, and termination costs in some cases.[184]

The 2020 Fertilizer Use Survey in Ontario demonstrated that the costs of nitrogen management BMPs are also preventing adoption. Soil testing, or an alternative baseline assessment, is one of the first steps to developing a plan to more efficiently use nitrogen fertilizers. The survey showed that soil testing for nitrogen is a barrier for about 20% of respondents. About the same number of respondents indicated they had not put a 4R™ nutrient management plan in place due to the costs associated with it. However, cost was a significantly larger barrier when considering the actual practices needed to comply with 4R™, as just under 40% of respondents indicated that cost was a prominent reason for not adopting 4R™.[185]

Previous studies in the US corn belt have corroborated the Fertilizer Use Survey, suggesting that the costs are an important barriers to 4R™ adoption. For instance, they were cited as the main barrier to 4R™ adoption in a survey of agriculture retailers and Soil and Water Conservation Districts (SWCD) in three regions where the main crop consisted of corn and soybean systems.[186]

Another US survey examined specific 4R™ practices such as subsurface fertilizer placement technology, and found that over 50% of farmers agreed or strongly agreed that the cost was too high to adopt the technology.[187] In addition, farmers also highlighted that the profit-margin associated with some soil health practices, such as planting winter wheat as a cover crop, were too small to convince them to undertake the practice. Similarly, approximately 35% of corn and soybean farmers in Illinois were uncertain whether the short-term costs of cover cropping outweigh the long-term benefits.[188] These surveys emphasize the impact of upfront and recurring costs on producers' profits, which limits their peak adoption level.[189]

3. Knowledge or Complexity Associated with Implementing New Practices

If a farmer needs significant new knowledge to implement or use a new practice, it generally means that the technology or practice will diffuse much slower amongst the population; however, requiring new knowledge does not meaningfully impact the overall adoption potential of the technology or practice. In other words, lacking the relevant skills and knowledge to implement a practice does not impact the overall number of producers who will adopt it in the long-term, but does impact how quickly producers will decide to adopt the new technology or practice.[190]

Certain soil health and nitrogen management practices have been associated with knowledge and complexity barriers. For instance, one study shows that cover cropping, diversifying crop rotations, and nutrient management all raise concerns regarding the complexity of the management system.[191] Surveys have also found that between 18% and 25% of producers do not implement a nutrient management plan, or 4R™ practices more generally, because of a lack of knowledge or high complexity.[192] In addition, knowledge was identified as a barrier for soil testing and information collection, and in particular, access to assistance to assess soil data or tools that assist the producer with performing their own analysis.[193] Other studies have suggested that although many PEI farmers are aware of practices like cover cropping, they do not always know what species to plant or how to incorporate them into the primary production systems to produce the intended conservation and economic benefits.[194]

4. Perceived Effectiveness

In some cases producers may be unaware or skeptical of the benefits provided by nutrient management and soil health BMPs. The Fertilizer Use Survey in Ontario shows that about 16% of producers felt that nutrient management plans had yet to prove they were actually beneficial and provided similar feedback about 4R™ practices more generally – about 13% of respondents stated that 4R™ practices had not yet proven they provide a benefit to the farmer. A further 13% indicated that they did not think soil tests were that useful, with 7% going as far as saying they do not trust soil test results at all.[195]

In a study of farmers in the Lake Erie basin, 57% of respondents emphasized that they use a 'wait and see' approach, where someone else must test out a technology first and show that it works in order for them to consider adopting it.[196] Some farmers also noted they might be willing to try a test version of a 4R™ technology but would likely not implement it on their own without having its effectiveness proven by someone else first.[197] Related to this, one study found that producers in Ontario needed more regionally-specific data on what cover crop practices or varieties they should be using. This lack of regional data was identified as an adoption barrier and emphasizes that producers want a clear understanding of how the practice will work for them before they decide to adopt the practice themselves.[198]

Another study examined corn and soybean farmers' reactions to a variety of 4R™ practices and found that many producers apply fertilizers before rainfall because they believe the weather to be too unpredictable and out of their control.[199] By increasing farmers' perceptions of their own ability to make a difference through 4R™ practices and technologies, adoption rates were anticipated to increase.[200]

Other studies have found similar results. Increasing the perceived efficacy of delaying broadcast application is anticipated to increase its adoption by up to 13%.[201] Similarly, when the efficacy of soil-related conservation practices is demonstrated to farmers, they are more likely to adopt them. Farmers who had attended a field day or tour that demonstrated soil conservation practices at work were 2.5 and 1.5 times more likely to adopt specific BMPs such as residue management and strip/contour cropping, respectively.[202] This tactic could be especially useful for practices like conservation tillage, as some research has identified the 'adaptability' of this practice to different contexts and cropping systems to be barrier for Ontario producers.[203]

5. Time Constraints and Convenience

Time constraints affect the ease and convenience of on-farm management, and are another major barrier to the adoption of nutrient management and soil health BMPs. Time constraints are predicted to affect the peak adoption level of a practice or technology – meaning that if a practice is inconvenient – less producers will be likely to adopt it overall.[204] To take an example from the US, farmers perceive that some 4R™ alternatives are more time-consuming than current practices – such as alternatives to broadcast application of seeds or nutrients, which approximately 32% of surveyed farmers agreed or strongly agreed was too time consuming for them to consider using.[205] In another US study, 23% of the farmers who described themselves as not likely to try new fertilizer practices ranked the extra time requirements as their top barrier to adoption.[206]

In Ontario, about 35% of respondents to the Fertilizer Use Survey indicated that the timing required to use 4R™ practices does not fit with their crop priorities. In addition, 26% stated that they did not have enough time or manpower to use 4R™ practices and 17% suggested storage and trucking logistics were a barrier to using 4R™ practices. Finally, 17% indicated that they did not have enough time to conduct a nitrogen soil test on annual basis.[207] For soil health BMPs, increased labour was identified as a barrier for cover cropping, grazing or pasture management practices, and integrated pest management practices. Conservation buffers areas also presented ease and convenience barriers, including the perception that buffer areas were an impediment to agricultural land and that attempting to work around them with some farm equipment added significant difficulty to farm management.[208]

3.3.1 Adoption Barriers Specific to PEI

6. Limitations on Farm Size

Unlike Ontario, PEI deals with two unique limitations on farm size: a 1,000 acre maximum personal farm size, and a 3,000 acre maximum corporate farm size, both of which are restricted under PEI's Lands Protection Act. Enterprise scale (such as farm size) potentially limits the peak adoption level that a technology or practice can achieve.[209] Limits on the total farm size that a person or corporation may own, combined with product price volatility, pose a unique challenge to PEI potato producers. PEI potato farms receive some of the lowest compensation for their product, and prices can fluctuate year to year by over 40%.[210] In combination with smaller farm sizes (and hence, reduced economies of scale), these price fluctuations make farmers more averse to experimenting with less familiar or 'riskier' BMPs.

7. Restrictions on Licencing High-capacity Wells

PEI potato producers also struggle with access to irrigation water. A moratorium was established in 2002 on high capacity wells for agricultural irrigation. This was imposed because groundwater is the main source of drinking water on the island, and there have been concerns (whether justified or not) about possible negative repercussions for future water supply and water quality if the use of high capacity wells were to continue unabated. PEI is the only province to obtain 100% of its water from groundwater sources, making effective management of groundwater critical to provincial policymakers and local communities.

High-capacity wells refer to any well that produces a flow-volume in excess of four liters per second. PEI farmers require a Groundwater Extraction Permit to use them.[211] In 2014, the PEI Federation of Agriculture (PEIFA) requested a lifting on the moratorium for high-capacity well permits, based on evidence from the Department of the Environment stating that the capacity of groundwater was adequate for long-term sustainability.[212] PEIFA additionally proposed that the moratorium was contributing to negative environmental outcomes by limiting farmer's irrigation abilities, as a lack of irrigation leads to insufficient water supply for crops, inhibiting crop growth and decreasing fertilizer efficiency.[213] When the applied nutrients from fertilizer (or manure) are not taken up by crops, they are left to build up in the soil; this increases the risk of run-off and groundwater impacts. PEIFA also highlighted that this reduction in irrigation capacity was leading to increased pesticide use due to increased stress on the crops during growth.[214] Based on these considerations, workshop participants discussed the possibility of selectively permitting additional high-capacity wells, conditional on farmers adopting a set of appropriate BMPs (e.g., cover crops, etc.).

8. Lack of Consumer Demand for Alternative Potato Varieties

The dominant potato variety in PEI is the Russet Burbank, which is a long-season variety with high N requirements.[215] The Russet Burbank is overwhelmingly popular on the Island due to the need to meet the demands of downstream clients such as French fry processors and restaurant chains. This leads to fewer economic opportunities for PEI farmers to grow alternative potato varieties that have lower N fertilizer requirements (or less negative impacts on soil health).[216]

As a result, some participants at our Charlottetown workshop called for marketing and public information campaigns to change consumer preferences surrounding the demand for the Russet Burbank. The implicit theory of change was that by altering consumer preferences for French fries with different shapes and textures, food processing firms and restaurants would be more willing to source shorter season, less N-demanding potato varieties. This would enable farmers to cultivate alternative potato varieties without having to worry about losing their market access with food processors and restaurants.

A few modest inroads have been made on this front – in the past few years McDonald's North America has expanded their list of accepted potato varieties – but much more could be done. As such, it may be worth exploring collaborative efforts among governments, the food processing and restaurant industries, and environmental NGOs to directly engage consumers and see how much the latter are willing to change their preferences for different potato varieties in their French fries.

The Russet Burbank potato varietal is overwhelmingly popular on the Island due to the need to meet the demands of downstream clients such as French fry processors and restaurant chains. This leads to fewer economic opportunities for PEI farmers to grow alternative potato varieties that have lower N fertilizer requirements (or less negative impacts on soil health).

3.3.2 The Role of Policy in Addressing Barriers

This section has made clear that any adequate solutions to the problem of nitrogen fertilizer overapplication and deteriorating soil health are going to have to address five major barriers: (1) managing production risk; (2) adoption and management costs; (3) improving knowledge or increasing resource availability to help farmers implement and use BMPs effectively; (4) demonstrating the efficacy of NMP and BMPs; (5) addressing time constraints.

Financial incentives can play an important role in either directly addressing or compensating for these barriers. Most obviously, they can help compensate for the direct costs of NMP/BMP adoption, and they can also play a significant role in addressing production risk. Interventions such as improved extension or farmer to farmer demonstrations can help address the issues concerning the knowledge base required to implement NMPs and BMPs, and enhance their perceived efficacy.

Time constraints to implement NMPs and BMPs are the most difficult barriers to directly address through policy, although training through extension and demonstration efforts and compensating for the foregone time to implement these practices can help mitigate some of these issues.

With this in mind, the following three sections of this report examines the role and performance of current and existing programs in encouraging adoption and improving environmental and economic outcomes. Section 4 provides a brief overview of policy principles for managing nitrogen fertilizer application, section 5 reviews current programs, and section 6 assesses five proposed policies to increase NMP and BMP adoption by addressing these barriers.

4. POLICY PRINCIPLES

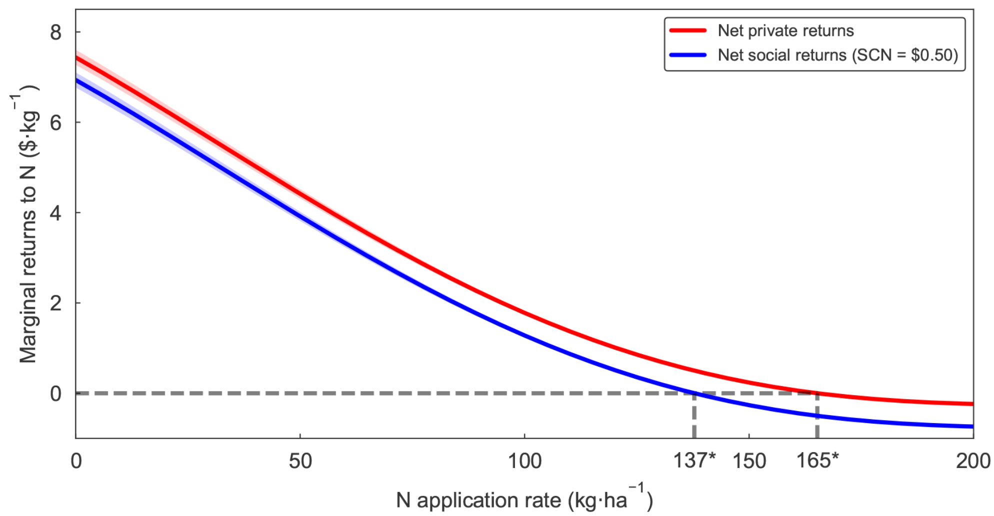
4.1 Private vs. Socially Optimal Fertilizer Application Rates

Designing policy for optimal N fertilizer use requires an understanding of both the private and the socially optimal rates of N fertilizer application, since this impacts the choice of policy instrument. From the private perspective, farmers are expected to apply N fertilizer at the rate that will maximize their yield and ensure they achieve the greatest profit each growing season, but there is evidence that farmers tend to apply N fertilizers above recommended rates.[217] Wagner-Riddle and Weersink explain that yield response or total value produced (TVP) per unit of land area can be expressed as a quadratic function, due to the fact that farmers tend to be price takers. This means that yield response is greater at lower N application rates and that yields will only increase to a certain peak level. Once that peak level has been reached, additional N applications reduce TVP and begin to reduce the farmer's potential profit.

The privately optimal rate of N application is the application rate which produces the maximum amount of benefit for producers based on the market price of N inputs and the expected yield.[218] However, production costs are not the only costs that need to be considered. The application of N fertilizer is also associated with a significant number of environmental externalities (i.e., water pollution and GHG emissions). The costs of these externalities are generally not borne by the individuals deciding upon the application rate (i.e., producers). This is where the social cost of N becomes important, as it allows for the costs of the externalities to be included in the evaluation of production decisions. The socially optimal rate of N application ensures that the greatest net benefit to society is achieved, after considering the cost of the externalities to society and the private costs to the farmer.[219]

The social cost of N accounts for both the private costs to the producer and the monetization of a variety of non-market assets (i.e., human health, clean air, clean water) that are impacted by the producer's decisions. The socially optimal rate of N application is expected to be lower than the privately optimal rate when there are negative externalities associated with the producer's practices.[220] For example, N application is known to negatively impact water quality and so by including the cost of damage to water quality in the cost of each kilogram of N, the production costs increase.

Figure 9. Net Private and Social Returns from N Application (Social Cost of N = $0.50)

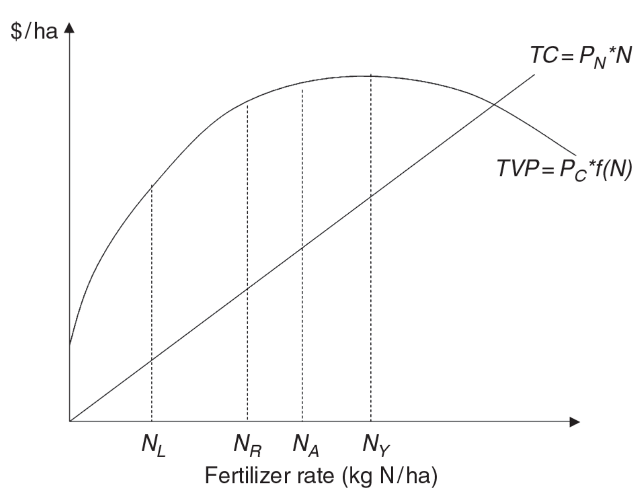


Source: Gourevitch, J. D., Keeler, B. L., & Ricketts, T. H. (2018). Determining socially optimal rates of nitrogen fertilizer application. *Agriculture, Ecosystems and Environment*, *254*, 292–299. https://doi.org/10.1016/j.agee.2017.12.002

Gourevitch and colleagues used a mid-range estimate of $0.50/kg N to demonstrate the impact of including the social cost of N in producer decision-making. In this scenario, the socially optimal rate of N application is equal to around 137 kg N/ha, down from 165 kg N/ha when considering only the private costs. At the socially optimal rate, producer net returns decrease by $5.95/ha; however, the avoided social costs are expected to be more than double that at $13.50/ha. These estimates show that reducing the application rate generates significant net social benefits, which outweigh the costs to the producer by $7.50/ha.[221] Figure 9 displays the results of Gourevitch and colleagues' research.

Although quantifying social costs can be a complex exercise, there is consensus that N application creates significant negative externalities that impact air, water, and human health. Policy makers need to consider the on-farm economics of the production decision and the social costs of N application in order to properly design policy that benefits both parties. Figure 10 provides a simplified overview of the farm-level economics involved in deciding upon the N fertilizer application, taking into account both private and public benefits.[222] The dashed line NA represents the current actual rate of N application; NR represents the profit maximizing or privately optimal rate of N fertilizer application; NY represents the yield maximizing rate; and NL represents a lower N rate that reduces GHG emissions and only slightly reduces on-farm profits. The application level corresponding to N_L in this diagram is for illustrative purposes and is not based on an estimate of social costs.

Figure 10. Overview of Fertilizer Application Rate Economics[223]



Source: Wagner-Riddle, C., & Weersink, A. (2011). 12 Net Agricultural Greenhouse Gases. *Sustaining Soil Productivity in Response to Global Climate Change*, 169. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1002/9780470960257.ch12

Recall that the plateau of the TVP curve suggests that a wide range of application rates result in approximately the same value per unit of land area, meaning that the costs to the producer of reducing the N application rate from N_R to N_L are likely small. However, this reduction in the N rate would result in far less GHG emissions. Therefore, Wagner-Riddle and Weersink identify N_L, from Figure 10, as the application rate that policymakers should target to control environmental externalities.[224]

Based on Figure 10, findings which suggest that farmers tend to overapply may seem counterintuitive,[225] as Wagner-Riddle and Weersink's research demonstrates that lowering the application rate from N_A to N_R would improve the producer's profit.[226] In this case, N_R is the equivalent of Gourevitch and colleagues' privately optimal rate of N application discussed earlier, as it is the point at which private benefits (i.e., profits) are maximized based on yield value and production cost considerations.[227] Due to the plateau in yield response occurring near the peak of the TVP curve, N_R, N_A, and N_Y all produce approximately the same TVP, but have significantly different production costs. This means that any additional N application above N_R reduces the private benefits (i.e., profits).

As was discussed previously, there are a number of barriers that make farmers reluctant to move from NA to NR, which may include behavioral factors such as risk preferences. These behavioural factors, along with the appropriate policy approaches to address adoption barriers, are discussed extensively in section 6 of this report.

5. REVIEW OF CURRENT PROGRAMS

Federal and provincial governments, ENGOS, Ontario Regional Conservation Authorities and industry are already implementing programs that help improve N fertilizer management and soil health in Ontario and PEI. These programs have provided an important foundation for the development of future policies and programs that can take Ontario and PEI agriculture to the next level of their clean growth ambitions.

This section provides a representative (but not exhaustive) overview of nutrient management and soil health programs in each of these jurisdictions, drawing from both a literature review as well as comments from workshop participants. This is followed by a synthesis of our workshop participants' general views (i.e., areas of broad agreement in both workshops) on which components of these programs are working well, as well as aspects of current programs that are at cross-purposes with efficient nutrient management and soil health objectives.

5.1 Ontario

5.1.1 Provincial Programs (Including Programs Jointly Funded Under the Canadian Agricultural Partnership)

The Environmental Stewardship Program (funded via the Canadian Agricultural Partnership [CAP]) is the Ontario government's main vehicle for supporting BMP adoption, through cost-share funding support to farmers and agri-businesses. The Environmental Stewardship Program offers a range of cost-shares to support BMPs such as nutrient management and soil health planning, tillage and nutrient application equipment modifications, cover cropping, and nutrient recovery from wastewater, all of which have cost-shares covering 30-50% of eligible expenses, with funding caps ranging between $8,000 and $25,000.[228]

The Ontario government has also introduced a number of spatially targeted nutrient management programs at the watershed scale in the Lake Erie and Lake St. Clair watersheds, with an emphasis on managing phosphorous runoff. These include the same type of nutrient management projects; although the cost-share percentages are considerably higher at 45-65% of eligible costs (this increases the cost share by an additional 15% of total costs).[229]

Moreover, in Ontario, farmers can only submit applications for two projects at a time and each cost-share project requires its own individual application. However, there is no limit to the quantity of cost-share projects that can be applied to or implemented over the five-year span of the CAP. Anecdotal evidence from the workshop suggests that these application restrictions predispose producers towards BMPs which offer 'win-win' private benefits and environmental benefits. This (along with other considerations) may partially explain the limited uptake of programs such as the provincial Fragile Land Retirement Program.[230]

OMAFRA has also recently introduced the Ontario Soil Health Strategy as part of its attempts to combat soil erosion and degradation in the province.[231] The Strategy runs from 2018-2030 and is guided by the following priority actions: building SOM, diversifying crops, minimizing soil disturbance, maintaining living roots throughout the year, and keeping the soil covered.[232] The program outlines a comprehensive suite of BMPs, such as cover crops and more diverse rotations, all animated by the understanding that healthy soil is productive soil.[233] There are a variety of goals and objectives for this program, including developing the capacity to track soil health changes, making soil health data publicly available (where possible), and conducting ongoing research to support soil health innovations. The program also stresses the need to re-evaluate existing incentives or create new ones in order to motivate the adoption of soil health BMPs across Ontario.

In addition to cost-share and other programs, the participants at the Guelph workshop highlighted that the online tools being made available to farmers were effective for facilitating BMP adoption. One promising example of this was the forthcoming OMAFRA GHG calculator, which is based on AAFC's Holos software. Holos software estimates the GHG emissions for each individual farm based on the farm's input and management practices, and it can help test different ways of reducing on-farm GHG emissions. Participants suggested its implementation would encourage data collection and support effective policies. However, limited access to high-speed internet in some areas is preventing farmers from realizing the full potential of these tools.

5.1.2 Federal Programs

The Agricultural Greenhouse Gases Program (AGGP) is an AAFC research program that provides support to academia for research in support of technologies, BMPs or practices that reduce the agriculture sector's GHG footprint.[234] The program is in its second phase and offers a total of $27 million in funding over the program's lifetime (2016 to 2021), with individual projects being eligible for up to $2 million in funding.[235] Relevant approved phase 2 projects in Ontario include riparian buffer plantings, developing cost-effective tools to measure SOC, and nutrient BMPs.[236]

During phase one of the AGGP (spanning from 2010 to 2016), a goal was set to develop at least 12 new agricultural BMPs over the duration of the program.[237,238] This goal was achieved halfway through the program in 2013.[239] A 2014 review of the first phase's progress found that $5 million of BMP research funding had been allocated to seven new studies of cropping systems,[240] including a project at the University of Guelph which uses aerial sensors to develop rapid, cost-effective methods for farmers to measure SOC levels in their fields.[241] In addition, the AGGP also funded research on the economic and environmental benefits of adopting NERPs through 4R™ Nutrient Stewardship (for more on the economic environmental benefits of 4R™ nutrient stewardship and NMP, see section 3 of this report as well as the technical Appendix).[242]

5.1.3 Other Programs

Finally, the 4R™,[243] Nutrient Stewardship Certification Program is one of the most prominent industry-led initiatives, offering tangible environmental and economic benefits to its users. This national program has developed a set of standards which reflect the specific circumstances of Ontario's agriculture sector, and offers specific certification programs for crop advisors and retailers to communicate the value of implementing 4R™ practices. The program aims to improve nutrient availability and uptake efficiency, improve soil health and groundwater quality, encourage data and BMP sharing among farmers, and incentivize the adoption of novel research and technologies for nutrient management.[244]

In the 4R™ program, farmers work with certified retailers and crop advisors to develop comprehensive farm management plans,[245] and farmers receive advice on which BMPs are best adapted to their farm's climate, soil, crop and operational conditions.[246] In a survey of Ontario farmers, 68% reported practicing some form of 4R™ Nutrient Stewardship and 59% reported that 4R™ Nutrient Stewardship practices were helping them achieve their sustainability goals.[247] Sustainability is measured through the use of specific Key Performance Indicators, such as acres under a NERP, tonnes of CO_2 equivalent emissions reduced, implementing 4R™ practices in sensitive areas, researching best practice on phosphorous and N application, and coordinating with conservation authorities to protect groundwater and watersheds.[248] The program is comprehensive, with certified professionals providing incremental improvements over the course of a two year audit cycle.[249]

5.2 Prince Edward Island

5.2.1 Provincial Programs (Including Programs Jointly Funded Under the Canadian Agricultural Partnership)

PEI's Agriculture Stewardship Program (ASP) (funded through the CAP) offers technical and financial support for eligible BMPs and technologies relevant to N fertilizer management and soil health, including NMP, spring tillage, and precision agriculture.[250] ASP offers a 50% cost share for NMP, a $25/ac cost share for Spring Tillage BMPs, among other relevant BMPs. Cost share for the two BMPs is currently capped at a maximum of $5,000.[251] In 2018, 24 soil health BMP projects, such as winter cover cropping, spring tillage and NMP, were undertaken to reduce environmental risk in PEI's agriculture sector.[252]

The ASP also offers a $35 cost share BMP for each acre under cover crops, capped at a maximum of $1,000 per field and $3,000 per year. Workshop participants highlighted that this cost-share scheme was effective in increasing the use of cover cropping on PEI farms. However, they argued that the cap on total acreage that could be enrolled under the program was a barrier to scaling up participation rates and fully realizing the program's benefits. The current cost-share incentives translate to approximately 28.5 acres per field and 85 total acres per year being covered by the cost-share.[253] Although applicants can reapply for cost-share funding, the project only allows for a maximum of $6,000 in funding over the full five-year lifespan (2018-2023) of the CAP framework, which represents approximately 170 acres. With an average farm size of 425 acres in PEI,[254] the cost-share provides incentives for farmers to plant cover crops on a cumulative total of 20% of the average farm's acreage over the course of two years. Raising the funding cap on this BMP could be beneficial to improve participation rates and environmental outcomes in PEI.

Participants in the PEI workshop also noted that NMPs had very low adoption rates in the province. PEI currently offers a 50% cost-share for this practice. Despite this, participants identified the complexity of the NMP along with administrative costs such as extensive paperwork and reporting requirements to be significant barriers to NMP adoption.

5.2.2 Federal Programs

Similar to Ontario, the AGGP program is also active in PEI, and provides up to $2 million in support for the development of technologies, BMPs or practices that reduce the agriculture sector's GHG footprint.[255] Approved projects include initiatives to assess soil health and plant riparian vegetation in PEI.[256] Furthermore, in 2017 the AGGP also funded research which assessed the effectiveness of willow tree buffer strips at filtering out agricultural pollutants released from PEI farms.[257] This project's goal was to determine the GHG emissions reduction potential of riparian buffer strips, through their capacities to sequester carbon and capture N from agricultural run-off. Although no impact evaluations of the program have been publicly released to date, PEIFA estimated that planting willow buffer strips to 123.55 ac/year of riparian area in PEI over the next five-years (and assuming a three-year potato rotation for simplicity) would reduce GHG emissions by 9.7kt CO_2 – both from enhanced carbon sequestration and reduced N_2O emissions.[258] This is equivalent to 2.4% of PEI's total agricultural sector GHG emissions in 2018.[259]

In addition to the AGGP and its contributions to CAP, the federal government recently invested just under $24-million in three PEI programs through the Low Carbon Economy Fund (LCEF).[260] PEI matched the investment, totalling $47.8-million, to support programs with the goal of reducing GHG emissions in the built environment and in agriculture (including reducing GHG emissions from crop production), and promoting the use of forests for carbon sequestration.[261]

Federal and provincial governments have also collaborated to create the Living Laboratories Initiative, an integrated approach to agricultural innovation which brings together farmers, scientists and other partners to co-develop, test, and monitor new practices and technologies in a real-life context.[262] PEI is home to the very first living lab site in Canada. The initiative is being implemented by East Prince Agri-Environment Association, a non-profit representing 13 PEI organizations devoted to sustainable agriculture, who will collaborate with science teams and other partners to develop and evaluate eight specific BMPs – those related to fertilizer management and soil conservation including fall-seeded cover cropping, tillage practices, and using slow-release fertilizer products.[263,264]

As of spring 2019, the PEI Livings Labs Initiative began to pilot BMP projects on nutrient stewardship, conservation cropping, energy efficiency and livestock feeding strategies, in an attempt to reduce the agriculture sector's GHG footprint, which currently accounts for approximately 25% of all GHG emissions in PEI.[265] These pilots are expected to continue to be released throughout 2021 in the hopes of offering environmental solutions while maintaining the viability of the agriculture sector.[266]

5.2.3 Other Programs

Another notable current program in PEI is the Alternative Land Use Services (ALUS) program, which uses a payment for ecosystem services model to achieve its four main goals; namely reducing soil erosion, improving water quality, improving biodiversity, and mitigating the impacts of climate change. ALUS offers funding for a variety of BMPs – although none are directly related to nutrient management, several aim to reduce nutrient concentrations in waterways (among other water quality objectives), including payments of $74.87/ac/year for expanding riparian buffer zones, $60.70/ac/year for retiring high sloping lands, and $0.30/metre/year for maintaining livestock fencing maintenance adjacent to watercourses.[267]

Finally, the 4R™ Nutrient Certification Program also has a significant presence in PEI. This program has developed a set of standards reflecting the specific circumstances of PEI's agriculture sector.[268] The program aims to improve nutrient availability and uptake efficiency, improve soil and groundwater health, encourage data and BMP sharing among farmers, and encourage the adoption of modernized nutrient management research and technologies.[269] These nutrient management practices include sub-surface phosphorous banding, nutrient injection, and encouraging the use of nitrification inhibitors or slow-release fertilizer technologies. Data collection focusses on capturing and monitoring watershed data, and creating farm-level or regionally-grounded application plans.

5.3 Workshop Participants' General Comments on Performance of Current Programs

In addition to comments on specific programs, participants at the Guelph and Charlottetown workshops also provided more general assessments of the performance of agri-environmental programs in the two provinces. Two main aspects of current programs were discussed: how they were perceived as being effective, and how they might be working at cross-purposes with efficient nutrient management and soil health objectives.

5.3.1 Programs Perceived as Effective

In general, participants considered the EFP and cost-share processes as well as 4R™ certification to be highly effective programs to tackle nutrient management problems in their respective provinces.

EFPs and Cost-share

Participants commented that the EFP was extremely successful in introducing beneficial management practices to farmers, providing them with the opportunity to adopt a variety of BMPs with significant environmental benefits.

However, opinions were divided on some of the other overarching aspects of cost-share programs. On the one hand, some participants argued that there are insufficient incentives for early adoption or for more innovative but risky BMPs. As a result, these adopters bear the costs of being first-movers for riskier BMPs (although to be fair, they also reap the potential benefits). On the other hand, some participants argued that the majority of participants in the EFP process and cost-share programs were the innovators and early adopters; from these participants' perspective, the main problem was encouraging BMP adoption among a broader group of farmers, rather than "the usual suspects."[270] As mentioned in the barriers section, this suggests that new policy approaches should be introduced as a complement or (where appropriate) substitute to cost-share. These policies should focus on de-risking BMPs, improving knowledge required to implement them, and demonstrating their efficacy among farmers (see section 6 for further discussion of potential policy options).

4R™ Certification

In addition to the EFP and cost-share programs, 4R™ certification was considered a very successful program for making science-based recommendations on the farm. However, workshop participants argued that better integrating 4R™ nutrient management with manure management is an important area that warrants more attention.

One challenge identified with the program was that certified crop advisory and agri-retailers currently have no incentive to become 4R™ certified, save for the possible customer loyalty and reputational benefits. Workshop participants argued that agri-retailors might be reluctant to become 4R™ certified and promote NMP or nutrient management BMPs for two reasons. First, if their recommendations regarding source, rate, timing, or placement result in yield or profit losses for their clients, they face reputational risks, and may lose their customers. This might make them reluctant to provide recommendations for specific BMPs if these BMPs are relatively risky (e.g., as measured by variability in yield outcomes), even if they would improve their clients' income on average. Second, agri-retailers may face a conflict of interest; some nutrient management BMPs may in fact reduce the volume of sales that retailers would otherwise be making (e.g., of fertilizer).

In addition to designing policies to directly de-risk BMPs among producers themselves (see the policy options in section 6 for more discussion), one of the potential avenues for policymakers to compensate for reputational risks assumed by certified crop advisors and agri-retailers would be to offer an incentive program for the latter to become 4R™ certified. By contrast, the risk that agri-retailers might recommend excessively high N application rates could potentially be mitigated through requirements that certified crop advisors or agri-retailers base their agronomic advice on a mandatory soil health test.

In general, participants considered the EFP and cost-share processes as well as 4RTM certification to be highly effective programs to tackle nutrient management problems in their respective provinces.

5.3.2 Perceived Program Weaknesses

Participants also commented on aspects of programs and policies that were perceived as posing a barrier to NMP or BMP adoption, or were undermining efficient N fertilizer management. Workshop participants also emphasized the need for more integrated and streamlined programs, as well as improvements to the research policy interface.

More Integrated and Streamlined Programs

Another overarching theme concerned the perceived lack of integrated and streamlined policies and programs. Time is a very important limiting factor for many farmers, many of whom feel overloaded with information on the various eligible programs and practices. Although the cost-share programs offered through the CAP are already fairly consolidated within each province (since they generally offer one joint federal-provincial agri-environmental program per province), some stakeholders emphasized the need for a harmonized set of programs across governments and other organizations (e.g., ENGOs), so farmers can make more efficient decisions on which practices to adopt and which programs to enroll in.

Given that farmers are a heterogeneous group with different resources, objectives, risk tolerance etc., there are trade-offs to further consolidating or streamlining programs, since there will be fewer options to meet farmers' specific needs. However, governments could still play a role in making the entire system of incentives easier to navigate for farmers. One possible means assisting with this process could be to create an online 'dashboard' for producers – or a large brochure (or group of brochures) – that would allow farmers to identify their BMPs of interest, and then provide them guidance and information on all of the federal, provincial, ENGO, etc. programs that are offering extension and cost-share services related to that BMP. That would enable them to quickly identify the relevant government and ENGO supports that are directed towards their interests and needs.

Improving the Research-policy Interface

Participants highlighted two important areas for improving the research-policy interface: (1) at the 'front end' where agronomic research informs recommended application rates, and (2) at the 'back end' in terms of understanding the impacts of particular BMPs – and the programs intended to incentivize their adoption – on environmental and economic outcomes.

Participants argued that there is a need for stronger feedback loops from research to policy on optimal fertilizer application rates. Stakeholders argued that government and industry research sometimes leads to very different recommendations on optimum application rate, which can cause confusion amongst producers. They argued that the results of ongoing basic agronomic research should be used to more regularly update the prescribed nutrient application guidelines.

They also spoke to the need for improved benchmarking and data gathering related to nutrient management and soil health BMPs in the agriculture sector. In particular, field-level data is needed to fully evaluate the impacts of BMPs on desired outcomes such as reduced N_2O emissions, water quality, RSN, N runoff and leaching. However, there are many barriers to collecting, sharing and disseminating this data. Large scale, field-level monitoring data can be very costly to acquire. Data is held among various actors in the supply chain, and producers are particularly reluctant to share data. Moreover, strict interpretation of confidentiality constraints by various levels of government create severe restrictions to sharing this data with researchers and practitioners.

In addition to barriers to farm-level data collection, the nature of the data also makes program evaluation complicated. There is a lag between BMP adoption and environmental outcomes, farms may adopt multiple different BMPs, and outcomes are also affected by random factors such as weather conditions. Moreover, most agri-environmental programs are not implemented experimentally, which means that producers self-select into programs (which leads to selection bias that needs to be controlled for in program evaluations). Unless statistical techniques such as differences-in-differences analysis are used to control for the effects of these potential confounding variables, it is almost impossible to measure the impacts of agri-environmental programs and their associated BMPs (i.e., the environmental and economic benefits compared to what would have happened in the absence of the program).

6. POLICY OPTIONS FOR IMPROVING NITROGEN FERTILIZER EFFICIENCY

As we saw in the previous two sections, while current programs are having positive impacts on the environment and on farmers' livelihoods, the adoption of BMPs is being held back by a number of economic and behavioral factors, including: concerns about profit (traded off against risk); the costs and knowledge associated with transitioning to new practices; time constraints; and concerns about BMP effectiveness. Innovative approaches to agri-environmental policies can help change this dynamic by addressing these barriers, fostering behaviour change, and directly rewarding environmental stewardship.

SPI undertook research and convening to identify policy options that could address these barriers, and unlock broader and deeper improvements in nitrogen fertilizer management and soil health practices. Based on an initial scan of the literature and consultations with local and national experts, we identified five policy options for improving N fertilizer efficiency and soil health in our target production systems: (i) behavioral policy approaches (or 'nudges')[271]; (ii) BMP Insurance; (iii) changes to agricultural BRM programs such as AgriInvest, AgriInsurance and AgriStability; (iv) reverse auctions; (v) and carbon offsets.

For each policy option we draw on a literature review and key messages from workshop participants to provide a brief overview of how the policy works, highlight experience within Canada and other jurisdictions (where relevant), and provide an assessment of the strengths and weaknesses of the policy (including effectiveness at addressing the five adoption barriers above).

Given that behavioral approaches to agri-environmental policy contain different background assumptions compared to the other policy instruments discussed in this chapter, section 6.1 begins a more general overview of behavioral policy approaches and their relevance to agri-environmental policy.

6.1 Behavioral Policy Approaches

6.1.1 Overview: The MINDSPACE Framework

Behavioral economics supplements and extends mainstream economic theory by investigating how human decision making is affected by a number of 'cognitive biases' and other psychological and social influences. Traditional economics generally assumes that people, in the aggregate, tend to make decisions based on a rational calculation of cost and benefits (both monetary and non-monetary), while making the best use of the information, time and resources available to them. This is formally known as **expected utility theory**.

Under expected utility theory, when faced with a risky choice, decisionmakers (such as farmers) will choose the decision that maximizes their utility, taking into account all possible outcomes. This occurs by multiplying the probability of each possible outcome by its utility, and then summing up them all up. In expected utility theory, risk is measured in terms of the variance or standard deviation in outcomes (such as farm income), and attitudes towards risk are determined by the shape of the utility function.[272] Decisionmakers are **risk-averse** if they experience diminishing marginal utility of income, **risk-neutral** if they experience constant marginal utility, and **risk-prone** if they experience increasing marginal utility.[273]

Expected utility theory is a powerful descriptive model for decision-making under risk. However, the bulk of evidence suggests that most people – including farmers – do not reason or behave according to expected utility theory (which does not necessarily mean that they are being irrational).[274] Researchers have identified nine behavioral variables which sometimes deviate from expected utility theory and which are particularly relevant to agri-environmental policy. They are summarized in the mnemonic MINDSPACE[275]:

1. **Messenger**: We are heavily influenced by who communicates information to us.
2. **Incentives**: Our responses to incentives are shaped by predictable mental shortcuts such as strongly avoiding losses.
3. **Norms**: We are strongly influenced by what others do.
4. **Defaults**: We "go with the flow" of pre-set options.
5. **Salience**: Our attention is drawn to what is novel and seems relevant to us.
6. **Priming**: Our acts are often influenced by sub-conscious cues.
7. **Affect**: Our emotional associations can powerfully shape our actions.
8. **Commitment**: We seek to be consistent with our public promises, and reciprocate acts.
9. **Ego**: We act in ways that make us feel better about ourselves.

Several different types of behavioral policy interventions or 'nudges' could be designed for each these variables. Based on our literature review and consultation with subject matter experts, we identified three behavioral policy themes that appear particularly promising for improving nutrient management and soil health in Ontario and PEI systems: (1) understanding the role of risk preferences (especially loss aversion and probability weighting) to improve policy and program design; (2) designing collective bonus payments to reinforce social norms (beliefs about how peers behave) for efficient agricultural input use;[276] and (3) using trusted messengers to deliver information on BMPs and associated programs through agronomist-to-farmer and farmer-to-farmer extension and demonstration networks.[277] Options (1) and (2) are generally examples of **Incentives** under the MINDSPACE framework, whereas option (3) is a case of **Messenger** policy.

For each of these behavioral policy options, we briefly illustrate how each of these policies operate in real-life contexts through field experiments and choice experiments, and analyze their potential to address adoption barriers. We then discuss how they could be applied in the context of N fertilizer management in Ontario and PEI production systems. The next section begins with a review of available the literature on farmer risk preferences to better understand and predict nitrogen fertilizer application, BMP adoption, and agricultural program design.

6.1.2 Understanding the Role of Farmer Risk Preferences to Improve Policy

As was mentioned in the previous section, many aspects of people's behavior (including that of farmers) seem paradoxical from the perspective of expected utility theory. For instance, the same person might purchase both insurance and lottery tickets, even though the former activity implies risk aversion whereas the latter implies risk proneness.[278] These same kinds of behavioral anomalies can show up when farmers make risky decisions such as which crops to sow, how much inputs to apply, whether to participate in an agri-environmental program, or how much crop insurance to purchase. **Utility loss aversion** (hereafter abbreviated as 'loss aversion') and **probability weighting** (also known as 'probability distortion') are two of the most important behavioral factors affecting choice under risk.

Loss aversion occurs when decisionmakers experience greater disutility from potential losses compared to potential gains of the same financial magnitude. Unlike expected utility theory which assesses outcomes in terms of total income or background wealth, outcomes under loss aversion are framed as gains or losses relative to the decisionmakers' reference point. In the agricultural context, this reference point is usually interpreted as producers' *status quo* situation or current endowment, but it could include other possibilities such as the producers' expectations (e.g., the anticipated indemnity level of a crop insurance program).[279] Correctly identifying the reference point for loss aversion is extremely important, since peoples' behavior will differ depending on the reference point which they have adopted.[280]

Probability weighting occurs when decisionmakers over- or under-estimate the probability of certain events. Previous studies have typically found or assumed that the probability weighting function takes on an inverted S-shape (although this is not a strict requirement).[281] An inverted S-shaped probability weighting function implies that decisionmakers overweight high-impact, low-probability events (such as insurable losses or lottery winnings) while underweighting moderate and high-probability events, which helps resolve the apparent paradox of purchasing insurance and lottery tickets mentioned above.

It should be noted that risk aversion (or lack thereof), loss aversion and probability weighting are distinctive mechanisms that can operate independently, or in combination with each other.[282] In fact, there is considerable experimental evidence that individuals (including farmers) have heterogenous risk preferences – with some behaving according to the canons of expected utility theory (with or without risk aversion), and others exhibiting some combination of probability weighting and/or loss aversion.[283] These risk preferences and their associated behavioral anomalies need to be accounted for when assessing the adoption potential of BMPs and new technologies, or when designing agri-environmental policies.

In the next section, we use the examples of loss aversion and probability weighting to demonstrate the substantial implications that cognitive biases (and the broader psychological and social influences on decision-making more generally) have for agri-environmental policy, especially with regards to explaining farmers' behavior (using agricultural input use as a case study), their decisions on which BMPs and technologies to adopt, and for the design of incentive and insurance policies.

Potential Implications for Fertilizer and Other Agricultural Input Use

As we mentioned in section 3, there is substantial evidence that farmers are overapplying fertilizers (relative to the rate recommended by government advisory and extension services) because they believe it will advance their economic objectives. The literature on farmers' rationale for overapplying nitrogen fertilizer has produced inconsistent results. This is to be expected, since farmers are diverse and there are various factors which explain why different groups of farmers choose to overapply fertilizers.

Several factors need to be accounted for when explaining the tendency of some farmers to overapply nitrogen fertilizer, such as whether nitrogen fertilizer and favourable weather conditions are complements or substitutes, whether nitrogen fertilizer application is a risk-increasing or risk-reducing input (i.e., does applying additional nitrogen fertilizer increase or decrease production risk), producers' beliefs about the efficacy of nitrogen fertilizer application, as well as producers' risk preferences. These risk preferences include expected utility maximization (combined with risk aversion, risk neutrality, or risk-prone), as well as probability weighting and/or loss aversion. To keep the discussion manageable, we will focus on two main influences on fertilizer overapplication: whether nitrogen is a risk-increasing or risk decreasing input, and producers' risk preferences.

Although there are some exceptions, previous studies of the economics of nitrogen fertilizer use have generally concluded that nitrogen fertilizers are a risk-increasing input, since increasing fertilizer application increases the variance in producers' profits.[284] This gives rise to a puzzle, since farmers are generally slightly risk-averse,[285] and yet a proportion of them overapply nitrogen fertilizer. There are several possible explanations for this. One explanation might be that these farmers mistakenly believe that fertilizers are a risk-reducing input. Another is that those farmers who do overapply nitrogen fertilizer are risk-neutral (or perhaps even risk-prone).

Several factors need to be accounted for when explaining the tendency of some farmers to overapply nitrogen fertilizer, such as whether nitrogen fertilizer and favourable weather conditions are complements or substitutes, whether nitrogen fertilizer application is a risk-increasing or risk-reducing input (i.e., does applying additional nitrogen fertilizer increase or decrease production risk), producers' beliefs about the efficacy of nitrogen fertilizer application, as well as producers' risk preferences.

Alternatively, it might be the case that producers do not interpret risk in terms of the variance in the profit functions, but use a different measure of risk instead. For instance, producers might overapply nitrogen fertilizers to reduce the likelihood of profit shortfalls, thus acting as a form of 'insurance' ('risk as profit shortfall').[286] In contrast, other aspects of risk preferences such as loss aversion or probability weighing may be impacting decision-making.

Sheriff provides an example of this alternative understanding of the role of nitrogen fertilizers in managing production risk. While recognizing that farmers might be overapplying fertilizer in cases where the agronomic recommendations are too conservative, he argues that risk averse farmers would also overapply fertilizer at planting to minimize risks of sharp yield losses – in case they are unable to return to their fields for additional side-dress fertilizer applications due to wet weather. He also suggests that fertilizer *can* be a risk-reducing input under certain conditions, such as when soil nutrient levels are the sole source of uncertainty facing farmers, or if farmers are confident that wet weather will prohibit them from applying side dress.[287] Although not suggested by the author, it may also be the case that some farmers overapply fertilizer because they overweight the probability of wet weather, or perhaps due to loss aversion.

Other studies have questioned whether risk aversion explains fertilizer overapplication, at least in the context of Ontario corn producers. In a pair of studies comparing the recommended N application rate with the profit maximizing rate for seven field trials of corn yield to nitrogen on experimental plots over 8 years in Ontario, Rajsic and Weersink (2008) and Rajsic, Weersink and Gandorfer (2009) found that fertilizer overapplication was best explained by modelling farmers as risk-neutral, expected utility maximizers.[288] OMAFRA's ex ante recommended application rate (at the time of publication) was usually higher than the ex post profit-maximizing rate on the majority of sites. However, this discrepancy varied from site to site and from year to year – in years with good growing conditions, the recommended rate for less productive sites was much lower than the actual profit maximizing rate. Consequently, applying the recommended N rate for less productive sites could potentially lead to significant yield and income losses for these years.

Although the payoff function from fertilizer application was relatively flat,[289] the reduction in expected returns was steeper when application rates were reduced below agronomically recommended levels.[290] Since the cost of fertilizer over-application is generally small in comparison to the opportunity cost (forgone income and yield) of applying too little during good years, it is economically rational for risk-neutral farmers to apply higher-than-recommended rates of fertilizer to maximize their expected profits.[291] Practically speaking, farmers can visibly see when they have under-applied fertilizer but they rarely know when they have applied too much.[292]

By contrast, risk-averse farmers were predicted to apply less than the recommended fertilizer rate, since fertilizers were predicted to increase risk (in terms of the variance in profits). The authors also found little evidence that it would be economically beneficial for farmers to overapply fertilizer as a form of 'insurance' that reduces shortfalls in profit ('risk as profit shortfall').[293] Finally, the authors noted that information on the upcoming season's growing conditions would provide significant value for farmers when deciding how much nitrogen fertilizer to apply, especially on less productive sites.[294]

Rajsic, Weersink and Gandorfer's explanation that expected utility maximization for risk-neutral farmers provides one possible explanation for fertilizer overapplication. However, studies directly comparing expected utility theory to other models of risk preferences have generally found that most people do not conform to expected utility theory. Although there are fewer studies to draw from in this domain, this also appears to be true of farmers in both low-income and high-income countries.[295]

For instance, Bocquého and colleagues administered a lottery field experiment to a sample of French farmers and found that they are twice as sensitive to losses as they are to gains; they also overweight low-probability but extreme events.[296] Zhao and Yue evaluated the risk preferences of commodity and speciality crop producers in the US through a survey and found that producers weigh losses approximately 1.6 times greater than financial gains of the same magnitude. They also found that specialty crop producers showed a greater degree of loss aversion in comparison with commodity crop producers, as the former are more vulnerable to weather risks and have more intensive management requirements.[297]

Although few studies have assessed the effects of probability weighting and loss aversion on agricultural input use in developed countries, they are worth investigating as complementary explanations for why farmers overapply nitrogen fertilizer. For instance, producers might overapply nitrogen fertilizers if they overweight the probability of good weather (or high yields in years with good weather), or if they exhibit utility loss aversion and use maximum yield in years with good weather as their reference point.[298]

To provide an illustrative example: in a study of pesticide treatments by French farmers, Carpentier (2017) suggests that participants were generally loss averse. Producers exhibiting higher loss aversion are more likely to adopt a reference point where they administer regular pesticide treatments (as opposed to no pesticide treatment), with pesticides being modelled as a risk-reducing input. Combining regular pesticide application as the reference point with utility loss aversion makes producers experience greater disutility from pest-induced crop losses compared to pesticide application costs, especially when pesticide costs are low and/or producers estimate that pest infestations are highly probable. Farmers are thus motivated to administer pesticide treatments as a form of psychological 'self-insurance' against losses, even if the expected financial returns from these treatments are negative. However, increasing pesticide costs (such as through a pesticide tax) makes farmers more likely to change their reference point to the no pesticide treatment scenario instead, after which they administer less pesticide.[299,300]

In sum, the fact that some farmers overapply fertilizer despite it being a risk-increasing input is a phenomenon that needs to take into account a variety of factors, including producers' risk preferences and producers' subjective beliefs about the efficacy and risks associated with nitrogen fertilizer applications. Farmers are heterogenous, and it is unlikely that there will be a significant unique explanation for why farmers overapply fertilizers. Given that many farmers do not reason or behave according to expected utility theory, the role of producers' risk preferences (risk aversion, loss aversion, probability weighting) in nitrogen fertilizer application decisions should be tested in further studies. This is especially true in the case of PEI, since to our knowledge no study has tested alternative models of farmers' risk preferences in that province. These should take the form of lab experiments (with farmers as participants) or field experiments. Ideally, the experimental design would enable policymakers to assess heterogeneity in risk preferences among farmers, and directly test alternative risk preferences in order to eliminate rival explanations.[301]

Future studies should also investigate producers' beliefs about fertilizer application risk and efficacy (e.g., whether producers *believe* fertilizers are a risk-increasing or risk-reducing input), since these also influence fertilizer application decisions, and need to be considered alongside the other factors discussed in this section.

Implications for BMP and Technology Adoption

Loss aversion and over-weighting of low probability, high impact losses have been identified as two possible explanations for why producers might be reluctant to adopt otherwise profitable BMPs and technologies.[302] Some of Canada's agri-environmental programs struggle with low or moderate adoption rates for some BMPs, or with encouraging priority landowners to adopt BMPs (e.g., producers who are less prone to innovate or who are operating in areas with high environmental risks, such as sloped land or riparian areas). While some of this non-adoption may be due to the barriers mentioned in section 3.3, producer risk and other behavioral factors can also play an important role.

For instance, in a study on the adoption of insect-resistant crop varieties (specifically Bt cotton), it was determined that approximately 90% of the respondents exhibited some degree of loss aversion.[303] The results suggest that farmers who are one standard deviation more loss averse than the average risk-neutral farmer tend to be 12% less likely to adopt the new crop variety. As a result, loss averse producers are adopting the technology much later than the average producer. The findings also suggest that farmers who overweight low-probability but highly costly outcomes may be motivated to adopt the new technology earlier. Overall, it is suggested that loss averse farmers take longer to adopt Bt cotton because they need time to learn objectively about the risks of new technology before adopting. Given that Bt cotton is no riskier than the conventional variety, this suggests that farmers' overweighting of low probability impacts significantly influences their adoption decisions.[304]

Furthermore, a study of farmers in France also shows that loss aversion decreases the likelihood of adopting new crop types such as perennial energy crops. Bocquého and colleagues examine how loss aversion and probability weighting impact the adoption of perennial crops when switching away from annual crops. Depending on the reference point, it was found that a one unit increase in loss aversion could stimulate up to a three-unit reduction in the probability of participation. However, it was also shown that loss aversion depends heavily on a producer's reference point, as adoption impacts were not significant across certain levels of expected income and land-use types. For example, although loss aversion negatively impacted adoption when producers considered implementing the practice on regular cropland, it did not negatively impact adoption when they considered implementing the practice on marginal land. Additionally, when subjects overweigh small yet extreme probabilities (and outcomes are assessed relative to their reference point), the likelihood of adoption generally decreases.[305]

Implications for Incentive and Insurance Policies

By grounding policy design in a more realistic understanding of how producers think and behave, the field of behavioral economics also has important implications for designing incentives within agri-environmental policies and programs. Behavioral approaches have the potential to accelerate the adoption of BMPs that generate 'win-win' outcomes; for more costly BMPs subsidized through financial incentives such as cost-share, behavioral approaches can enhance program participation to improve their effectiveness.[306]

One recent study examined the potential implications of loss aversion on reducing administrative burden in agri-environmental policy design. In a randomized survey experiment conducted in the United Kingdom, farmers were assigned to either a treatment or a control for a prospective agri-environmental policy with a hypothetical base subsidy set at GBP 10,000 or CAD 16,900.[307] The control question used a loss frame, and asked producers how much of their CAD 16,900 subsidy they would willingly use to pay for a processing fee that shortens their application time from 10 hours to 1 hour. The treatment question used a gain frame, asked how much farmers would be willing to have their basic subsidy reduced in exchange for shortening program application times by the same amount as the control question. Producers assigned the treatment question were willing to have their subsidy reduced by CAD 5,300 in exchange for reduced processing times. This was more than 3 times the control group's willingness to pay for the processing fee to reduce wait times (which was CAD 1,400).[308]

What might explain this result? In the control question, the processing fee was *segregated* from the subsidy; this potentially sets the maximum subsidy as producers' reference point (CAD 16,900), from which the processing fee is experienced as a loss. By contrast, in the treatment question the processing fee was *integrated* with the subsidy, meaning that producers' reference point was potentially set by whatever subsidy the farmer was willing to accept in exchange for the reduced processing time. Under this reference point, any shortfall from the maximum subsidy (CAD 16,900) would be experienced as a foregone gain. Although the study results should be interpreted cautiously due to potential hypothetical bias from the survey format, the findings suggest that farmers might be willing to accept substantially lower subsidies in exchange for much faster processing times – provided that the subsidy and processing fee are integrated together within the program.

Loss-framed incentive contracts present another opportunity to leverage utility loss aversion to improve agri-environmental program outcomes. For instance, Hossain and List have assessed how the framing of a bonus payment can impact individual performance. Presenting individuals with a loss-framed contract (an opportunity to receive a maximum bonus payment, but explaining that the payment level will decrease over time if certain performance standards are not met), has been shown to be more effective at improving overall performance than providing incremental rewards each time the performance standard is met.[309] Loss framing could be applied to agri-environmental contracts by setting a maximum bonus payment based on a fixed performance target, such as the maximum area under cover cropping eligible for payment. Participants would be told that bonus payments are clawed back from the maximum total bonus based on the environmental results that were actually achieved, which could potentially stimulate greater effort from producers.[310]

Babcock's analysis of crop insurance coverage levels in the US further found that farmers generally purchase less insurance than predicted under expected utility theory. Using a narrowly framed reference point where insurance is understood as a stand-alone 'investment', rather than as a tool for managing whole-farm financial risks, the authors find that loss aversion and probability weighting leads to more accurate predictions of farmers' chosen level of crop insurance coverage. Under this reference point, gains occur when indemnities exceed the premiums paid, whereas losses occur when premiums exceed indemnities. Under this narrowly framed reference point, producers ignore market revenue, with yields and crop prices only mattering because they trigger an indemnity.[311]

This study has several implications for crop insurance policies. First, policy interventions may need to account for (or perhaps explicitly try to remedy) this narrower understanding of crop insurance among some farmers, rather than assuming all farmers treat insurance as a broader farm-level business management practice. Second, emphasizing the riskiness of crop production can help counteract probability weighting and make the benefits of insurance more salient, potentially increasing coverage levels.[312] Third, these findings suggest that increasing insurance premium subsidies (where justified on cost-benefit grounds) could provide a novel financial incentive for farmers to adopt BMPs (this will be further discussed in section 6.3). If farmers adopt the narrowly framed reference point, then further subsidizing insurance premiums renders them more likely to interpret their insurance coverage as exhibiting a 'positive return on investment.'

6.1.3 Collective Bonus Payments

Some BMPs are only effective at improving environmental outcomes if they are adopted at sufficiently large scales (this is especially true of practices that attempt to mitigate common-pool externalities such as fertilizer runoff, pesticide drift, or GHG emissions). Therefore, fostering a critical mass of adopters is often crucial to the effectiveness of environmental policies that promote BMPs. This is one area where nudges such as collective bonuses may be particularly effective for fostering collective action.

To provide a concrete example, many of the European Union's agri-environmental schemes (AES) struggle with low participation rates. One recent study examined the preferences of winegrowers in France for innovative herbicide reduction contracts to improve water quality.[313] The contracts combined an individual payment with a collective bonus payment that is disbursed when a certain proportion of total farm area is enrolled at the regional level. The study found that the collective bonus increased the participation rate as well as the total area of land that each farmer was willing to enroll in the program. Perhaps more surprisingly, the farmers preferred the collective bonus to an equivalent increase in individual payments.[314]

Although the precise psychological mechanisms were not identified in the study, the collective bonuses were hypothesized to increase BMP adoption in three ways. First, reducing pesticide use can only have significant impacts on a watershed scale if a sufficiently large number of farmers adopt this practice within the watershed. In the absence of a collective bonus, farmer may be discouraged from adopting the practice due to a belief that their actions will make no real difference (low perceived efficacy). Second, farmers' choice to participate in a program is influenced by their desire to receive the same benefits as their peers. Third, by making participation in the pesticide reduction contract more commonplace, a collective bonus can encourage a new social norm towards pro-environmental practices, which can provide additional motivation farmers to participate in the program.[315]

Collective bonus options received a lot of support and enthusiasm from workshop participants. The main selling point was that they would promote farmer buy-in to programs, since farmers are more likely to adopt practices that have already been adopted by their neighbours. When producers see many of their neighbours or members of their community adopting a certain practice, they likely perceive the practice as effective. They also have the potential to address some of the adoption barriers identified in section 3.3 of this report. This instrument's capacity to spur collective action could assist first-time adopters to move faster up the learning curve through knowledge spillovers from more experienced farmers. In addition, the program's financial payouts partially compensate for the costs of BMP adoption. However, the instrument is not directly suited to address farmers' time constraints in adopting new practices. This being said, payments made through the program could help compensate them for the opportunity cost of their time and accelerating the learning process can help alleviate producers' time constraints.

However, designing and implementing collective bonus programs requires careful consideration of alternative program designs. For instance, some participants believed that a practice-based approach should be used – where the collective bonus depends on all farmers adopting specific BMPs within the targeted region. However, others argued that an outcomes-based approach might be preferable – where payment is conditional on achieving a collective environmental target, rather than rewarding collective adoption of specific BMPs. Some argued that an outcome-based approach would further tap into farmers' sense of community and foster innovation among farmers.

A practice-based approach is probably the more suitable policy in the majority of cases where policymakers are seeking to improve nutrient management, water quality and soil health, since the target BMPs are easily observed or verified (e.g., more diverse and complex rotations, or variable rate fertilizer application technology), whereas it is relatively more difficult or costly to monitor the environmental outcomes (e.g., N_2O emissions reductions, or reductions in runoff and associated improvements to water quality).

However, an outcome-based approach might be feasible in cases where environmental outcomes can be monitored at a reasonable cost. Soil health indicators such as SOM or RSN are potential candidates here, although in this case the expected benefits of the outcome-based approach need to be balanced against the monitoring costs. This is one potential area where pilot projects could help address which of the two approaches is more cost-effective.

6.1.4 Trusted Messengers

People are more likely to change their opinions about an issue when the message is delivered by someone they trust – a fact no different in the agricultural context. A nudge which simply identifies and enlists the right messenger for an agri-environmental program can have a positive impact on adoption.

Communicating sustainable production practices through trusted messengers can also play an important role in improving producers' knowledge of BMP implementation, as well as perceptions of BMP effectiveness – two major barriers to adoption. In addition, the knowledge transfer from trusted messengers can reduce the time needed to learn and implement the practice. However, this instrument cannot address barriers such as production risk and adoption costs, since it does not provide any financial incentives.

Although messenger nudges were extremely well received by workshop participants, they cautioned that the different farmers have different perceptions of who they consider to be knowledgeable, trusted messengers. For instance, studies in Atlantic Canada have found that producers prefer their information to come from interpersonal sources, such as peer farmers and family members, or government agencies such as provincial departments of agriculture and AAFC.[316] This was echoed by our Charlottetown workshop participants, who highlighted the close ties between producers and provincial government representatives.

The previously mentioned survey also identified agricultural research and information centers, as trusted messengers (ranking them within the top five preferred information sources in Atlantic Canada). Conversely, private sources were scarcely identified in this survey, with agricultural consultants being the only private source appearing on the list at number nine (and with a usage rate of 59 to 63%).[317] Similarly, studies in Ontario have found that producers regard government agencies, specifically OMAFRA and various Regional Conservation Authorities, as preferred sources of information when the topic relates to environmental stewardship or BMPs.[318]

Participants from both workshops also consistently identified fellow farmers as the trusted messenger par excellence. Peer-to-peer communication, extension and demonstration were cited as the most effective way to promote programs and increase adoption.

Participants from both workshops also consistently identified fellow farmers as the trusted messenger *par excellence*. Peer-to-peer communication, extension and demonstration were cited as the most effective way to promote programs and increase adoption. The high degree of trust in fellow farmers is also supported by the broader literature on the adoption of agricultural practices, which has emphasized the importance of farmer networks in fostering adoption.[319] In addition to providing novel information, participants argued that peer-to-peer knowledge transfer can help shift social norms to make a longer-lasting impact. In addition to fellow farmers, workshop participants also noted that certified crop advisors could serve as trusted messengers.

Workshop participants emphasized that, regardless of who plays the role of messenger, relatively small changes to the settings in which messengers and producers interact with one another can also have an important impact on fostering producers' interest and increasing adoption rates. For instance, having governments provide grants to organizations that host on-farm and interactive demonstration events with messengers and producers – or even more informal social gatherings ('kitchen table conversations') – can promote better communication between farmers, the implementing organization, and government staff, and also result in higher program buy-in.

Participants identified a number of good practices for enrolling farmers to serve as trusted messengers. One of these was to offer them a financial reward for the services they are providing to the broader community. However, participants cautioned that many farmers can be quite reluctant to deliver formal presentations to their community, because they do not want to project an air of superiority. Consequently, convening more informal and smaller-scale meetings along the lines mentioned above was seen as a viable alternative. Finally, in cases where local producers are still reluctant to play the role of messenger, another option identified by participants was to fly in progressive or leading-edge farmers from other jurisdictions (e.g., flying in an innovative potato farmer from Alberta to deliver a presentation to PEI producers). Workshop producers suggested that farmers from other jurisdictions are often less shy in presenting their know-how to producers from outside their region. Although they are not 'locals', they still provide very useful information for local farmers due to their detailed knowledge of the production dynamics for the cropping system in question.

Participants also identified several local organizations that are leading the way in the use of messenger tactics, including the Soil Health Network in Ontario, who are currently profiling and championing local farmers implementing good practices. In addition, the Innovative Farmers Association of Ontario encourages cropping practices which enhance soil health by organizing workshops and presentations, which provides a friendly environment for information sharing. This organization also encourages farmers to participate in workshops and farm trials that increase their understanding of soil health, and cooperates with researchers, agribusiness and government to enhance development and adoption of innovative practices in the agriculture space.[320]

Other examples of effective messenger tactics cited in the workshop include PEI providing cost-supports share for BMP demonstrations and field trials, as well as Quebec dairy farmers who are promoting an exchange of knowledge and practices through strong networks of farm management groups.

6.1.5 Assessment

Previous literature has identified several advantages associated with these types of behavioral policies[321] compared to more traditional environmental policy instruments. They are relatively cost-effective for governments to implement,[322] and they generally do not introduce additional regulatory distortions (e.g., changes to input or output prices due to regulation), or impose significant financial burdens on farmers. Nudges can also promote farmer cooperation resulting in social networks – directly connected groups of farmers that share information and influence natural resource management practices in rural communities,[323] as well as knowledge spillovers where other farmers acquire knowledge of the BMP and its benefits, either from direct observation or communication.[324] Both of these can enhance the impact of programs and policies by inducing additional adoption.

Many of our workshop participants across all sectors expressed interest and enthusiasm in behavioral approaches, arguing that nudges and other behavioral interventions should be considered in the design and implementation of every policy or program in the agriculture sector. However, there was an overarching consensus that the values and motivations driving farmer decision-making remain poorly understood. Despite the wealth of research on the various influences, barriers and enablers of adoption behavior mentioned earlier, a coherent and systematic **ranking** of these psychological, demographic and economic variables is missing. To improve environmental policy in agriculture, more structured research should be conducted to better understand and predict the heterogeneous psychological, social and economic factors that influence farmer decision-making. For instance, this could include testing whether cognitive factors such as discount rates or demographic factors such as age or education levels play a greater role in BMP adoption.[325]

6.2 Piloting a 'BMP Insurance' Scheme

6.2.1 Overview

BMP insurance programs provide farmers with financial support for any loss of yields or income arising from the implementation of BMPs, thus acting as a form of 'insurance' against the production risks associated with the BMP. These programs typically require producers to establish 'control strips' to which they apply business-as-usual nutrient management practices, while the rest of the field is managed using the insured BMP. By compensating producers in the event of a loss, the BMP insurance policy aims to incentivize adoption by reducing both actual and perceived production risks associated with BMP adoption.

Once the adoption of the BMP reaches a certain penetration rate, the insurance scheme could potentially be phased out as producers become more familiar with the target BMPs, and producers and policymakers are made more familiar with the actual risk or reward spread of the practice. Another value-add of this policy is that it encourages producers to conduct their own trials and judge the effectiveness of the BMP for themselves. This policy should be coupled with crop advisor or agronomist support to ensure that the BMP is implemented properly and farmers reap both the productive and environmental benefits.

6.2.2 Jurisdictional Experience

The US has had extensive experience with BMP insurance schemes through its BMP Challenge Program, which officially operated from 2004 to 2014. The program worked with farmers to implement BMPs by offering a safety net program that compensated farmers for any loss in profits (including input costs) that resulted from implementing conservation tillage or nutrient management practices.[326] The program was primarily funded by the USDA Natural Resource Conservation Service. There was a fixed cap on the amount of land that each farmer could enroll under the program (up to 100 acres) which depended on the type of BMP adopted, its associated risk, and funding availability. However, there was no cap on the number of years that farmers were eligible to participate.[327]

There is some evidence that the program was at least partially successful in de-risking conservation tillage and nutrient management practices. A survey of past program participants showed that the majority of participants maintained the adopted BMPs (at least to some degree) on the majority of their acreage after one year of participating in the program.[328]

PEI also has previous experience to draw from in this area. The PEI Ecological Goods and Services (EG&S) pilot – a two-year pilot project completed in 2009, which formed the basis of PEI's ongoing Alternative Land Use Services program – implemented an innovative BMP insurance program.[329] Similar to the BMP Challenge Program, farmers implemented split field trials for nutrient management BMPs alongside a control plot. However, unlike the US program, in the EG&S pilot farmers were fully insured against *yield* losses resulting from the BMP, rather than profit losses. The insurance policy was provided by the PEI Agricultural Insurance Corporation, a crown corporation that provides crop insurance in PEI.

During the two years in which the pilot was implemented, no participating producers experienced a decrease in their yields, and hence no money was paid out as part of the insurance policy.[330] However, there were still costs associated with the government underwriting the insurance policy to the Agricultural Insurance Corporation, as well as the costs of designing and administering the pilot. Both of these costs were relatively high and were identified as two of the pilot's main weaknesses by workshop participants. However, one PEI government representative at the Charlottetown workshop noted that their main objective was to get the pilot project up and running quickly, rather than to deliver the most efficient pilot possible in such a short time frame. In light of this, they were confident that the government could deliver a much more efficient BMP insurance program if they decided to scale it.

Based on the experience from these two jurisdictions, we would recommend that a BMP insurance program compensate farmers against any potential loss in *profits* arising from the implementation of N fertilizer BMPs (this approach could potentially be extended to soil health BMPs as well), since compensation based on yield levels is really just an imperfect surrogate for changes in profits (and which does not necessarily take into account changes in input costs or in crop prices).

6.2.3 Assessment

Workshop participants showed significant interest in BMP insurance; they were particularly attracted to the fact that the program does not consist of unconditional financial transfers and only compensates farmers for adverse outcomes. Another advantage of BMP insurance schemes is that they are a very broad-ranging tool that can address heterogeneity in producers' preferences and costs of BMP adoption. Such schemes do not presuppose knowledge of producers' attitudes towards risk (e.g., risk neutrality or risk-aversion, probability weighting, or loss aversion), since the BMP insurance will provide a payout for any profit or yield loss compared to the control plot. Moreover, the literature on flat payoff functions for nitrogen application and yield response[331] mentioned in section 4 suggest that payouts under a BMP insurance scheme are likely to be modest.[332]

BMP insurance is also well suited to address barriers to adoption such as production risk, by compensating farmers for any loss associated with BMP adoption. Since farmers manage a trial and control field concurrently under most BMP insurance schemes, this program can help enhance farmers' knowledge of the BMP and its effectiveness through hands-on training and exposure. Moreover, the absence of insurance payouts in cases of successful BMP adoption could potentially reinforce perceptions of efficacy (since the prospect of a payout potentially makes the effectiveness of the practice more salient for farmers). The insurance payout also reduces farmers' opportunity cost of time for adopting a BMP, and coupling the program with crop advisor or agronomist support will facilitate knowledge transfer and reduce the time needed to adoption and master the practice. However, compensating farmers only in the event of a loss does not do anything to alleviate the potential adoption costs incurred by the practice (although on the other hand, more efficient nutrient management has the potential to increase producers' income).

However, the workshop participants also identified a number of challenges to designing and implementing a BMP insurance program at scale. Transaction costs were the primary concern identified with the program, while other concerns included logistical, monitoring and enforcement challenges (since fertilizer application is less readily observable compared to other practices).

On the topic of transaction costs, monitoring each farm individually ensures that each BMP insurance assessment and payment is fair for producers, but it potentially limits the scalability and cost-effectiveness of the program. An alternative program design could be to set BMP insurance compensation levels based on the average regional or district yields for the relevant commodities. This would reduce program monitoring costs, but it could also reduce program participation from specific farmer groups, since BMPs impose heterogenous costs and benefits on farmers, and farmers may believe that the local average yields are not reflective of their particular circumstances.[333]

These concerns about transaction costs and the suitability of using average yields for BMP insurance assessments have been echoed in a recent experimental study. Palm-Foster and colleagues used an experimental auction to investigate farmers' preferences for compensation schemes to promote phosphorous abatement in agricultural watersheds. Through this auction, farmers were offered either a direct payment to adopt a phosphorous application rate BMP, or a direct payment in combination with free BMP insurance for the same. Somewhat surprisingly, farmers demanded higher payments when offered the free BMP insurance compared to direct payments alone. The key reasons cited by farmers for the higher requested payments were the program's perceived transaction costs, as well as skepticism that the BMP insurance scheme would not accurately estimate losses on their farm.[334]

In light of these issues, policymakers should attempt to carefully assess whether the benefits of BMP insurance schemes outweigh the cost by piloting a few key design possibilities and foster program learning over time. One possible strategy to manage this trade-off between the two design options might be to give farmers the choice between setting BMP insurance compensation based on control plots, or on average regional yields, and vary their supplementary payments accordingly (e.g., little or no direct payment for BMP insurance established on a split field trial, more substantial payments for BMP insurance based on deviations from average regional yields).[335] Payment rates could then be adjusted over time as policymakers and farmers learn about the actual expected returns and production risks of the associated practices.

Another potential option for mitigating risk perceptions associated with BMP insurance would be to offer free soil testing in lieu of a direct payment. If farmers are empowered with accurate information on soil nutrient balances and their implications for N application rates, they may be more willing to adopt NMP and the associated BMP insurance schemes. Moreover, some governments are already subsidizing soil tests, so these subsidies could be drawn from an existing funding envelope.

Workshop participants also explored the possibility of reducing transaction costs by partnering with agricultural equipment retailers in delivering BMP insurance schemes. Retailers could assist in streamlining program reporting by sending a copy of their clients' invoice (e.g., for the fertilizer rates prescribed or applied as part of NMP or a 4R™ compliant plan) to the government. However, workshop participants conceded that the producer is ultimately responsible for implementing the agri-retailer or agronomists' advice, which raises the question of cost-effective monitoring and enforcement.

Finally, BMP insurance programs also have the potential to create unintended consequences due to moral hazard problems (where people undertake riskier behavior because some other party is assuming some or all of the risk). The moral hazard effect might lead to producers deliberately mismanaging their land under BMP insurance so as to maximize their insurance claims. However, policymakers have several mechanisms at their disposal to mitigate moral hazard, including mandatory documentation requirements; requiring that the BMP or NMP be designed by a certified crop consultant; or denying claims where there is evidence of different management practices (besides the BMP) being applied between treatment and control plots.[336]

6.3 Reforms to Business Risk Management Programs

Many producers are concerned about the various business and environmental risks facing their operations; Canada's BRM programs such as AgriInvest, AgriInsurance and AgriStability have been designed to address these risks.

The Prime Minister's 2019 mandate letter to the Minister of Agriculture also explicitly includes a review of BRM programs (AgriStability in particular). This presents an important window of opportunity to modify existing programs (or design new ones) to better address some of these business and environmental risks while also encouraging BMP adoption. We will focus on three potential reforms to BRM programs: offering an increased matching investment under AgriInvest; offering lower insurance premiums under AgriInsurance; as well as potentially modifying AgriStability.[337] We also review a recent assessment of the combined effects of AgriInvest and AgriStability on farm profits and environmental stewardship.

6.3.1 Offering an Increased Matching Investment Under Agriinvest

Overview

AgriInvest is a savings account with a matching contribution from federal and provincial governments, and is one of the main BRM programs under the CAP.[338] The federal government implements this program in all provinces except for Quebec, where it is delivered by *La Financière Agricole*.[339] It is based on a 60:40 cost-share between the federal government and provincial or territorial governments.[340] The federal government spent $187 million on AgriInvest in 2016-2017.[341]

Each year, farmers can invest up to 100% of their allowable net sales to their AgriInvest account; the government provides a 1% match on deposits into the account, capped at $10,000 per year.[342] The AgriInvest accounts are held in non-governmental financial institutions and receive a market rate of return.[343] The program has enjoyed high participation rates, with 75% and 82% of producers participating in the program from 2007 to 2014.[344]

Assessment

This approach received a good deal of support from workshop participants in both Ontario and PEI. The low administrative costs for governments was one of the main attractive features, as it would involve modifying a program framework that is already in place and that has a high participation rate.

Increased matching investment under AgriInvest is well suited to lessen the impact of barriers such as production risks and adoption costs. Providing an additional payment contingent on BMP adoption would help support producers by covering some of their adoption costs, as well as any potential loss of income from production. Similar to any financial incentive, payments made through the program also help compensate farmers for the opportunity cost of time. However, this instrument doesn't address non-financial barriers such as knowledge required to implement the relevant BMPs, or farmers' perception of their efficacy.

On the other hand, views from the peer-reviewed literature are more cautious. Although the primary objective of the program is to assist producers experiencing small reductions in income and encourage investments to manage business risk, there are no restrictions on the timing of withdrawals, and withdrawals are not limited to bad years. As such, it is more of an income support program than a risk management program *per se*. Moreover, the fact that the government contributions are taxed when money is withdrawn – whereas producers' contributions are taxed in the year they are earned – might provide an incentive to withdraw money in bad years.[345]

There is some debate as to whether increasing matching investments under AgriInvest might serve as an effective tool for incentivizing BMP adoption. Rude and Weersink note that based on the estimated costs of environmental cross-compliance (between 2-4% of producers' total costs), AgriInvest's matching contribution of 1% of total net allowable sales might be too low to incentivize the adoption of most BMPs.[346,347] As such, one policy avenue to incentivize BMP adoption would be to offer an increased funding match of 1-2% (capped at $20,000-$30,000) for those producers who are willing to adopt a suite of nutrient management practices or other BMPs. This flexible framework would enable producers to retain access to existing business risk support programs while providing extra incentivizes for BMP adoption, and would build on existing programs to lower administrative costs.

The one major drawback to this approach is that it would be difficult to quickly implement these program reforms, due to the need to coordinate and secure approval from all provincial and territorial governments.

6.3.2 Offering Lower Insurance Premiums Under Agriinsurance

Overview

Under this approach, producers would be offered lower insurance premiums if they were to adopt nutrient management or soil health BMPs. This would likely tie AgriInsurance to the implementation of NMP and its recommended BMPs, as is currently the case in Quebec. However, some of the more costly practices could be perhaps further incentivized through existing cost-share programs, or through the other changes to BRM programs discussed in this section.

AgriInsurance is a federal-provincial-producer cost-share program that stabilizes a producer's income by minimizing the impact of production losses (past a pre-determined threshold) for eligible commodities caused by severe and uncontrollable natural hazards such as drought, flood, wind, frost, excessive rain, heat, snow, uncontrolled disease, insect infestations and wildlife damage. Each province develops and delivers AgriInsurance plans in accordance with the Farm Income Protection Act, the Canada Production Insurance Regulations and Multilateral Framework Agreements.[348] Both levels of government (federal and provincial-territorial) bear the administrative costs; they also cover 60% of the insurance premiums while producers pay for the remaining 40%.[349] In 2016-2017, the federal government spent $704-million on AgriInsurance.[350] The value of insured crop production compared to total production was 76% in 2014-2015, more or less equal to the program target of 75% of total crop production.[351]

Jurisdictional Review

PEI already has experience with tying insurance premiums to environmental management. In 2003, PEI introduced a 3% discount on total crop insurance premiums for producers who completed the EFP training. In 2008, a Soils and Water Conservation discount was introduced for those producers who used a dyker[352] on soils used for potato production.[353]

In the US, the Iowa Department of Agriculture and Land Stewardship is also showing leadership in this space. The *Crop Insurance Demonstration Project* is a three-year joint project between the Iowa Department of Agriculture and Land Stewardship and the USDA Risk Management Agency to increase the use of cover crops in Iowa. Funding will be provided through RMA as an additional insurance premium discount through normal crop insurance processes. Fall-planted cover crops with a spring-planted cash crop are eligible for up to $5/acre in reduced crop insurance premiums.[354] The funding is allocated on a first-come-first-served basis with no cap on acres per individual; funding is capped at the amount that is already insured under contract with USDA Risk Management Agency.[355] Moreover, eligible acres must not be already enrolled under another state or federal cost-share program. The program started in 2017 and continued until 2020. In the first two years of the program, more than 1,200 farmers equal to 0.7% of farms in Iowa applied to this program and collectively planted over 300,000 acres of cover crops, encompassing approximately 0.5% of farmland in the state.[356,357]

We might also see federal US government action on this issue as well. There is currently a proposed bill in the US congress that includes crop insurance discounts for agricultural risk reduction practices. The Agriculture Resilience Act sets an ambitious goal for the US agricultural sector to achieve a minimum 50% reduction in net GHGs from 2010 levels by no later than 2030, and to attain net-zero emissions by no later than 2040. If this bill is passed and made effective by the 2021 reinsurance year, the USDA may provide a crop insurance premium discount for producers of agricultural commodities who adopt risk-reducing farming practices. Eligible practices include the use of cover crops, resource-conserving crop rotations, management-intensive rotational grazing, composting, and other farming practices that reduce risk and promote soil health.[358]

Assessment

Participants supported this approach because it builds on a well-established insurance program, which can reduce program implementation costs. Given that AgriInsurance already provides subsidies to the producer, tying this subsidy to BMP adoption was perceived as a relatively straightforward and cost-effective means of enhancing the sector's environmental performance.

Lowering insurance premiums under AgriInsurance would increase farmers' disposable income, and hence would help reduce production risks and adoption costs and also indirectly compensate for producers for the opportunity costs of their time. However, the less tangible link between BMP adoption and additional income might make AgriInsurance less effective in addressing production risk compared to AgriInvest. Moreover, this instrument doesn't address any of the non-financial barriers to adoption.

One recent study analysed the potential for tying crop insurance premium discounts to pest management BMPs in Saskatchewan. Premium discounts/surcharges in this province are currently calculated by comparing the individual's historical losses to area losses. When an increase in the size or number of losses is experienced, the discount (if present) is reduced or a surcharge is increased. Premium discounts/surcharge premiums are capped at 50%.[359]

Beckie and colleagues argue that the discount on premiums can be tied to pest management BMPs such as more diverse crop rotations, since it is an easily observable and verifiable BMP. However, it is important to account for the differences in geographical location and soil type that might limit the ability of some producers to adopt the rotation. The discount should also reflect the current adoption rate and the cost of implementation, with higher discounts offered for BMPs with higher costs or lower adoption rates. The intention in either case would be to further encourage the uptake of BMPs that would not otherwise be adopted, although only a fraction of the adoption cost would be subsidized.[360]

However, workshop participants indicated that policymakers should retain the existing program and expand on it. The expanded version of the program would be voluntary and would provide additional insurance premium discounts for BMP adoption on top of the existing program, so producers who are not interested in BMP adoption would still have access to the existing program. This approach could further incentivize BMP adoption by offering further discounts based on the number of adopted BMPs, up to some predetermined cap.

Moreover, as was mentioned previously, the need to coordinate and secure approval from all provincial and territorial governments on any proposed changes to BRM programs constitutes a considerable drawback.

6.3.3 Modifying AgriStability

Overview

AgriStability supports producers' incomes in case they experience a large drop in their margins. Retroactive to 2020, the reference margin limit was removed from AgriStability to better support producers through adverse conditions and COVID-19 impacts in recent growing seasons. The payment is activated when the current year program margin[361] falls below 70% of the reference margin.[362] The value of the payment is equal to 70% of the *difference* between the producer's current year net margin and the 70% threshold of the reference margin. For example, take a producer with a reference margin of $100,000 (which equals a 70% threshold worth $70,000). In a year where their net margin drops to $50,000, the producer would be paid $14,000, since this is equal to 70% of the $20,000 difference between their current net margin and 70% of their reference margin ($70,000),[363,364] AgriStability is cost-shared 60:40 between the federal government and provincial or territorial governments.[365] In 2016-2017, more than $357 million in funding was disbursed by this program.[366]

Assessment

Support payments from AgriStability have been clawed back in recent years. In 2008, the threshold was set at 85%, but in 2013 it was reduced to 70%. The program also transitioned from a step-wise approach to compensation (70% of the difference between reference margin and current year margin for losses between 70-85% of the reference margin; 80% contribution for any further losses) to a flat compensation rate (70% of the difference between the 70% of reference margin and current year margin)."

Although this reduction may not appear substantial at first glance, the has significant impacts for on-farm income. Take the previously mentioned example of the farmer with a $100,000 reference margin and a current year margin of $50,000. Under the 70% threshold, the farmer receives $14,000 from AgriStability and loses the remaining $36,000. However, with the 85% threshold, the government contribution would be $26,500[367] and the remaining $23,500 would be absorbed by the farmer. The 70% threshold effectively reduces the government's contribution by 47%.[368] For these and other reasons, producer groups have continued to recommend that the 85% margin be restored.[369]

In addition, the fact that this program is delivered based on producers' margin makes it more challenging to deliver in a timely manner. The program relies on tax data, which producers only submit in the spring after the previous years' production. This reduces the speed at which support payments can be made to producers.[370]

In light of this, it is perhaps unsurprising that AgriStability participation rate is trending downwards. From 2007 to 2014, producer's participation rates declined from 57% to 33%, falling well short of the 50% target.[371] This decline can be attributed to the complexity of the program, time delays in receiving payments, as well as the reduction in the threshold margin for activating the payments.

Research also suggests that AgriStability may be distorting input use, by favouring purchased inputs (e.g., chemicals, fertilizer, energy, etc.) over farmer-owned inputs (e.g., land, farm labor/management inputs etc.). This implicit subsidy reduces the effective price of purchased inputs and may inadvertently increase fertilizer use, thereby worsening producers' environmental footprint. Market-level simulations show that while the program did increase production by 2%, it also induced a 7.7% increase the use of chemicals, energy and fertilizer, without a noticeable increase in acreage under crop cultivation.[372,373,374] This raises the question as to whether this increased input use was agronomically and economically efficient.

Redesigning AgriStability was supported by the participants, since a significant amount of money is injected into the program each year. However, many participants cautioned that AgriStability is not as effective as it could or should be, since the 30% reduction in margins required over one year to trigger payments is extremely high, making many producers ineligible for accessing payments from this program.

Modifying AgriStability is well suited to reduce production risk by compensating farmers in the event of a loss below their reference margin. This program could also impact adoption by reducing BMP adoption costs, although to a lesser degree since the payment is activated after the loss has happened and not at the onset of adoption. Similar to other financial instruments, modifications to AgriStability compensate farmers for the opportunity cost of extra time devoted to BMP implementation. However, this instrument is not suited to address knowledge gaps and farmers' perception of sustainable practices.

As was mentioned previously, reviewing the BRM programs with a special focus on AgriStability is part of AAFC's current mandate. Such a review could provide an opportunity to consider redesigning the program in such a way that it would incentivize BMPs[375] – for instance, by restoring the 85% reference margin conditional on the adoption of a nutrient management or soil health BMP.

This being said, as with all of the other proposed reforms to BRM programs, the need to coordinate and secure approval from all provincial and territorial governments on any proposed changes to BRM programs means that this option requires significant time and effort at both the administrative and political levels.

6.3.4 Assessment of Combined BRM Reforms

A recent study evaluated the combined impacts of AgriInvest, AgriInsurance and AgriStability on farm financial performance and environmental stewardship for a representative Alberta cropping system.[376] It found that the subsidization built into BRM programs under Growing Forward 2 improved farms' net present value (NPV) from $29.13/ac to $43.18/ac.[377] Although BRM participation increased the *absolute variability* in NPV,[378] participation decreased *relative variability* by 27%.[379] This means that the risk reduction benefits in the BRM program structure are mainly due to the fact that the expected increase in the net present value of cash flows exceeds the slight increase in cash flow variability. The upshot is that BRM programs do not stabilize returns over time so much as they 'lessen the troughs' on returns.

When it comes to the impacts of BRM program on BMP adoption, the results of this study are mixed and depend on the type of BMP adopted. The positive net benefits of BMP adoption are further increased under BRM if the adopted BMP offers private net benefits (even in the absence of the subsidy). For instance, implementing winter wheat as a BMP offers benefits in the form of increased profits, and this positive incentive is further reinforced through BRM programs. However, participation in the BRM program further disincentives the adoption of BMPs with high opportunity costs, such as taking land out of production.[380]

6.4 Reverse Auctions

6.4.1 Overview

Setting the appropriate payment levels for BMP adoption can be challenging for government and conservation organizations. Governments face an information asymmetry, since producers generally have a better knowledge of the cost of implementing BMPs compared to governments. This can reduce the cost-effectiveness of BMP programs, since governments might be paying producers more than is necessary to adopt the practice (leading to less money to pay other producers for environmental improvement). Reverse auctions can help address this challenge by creating a competitive process through which producers are incentivized to reveal more accurate information about their true costs of implementing BMPs.

Reverse auctions are markets featuring one centralized buyer of environmental services (either a government or an ENGO), with numerous private landowners acting as sellers. Landowners submit competitive bids to implement BMPs, and bids are assessed and chosen based on the best value for money (environmental improvement per dollar spent) – usually by using an environmental benefits index.[381]

6.4.2 Jurisdictional Review

Ontario already has some experience with using reverse auctions (and similar instruments) to enhance conservation and water quality, such as the Water's Edge Transformation Program (WET) and the Grassland Habitat Farm Incentive Program (GHFIP), both implemented by the Ontario Soil and Crop Improvement Association (OSCIA).[382] The WET was a cost-share program primarily intended to encourage the adoption of BMPs to improve water quality, limit nutrient leaching and runoff, and reduce overall on-farm vulnerabilities in the Lake Simcoe, Nottawasaga, and Severn Sound watersheds. The GHFIP program was a cost-share program targeting BMPs that enhanced habitat for grassland bird species in Ontario.

Reverse auctions were used to set the cost-share rates for producers. As with other reverse auctions, both programs allocated funds based on a competitive process, and bids were ranked based on the highest ratio of environmental benefit to cost. The WET program required consultation with watershed specialists to assess the farm site's potential for water quality improvements. The need to engage with technical experts increased collaboration between farmers, conservation authorities and local stewardship organizations. However, relying on consultants' direct involvement may limit the scalability of such an approach. Moreover, both programs featured an online application process, which could pose a barrier to participation for some producers. Additionally, as with many reverse auctions, these programs also had relatively high administrative and overhead costs.

Despite these hurdles, stakeholder perceptions of at least one of the programs have been favourable. A 2013-2014 analysis of the GHFIP shows that that the majority of producers were either satisfied or very satisfied with their GHFIP projects. OSCIA has continued to use the GHFIP model to deliver the Grassland Stewardship Program (GSP).

Other jurisdictions have also deployed innovative reverse auction designs to improve water quality. For instance, the UK is currently using reverse auctions to incentivize BMPs that reduce N runoff. The program initially started in 2015 as the result of the Wessex Water Company being mandated to either reduce its nitrate load into Poole Harbour, or else construct a nitrate treatment plant instead. The treatment plant would cost £6 million to build with an annual operating cost of £400,000. Instead of constructing the water treatment plant, Wessex Water Company decided to target farmers (the main contributors to nitrate loading) through a reverse auction. The program features a user-friendly online 'dashboard' which enables farmers to customize their bids. The auction has reduced N fertilizer runoff through cover cropping at approximately two-thirds of the cost of traditional stewardship programs to support cover cropping (£30.76/ac compared to £46.13/ac), and the savings are even greater if the avoided construction and maintenance costs for the water treatment plant are used as the comparator.[383]

6.4.3 Assessment

Reverse auctions can positively impact production risk and cover adoption costs by offering compensation that matches the farmers' perceived total cost of BMP implementation (as revealed by their auction bid), although only winning bidders would receive these benefits. In addition, reverse auction indirectly lessens time constraint as a barrier by indirectly compensating producers for their time. However, this is potentially offset by the transaction costs associated with reverse auctions for producers (time required to prepare a bid etc.) and could even exacerbate their time constraints. Moreover, this instrument is not suited to address farmers' knowledge gaps or address their perception of BMP effectiveness.

There may also be limits in the scope of reverse auctions. To date, most reverse auctions pertaining to GHG emissions reductions, water quality or soil health have focused on non-fertilizer BMPs (e.g., cover crops, or riparian vegetation), since these are more readily observable. However, researchers are beginning to consider fertilizer rate and timing BMPs in experimental reverse auction designs, and this could be a promising new opportunity for effective agri-environmental policy.[384] Although fertilizer applications are generally difficult to observe and hence more challenging to include in a reverse auction than more readily observable practices, the logistical requirements are presumably on the same footing as those needed to establish compliance with a NERP protocol or a BMP insurance program. Moreover, in cases where the nutrient management is supported by variable rate application technology, the fertilizer application data could potentially be used for verifying compliance.

Participants considered reverse auctions to be a cost-effective policy instrument in principle. However, they were not seen as a high priority by workshop participants for a number of reasons. First, some farming communities may not find them to be socially acceptable. The tight cohesion of many farming communities might limit the appeal and perceived fairness of any instrument that required landowners to compete with one another in submitting their bids, or which discriminated payments among winning bidders (i.e., different producers receive different payments for the same BMP). These concerns have also been echoed in reverse auction program documents from other jurisdictions. A survey of participants in a UK reverse auction program that distributed grants for extending woodland area shows that one-third of the respondents were dissatisfied with the program. The program allegedly resulted in resentment among farmers, due to issues such as higher payments being issued to their neighbors for the same BMP, and because the auction allegedly rewarded more risk-tolerant behavior among participants.[385]

Second, participants also noted that if a farmer submitted a bid to a reverse auction but failed to win it and receive funding for the proposed BMP, then they may simply refuse to adopt the BMP in the future 'out of spite.' Finally, as was mentioned previously, monitoring reduced fertilizer application rates could be costly. Therefore, it might be more appropriate to implement reverse auctions for highly visible BMPs such as riparian buffers, livestock exclusion fencing in riparian areas, or cover crops.

Structuring auctions to provide an equal payment to all winning bidders is one possible means of addressing the first challenge, since it ensures that all landowners whose bids were selected receive an equal reward (this is known a 'uniform price auction'). Moreover, many farmers are used to engaging in competitive auctions for other goods such as land and farm equipment, and governments in Australia and other jurisdictions have run many successful reverse auctions. Both of these considerations suggest that the challenges for promoting the social acceptability of reverse auctions are not necessarily insurmountable. Nevertheless, further research on which features of the reverse auction design and the overall social context best predict participation rates and broader social acceptance of reverse auctions would be valuable for policymakers attempting to design them in novel decision contexts.

6.5 Carbon Offsets

6.5.1 Overview

Carbon offset credits enable individuals, firms or governments to offset their GHG emissions by paying for GHG reductions undertaken by other firms or private landowners. Carbon offset markets can facilitate the adoption of N fertilizer management BMPs by providing an additional revenue stream for producers.

There are several NERPs active on the voluntary carbon market in the US, which issue credits to producers who have adopted nutrient management BMPs.[386] Climate Trust estimated that nutrient management techniques have the potential to create between 770,000 to 2.7 million offsets credits.[387] This is equal to approximately 1-3% of the 86 million credits that were traded on the global voluntary carbon offset market in 2014.[388]

6.5.2 Jurisdictional Review

Several Canadian jurisdictions have been in the process of developing N_2O emissions reduction protocols for GHG compliance markets, but progress has been slow. Under the federal Greenhouse Gas Pollution Pricing Act (GGPPA), emissions-intensive, trade-exposed firms are required to reduce their GHG emissions intensity by a fixed threshold; for any emissions exceeding the threshold, the firm must either pay the carbon price, purchase an emissions credit from another firm, or purchase a GHG offset.

Provincial governments have been the initial movers on NERP. Alberta was the first province to develop a NERP in 2010, which focused on the 4R™ framework. This protocol would have enabled producers to sell their credits to large industrial emitters.[389] Operationalization of the protocol has been delayed due to its complexity, as well as the measurements and verification required.[390] Ontario was also in the process of developing a NERP as part of its cap and trade program, but it was discontinued with the wind-down of cap and trade in 2018.

Despite these setbacks, NERP offset opportunities may eventually develop within federal or provincial compliance markets. For instance, the Federal Greenhouse Gas Offset System recently released its first list of eligible carbon offset protocols.[391] Although the first list of eligible federal protocols were all based on existing provincial protocols,[392] a NERP protocol could potentially be included in subsequent rounds of protocol development.

6.5.3 Assessment

Carbon offsets have a number of attractive features, such as incentivizing GHG abatement from economic sectors that are not easily covered under conventional pricing schemes, such as agriculture (due to the diffuse nature of GHG emissions). They can also lower the cost of compliance with GHG policy, which can help increase industry acceptance of carbon pricing and potentially make carbon pricing schemes more stringent or ambitious over time. They also have the potential to incentivize nutrient management BMP adoption with minimal regulation or fiscal transfers from governments, and they could also capture the heterogeneity in N fertilizer GHG abatement costs through differentiated protocols for cropping systems and soil types.

Carbon offsets can address adoption costs by providing an additional income stream for those who decide to change their management practices. A properly designed carbon offset should also compensate the farmer, at least partially, for the production risk associated with practice adoption (discussed more below). However, the extent of the offset's impact depends largely on the price of offsets traded in the market. The additional income stream can also indirectly compensates farmers for the opportunity cost of time. Moreover, to the extent that offsets are real, verifiable and additional, they help reinforce producers' perceptions of the efficacy of their adopted BMPs. Having significant science behind the protocols and concrete estimates of the impacts of practice change signal to producers that adopting the offsetting practice will be effective.

Participants considered NERP carbon offsets to be a viable policy instrument if the protocol design and implementation could be nimble enough to overcome transaction costs and measurement complexities, while still safeguarding against problems with **additionality** and **leakage**.[393] Current NERP protocols in the United States have low adoption rates, which may reflect some of these transaction costs. However, efforts are underway to further streamline different protocols and make protocols technically easier to implement.[394] Employing the use of credit aggregators which certify many small farmers to sell the credits to buyers is another option, such as the one being used for Alberta's conservation cropping carbon offset protocol.[395]

Additionality refers to ensuring that the environmental benefits of the practice are incremental, and that producers would not have implemented the practice in the absence of the offset. For instance, several studies have suggested that 4R™ nutrient management practices exhibit positive financial returns on average – although the financial returns may be quite heterogeneous for individual producers due to variation in costs of BMP adoption or opportunity costs, etc. Nevertheless, if NERP is profitable on average, then the practice might generally be in farmers' private economic interest to adopt. If this is the case, any proposed additionality from a NERP offset would only be temporary (since, if profitable, the producer would eventually adopt it with or without the offset payment). On the other hand, the low adoption rate of the NERP (as well as profitable nutrient management practices more generally) potentially suggests that financial additionality (at least in conventional terms of a positive net present value for the average producer) might not be the most appropriate metric for assessing additionality for this type of BMP. Alternatively, it may suggest that the profitability of some of these practices has been overestimated.

Leakage refers to GHG emissions increasing outside of the project boundary as a result of the project activities. For instance, the American Carbon Registry methodology for N_2O Emission Reductions through Changes in Fertilizer Management accounts for leakage only if the yield decreases by more than 5% in the project boundary, and if the N fertilizer application increases on the land outside of the project area.[396]

Finally, to best motivate producers to participate in the offset market, credits should compensate farmers for the costs of the practice change as well as the production risks associated with practice change. One study estimated the N_2O emission reduction from protocols under the American Carbon Registry and Verified Carbon Standard and found that the potential emissions reductions from variable rate N application were in the range of 0.03 to 0.065 Mg CO_2e/ac and for the split N application 0.11 Mg CO_2e/ac. Assuming that the price of carbon credits is in the range of $5-50 per metric tonne of CO_2, offset payments would then range from $0.14/ac to $5.26/ac, which may not be sufficient to reduce the perceived riskiness of the NERP protocol practices.[397]

One straightforward method for addressing the technical issues associated with additionality and leakage for NERP offsets would be to set a strict limit on the share of offsets that can be purchased by firms for regulatory compliance, as is the case with California. California's Cap and Trade Program stipulates that firms could meet no more than 8% of their total compliance obligations using carbon offsets.[398] This would incentivize participation in NERP protocols by farmers without potentially inundating the market with low-cost offsets (some of which might not be additional).

All of these considerations suggest that under the right conditions, NERP offsets can make an important contribution to reducing N_20 emissions by incentivizing the adoption of N fertilizer management BMPs. However, due to the absence of any compliance protocols at the federal or provincial levels, seizing this opportunity at scale is likely to be more of a marathon than a sprint.

6.6 Other Policy Options

In addition to the five policy options presented at the workshop, participants outlined a number of other key policy areas and policy options that could be addressed, such as:

- **Improving data collection** – participants commented that evaluating any proposed policy in this space critically depends on data availability, especially for baseline levels of fertilizer application rates, as well as outcomes from previous policies implemented in the agricultural sector. Whether efficient N fertilizer management, soil health measures, or other issues, successful policy design in the agriculture sector largely depends on overcoming persistent data gaps.
- **Tax and credit rebates for N fertilizer application rates** – this framework would provide tax credits to producers who apply less than the recommended amount of fertilizer; whereas an escalating tax would be applied to producers when their fertilizer application rates exceed a pre-determined baseline. However, there should be measures in place to address the possibility of GHGs being displaced from one growing season to the next – e.g., farmers stockpiling fertilizer when growing cover crops such as winter wheat and using it on the cash crop in the next growing season). This could be accomplished through nutrient budgeting systems that account for N inflows and removal pathways on the farm.
- European countries have extensive experience with nutrient budgeting systems, which could support such a tax and rebate approach. Nutrient budgeting accounts for N inflows into the farm such as N fertilizer and manure, as well as N removal pathways such as crop and animal production. In 1998, the Netherlands implemented the Mineral Accounting System (MINAS) which taxed all nutrients that were generated on-farm past a certain threshold. This system was subsequently banned in 2003 by the EU Court of Justice as the loss standards (loss of nutrients allowed because they are unavoidable or at an acceptable level) implicitly allowed the EU legal limit of 68.8 kg/ac N in on-farm manure application.[399] In addition, they were not sufficient to limit the total application of fertilizer. The system also allowed for paying levies in case of exceeding the loss standard.[400]
- The Netherlands also has a nutrient management tool for dairy farms called the Dutch Annual Nutrient Cycling Management (ANCA) which is mandatory for all dairy farms since 2016. Farmers who are not enrolled in the program are not allowed to deliver milk to the milk processing industries. In Switzerland, receiving subsidies is conditional on presenting an individual farm nutrient budget for N and phosphorous, called "Suisse Balance," to demonstrate environmental performance to regulators.[401]
- **Regulation** – although rarely popular among producers and industry, regulation should be recognized as a viable policy option, especially for addressing worsening environmental externalities from activities that are profitable for producers. There are already some provincial government precedents in the area of water quality and nutrient management to draw lessons from – for instance, PEI requires that farmers establish mandatory riparian buffers of 15 meters along watercourses, and offers subsidies for expanding buffer length above this limit.[402] Alternatively, tying regulations to cross-compliance within existing BRM programs might be one means of them more palatable – such as making access to existing AgriInvest funds conditional on BMP adoption.
- If regulatory approaches are the most appropriate tool for tackling an agri-environmental issue but cannot be used due to their perceived political cost, then another option could be to 'nudge' farmers to adopt BMPs to address the externality, even if these BMPs impose net costs on farmers. Although there may be some merit to this approach, it should not be taken lightly – the entire point of nudge interventions is to change the decision context so as to make agents better off *according to their own values and standards*. Even if policymakers believe that regulations or other instruments are justified to internalize otherwise unpriced environmental externalities, attempting to design nudges that impose net costs on agricultural producers could significantly backfire and them distrustful of *all* nudges, even those that are meant to be welfare enhancing (or which make no difference to producer welfare).
- **Support for advanced soil testing –** soil testing is a vital component of sustainable nutrient management practices. Soil N testing helps improve nutrient management by providing producers with actionable information on residual soil nitrogen levels, which can then be used to tailor the timing and rate of nitrogen fertilizer application in the subsequent growing season. Workshop participants favored this approach as it would help standardize farmers' application rates based on scientific evidence. In addition, it also indirectly binds the recommendations made by agri-retailors (since they should not make recommendations that run contrary to the test results). Workshop participants also noted that despite the benefits of soil N testing in efficient nutrient management, the extra costs of the test discourage some farmers to regularly perform it on-farm. Although PEI and Ontario currently offer cost-share incentives to partially compensate farmers for performing these tests as part of a NMP, policymakers may wish to augment the cost share to further incentivize adoption.
- **Increased support for producers to plant cover crops and longer crop rotations** – however, both of these proposals would require further analysis. With regards to crop rotations, this could include increasing the per farm cap on cost-share funding (currently pegged at $8,000) if producers adopt longer crop rotations (e.g., 4-5 year rotations).
- For PEI, cover crop incentives are $35 of assistance per acre up to a maximum of $1,000 per field ($3,000 per year) available for eligible Winter Cover Crop expenses, capped at $6,000 over the life of the CAP Framework Agreement (2018-2023). Policymakers may wish to extend the cap to $9,000 to encourage more continued cover crop establishment over the lifetime of the CAP Framework Agreement.

7. SYNTHESIS AND POLICY CONSIDERATIONS

7.1 Synthesis

Our literature review and workshop participants identified strengths with all five policy options, although some policies were seen as better at solving certain kinds of problems rather than others, and some of the policies were considered less of a priority in the ON or PEI contexts.

Workshop participants from all sectors identified the importance of trusted messengers, stating that they should be considered essential for implementing *any* policy. Fellow producers were frequently identified as the most trusted messenger, although government extension staff and certified crop advisors were also considered important. Trusted messengers can provide knowledge to other producers, teaching them how to effectively implement a BMP on their farm. This process can enhance a producer's perception of the BMP's efficacy and also saves the producer time and effort in learning about the BMP on their own. For these reasons, trusted messenger tactics address multiple important barriers to BMP adoption and play a vital complementary role to the other policies in this section.

BMP insurance was identified as one of the strongest policy candidates for encouraging NMP in Ontario and PEI, due to the strong potential for de-risking existing BMPs and because a payout is only provided in the event of a loss. Moreover, if the payoff function for N fertilizer applications is flat (as has been argued elsewhere),[403] then the cost of potential payouts under a BMP insurance scheme are likely to be modest. The side-by-side trial structure and crop advisor support found in BMP insurance programs also present the opportunity to enhance producers' knowledge of BMP implementation and the perception of BMP effectiveness over time.

Reforming BRM programs so that they offer enhanced benefits conditional on BMP adoption is another policy with high potential, especially increasing the matching investment under AgriInvest and lowering insurance premiums under

AgriInsurance. Both of these have the potential to reduce production risk and compensate for some of the costs of BMP adoption. These could potentially be piloted in the short-to-medium term, but it would be difficult to move quickly on wide-ranging program reforms because they require extensive coordination and approval between the federal, provincial and territorial governments. The additional incentives created by these changes can also compensate producers for the cost of their time – associated with adopting or implementing a new practice.

Collective bonus payments were seen as another potentially attractive option, since they tap into farmers' sense of community-mindedness and the financial incentives can be used to encourage the adoption of both nitrogen management and soil health BMPs. Collective adoption bonuses can also address knowledge and time barriers through the knowledge spillover effect, where experienced producers in the region impart their experience upon 'newer' adopters to help them move up the learning curve more quickly. At this stage it might be more feasible to use this tool to reward practice-based targets (collective adoption of a desired BMP) rather than outcome-based targets. Alternatively, pilot projects could be devised to test which of these strategies is more effective.

By contrast, PEI and ON policymakers were not as interested in implementing reverse auctions at this time, despite their high potential for cost-effectiveness and their flexibility as a policy tool (i.e., potential to design auctions for multiple kinds of BMPs). Reverse auctions have value because they allow the producer to specify the subsidy level (within a certain capped amount), meaning that the subsidy would likely compensate the producer for all the costs they deem relevant, inclusive of risk, time, or recurring costs. However, provincial government policymakers and others frequently cited reverse auctions' potential to create distributive conflict among farmers as an important drawback. Reverse auctions also tend to have high transaction costs that might increase time costs or inconvenience, although well-designed auctions can partially mitigate these concerns.

NERP carbon offsets protocols can contribute to agricultural N_2O emissions reductions and shift some of the costs of incentivizing BMP adoption from governments to industry. The incentive offered by an NERP could compensate producers for the cost of adoption and the cost of their time. In addition, we suggest that a properly designed offset also compensate for the production risk associated with practice change. The scalability of this approach is limited to voluntary carbon markets until a NERP protocol emerges in federal or provincial compliance offset markets. Emerging NERP protocols should be stringent and account for additionality and leakage risks, as well as be rooted in science and have clear estimates of the potential credits a produce can earn. These considerations may help enhance the perceived effectiveness of the nitrogen management BMPs the NERP covers. Offsets should only be considered as a medium or long-term substitute for the other policies discussed here - until an NERP protocol becomes available.

Table 3 summarizes this section and presents the potential of each policy instrument to address the five adoption barriers discussed in section 3.3, while Table 4 summarizes the more general benefits and drawbacks of the policy options, as well as potential mitigation measures.

Table 3. Mapping of Policy Instruments to BMPs and Adoption Barriers

Policy Instrument	Adoption Barrier to Address				
	Address Production Risk	Upfront & Recurring Costs	Knowledge & Complexity	Improve Perceived Effectiveness	Time Constraints & Convenience
Cost-share		✓			✓
Collective Adoption Bonus Payment		✓	✓	✓	✓
Trusted Messengers			✓	✓	✓
BMP Insurance	✓		✓	✓	✓
Increased Matching Investment Under AgriInvest	✓	✓			✓
Lower Insurance Premiums Under AgriInsurance	✓	✓			✓
Modifying AgriStability	✓	✓			✓
Reverse Auctions	✓	✓			
Carbon Offsets (NERP)	✓	✓		✓	✓

Table 4. Summary of Workshop Participants' Comments on Policy Options

Policy Instrument	Supporting Points	Risks, Drawbacks, Suggestions for Improvement	Potential Risk Mitigation Approaches When Applicable
1. Behavioral Interventions			
a) Collective bonus payments Making BMP payments conditional on collectively reaching an environmental goal or implementing a best management practice	• Draws upon social norms which provides additional motivation for adoption • Possibility of collectively achieving environmental outcomes may result in higher uptake of the programs • Farmers want to receive the same benefits as their neighbors	• Trade-offs in deciding between practice-based or outcome-based programs • Practice-based: may not be sufficient for achieving an environmental target • Outcome-based: some outcomes (e.g., water quality) may be difficult to causally attribute to practice adoption	• Deploy pilot studies to better assess the strengths and weaknesses of both types of schemes
b) Trusted Messengers Using trusted messengers to communicate the BMP and its benefits to farmers	• Builds on established trust and relationships e.g., fellow producers, government and private sector extension agents, agri-retailers, and producer networks in Quebec	• Messengers should be knowledgeable about the proposed practice or policy, and have adopted it themselves • Producers may be reluctant to serve as messengers (despite being the messenger most preferred by other farmers)	• Provide training and financial incentives for trusted agents within the farming community to promote BMPs • Failing that, 'fly in' expert producers from comparable production systems from other regions/jurisdictions
2. Carbon Offsets			
	• Potentially cost-effective tool for GHG emissions reduction • Extra income stream for adopting the practice • Transfers some fiscal costs of encouraging BMP adoption from the government to industry	• High transaction costs • Measurement complexities • Potential problems with permanence, additionality and leakage • Low credit price	• Use carbon credit aggregators • Work with federal and provincial governments to develop credible protocols
3. BMP Insurance			
Compensating farmers for loss in profit or yield as the result of BMP adoption	• Increases adoption by de-risking BMPs • The program only compensates farmers for adverse outcomes • Similar programs already piloted in US and PEI	• High transaction costs • Difficulties in monitoring and enforcement • May lead to perverse incentives to poorly manage the land under the insurance policy	• To reduce transaction costs, the design of the program can base comparison on the average regional yield rather than the individual farm outcomes • Combine BMP insurance with other payments if necessary (cash or in-kind supports) • Address perverse incentives through audit and reporting requirements
4. Reforming BRM Programs			
a) Increased matching in Agri-Invest	• Low implementation cost • Current program matching dollars not sufficient for cross compliance	• Requires coordination and agreement among all FPT governments (time-consuming) • Need to carefully consider increasing the matching payments and keep the program inclusive	• The program should adopt a tiered approach and maintain access to Agri-Invest for non-adopters of BMPs
b) Lower insurance premium on AgriInsurance conditional on BMP adoption	• Low implementation cost • Experience with similar tools within Canada and elsewhere e.g., PEI and Iowa Department of Agriculture • Potential to reward producers who are already practicing high-resilience agriculture and encourage new adopters	• Requires coordination and agreement among all FPT governments (time-consuming)	• The program should adopt a tiered approach and maintain access to Agri-Insurance for non-adopters of BMPs
c) Modify AgriStability by restoring the 85% reference margin conditional on the adoption of a nutrient management or soil health BMP	• Increased program eligibility (current 30% threshold for drop in profit margins is too high for most farmers to be eligible for the program)	• Requires coordination and agreement among all FPT governments (time-consuming) • Possible distortions to input use by penalizing the use of farmers' own inputs (could be fixed)	• Deploy pilot studies to better assess the strengths and weaknesses of modifying criteria
5. Reverse Auction			
	• Cost-effective • Room for flexibility and innovation	• Can undermine community cohesion by dividing farmers into losers and winners • Losers may have a negative view of the program or targeted BMPs • High monitoring costs for some BMPs (e.g., reduced fertilizer application)	• Use uniform payments for auction participants • Use reverse auction as an intermediary program to understand farmers' payment preferences; use this information to design more broad-based programs such as targeted cost-share

7.2 Cross-cutting Policy Considerations, and Next Steps

In addition to the individual policy options discussed above, a number of cross-cutting policy considerations emerged from the research and workshop discussions. The research findings on policy options also provide insights on where this research should be piloted and extended.

First, as was mentioned previously, there is an urgent need for improved benchmarking and data-gathering on environmental performance in the agriculture sector, and for nutrient management in particular. The state of available data makes it difficult to credibly estimate farmers' actual fertilizer application rates for various staple crops. Field-level data are also needed to fully evaluate the impacts of BMPs on environmental outcomes such as reduced N_2O emissions, water quality, residual soil nitrogen, N runoff and leaching. All levels of government, the private sector and research organizations should make concerted efforts to share their rich datasets on input use, soil health and BMP adoption with one another, as well as with the broader research community (while respecting concerns about confidentiality).

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Second, improving agri-environmental policies also relies on strengthening our understanding of farmers' motivations and factors influencing their adoption decisions, but important research and knowledge gaps remain within the Canadian context. There is a clear need for a literature synthesis that attempts to quantify the contribution of the relevant geographic, psychological, social, economic, and demographic factors affecting adoption. Addressing these gaps would provide valuable insights to policymakers when considering future iterations of the CAP, to give one example. Despite the success of the EFP process and cost-share programs in sensitizing producers to BMPs, the EFP frequently suffers from relatively low participation rates in certain areas (e.g., in specific program streams within the respective provincial processes; and in the prairies more generally). Research into farmers' decision-making can act as a feedback loop to enhance the effectiveness of cost-share programs and the EFP process, and enhance the adoption of BMPs.

Finally, designing and implementing pilot projects which test some of the policy options outlined in this report and the associated mechanisms of behavior change among farmers would constitute a logical next step. Ideally, these pilots should harness quasi-experimental research designs that feature treatment and control groups at distinct study sites, and test some of the outstanding research questions concerning farmers' nutrient management practices and risk preferences outlined in this report (e.g., the impact of probability weighting or loss aversion on fertilizer application rates, or of social norms on BMP adoption). This approach would provide rich insights to help improve the design of new and existing programs, and foster continuous improvement in agri-environmental policy.

8. CONCLUSION

Corn-soybean winter wheat systems in Ontario and potato systems in PEI both emit substantial amounts of N_2O annually, primarily from agricultural soils. Assessments of the current state of play in both of these provinces show that fertilizer application rates have been rising over the past decade while measures of soil health, such as SOC, are in decline. Simultaneously, water quality impacts are becoming of increasing concern, as elevated groundwater nitrate levels and algal blooms continue to reduce the quality of life of Prince Edward Islanders and Ontarians.

The Government of Canada's target to reduce GHG emissions by 30% below 2005 levels – combined with the commitment to a 30% reduction (from 2020 levels) in GHG emissions from nitrogen fertilizer by 2030 – make it clear that ambitious new policies are needed to ensure a sustainable and prosperous future for the agriculture sector.[404] AAFC's February 2022 discussion paper on the fertilizer emission reduction target states that while existing initiatives are 'moving the needle,' additional actions and initiatives will be required to meet the target.[405] Focusing on improving nutrient management and soil health in two of the largest cropping systems in Ontario and PEI provides a solid foundation for clean growth in the agriculture sector, and is one that can be applied to new cropping systems within these provinces and elsewhere in the future.

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Our report highlights the leading practices that farmers can adopt to assist with achieving these environmental objectives, while also preserving or enhancing the profitability of their operations. This is because many of the identified BMPs exhibit great potential to reduce GHG emissions, lower risks to water quality, enhance soil health, and improve or maintain yields. Additionally, a number of BMPs such as NMP and diversifying crop rotations offer cost savings that further increase net returns to producers over time. Our analysis of all five BMPs (and associated sub-practices) clearly demonstrates the variety of methods available to producers to improve their sustainability and their profitability.

Despite these benefits, our literature review and convening have identified a variety of barriers to adoption for Ontario and PEI farmers. The main barriers are concerns about profit (traded off against risk), upfront and recurring costs for farmers, knowledge needed to effectively implement the BMPs, perceived efficacy of the BMPs, and time constraints or inconvenience. Three additional adoption barriers unique to the PEI context were also identified, namely: limitations on farm size; the moratorium on high-capacity wells for irrigation; and lack of consumer demand for alternative potato varieties.

The performance of current policies to promote nutrient management and soil health is mixed, and the persistence of these barriers indicates that examining a broader set of policy options has the potential to significantly improve outcomes. Behavioral approaches to policy design such as collective bonus payments or using trusted messengers have significant potential to increase BMP adoption and cost-effectiveness. These could complement innovative program designs like BMP insurance, or modifications to existing BRM programs. Each of the policy tools have their strengths and weaknesses – but through coordination between governments/industry/producers, and smart program design that addresses the diversity within the agriculture sector, these policy options and programs have real potential to 'move the needle' even further on economic and environmental outcomes in these crop production systems.

With the knowledge and tools collected through extensive research and convening, SPI has identified a comprehensive set of policy options and programs that can help Canada meet its nitrogen fertilizer emissions reduction target, increase the sustainability of the agriculture sector, and maintain the economic viability of farmer's operations. The next steps is for policymakers to pilot these tools and programs to gauge their effectiveness in motivating the adoption of nutrient management and soil health BMPs in Canada. By identifying the proposed tools and programs with the highest degree of environmental and economic impact, Canada will advance its clean growth objectives and move us one step closer to having a high-performing, efficient, and sustainable agricultural sector.

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TECHNICAL APPENDIX A: FERTILIZER RATE, SOURCE, TIMING AND PLACEMENT BMPS

A1. Ontario

Applying efficient fertilizers at the proper time – just before plants experience fast uptake of N when they need it most – can lead to large decreases in N losses. Application **timing** has a direct impact on N_2O emissions, leading to N loss reductions as high as 75%.[406] Studies conducted in the US corn belt have quantified the effect of altering application timing to reduce emissions. For instance, shifting fertilizer application from fall to spring reduces CO_2e emissions by approximately 0.08 Mt/ac.[407] Changing application timing to the spring can also be very beneficial to farmers, as up to 50% of the N applied in fall can be lost due to leaching or denitrification over the winter in Ontario. Research also shows that the same amount of N applied in the spring time might actually provide small yield benefits.[408]

Optimized application **rates** can achieve further reductions in N_2O emissions. Location, timing and growing conditions, farm management systems and crop choice all interact with each other, which can pose challenges to specifying the best fertilizer application rate for a given plot of land or crop system.[409] To properly quantify the optimal application rate, agronomists recommend taking an advanced soil sample to gauge RSN – the N that is already present in the soil. Decision support programs such as NumericAg[410] combined with increasingly detailed soil data can help producers better predict the improved application rate to minimize waste and lost yield. This can make the optimal application rate increasingly efficient as blends of mineral fertilizer are matched with RSN levels at the eight-leaf stage in corn growth.

Improved N fertilizer **sources** – such as N and nitrification inhibitors, or urea and urease inhibitors – work together to form a much more efficient N cycle. On its own, improved fertilizer sources can reduce N_2O emissions anywhere between 40% and 60% (depending on climatic conditions).[411] Using improved N fertilizer sources also impacts crop yields. Studies of corn in Ontario show that using Urea Ammonium Nitrate (UAN) fertilizer with a nitrification inhibitor can increase corn yield by up to 9 bu/ac, compared to using UAN alone.[412] However, this yield increase does come at a cost. For example, UAN treated with Agrotain™ (a form of nitrification inhibitor) costs approximately 10% more than using UAN alone.[413]

Improved fertilizer **placement** can also make a significant economic and environmental difference on the farm. In conjunction with other fertilizer management practices, judicious injections of N fertilizer into the soil (otherwise known as subsurface placement) has the potential to increase crop yield by up to 7%.[414] Combining injected placement with UAN fertilizer was found to help improve corn yields by nearly 20% when compared to traditional broadcast application.[415] Fertilizer placement also offers a number of environmental co-benefits. Banded fertilizer application[416] can inhibit ammonia volatilization into the atmosphere by up to 17% when compared to surface application;[417] while injected fertilizer can further inhibit this same phenomenon by up to 77%, when compared to broadcast application.[418,419]

Appendix Table 1. Ontario Corn/Soybean/Winter Wheat – Rate, Source, Timing and Placement BMPs

BMP	Productivity	Cost	GHG	Water Quality	Soil Health
Application Rate	**Ontario Corn** Decrease in net returns to farmer of $33.59/ac for 33% under application compared to recommended (OMAFRA, 2019) Increase in net returns to farmer of $17/ac when applying at the Maximum Economic Rate of Nitrogen (MERN) when compared to 33% over-application (OMAFRA, 2019) Fertilizer Cost reduction valued at $10.28 per ac (USD$) (ICF International, 2013)	**GreenSeekerTM VRT (US Corn Belt)** Initial Capital investment of approximately USD $22,000	**US Corn Belt** Reducing N fertilizer application rates by 10% eliminates about 0.03mt CO2e/ac in corn production (ICF International, 2013)	**Ontario Corn** P losses to runoff: 60% decrease (4R Findings, 2020)	**Iowa Corn (Applying AONR vs. Control)** SOC (g/kg) concentrations increased by between 7 and 20% Gross ammonification reduced by 12-15% (linked to increases in SOM stocks) (Mahal et al., 2019)
Application Source	**Ontario Corn (Side-dressed w/ Anhydrous ammonia (AA) vs. w/ UAN alone)** Yield increase of 19 bushels per ac (Ball, 2013) **Ontario Corn (UAN w/ Nitrification Inhibitor vs. UAN alone)** Yield increase of 8 bushels per ac (Ball, 2013)	**Ontario Cost of Fertilizer Ingredients** UAN treated w/ Agrotain™ (inhibitor) costs 10.2% more than UAN alone (Mussell et al., 2015) **Ontario Cost of Fertilizer Ingredients** UAN relative cost per unit of nutrient = $1.10 (OMAFRA, 2019) AA relative cost per unit of nutrient = $0.83 (OMAFRA, 2019)	**Ontario Corn** GHG reductions up to 75% when combining UAN with nitrification and urease inhibitors at the eighth-leaf growth stage (4R Findings, 2020)	**Ontario Corn (UAN alone (baseline), UAN w/ inhibitor & AA)** UAN w/ inhibitor and AA reduced nitrate-N concentration in soil water by 50 and 75%, respectively, compared to UAN alone (Ball, 2013)	**ND**
Application Timing	**Ontario Winter Wheat** Split N Application vs. Single Application – Yield and Protein Increase of 0.5% on average (OMAFRA, 2017) Incorporating 50-100% Environmentally Stable N Fertilizer (poly coated urea) to **delay N availability** increased protein content by 0.5-0.75% with no yield impact (OMAFRA, 2017)	**Costs Associated with Spring Application (Canada)** Monetary Cost: Fertilizer prices are usually lower in the fall – requires purchasing then storage on farmers part Time Cost: Spring application interferes with seeding and coincides with an already busy season on the farm (Mussell et al., 2015)	**US Corn Belt (Switching from Fall to Spring application)** Reduction of 0.08Mt CO_2e per ac (ICF International, 2013) **Ontario (Switching from Fall to Spring Application)** 100% adoption scenario (Fertilizer + Manure) results in 12% reduction in N_2O emissions (Duke, 2006)	**Ontario Cereal Crops (Fall N Application)** Over 50% of N applied in the fall can be lost to leaching and denitrification over winter (OMAFRA, 2017)	**ND**
Application Placement	**Ontario Corn** 20% Increase when injecting + UAN fertilizer (compared to broadcasting) (4R Findings, 2020) **Ontario Corn** Injecting N fertilizer into the soil increase yields by as much as 7% + totally eliminates harmful ammonia loss to the soil (4R Findings, 2020)	**Costs Associated with Injection (Missouri Corn-Soybean)** Monetary Cost: Injection equipment costs 25 to 70% more than surface applicators (Lory et al., 2018) Time Cost: injection placement typically takes more time than surface application (Lory et al., 2018)	**Ontario (Surface vs. Shallow Banded Urea Application)** Reduces ammonia volatilization by 17% (Ball, 2013) **Ontario Corn** Broadcast & Incorporate reduced ammonia volatilization by 27% compared to broadcast (Drury et al., 2017) Injection reduced ammonia volatilization by 77% compared to broadcast (Drury et al., 2017)	**Lake Erie Basin Comparisons** Banding can almost completely eliminate P load in surface runoff (approximately 90% reduction compared to broadcast) (Williams & King, 2017) In rainfall simulations injection reduced P concentration in runoff by approximately 50% compared to broadcast application (Williams & King, 2017)	**Minnesota Corn and Potato** Injecting AA can increase SOM levels closer to the surface but stimulates more nitrification than Broadcast Urea application (Fujinuma et al., 2011)

A2. PEI

One of the most effective measures to reduce N loss is by improving the timing of fertilizer application through split-application processes, where various quantities of N are spread out over multiple applications. This practice is effective because a single heavy dose application of N before or after planting can increase the risk of N loss through leaching.[420] Early in the growing season, very high N rates can also result in undesired growth effects such as delayed tuberization, slow skin development, and reduced specific gravity.[421,422] Similarly, splitting N fertilizer by applying 60% at planting and 40% at hilling helps improve the timing of N supply to the plant, producing the same or better crop yield while reducing GHG emissions. Another strategy for improving application timing is to delay the plowing of forages.[423] Delaying the earlier herbicidal termination of forage until spring reduces forage-phase nitrate leaching loss by 20% to 61%.[424]

Banded fertilizer application is a common practice to improve fertilizer **placement** in potato cultivation, and provides for optimum growing and reduced surface runoff into PEI waterways.[425] Banded fertilizer application is often combined with conservation tillage (for further discussion of conservation tillage, see section 3.2.2).

Improved fertilizer sources have also been developed to better suit the timing of plant growth and nutrient uptake, including controlled release fertilizer and foliar N products.[426] N inhibitors are one promising technology to help mitigate the loss of N to the atmosphere. They are most effective when used on acidic, coarse-textured soils that have relatively high N application rates.[427] These conditions make this BMP a good fit for PEI potato production where N is a limiting nutrient, the average pH ranges from between 5 and 7.2, and the soil is commonly coarse textured.[428] The use of inhibitors combined with reduced fertilizer application rates (to reflect increased efficiency) helps maintain yields, while reducing environmental impact.

Other improved application sources include enhanced efficiency fertilizers (EEFs). EEF is a broad term describing a variety of fertilizers that share the goal of optimizing nutrient uptake and reducing nutrient loss. EEFs tend to cost approximately 20 to 50% more than regular fertilizers; however, they can reduce total N application requirements by up to 15%. If 25% of PEI potato producers committed to replacing 33% of their current fertilizer applications with EEFs, it is estimated that approximately 10 kt of CO_2e emissions could be eliminated per year.[429] Relative to the total emissions from the PEI agriculture sector in 2018, this represents a 2.5% reduction in CO_2e emissions annually. Finally, a Quebec study comparing two specific types of EEFs – Environmentally Smart N (ESN) and Calcium Ammonium Nitrate (CAN) – shows that ESN can increase marketable yield by over 12% and increase the amount of tubers falling into the ‘large-size’ category by 9%, when compared to CAN.[430,431]

To reduce the risk of excess RSN and ensure more judicious input use, farmers in PEI need to be conducting soil tests to determine the soil’s inherent N supply.[432] This knowledge allows farmers to become increasingly efficient, improving their profitability and sustainability. During the 130-day growing period, there is considerable farm-to-farm variation in the estimated amount of N mineralization. Field experiments have confirmed that the mean amount of N mineralized over the growing period was 26.3 kg/ac, yet the range among fields was 12.55-44.92kg/ac. As previously mentioned, N mineralization matters because high levels of N over-application create a strong potential for NO_3 leaching.[433] PEI is especially vulnerable to the negative environmental impacts of N leaching, considering that 100% of the water supply is from groundwater.

Appendix Table 2. Pei Potatoes – Rate, Source, Timing And Placement BMPs

BMP	Productivity	Cost	GHG	Water Quality	Soil Health
Application Rate	**New Brunswick Potatoes (Over application decreases efficiency)** Moving from 90% to 100% yield more than doubles N fertilizer requirement from 30.35kg N/ac to 61.92kg N/ac (Zebarth et al., 2012)	**Idaho Potato (Fertilizer & Pesticide Application Strategies) (USD$)** High-input, yield maximizing, calendar based approach costs between 1.7 and 13.2% more (in terms of fertilizer and pesticide costs) when compared to fields that used research-based BMPs to manage potato production (Hopkins et al., 2007)	**PEI Potatoes (Site specific N assessments to inform application)** Reduction in N application rate of 20.23kg/ac scenario eliminates 11.3kt of CO_2e per year (PEIFA, 2019)	**New Brunswick Potatoes** On average Optimal N Fertilizer rate can reduce RSN by over 50% compared to over application (101.17kg N/ac) (Zebarth et al., 2012)	**ND**
Application Source	**Eastern Canada Potatoes (Calcium Ammonium Nitrate (CAN) vs. ESN)** ESN increased marketable yield by 12.6% ESN increased proportion of tubers falling into the large and medium category by 9% (Zebarth et al., 2012)	**PEI Potatoes** Enhanced Efficiency Fertilizers (EEF) cost 20 to 50% more than regular fertilizer Reduction in total N required helps offset some of the cost but not all (study assumes possible 15% reduction in total N requirement with EEF use) (PEIFA, 2019)	**PEI Potatoes (substituting 33% of traditional N with EEF)** 25% adoption scenario eliminates 3.71kt of CO_2e per year (PEIFA, 2019)	**Minnesota Potato (Split urea applications vs. single coated urea fertilizer application)** Polyolefin coated urea application reduced leaching during the growing season by 34 to 49% (Zvomuya et al. 2003)	**PEI Potatoes (N mineral fertilizer vs organic fertilizers)** No significant impact on total N or total C in SOM (Nyiraneza et al., 2015)
Application Timing	**PEI Potatoes (Split N Application)** No yield impact Potential negative yield and tuber size impact in drier years (Zebarth et al., 2004) **PEI Potatoes** Delaying fall forage to spring did not significantly impact yields (Khakbazan et al., 2019)	**PEI Potatoes** Splitting N applications does not pose significant cost changes (PEIFA, 2019) Delaying fall forage to spring did not significantly impact total costs Labour costs for spring forage tended to be slightly higher (+$23/ac) but represented less than 1% of total cost (Khakbazan et al., 2019)	**PEI Potatoes (delaying at least 33% of N application until just before hilling)** 50% adoption scenario can eliminate 4kt of CO_2e per year (PEIFA, 2019)	PEI Potatoes Delaying the termination of forage until spring reduces forage-phase nitrate leaching loss by 20% to 61% (Jiang et al., 2014)	**ND**
Application Placement	**US Potatoes (Broadcast vs. Banded N application)** Banded application increased yield by 9% (Westermann et al., 1996) **Atlantic Canada Potatoes (Soil application vs. Soil + Foliar application)** No yield impact for N reductions (72.84 vs. 36.42 kg N/ac = similar yield) (Burton et al., 2019)	**ND**	**New Brunswick Potatoes** Banding slows the transformation of ammonium-based fertilizer into nitrates, reducing potential N_2O emissions early in the growing season (Zebarth et al., 2011)	**US Potatoes (Broadcast vs. Banded N application)** Banded application increased N uptake by 28% (Westermann et al., 1996) **New Brunswick Potatoes** Banding slows transformation of fertilizer into nitrates which reduces leaching losses early in the growing season (Zebarth et al., 2011)	**ND**

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282 There are a number of competing theories about risk preferences which incorporate some combination of utility loss aversion and/or probability weighting, the two most popular of which are rank-dependent utility theory and cumulative prospect theory. Rank-dependent utility theory incorporates probability weighting, but no loss aversion or reference point. Under cumulative prospect theory, utility loss aversion is combined with a form of probability weighting known as 'probabilistic loss aversion', in which probabilities are weighted differently for gains or losses relative to the subjects' reference point. Rank-Dependent Utility Theory was introduced in Quiggin, J. (1982). A theory of anticipated utility. *Journal of Economic Behavior and Organization*, 3, 323–343; cumulative prospect theory was introduced in Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representations of uncertainty. Journal of Risk and Uncertainty, 5, 297–323.

The evidence for each of these theories of risk preferences and their core postulates is mixed, because it is difficult to precisely test them and eliminate rival explanations, especially in non-experimental settings. It is beyond the scope of this report to argue which of these models of choice under risk outperforms its rivals. We instead argue that probability weighting (with or without a reference point) and loss aversion deviate from the predictions of expected utility theory in policy-relevant ways, and all are important to consider when designing agri-environmental policy. For an exceptionally clear elucidation of the different models of choice under risk and the study designs needed to test them, see Hofmeyr, A. & Kincaid, H. (2019) Prospect theory in the wild: how good is the nonexperimental evidence for prospect theory?, *Journal of Economic Methodology*, 26:1, 13-31, DOI: 10.1080/1350178X.2018.1561072.

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290 Pannell, D. (2017). Economic perspectives on nitrogen in farming systems: managing trade-offs between production, risk and the environment. *Soil Research* 55(6): 473-478. https://doi.org/10.1071/SR16284.

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293 Rajsic, P., Weersink, A., & Gandorfer, M. (2009). Risk and Nitrogen Application Levels. *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie,* 57(2), 223–239. https://doi.org/10.1111/j.1744-7976.2009.01149.x

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300 However, other studies have concluded that in some cases, utility loss aversion or probability weighting potentially influences farmers to apply *less* agricultural inputs such as pesticides or fertilizers. See Liu, E. M. and Huang, J. (2013). Risk Preferences and Pesticide Use by Cotton Farmers in China. Journal of Development Economics 103: 202-215; Holden, S.T. and John Quiggin. (2018). Probability Weighting and Fertilizer Use in a State-Contingent Framework. *Presentation to the 30th International Conference of Agricultural Economists, July 28-August 02, 2018, Vancouver*. Retrieved from: https://ageconsearch.umn.edu/record/277355?ln=en. These studies suggest the impact of loss aversion and probability weighting on input use is case-specific, and depends on factors such as whether the input poses on-farm health risks (such as pesticides in the case of Liu et al. 2013), and whether subjects are overweighting low-probability downside risks (such as the impact of low-probability drought on fertilizer application in the case of Holden and Quiggin 2018).

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362 The reference margin is either the average program margin for three of the past five years (the lowest and highest margins are dropped from the calculation) or average allowable expenses for the years used to calculate reference margin (whichever of the two is lower).

363 ($70,000 – $50,000) * 0.7 = $20,000* 0.7 = 14,000.

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366 *Ibid.*

367 In this case, the decline in the margin is $50,000. In the AgriStability framework in Growing Forward 1, the first $15,000 of the loss would be without compensation (the difference between the reference margin and the 85% of the reference margin is without compensation). The loss between 70% and 85% of the reference margin ($15,000) would receive a 70% contribution from the government equal to $10,500, and the remaining loss ($50,000 – (2*$15,000) = $20,000) would receive an 80% contribution from the government (80% *$20,000 = $16,000). In this framework the total government contribution would be $26,500 ($10,500 + $16,000 = $26,500).

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377 Net present value is the present value of future net cash flows. Net cash flow refers to sum of farms revenue from crop sales minus sum of variable expenses related to inputs uses in crop production and annual machinery depreciation expense, plus or minus any cash flows associated with BRM programs.

378 Absolute variability of NPV measured using the standard deviation.

379 Relative variability of NPV is measured using the coefficient of variation (CV). CV is defined as the ratio of the standard deviation to the mean.

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