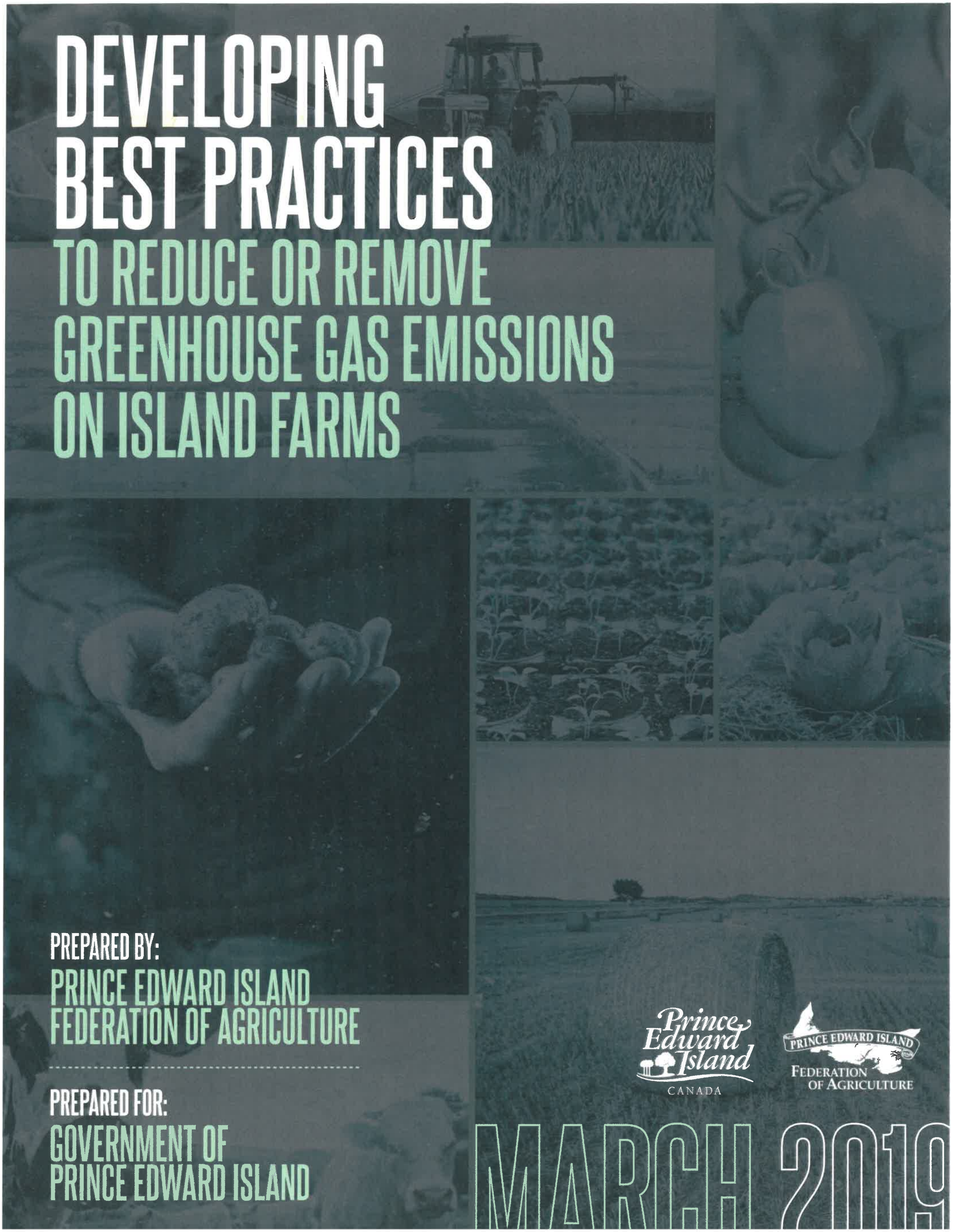

DEVELOPING BEST PRACTICES TO REDUCE OR REMOVE GREENHOUSE GAS EMISSIONS ON ISLAND FARMS

PREPARED BY:

PRINCE EDWARD ISLAND
FEDERATION OF AGRICULTURE

PREPARED FOR:

GOVERNMENT OF
PRINCE EDWARD ISLAND

MARCH 2019

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EXECUTIVE SUMMARY

It is becoming increasingly apparent that our society must undertake significant efforts to reduce greenhouse gas (GHG) emissions, in order to limit the extent of climate change.

This report examines opportunities to reduce the GHG emissions, or increase carbon storage, in the agricultural sector in Prince Edward Island. We do this by first examining the current state of agriculture in the province and its greenhouse gas emissions. The state of knowledge supporting the reduction of GHG from agricultural practices relevant to PEI is then reviewed.

Finally, we evaluate a suite beneficial management practices which we have judged to be most likely to be effective in reducing GHG emissions from the agriculture sector (Table 1).

The greatest reductions result from measures to sequester carbon in soil, but these measures would eventually saturate and cease to result in emission reductions. The measures associated with reductions in N2O and CH4 emissions do not saturate and would continue to deliver emissions reductions on an annual basis.

Table 1: Listing of Beneficial Management Practices examined to reduce greenhouse gas emissions from the agriculture sector in Prince Edward Island.

Beneficial Management Practice	Research Cycle Stage	Magnitude of Reduction	Certainty of Magnitude of Reduction	Timeframe for adoption (years)
Cover Crops				
BMP 1 Cover Cropping within Potato and Corn Production Systems	2.0	12.7 kT CO2e/y	Medium	5
Increasing Soil Organic Matter				
BMP 2 Reduced intensity, depth and frequency of tillage	2.5	73 kT CO2e + 1.7 kT CO2e/y	Medium	5
BMP 3 Use of Full-Season Soil-Building Rotation Crops	4.0	22 kT CO2e/y	High	2
Improved Nitrogen Fertilizer Management				
BMP 4 Site-specific "Right Rate" N recommendations	3.0	13.3 kT CO2e/y	High	3
BMP 5 Use of Enhanced Efficiency Fertilizers	4.5	25% = 3.7 kTCO2e/y 50% = 5.8 kTCO2e/y	High	Now
AgroForestry				
BMP 6 Willow plantations in field edge and riparian areas	2.5	9.2 kt CO2e y-1	High	3
Manure Management				
BMP 7 Manure Storage Management to reduce CH4 Emissions (pit covers, composting)	4.0	50-70% CH4 reduction	Medium	Now

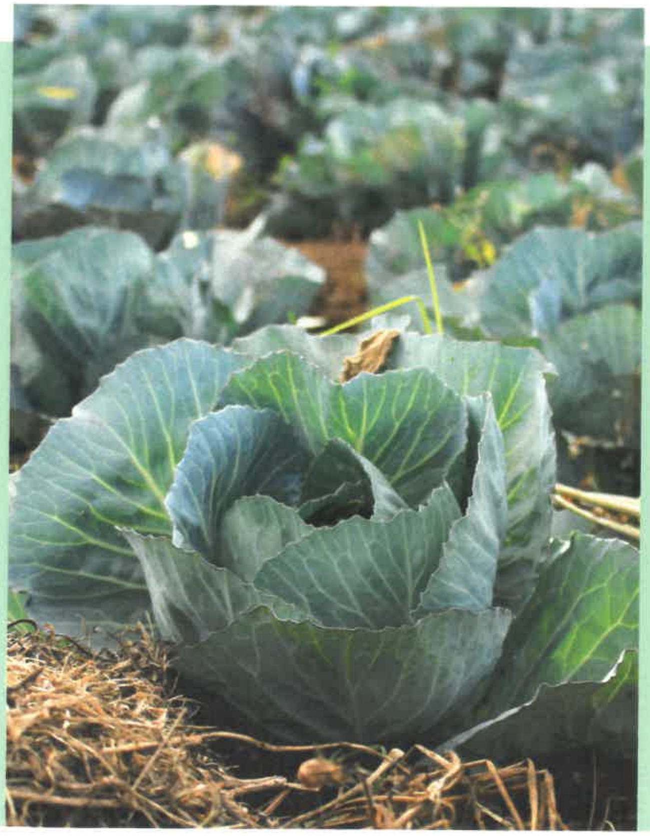
Beneficial Management Practice	Research Cycle Stage	Magnitude of Reduction	Certainty of Magnitude of Reduction	Timeframe for adoption (years)
Animal Management BMP 8 Methane reduction from ruminants using feed additives (seaweed, vegetable oils, Carinata)	3.0	30-60% CH4 reduction	Medium	1-2
Improved On-Farm Energy Efficiency BMP 9 Alternate energy audit and applications for high-usage farms	3.0	2.5kg CO2eq per Kw diverted	High	2-3

i. INTRODUCTION AND BACKGROUND

The Prince Edward Island Federation of Agriculture (PEIFA) is pleased to present the Government of Prince Edward Island with a report that identifies those farm practices that offer beneficial opportunities for our sector to reduce greenhouse gas emissions (GHG's). This project was funded through Environment and Climate Change Canada's Low Carbon Leadership Fund (LCEF) as an integral element of the Pan-Canadian Framework on Clean Growth and Climate Change.

Our leadership on this project is based upon the PEIFA's recognition that agriculture contributes towards GHG emissions and that the sector has a critically important role to play in reducing emissions and/or sequestering carbon. Given that most farm-related emissions are produced by livestock, manure, and the use of nitrogen fertilizers, actions at the farm level will be required to reduce emissions.

As we have noted before, a systematic effort to identify and promote farm practices that assist in reducing GHG's is closely aligned with PEIFA's ongoing involvement with Enhanced Environmental Farm Plan (EFP). The PEIFA, under separate contract, administers the Enhanced Environmental Farm Plan (EFP) for the Province of Prince Edward Island and has done so for some time. As part of an overall project program review process PEIFA is conducting an extensive review current content, including aspects such as nutrient management, soil management, pest management, erosion control structures, etc., and update the content accordingly. This current report will support our sector's ongoing efforts to systematically improve farm management practices.



ii. PROJECT SCOPE

In undertaking this project, we examined opportunities for GHG mitigation measures in a number of areas. These areas were identified by a working group set up under the auspices of PEI's Climate Change Working Group. This group was made up of representatives from the provincial government AAFC, producer associations, researchers, extension workers and other agricultural stakeholders. The goal of the working group was to identify GHG mitigation measures that help to both protect the environment as well as improve the competitiveness of producers. The working list they came up with included:

1. Nutrient Stewardship
2. Conservation cropping
3. Energy efficiency
4. Feeding strategies for cattle
5. Performance tracking and cattle sorting improvements
6. Feeding technologies and innovative techniques to improve true feed efficiency
7. Dairy production systems, including milking technology
8. Food loss in agricultural production and post-harvest handling and storage

Our project team used this list as our starting point. The terms of reference required that we produce six (6) BMP's covering off three areas: nitrogen stewardship in cropping, (2) livestock production, and (3) energy efficiency.

As a result of the research undertaken, this report includes nine (9) BMP's in the following areas:

BMP 1: Use of cover crops to increase soil organic matter, reduce residual soil nitrogen and control disease in potato rotations.

BMP 2: Increasing soil organic matter content

BMP 3 Increased use of soil-building rotation crops

BMP 4: Improved nitrogen fertilizer management through implementation of 4R management

BMP 5 Site-specific "Right Rate" N recommendations

BMP 6: Willow plantations in field edge and riparian areas

BMP 7: Improved manure management and utilization

BMP 8: Animal management for GHG reduction

BMP 9: Improved on-farm energy efficiency

The goal of this project is to have these BMP's piloted by producers on PEI and assessed for both the benefits they produce as well as their impact on GHG mitigation.

iii. PROJECT RESEARCH METHODOLOGY AND APPROACH

Literature Review: A comprehensive literature review was undertaken to assess relevant academic and scientific literature pertaining to agricultural-related GHG's on PEI to serve as the basis for identifying opportunities for mitigation.

Stakeholder Group Engagement: As part of the research effort, input was gathered from academic researchers, extension professionals, government officials, and a number of agricultural industry organizations. In total X individuals and Y organizations were consulted. A core focus of this effort was to understand potential BMP's already being implemented on Island farms that could be built upon with further testing.

Data Analysis and Initial BMP Drafting: The findings from the literature review and stakeholder engagement were analyzed and initial BMP's were developed.

Stakeholder Validation: Preliminary BMP's were shared with X producers and stakeholders to solicit input on appropriateness of the reduction measures and to assess potential producer interest in piloting the BMP's.

Final Report and BMP Drafting: Based upon the further input received during the validation phase, the overall report was finalized and the BMP's were reduced to 9 and finalized. It should be noted that we anticipate making further changes and/or additions to both the report in general and the BMP's in particular.

iv. ORGANIZATION OF REPORT

The report is divided into the follow sections:

Section One:
The Policy Context of GHG Mitigation

Section Two:
The PEI Agriculture Sector and the GHG Equation

Section Three:
State of Knowledge on GHG Emissions

Section Four:
Sector Awareness of GHG Mitigation Opportunities

Section Five:
Beneficial Management Practices (BMP's) for the Agricultural Sector

Section Six:
Producer Feedback and Potential Involvement in BMP Pilot Testing

It should be noted that for the purpose of referencing sources, references are listed at the end of each section to make it easy for the reader to consult the sources used in the drafting of specific sections of the report.

Further, for the purposes of distribution to producers or others, individual BMP's and/or the section on the BMP's will be assembled as separate, stand-along digital and print documents to make it easier to circulate.

SECTION
ONE.

SECTION ONE

THE POLICY CONTEXTS OF GHG MITIGATION

INTERNATIONAL POLICY CONTEXT

1.1 Canada has had a long history of engagement in the climate change issue. At the 1992 Earth Summit in Rio de Janeiro, Canada become one of the founding member countries in ratifying the United Nations Framework Convention on Climate Change (UNFCC). At the third meeting of the Conference of the Parties to the UNFCC in 1997, the Kyoto Protocol was adopted under the United Nations Framework Convention on Climate Change. In the following year, Canada signed the Kyoto Protocol and formally ratified it in 2002. Canada committed to reducing GHG emissions to an average of 6 percent below its 1990 emission level over the 2008-2012 period. Sufficient number of countries (55 countries, representing 55% of global emissions) ratified the protocol by 2005, and the Kyoto Protocol formally came into effect in that year.

The United Nations Framework Convention on Climate Change (UNFCCC), one of three conventions adopted at the Rio Earth Summit in 1992, entered into force in 1994. Ratified by 197 countries including Canada, parties to the Convention must submit national reports on implementation of the Convention to the annual Conference of the Parties. The required reporting differs for Annex I and non-Annex I Parties. Canada, an Annex I Party, provides annual national GHG inventories covering emissions, and removals of direct GHGs from the energy, industrial processes, solvents, agriculture, land use and land use change in forestry (LULUCF), as well as waste sectors, for all years from the base year to the most recent year. It is important to note that these emissions estimates are generally based on indirect assessments of emissions-based activities, such as nitrogen fertilizer sales and/or the modelling of GHG emissions, rather than direct measurements of emissions. It is therefore useful to consider what is actually the basis of reporting (e.g., amount of N fertilizer sold), in assessing beneficial management practices for reducing reported GHG emissions.

At its eighth session (2002), the Conference of the Parties requested the secretariat to publish on its web site the annual inventory submissions, consisting of the national inventory reports (NIR) and common reporting format (CRF) of all Parties included in Annex I to the Convention. The NIRs contain detailed descriptive and numerical information, and the CRF tables contain all greenhouse gas (GHG) emissions and removals, implied emission factors and activity data.

At its nineteenth session (2013), the Conference of the Parties adopted Decision 24/CP.19 which outlined new reporting guidelines on annual greenhouse gas inventories and tables of the common reporting format, to implement the use of the 2006 IPCC Guidelines for National Greenhouse Gas inventories.

NATIONAL

1.2 The federal policies to achieve the commitments have evolved over the years. In 2000 the federal government released Action Plan 2000 on Climate Change committing to reducing GHG emissions by 65 Mt CO2e/y from 2008 to 2012.

In 2005, the federal government released Project Green– Moving Forward on Climate Change: A Plan for Honouring Our Kyoto Commitment, committing to reducing GHG emissions by 270 MtCO2e/y from 2008 to 2012.

In 2007, Environment Canada released its first climate change plan, as required by the Kyoto Protocol Implementation Act, which indicated that Canada's target was to reduce GHG emissions to an average of 6 percent below its 1990 emission level, over the 2008-2012 period. The plan reiterated the government's commitment, as indicated in Turning the Corner, and added a commitment to reduce Canada's total GHG emissions by 60 to 70 percent by 2050. These targets were repeated in the 2008 and 2009 climate change plans.

In 2010, Canada committed to reducing greenhouse gas (GHG) emissions by 17 percent below its 2005 level by 2020 under the Copenhagen Accord. Canada's submission to the United Nations Framework Convention on Climate Change noted that this target was to be aligned with the final economy-wide emissions target of the United States, in enacted legislation.

In the same year, Canada committed to reducing GHG emissions by 17 percent below its 2005 level by 2020, under the new Federal Sustainable Development Strategy.

In 2011, upon return from the Conference of the Parties to the United Nations Framework Convention on Climate Change in December 2011, the Minister of the Environment announced that Canada will formally withdraw from the Kyoto Protocol.

In 2015, prior to the UN Climate Change Conference in Paris, December 2015, as part of the Paris Agreement, Canada indicated that it would reduce its greenhouse gas emissions by 30 percent compared to 2005 levels, and that it would do so by 2030. Further, Canada and 192 other countries committed to the 2030 Agenda for Sustainable Development, and to achieving the related 17 Sustainable Development Goals by 2030.

As part of Canada's commitments to the UNFCC, it has committed to submitting an annual inventory of GHG emissions. The Pollutant Inventories and Reporting Division of Environment and Climate Change Canada (ECCC) is the single national entity with responsibility for preparing and submitting the National Inventory to the UNFCCC, and for managing the supporting processes and procedures. The inventory is prepared in accordance with the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines on annual inventories (Decision 24/CP.19). Inventory estimates are determined by methods and models developed with in-house expertise, as well as from published data, data reported by industry, or methods developed by the Intergovernmental Panel on Climate Change (IPCC).

The submission to the UNFCCC contains information not only on the magnitude of emissions, but also relevant information on how the information was collected, its quality, and descriptions of any additional analysis.

Chapter 1 (Introduction) provides an overview of Canada's legal, institutional and procedural arrangements for producing the inventory (i.e. the national inventory arrangements), quality assurance and quality control procedures as well as a description of Canada's facility emission-reporting system.

Chapter 2 provides an analysis of Canada's GHG emission trends in accordance with the UNFCCC reporting structure, as well as a breakdown of emission trends by Canadian economic sectors.

Chapters 3 to 7 provide descriptions and additional analysis for each sector, according to UNFCCC reporting requirements. Chapter 8 presents a summary of recalculations and planned improvements.

Annexes 1 to 7 provide a key category analysis, inventory uncertainty assessment, and detailed explanations of estimation methodologies, Canada's energy balance, completeness assessments, emission factors and information on ozone and aerosol precursors.

Annexes 8 to 13 present rounding procedures, summary tables of GHG emissions at the national level and for each provincial and territorial jurisdiction, sector and gas, as well as additional details on the GHG intensity of electricity generation.

Detailed GHG data is also available on the Government of Canada's Open Data website.

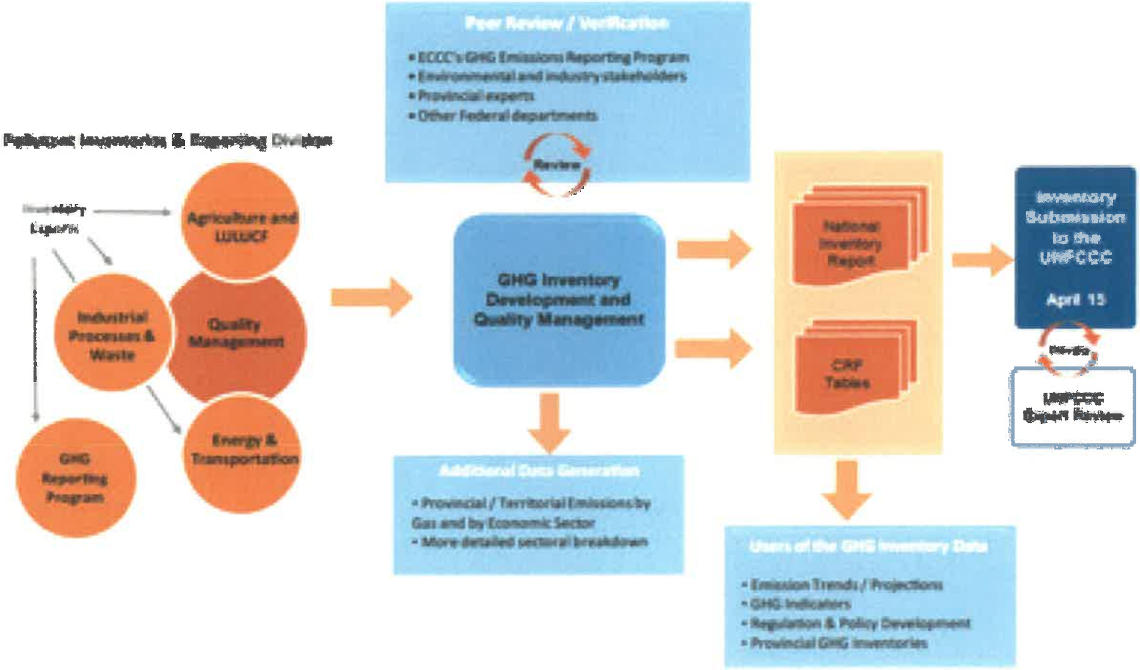


Figure 1: Partners and Contributors to ECCC's Greenhouse Gas Inventory (ECCC NIR, 2016).

FEDERAL GREENHOUSE GAS PROGRAMS

As part of its commitment to reduce greenhouse gas emissions from agriculture, the federal government has introduced various funding programs to support research, and to assist producers in adopting mitigation and adaptation strategies. This effort began with Canada's Green Plan in 1990. The Agriculture Table, as part of the National Climate Change Process, created the Climate Change Funding Initiative in Agriculture. This initiative supported research in the mitigation of climate change in the agriculture sector in Canada. More recently, through federal-provincial Growing Forward programs and currently the Canadian Agriculture Partnership, the federal and provincial governments continue to support efforts to mitigate GHG emissions and enable the agriculture sector to adapt to climate change.

AGRICULTURAL INDUSTRY AND SOCIAL INITIATIVES TO MITIGATE GREENHOUSE GAS EMISSIONS

Industry has also been active in developing and promoting practices that reduce greenhouse gas emissions from the agriculture sector in Canada. Fertilizer Canada has developed the 4R Stewardship Program which promotes the efficient use of fertilizers. There are also supply chain efforts, such as Field to Market, which promote the marketing of sustainable agricultural production practices that reduce GHG emissions. There are also broader initiatives to reduce GHG emissions that include agricultural production practices such as Project Drawdown.

PROVINCIAL PROGRAMS

An earlier policy document, Prince Edward Island and Climate Change: A Strategy for Reducing the Impacts of Global Warming identified four main goals to:

- Reducing greenhouse gas emissions to mitigate the effects of global warming
- Enhancing carbon sinks to reduce the harmful build-up of CO2 in our atmosphere
- Improving our ability to adapt to climate change
- Increasing public awareness

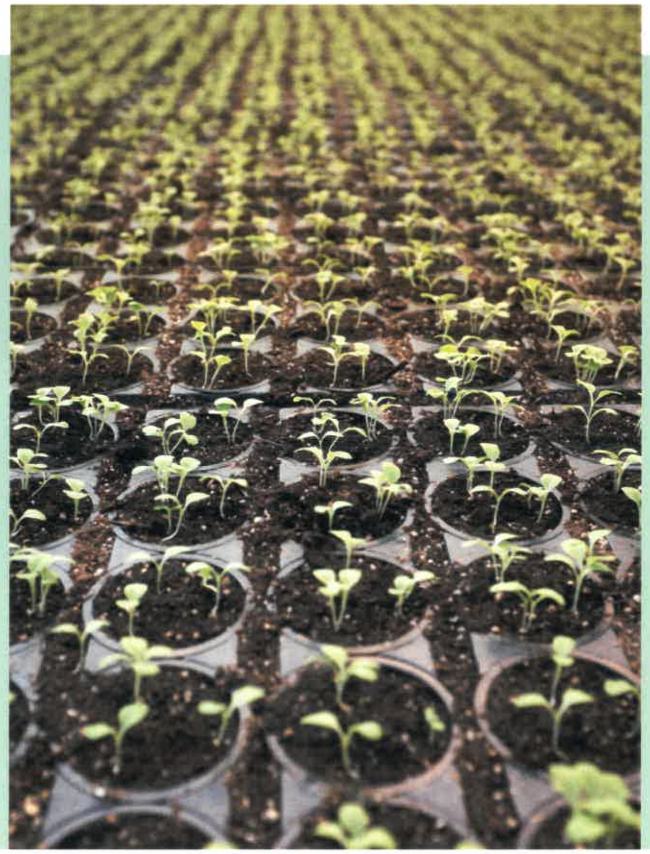
Further, in this plan the government of PEI commitment to:

- provide incentives to landowners to remove marginal land from agricultural production, if coupled with a program of reforestation, with approved Management Plans. Re-forested land will be designated as environmentally sensitive land and removed from land holding limits.
- promote the use of reduced tillage management, cover crops, improved manure storage systems and nutrient management systems, and evaluate the level of greenhouse gas mitigation that these practices provide the agricultural sector.

In its current policy document, Climate Change Action Plant 2018-2023, the government of PEI highlighted five action areas:

- Adapting to Climate Change
- Reducing Greenhouse Gas Emissions
- Carbon Sequestration
- Education and Capacity Building
- Research and Knowledge Building

The document reaffirms the commitments to promote the sequestration of carbon in agricultural and forest systems, through Alternate Land Use Services (ALUS) and Forest Enhancement Programs (FEP), and a commitment to consult with farmers to develop a series of farm practices that reduce GHG emissions and better sequester carbon, by piloting GHG emissions reduction plans on 20 to 30 participating farms.



OPPORTUNITIES TO REDUCE THE CARBON FOOTPRINT OF AGRICULTURE IN PRINCE EDWARD ISLAND

Unlike other sectors of the economy, the emission of GHG from agriculture is not solely related to CO2 emissions associated with energy use. In agriculture, much of the GHG production is a result of N2O and CH4 production, as a result of biological processes occurring under environmental conditions. This presents a significant opportunity, as both N2O and CH4 are more potent GHGs than is CO2 It also poses a challenge, in that emissions reduction under environmental conditions is less easily achieved.

The development of beneficial management practices (BMPs) for the reduction of GHG emissions requires an understanding of the science underlying the biological processes and environmental conditions generating the gas. In this report, we review the relevant understanding of the factors that influence GHG emissions from PEI's agriculture sector.

It is also important to understand the nature of the nature of PEI's agriculture sector, and the resources upon which it is based, in assessing the potential opportunities for GHG emissions reduction. We provide a survey of the current practice of agriculture in PEI, and the GHG emissions associated with those practices.

In addition, since the emissions are not directly related to increased energy efficiency, the costs and benefits to the producer must be examined. Where there are not clear economic benefits to the producer, policy instruments need to be developed to encourage adoption. In most cases the generation of N2O or CH4 represent inefficiencies in nutrient or feed utilization and therefore there are both economic benefits in the adoption of more efficient practices, as well as positive environmental outcomes.

It is important in the development of BMPs that, not only do we assess the potential for GHG emissions reduction, but also the agronomic and economic implications of adoption and potential scientific, technological, agronomic or policy barriers to adoption. In developing the list of potential BMPs for consideration in PEI we assessed these factors.

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SECTION
TWO.

SECTION TWO

OVERVIEW OF PEI AGRICULTURE AND ITS GHG EMISSION SOURCES

This chapter begins by laying out the state of agriculture on PEI over the past several years, as a means of illustrating trends in changing agricultural land use, and changing land use in general. It then focuses on land use today, specifically the changing crop acreage by type of crop. Following this basic data, each commodity is described in terms of land or animal GHG soúrces.

Finally, the latter parts of this section describe in detail the three major types of GHG gases by commodity source: Nitrous Oxide (N2O), Methane (CH4) and Carbon Dioxide (CO2).

This data was used in this report to determine the amount of GHG emission reductions that can be expected by the suggested Beneficial Management practices (BMPs), based on the number of acres of pertinent cropland potentially affected by BMP application.

CURRENT LAND USE

Prince Edward Island consists of a total land area of 575,335 Hectares or 1,421,684 acres. Today, of this total land area, 575,490 acres (40.4%) were dedicated to agricultural use in 2016, the last census data available. As a trend analysis, the total farm area over which farmers had steward-ship in Prince Edward Island decreased 3.2% from 2011 to 575,490 acres in 2016, while cropland declined 2.5% to 400,322 acres.

Comparatively, 38% of PEI's land area was dedicated to agriculture in year 2000, only slightly less than PEI's forested area. Prior to that, the amount of agricultural land had incrementally decreased since 1980, as seen in Table II and III below. (Tables I-IV from PEI Department of Forestry Land Biomass Inventory Inventory, 2000, 2010)

TABLE I:

Summary of Land Use on Prince Edward Island in 2000

Land use	**Hectares**
Forestry	256,900
Agriculture	222,095
Wetlands	35,996
No use evident	16,208
Transportation	12,588
Residential	12,365
Tidal water	7,111
Urban	5,341
Industrial	3,016
Recreation	2,157
Commercial	883
Institutional	676
Total	**575,335**

TABLE II

Comparison with earlier inventories
(Selected figures from the 1980,1990
and 2000 Forest Biomass Inventories)

Land use	**1980** hectares	**1990** hectares	**2000** hectares
Forest	273,594	279,193	263,207
Agriculture	231,590	226,952	222,094
Cleared land	18,105	20,631	16,208
Total	**574,472**	**575,525**	**575,330**

Of PEI's agricultural land area, cropland is by far the largest percentage (over 95%), as seen in Table III. No data is available on the amount of this cropland that is devoted to pastureland.

TABLE III

Area of PEI Agriculture land use by sub-use

Land Use	**Hectares**
Crops	211,454
Farmsteads	4,530
Hedgerows	5,875
Feedlots	161
Orchards	45
Nurseries	27
Major manure storage areas	2
Total	**222,094**

Within these farm lands, PEI produces a variety of field crops, which vary widely in their percentage of total cropland, as seen in Table IV below.

TABLE IV

Agricultural land cover classified with a sub use of Crops

Crop	Hectares
Hay	81,451
Grain	60,968
Potatoes	47,664
Pasture	13,356
Blueberries	3,527
Cranberries	50
Other crops (vegetables)	4,343
Bare ground	31
Buildings	62
Surface Water	2
Total	**211,454**

More recent data from the PEI Forestry Mapping Division shows the following recent trends in changing land usage

(Table V).
Since the previous estimate in 2000, the area in agriculture decreased by 1.3 per cent. Over the past decade, the area of abandoned agricultural land increased by 4 per cent to more than 22,000ha. As much of this area is marginal farm land, there is a low probability that it will serve an agricultural purpose in the short-term. If left alone, much of this area will naturally transition to forest land use.

TABLE V

Land use category estimates for 2010

Type	Hectares	%	% change (from 2000)
Forest	250,084	43.9	-1.3
Agriculture	215,004	37.8	-1.3
Abandoned Agriculture	22,319	3.9	+1.1
Wetland & Sand Dunes	39,366	6.9	+0.5
Transport	12,828	2.3	+0.1
Other (urban, developed)	29,689	5.2	+0.9
Total	**569,290**	**100**	

Since 2000, agriculture accounted for the largest conversion from forest. The majority of this land use conversion was due to establishment / expansion of new blueberry fields. This trend has now slowed.

The area of farmland under the currently legislated 15m "Buffer Zone" is 27,300Ha., with 3948.7Ha., deemed as "farmable" and 23,351.3 Ha. as "non-farmable".

Following is a set of maps, produced by the PEI Mapping Division, using the most recent land use data from 2000 and 2010, by crop type, showing a 10-year change in land use patterns (Fig. 1, Fig.2).

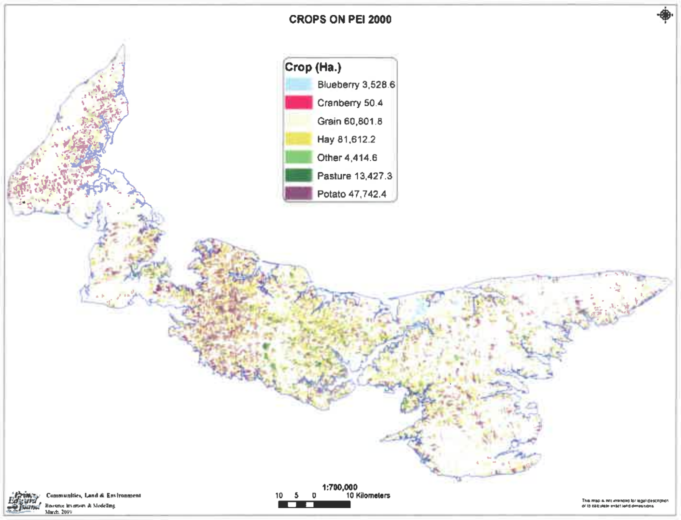


Fig. 1. Map of PEI cropland locations in 2000 (PEI Mapping Division, 2019)

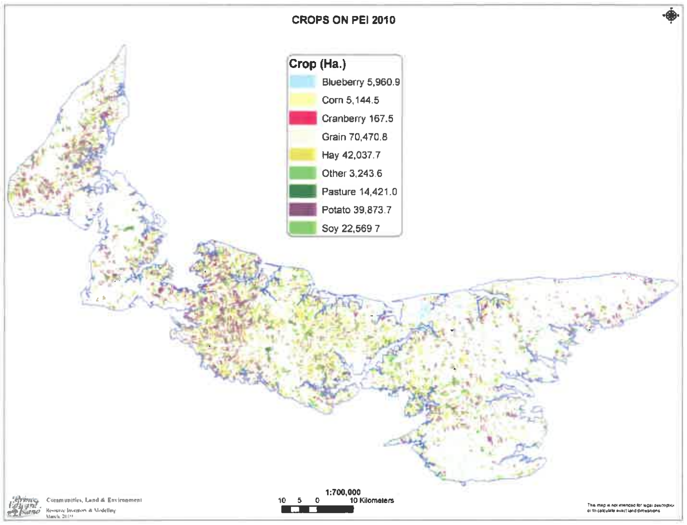


Fig. 2. Map of PEI cropland locations in 2010 (PEI Mapping Division, 2019)

ENVIRONMENTAL IMPACTS OF AGRICULTURE

The practice of agriculture occurs in intimate association with the environment and as a result has a significant potential to impact that environment. Agriculture and Agri-Food Canada has undertaken an effort to quantify the potential for environmental impact of agricultural operations in its Agri-Environmental Indicator reporting, the most recent of which (Report #4) was published in 2016 (Clearwater et al., 2016). Based on the 2011 Agricultural Census, there was 240,514 ha of farmland with 69% reported to be in cropland, 7% in pasture, and 23% in other land uses (Clearwater et al., 2016). They note increased in the intensity of land use for large areas of PEI (Fig. 3a) and moderate to large decreases the amount of soil cover (Fig. 3b). For the province as a whole there have been relatively little change in annual soil cover days over the past 20 years with 98% of PEI's cropland in the moderate category at approximately ~190 days of cover. The risk of soil erosion ranges from very low to moderate (Fig. 3c).

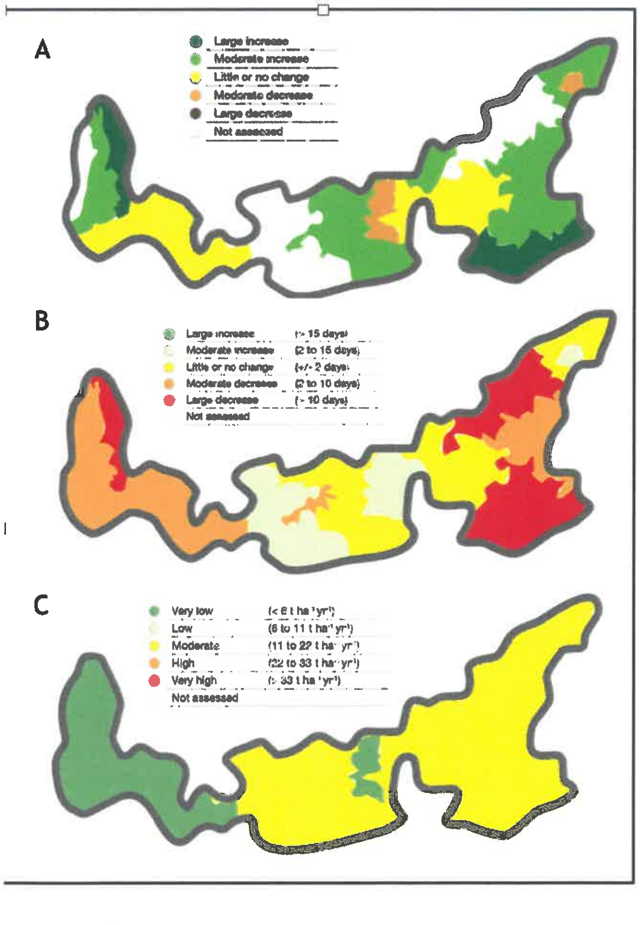


Figure 3: Change in A) agricultural land use intensity (ratio of cropland to total farm area) and B) soil cover in Prince Edward Island between 1981 and 2011 and C) integrated risk of soil erosion (water, wind and tillage erosion combined in 2011. Based on the Census of Agriculture interpolated to Soil Landscapes of Canada (SLC). (From Clearwater et al., 2016).

In the earlier third report, Agi-Environmental Indicators were reviewed on a province-by-province basis (Eilers et al., 2010). This analysis was based on the results of the 2006 Agricultural Census. The report noted a decline in land area in agriculture, in particular a decrease in the amount of land in perennial crops. They also noted a decline in animal numbers.

In 2006, Prince Edward Island farmland is concentrated in the high (28%) and moderate (72%) soil cover day classes. The high levels of soil cover are due to frequent use of perennial crops and cereal grains in the crop rotations, as well as relatively high proportions of winter cereals (Eilers et al., 2010).

The following sections focus on the sources of GHG emissions by commodity activity, and the practices that contribute to GHG emissions.

DYNAMICS OF THE N CYCLE AND HYDROLOGY IN PRINCE EDWARD ISLAND

Prince Edward Island is the only province in Canada that is 100% dependent on groundwater as a drinking water source (Savard et al. 2007). As a result, groundwater protection has been the subject of a number of studies examining the relationship between agriculture and NO3- impacts on groundwater (Savard et al. 2007). The insights this work has generated are also useful in understanding the potential for direct and in-direct N2O emissions and the opportunities for mitigation of these emissions.

The processes of the N cycle in a PEI context has been summarized by Savard et al. (2007) and are important in constructing N budgets (Fig. 4).

Figure 4: Conceptual diagram of the nitrogen cycle adapted to the context of Prince Edward Island (From Savard et al., 2007).

The major inputs to agro-ecosystems in PEI include the atmospheric N deposition of (~10 kg N ha-1 y-1), the application of nitrogen fertilizers (0 to 200 kg N ha-1 y-1 depending upon crop), soil N mineralization (25 - 75 kg N ha-1 y-1), animal manures and other organic wastes. The major removals from the system include nitrogen removed in plant harvest (50 to 100 kg N ha-1 y-1), denitrification (5 to 10 kg N ha-1 y-1), ammonia volatilization (5 to 10 kg N ha-1 y-1) and nitrate leaching (20 to 30 kg N ha-1 y-1).

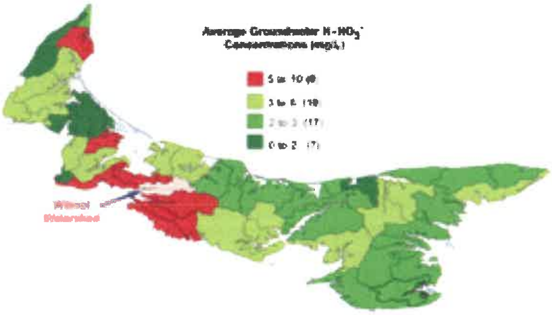


Figure 5: Mean nitrate concentrations for the main watershed of Prince Edward Island (from Savard et al., 2007).

Nitrate leaching is one of the primary environmental concerns associated with agricultural land management in PEI, due to the dependence on groundwater as source of drinking water.

Surveys of groundwater nitrate concentration have documented elevated nitrate concentrations (5 to 10 kg N ha-1 y-1) in the central portions of the province (Fig. 5).

Nitrogen losses from the ecosystem are strongly influenced by seasonal differences in hydrology. During the growing season (April to November), losses are primarily associated with N additions associated with N fertilization of agricultural crops (Fig. 6a). In the non-growing season losses occur as a result of residual soil nitrogen (RSN) remaining in agricultural fields as well as the mineralization of soil and crop residue nitrogen (Fig. 6b). In PEI the primary period of nitrate movement is the non-growing season. As a result, RSN is an important indicator of the potential for nitrate loading to groundwater, which is an indirect source of N2O. RSN is also an important indicator of over-winter N2O emissions.

Using modelling approaches, the agri-environmental indicator for GHG emissions presents the spatial distribution of estimated N2O emissions. The distribution of net agricultural GHG emissions ranged from moderate (1000 - 1500 kg CO2e ha-1 y-1) to very high (> 2000 kg CO2e ha-1 y-1) depending on location (Fig. 7).

Figure 7: Net agricultural GHG emissions from Prince Edward Island expressed per hectare of land in 2011 (kg CO2e ha-1) (From Clearwater et al., 2016).

PEI GHG EMISSIONS BY THE PEI AGRICULTURAL SECTOR

The most significant industries contributing to PEI's greenhouse gas emissions include transportation (48%), agriculture (25%), buildings (16%), waste (4%), light manufacturing, construction and forest resources (6%). For 2015 the total GHG emissions reported for PEI were 1.8 Mt CO2e y-1. At 0.4 Mt CO2e y-1 (400 kt CO2e y-1) of emissions, agriculture represents the second largest sector contributing to GHG emissions in 2015, representing 23% of PEI's total emissions.

It is estimated that agriculture generates 25% of total PEI GHG emissions, or 72 MT of CO2-equivalents annually. These emissions come mainly from livestock, manure and fertilizer use. Livestock produce methane gas from their digestion as well as manure. Nitrous oxides are given off from addition of synthetic or natural fertilizers and manure to croplands and pastures. On-farm fuel and other energy usage accounts for the balance of emissions.

Over the past two decades the trends in the emissions of GHG from the agriculture sector in PEI have reflected a decline in emissions associated with declines in animal production and on-farm fuel use. Emissions associated with crop production have varied considerably from year to year but, on average, have not declined.

It is important to note that reported GHG emissions from the agriculture sector do not include emissions associated with the change in carbon stocks associated with agricultural soil. Changes is soil carbon stocks are reported as part of Land Use and Land Use Change in Forestry (LULUCF). In this report we discuss BMPs that address reductions in N2O, CH4, reductions in energy use. We also discuss the opportunities to sequester carbon in agricultural soils. The GHG reductions are not reported as part of agriculture's GHG emissions but represent a significant opportunity to PEI's total GHG emissions.

In the release of A Climate Change Action Plan for the Province of Prince Edward Island 2018 - 2023, the Province committed to reduce GHG emissions to 30% below 2005 levels by 2030. In addition to commitments to reduce GHG emissions across all sectors, targeted measures included commitments to increase support for funding programs such as the Alternative Land UseServices (ALUS) program and the Forest Enhancement Program (FEP) as a means to increase carbon sequestration and enhance the resilience of those ecosystems to climate change and also to consult with farmers to develop a series of farm practices that reduce GHG emissions and better sequester carbon.

Further, the government committed to piloting Farm-specific GHG reduction plans on 20 to 30 participating farms. This report is designed to provide guidance in the selection and monitoring of these actions.

In PEI, agriculture represents the second largest sector contributing to GHG emissions and in 2016 represented 25% of total emissions (Fig. 8).

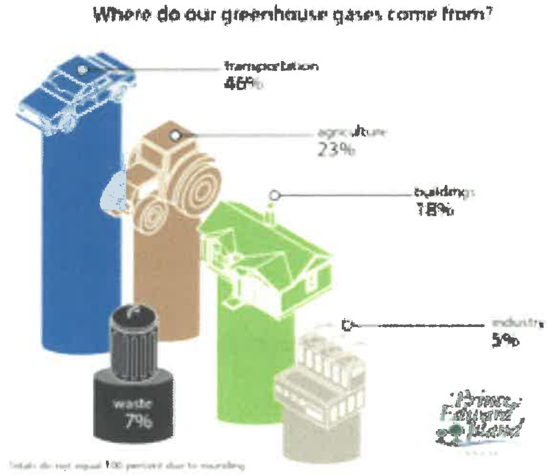


Figure 8. Sources of greenhouse gases in Prince Edward Island (PEI government, 2017)

Emissions associated with crop production have varied considerably from year to year but, on average, have not declined (Fig 9.).

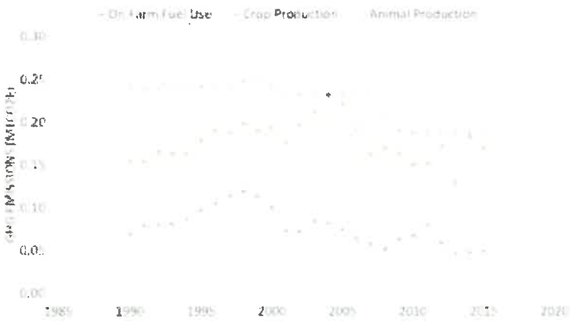


Figure 9. GHG emissions from crop production in PEI, 1985 to 2020.(Environment Canada,, 2016)

With the above general GHG emission information in mind, the authors provide a more detailed look at the major PEI agricultural sectors, and their GHG emissions sources and trends in the following sections.

POTATO PRODUCTION

Potato production is the largest crop in PEI, and therefore the largest potential source of greenhouse gas emissions. The land area being planted to potatoes has declined in PEI over the past two decades from about 45,000 ha (110,000 acres) in 1996 to approximately 35,000 ha (90,000 acres) in 2017 (Fig. 10.).

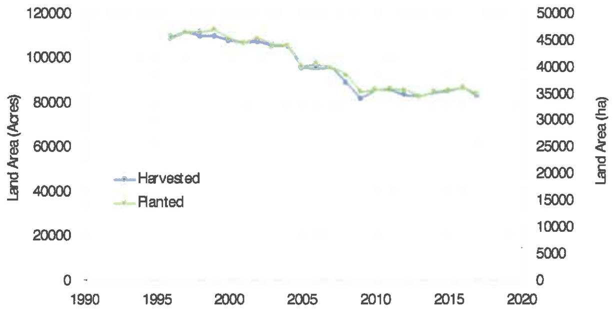


Figure 10: Number of acres planted to potato and harvested in PEI from 1996 to 2017 (PEI Potato Board).

The average potato yield has increased by about 10% over two decades from 32 tonnes/ha (250 cwt/acre) in 1996 to 35 tonnes/ha (280 cwt/acre) in 2017 (Fig. 11).

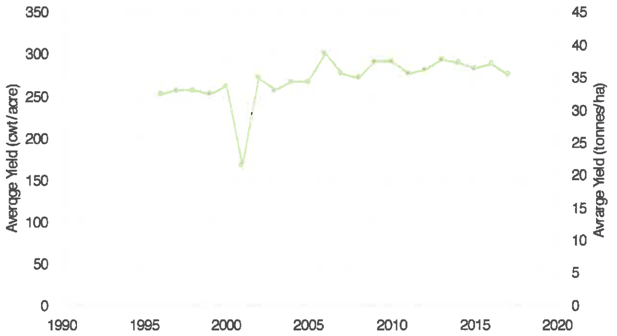


Figure 11: Average yield of potatoes in PEI from 1996 to 2017 (PEI Potato Board).

ANIMAL PRODUCTION

The majority of GHG emissions from animal production in PEI consist of methane from manure (all animals) and ruminant digestion and eructation (belching). Manure also generates nitrous oxide (N2O) during its breakdown in low-oxygen (anaerobic) environments, specifically if the stored manure is high-moisture, a such as is the case with hog manure, which is approximately 90% water, or with open pit storage of dairy and field windrow storage of beef manure, due to the addition of rain and snow.

Manure that is stored under cover, specifically beef and dairy, remains drier and outgases less methane. The situation can be further improved if the dry pile has carbon sources added to it.

PEI has specific Manure Management Guidelines, which are used by the Department of Communities, Lands & Environment to complete Environmental Impact Reviews for all farms wishing to add or expand manure storage structures.

The "Manure Management Guidelines in Prince Edward Island" gives direction for recommended manure management practices as well as serving as a guideline for anyone concerned with the establishment and operation of new livestock confinement facilities, expansion of existing livestock facilities or changes in land use in the rural area. It is the successor to the Draft 1986 Guidelines for Manure Management and Separation Distances in P.E.I.

In order to reduce the potential for environmental problems involving livestock agriculture, the concept of Minimum Separation Distance (MSD) between livestock facilities and other non-compatible land uses is included as a major component of the guidelines.

The guidelines are intended to compliment programs and statutory requirements under the Environment Protection Act, Public Health Act, Fisheries Act and other Acts that relate to agricultural use and the development of land and the enforcement of environmental quality.

These emissions and their potential for reduction are dealt with in detail in Section 4. "State of Knowledge".
In the USA, many States with large dairy and beef populations engage in a producer-led, state-sponsored manure exchange, where producers with more manure than they can feasibly use on their own land or share/swap with neighbouring farms make the excess available to the general public (gardeners, etc).

In PEI, the problem is not the lack or excess of manure per se, but the distance between the producer source and the end-user. Due to ever-increasing transportation costs, producers report that moving manure over any distance in excess of 10km is not feasible. This creates scenarios such as over-application of manure (reported mainly in hog manure) and difficulty obtaining the true fertilizer value of the manure from other farmer-buyers, such as the potato producers, who more often swap manure for a forage crop.

Depending on buy-in from existing manure-hauler services, and willingness of government (Prov/Fed) to provide start-up support for a provincial or local manure swapping system, a feasibility study would be required to determine equipment sources, costs and site(s) for regional storage. Potential costs to store all liquid manure (dairy, hog and perhaps liquefied beef as well) in centrally strategic locations near receptor farms would need to be studied as well.

Barriers to adoption of such a system include:

- producer awareness and willingness,
- start-up and operating costs,
- ability to obtain or share hauling and spreading equipment,
- potential buy-in from the two existing PEI manure removal and custom spreading companies.

FOLLOWING IS A DETAILED LOOK AT THE IMPACT OF EACH ANIMAL TYPE, IN TERMS OF GHG EMISSION SOURCES

BEEF

The beef industry is comprised of two main sectors; cow-calf operations where calves are raised to the feeder stage and beef feedlots that purchase the feeders to finish for market. The average cow-calf herd is 40 cows. Calves are sold to feedlots throughout the Maritimes, Ontario and Quebec. Feedlot operations are intrinsically linked to the potato sector by incorporating cull potatoes and crops used in the potato rotation as part of a beef feed ration.

The number of beef cattle has steadily declined since 2008, with a low of 17,445 head (steers, cows and heifers) in 2018. At an average manure production of 26kg per head per day, or 9.5MT annually per animal, this equates to about 166,000MT manure per year.

The majority of beef manure is held in open-sided, covered barns then moved as needed (2-3 times per year) to windrow storage heaps in nearby fields. Some farmers, such as Oyster Bed Organics & Compost, have purchased compost turning machinery (at a cost of about $25,000) to mix the windrows periodically. This, along with the aeration and carbon input of bedding materials (straw, sawdust, peat, etc), creates a good environment for effective composting, which retains more of the nitrogen nutrient value of the manure and lowers off-gassing of methane.

DAIRY

Dairy production has become highly specialized and mechanized. Quality standards are very high. Rigid inspection programs cover every phase of production, from the health of the cow through to the finished product. There are approximately 165 dairy farms on Prince Edward Island with milk cow herds ranging in number from 30 to more than 300 cows.

The total number of dairy cows has remained between 12,000 and 14,000 head over the past 12 years. In 2017 PEI farms held 12,805 head of dairy cattle. With an average manure output per cow of 22MT annually, this translates to ~282,000 MT manure generated annually on PEI dairy farms.

On PEI, dairy manure is about 60% water, making it challenging to pump and spread, compared to hog manure. Dairy farmers on PEI are the leaders in the adoption of manure storage, with the majority of dairy farms constructing or expanding concrete manure pits. Between 2009 and 2018, 17 dairy farms applied for environmental approval to build or expand manure storage pits.

Almost all of these pits are open on the top, allowing rain and snow to add water to the manure. While pit covers were introduced to several farms in the past, farmers report that a combination of expense and cover slippage due to weather was the reason that adoption of manure pit covers was abandoned.

Manure is pumped from these pits at least twice a year. There are only two commercial manure pumping, haulage and custom field spreading companies in PEI, only one of which is a registered septic pumper. These companies are very busy and deal mainly with hog and diary manure. Manure is pumped with large pumps that first stir the manure from the bottom to loosen and suspend the solids that collect at the bottom. This is time-consuming (1-2 hours), and is followed by pumping the manure into large tanker trucks. The manure is spread on the dairy farm fields, as well as sold to local farmers (mainly potato farms).

SWINE

Hog production on Prince Edward Island has stabilized with 16 commercial farms marketing in 2016 approximately 48,000 hogs, breeding stock, weaners and isoweans. These farms are highly mechanized and meet firm biosecurity standards. Several large operations produce disease free breeding stock to supply local operations and for export within Canada and worldwide. PEI benefits from its isolation from other swine producing regions, this enables superior disease control and improved herd health.

While the number of hogs has remained relatively the same in recent years, the number of hogs per farm has increased proportionally. This has resulted in several farms building larger manure pits, which are mainly uncovered. With an annual average manure production of 3kg/day manure, PEI hog production generates just over 1,100 MT of manure annually.

Hog manure, being from a monogastric animal, emits strong odors that limit the time and season the manure is sprayed or injected. More farmers that purchase hog manure are injecting it, with assistance from custom manure spreader services. However, a large proportion of hog manure is applied to fields within 5-8 km of the source, due to the cost of haulage of such high-moisture material. This has resulted in many cases in over-application onto nearby fields and pastureland owned by the hog farm.

Such over-application, driven by the low economic returns of selling the manure to distant farms, would result in application of more nitrogen than the field vegetation can uptake or the soil can hold. This scenario would increase the amount of greenhouse gas, specifically N2O, emitted from the field, and waste the nutrient potential of that manure.

POULTRY

Poultry production on PEI consists of eggs, broilers and turkeys.

There are currently seven registered egg quota holding farmers. These farms produce approximately 3.72 million dozen eggs with farm cash receipts of $6.78 million in 2016. PEI has two federally inspected egg grading stations.

Producers with less than 299 hens do not require quota, and broiler producers can raise up to 499 meat birds per year without being a registered quota holder. There are eight broiler farmers on PEI producing 5 million kilograms of meat, all of which is processed off Island.

PEI turkey farmers produce approximately 15,000 turkeys per year. An estimated value of the turkey products marketed on PEI is currently about $ 700,000. Current value added products include boneless and bone-in breast, ground, and turkey burgers, sausages and meatballs.

Most poultry farms on PEI are relatively small, with 1000 or more birds per flock. The total number of birds raised in PEI has been relatively stable, ranging between 430,000 in 1991 and 461,000 in 2016. With an average manure output of 50kg per bird annually, this equates to an output of 23,000MT poultry manure annually on PEI.

AGRICULTURAL GHG EMISSIONS ON PEI BY GHG GAS TYPE

NITROUS OXIDE EMISSIONS

The emissions of N2O from agriculture are reported to the UNFCCC in the general categories of direct emissions from soils, emissions associated with manure management and in-direct emissions. Direct N2O emissions are estimated based on N management-related activities such as N fertilizer sales or land use patterns. Activity data is translated into an emission using emission factors. These emission factors may be based on global data published by the IPCC (Tier I factors), country-specific, regional emission factors generated by reporting countries (Tier II factors), or site-specific emission factors support by emissions models (Tier III factors). Canada reports it N2O emission factors from agriculture using a mixture of Tier I and Tier II factors.

In agriculture the primary sources of nitrous oxide (N2O) are direct N2O emissions from the soil as a result of the biological processes of nitrification and denitrification. In these processes N2O is a an intermediate in the reaction pathway and is not the primary end-product. In humid ecozones such as Prince Edward Island (PEI), denitrification, particularly associated with rainfall and snowmelt events is the dominant source of N2O emissions (Risk et al., 2013; Rochette et al., 2018).

The known practices that would reduce agricultural NO2 emissions rely on improved management of cropping strategies, which include:

- precision agriculture to manage nitrogen inputs
- frequent soil nutrient testing & management
- N fertilizer reduction per crop where possible

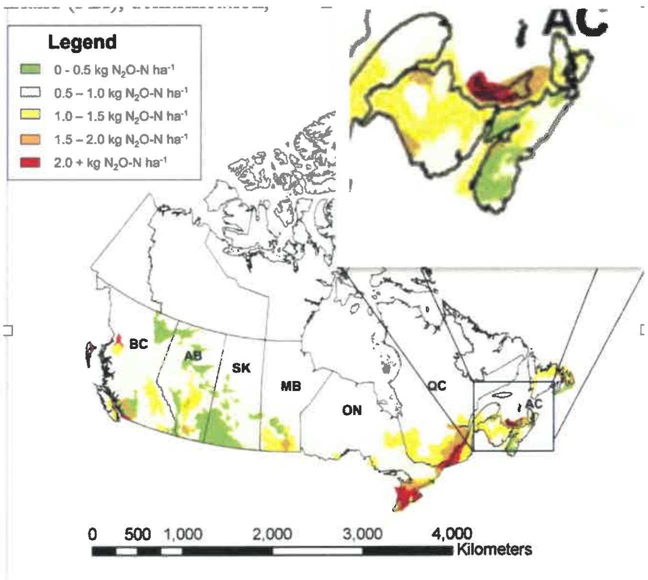


Figure 12: Annual N2O emissions associated with agricultural production in Atlantic Canada (Rochette et al. 2008a)

Direct N2O emissions are the result of the N2O emissions occurring in the soil as a direct result of N fertilizer additions (organic or inorganic). Direct N2O emissions resulted in 94 kT CO2e in PEI in 2015. Direct N2O emissions are currently being calculated using Tier II factors as described by Rochette et al. (2008a). This process uses a more detailed consideration of the management practices contributing to N2O emissions.

The potential for N2O emissions varies according to ecozone (Rochette et al., 2008a; Rochette et al., 2008b). Prince Edward Island (PEI), located in the Atlantic Maritime Ecozone, has annual emissions in the range of 1 to in excess of 2 kg N2O-N ha-1 (Fig. 12).

There are also indirect N2O emissions that result from N2O production from nitrogen lost from the soil as a result of ammonia volatilization or nitrate leaching. Indirect N2O emissions are reported using IPCC Tier 1 EF. Agriculture reported 20 kt CO2e of as a result of indirect N2O emissions in 2015.

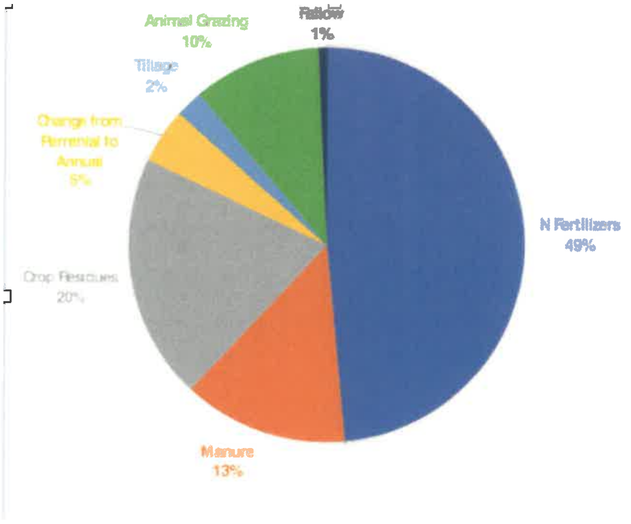


Figure 13: Percentage of sources contributing to N2O emissions in Atlantic Canada in 2005 as estimated presented by Rochette et al. (2008a).

Emissions Related to Nitrogen Fertilizer Use

The Tier I fertilizer-induced emission factor is 0.01 kg N2O-N kg-1 fertilizer N (Bouwman et al., 2002). To reflect country-specific and regional influences on emission factors the IPCC permits the determination of Tier II coefficients (Rochette et al., 2008b). Rochette et al.

(2008a,b) discuss the development of Canadian Tier II N2O emission factors for agriculture and the development of climate (EFeco) and effective (EFeff) emission factors (Table 6). Based on their assessment the dominant source of N2O in Atlantic Canada is primarily associated with the use of N fertilizers (49%), legume crop residues (20%) and manure management (13%) (Fig. 13).

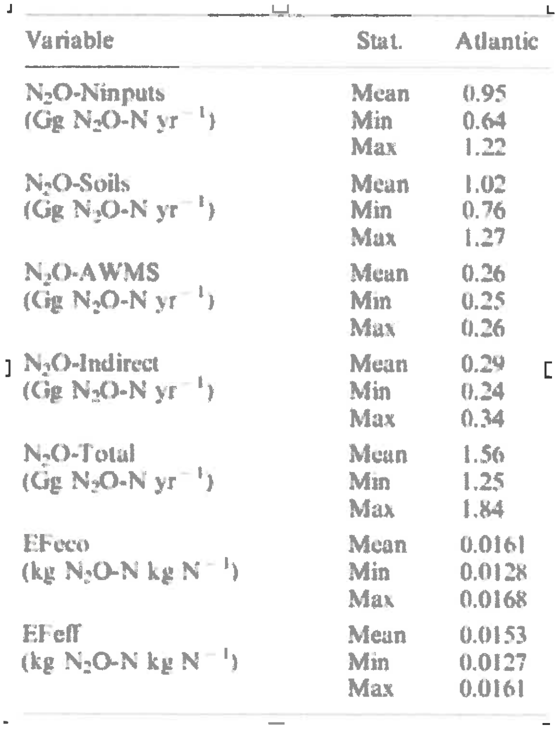
Canada currently reports direct N2O emissions from the agriculture sector using country-specific IPCC Tier 2 emission factors based on regression equations developed by (Rochette et al., 2008a) shown in Equations 1 and 2.

$$N_2OEForg = -1.4 + e^{[2.07+0.003CLAY-2.01PPE]} \quad \text{Eq. [1]}$$

Where N2OEForg is the N2O EF with organic N application (kg N2O-N kg -1 N), CLAY is clay content (g kg -1), and PPE is the ratio of the growing season precipitation to potential evapo-transpiration.

$$N_2OEFmin = -1.4 + e^{[-0.2982+0.00095P+0.0198Corg+0.0732Tair-0.4264Crop]} \quad \text{Eq. [2]}$$

Where N2OEFmin is the N2O EF with synthetic N application (kg N2O-N kg -1 N), P is the growing season precipitation from May to October (mm), Corg is the soil organic C content (g C kg -1), Tair is the temperature (C), and Crop is crop type.



Variable	Stat.	Atlantic
N_2O-Ninputs ($Gg\ N_2O$-$N\ yr^{-1}$)	Mean	0.95
	Min	0.64
	Max	1.22
N_2O-Soils ($Gg\ N_2O$-$N\ yr^{-1}$)	Mean	1.02
	Min	0.76
	Max	1.27
N_2O-AWMS ($Gg\ N_2O$-$N\ yr^{-1}$)	Mean	0.26
	Min	0.25
	Max	0.26
N_2O-Indirect ($Gg\ N_2O$-$N\ yr^{-1}$)	Mean	0.29
	Min	0.24
	Max	0.34
N_2O-Total ($Gg\ N_2O$-$N\ yr^{-1}$)	Mean	1.56
	Min	1.25
	Max	1.84
EFeco ($kg\ N_2O$-$N\ kg\ N^{-1}$)	Mean	0.0161
	Min	0.0128
	Max	0.0168
EFeff ($kg\ N_2O$-$N\ kg\ N^{-1}$)	Mean	0.0153
	Min	0.0127
	Max	0.0161

Table 6: Estimates of N2O emissions for Atlantic Canada and of the climate-dependent (EFeco) and effective (EFeff) emission factors. Values presented are the minimum, maximum and mean during the 1990-2005 period. (from Rochette et al., 2008a).

RESIDUAL SOIL NITROGEN

Since a significant component of direct N2O emissions occurs during the non-growing season and indirect N2O emissions are a result of nitrate leaching, one important approach to limit both N2O emissions and the potential for nitrate leaching to groundwater is to control the amount of nitrate remaining in the soil following harvest, referred to as residual soil nitrogen (RSN).

The agri-environmental RSN Indicator estimates the amount of nitrate remaining in the soil following the growing season. It is estimated as the difference between total N inputs to agricultural soils (fertilizer and manure, N fixation by leguminous plants, wet and dry atmospheric deposition) and total N outputs, which consist of harvested crops and gaseous losses including ammonia, nitrous oxide and nitrogen gas (N2) (Fig. 14, 15).

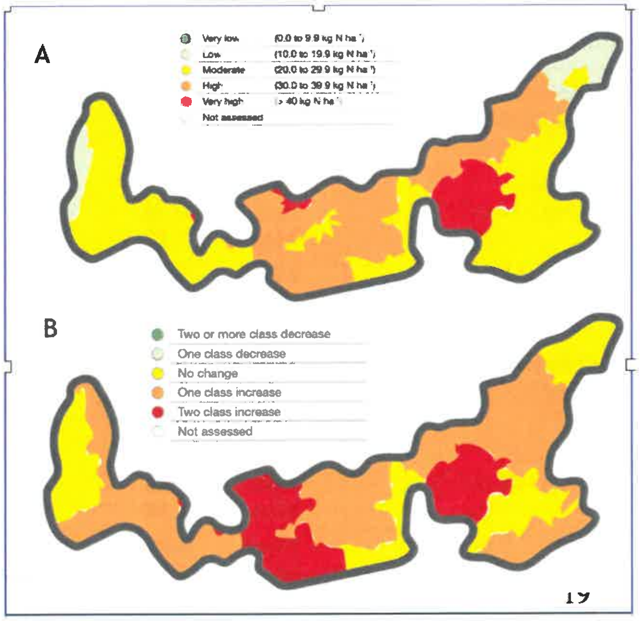


Figure 14: Residual soil nitrogen (A), change in residual soil nitrogen (B) on farmland in Prince Edward Island during the period 1981 to 2011. (From Clearwater et al., 2016).

The estimates of N inputs are driven by information collected in Agricultural Census and industry data. The RSN indicator is moderate to very high for most of PEI, and has increased from a predominantly low rating in 1981 to predominantly high and very high in 2001 onward. In 2011 there has been a decline in the very high rating class with more land falling into the moderate and high classes.

Nitrogen inputs increased from 90 kg N/ha in 1981 to a maximum of 146 kg N/ha in 2006, declining to 128 in 2011 (Fig. 14). The RSN in the Atlantic Maritime increased from 19.5 kg N/ha in 1981 to a maximum of 58.2 kg N/ha in 2001 followed by a decrease to 31.5 kg N/ha in 2011. In 2006, the Atlantic Maritime had the second highest RSN value of all agricultural ecozones.

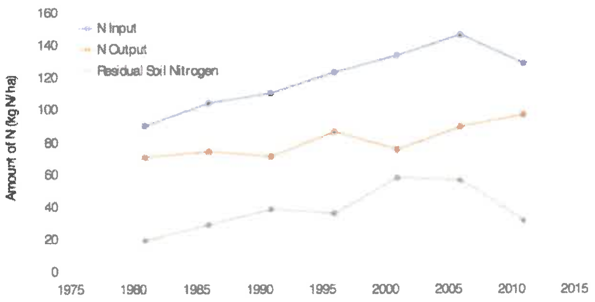


Figure 15: Residual soil nitrogen indicator, calculated as the difference between N inputs and outputs, for agricultural land in Prince Edward Island from 1981 to 2011. (Clearwater et al., 2016).

In a PEI survey of 26 fields following potato production in 2015 an average residual soil NO3- in the top 60 cm (24 inches) ranged from 0 to 250 kg N ha-1 and averaged 66.8 kg N ha-1 (Burton et al., 2017). In three years of side-by-side comparisons of grower standard practice and 4R suites Genesis Cropping Systems has demonstrated that 4R practices can reduce fall residual soil N by 30% (Fig. 16)

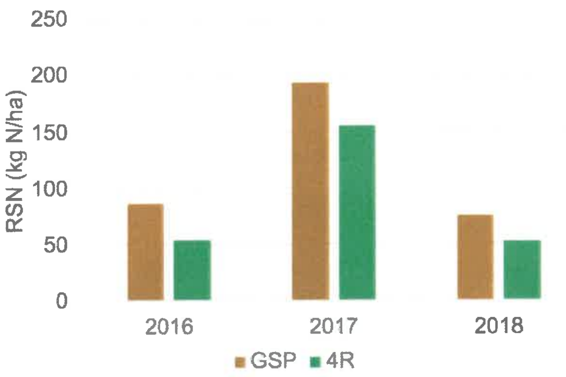


Figure16: Residual soil nitrogen in side-by-side comparisons of grower standard practice (GSP) and 4R management. (S. Watts, pers. comm.)

METHANE (CH4)

The main source of methane in agriculture is from ruminant livestock. Reduction opportunities that have proven to reduce methane on-farm elsewhere include the following animal management practices:

- feed composition improvement, including feed additives
- manure management (improved storage and usage)
- animal management (improved genetics)

Due to the difficulty of measuring methane from cattle or manure directly, and the lack of such research on PEI, no data exist for the amount of methane generated from PEI animal production. However, estimates can be made, based on research results from elsewhere, and the number of animals of each type raised annually on PEI.

For example, a lactating dairy cow produces about 400 grams of methane each day, or 146kg annually. But the negative effect on the climate of methane is 23 times higher than the effect of CO2. Therefore the release of about 150 kg methane per year for each cow is equivalent to about 3'400 kg CO2 per year. Beef animals generate equivalent amounts of methane or more.

Using the above rates and 2017 PEI statistics, PEI's 12,805 head of dairy cattle produced approximately 1,890MT of methane, equating to 43,000MT Co2 equivalents.

Using the same rates, PEI`s 17,445 beef animals generated about 2,616MT of methane, or ~60,000MT CO2 equivalents in 2018.

For a further understanding of methane emissions from Pei agriculture, see the earlier Animal Production section above.

CHANGES IN CARBON STORAGE (CO2)

Carbon dioxide is generated by the burning of fossil fuels, as well as out-gassing of CO2 from field storage of manure and organic matter breakdown in soils. On-farm CO2 emissions can be reduced through either reduction of emissions or sequestration of carbon from the atmosphere into the soil and growing plants or trees, as follows:

FIELD CARBON SEQUESTRATION

- conservation tillage
- no-till methods
- reducing "summer-fallow" of fields

FOSSIL FUEL USE REDUCTION

- usage of on-farm generated energy from by-products & wastes
- biogas (manure breakdown to flammable methane as fuel)
- combustion (wood, straw-bale, sawdust, peat or other plant based material)
- on-farm generation of "green" electricity
- solar panels
- wind turbines

AGRIFORESTRY (CO2)

- slash control & usage (biofuels, heating)
- pasture tree planting or reverting unused farmland to forests
- field C-sequestration

CARBON CHANGES IN PEI SOILS

In the UNFCCC reporting framework, the change in carbon stocks associated with agricultural soils and forests are reported separately under Land Use and Land Use Change in Forestry. As a result, these changes in carbon stocks are often not included in summaries of greenhouse gas emissions. None-the-less changes in the carbon content of agricultural soils represent a significant emission of CO2 and the potential for significant storage of carbon as a result of the adoption of soil conservation practices.

The decline in soil organic carbon in PEI is also reflected in the National Agri-Environmental Indicators (Fig. 17, Clearwater et al., 2016). These indicators highlight the health of Canada agriculture and agri-food sector. The Soil Organic Carbon Change Index (SOCC) calculates the change in soil carbon stored in croplands using the same procedures as are used to report these changes in the national inventory report and therefore are of particular relevance to this report.

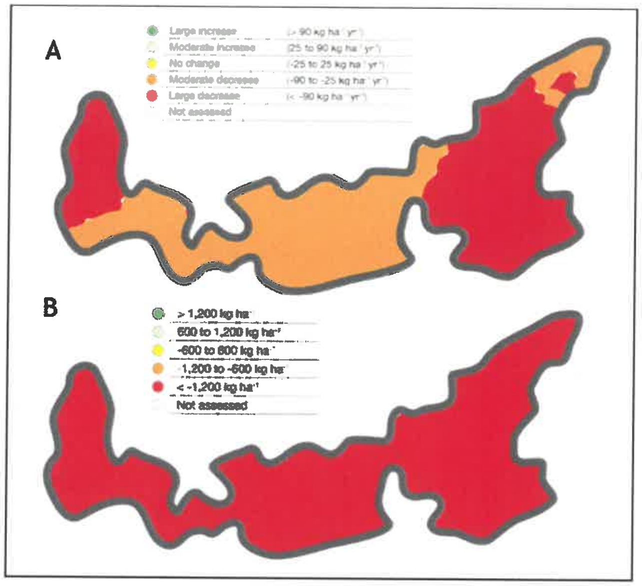


Figure 17: The change in A) soil organic carbon (kg C ha-1 y-1) and B) cumulative SOC change (kg C ha-1) from 1981 to 2011 due to land-use changes (e.g. forest to agriculture) and shifts between annual and perennial crops in Prince Edward Island (from Clearwater et al., 2016)

The indicator documents a continued decline in the soil organic carbon content of PEI crop lands with the trend being a more severe rate of decline in recent years. In 2011 almost 50% of PEI's cropland was estimated to be undergoing a decrease in soil organic carbon of greater than 90 kg C ha-1 y-1 . This decline is largely attributed to the move from perennial cropping practices (pasture) to annual cropping practices and the greater frequency of soil disturbance associated with annual crop production systems (Clearwater et al., 2016).

In PEI, the decline in SOM has also been documented in the Soil Quality Benchmark monitoring program undertaken by the PEI Department of Agriculture of Forestry over the past 20 years (Nyiraneza et al., 2017). Over an 18-year period, 56% of the total cropland area shifted from class 3 (3.1%-4% SOM) to class 2 (2%-3% SOM), equivalent to an approximate SOM decline of 1%. This amount corresponds to the loss of 0.05% SOM yr∔1 or 570 kg C ha-1 y-1. A figure well in excess of the 90 kg C ha-1 y-1 is now used as the highest soil organic C loss category on the Agri-Environmental Indicators. (Fig. 18)

It is important to note the Agri-Environmental Indicator estimate are based on modelling and the Soil Quality Benchmark study is based on measurements of actual decline in soil organic carbon.

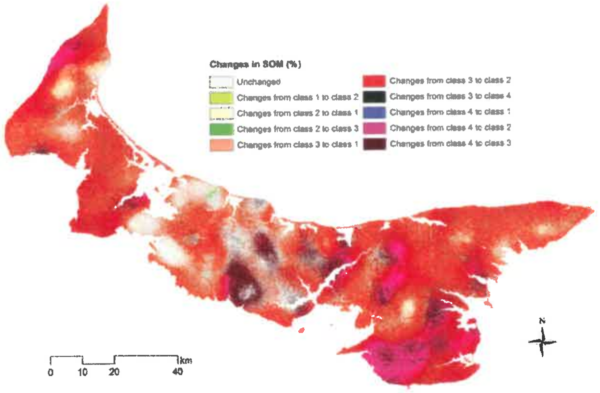


Figure 18: Changes in soil organic matter (SOM) between cycle 1 and cycle 6. Class 1, <2%; class 2, 2%-3%; class 3, 3.1%-4%; class 4, >4%. Data source: PEI Department of Agriculture and Fisheries. Nyiraneza et al. 2017

The trends indicated in the PEI soils quality database as reported by Nyiraneza et al. (2017) and the SOCC indicator are consistent and document a dramatic decline in the carbon content of PEI's cropland. This decline not only represents a significant emission of CO2 to the atmosphere, but also a decline in the health and resiliency of these croplands. BMPs which halt this decline and/or or reverse it will serve both to reduce GHG emissions but also increase the health and productivity of these production systems.

Expressed over 56% of the 575,335 hectares of land in PEI this represents a loss of ~ 184 kt C y-1 or ~ 673 kt CO2e y-1. This compares to the 1800 kt CO2e y-1 for the total GHG emissions from all economic sectors in PEI.

The 1% decrease in SOM over 56% of the total land area resulted in the emissions of 3.3 Mt of C or 12.1 Mt of CO2e over an 18-year period. The opportunity is that increasing SOM by 1% would result in an equivalent removal of CO2 from the atmosphere.

In the release of A Climate Change Action Plan for the Province of Prince Edward Island 2018 – 2023, the Province committed to reduce GHG emissions to 30% below 2005 levels by 2030. In addition to commitments to reduce GHG emissions across all sectors, targeted measures included commitments to increase support for funding programs such as the Alternative Land Use Services (ALUS) program and the Forest Enhancement Program (FEP) as a means to increase carbon sequestration and enhance the resilience of those ecosystems to climate change and also to consult with farmers to develop a series of farm practices that reduce GHG emissions and better sequester carbon. Further the government committed to piloting Farm-specific GHG reduction plans on 20 to 30 participating farms. Based on an assessment of the major sources of GHG emissions from PEI's agriculture sector targeting nitrogen fertilizer use, methane emissions from ruminants and soil carbon storage have the greatest potential to result in GHG reductions.

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SECTION
THREE.

3.1 Nitrous Oxide

3.2 Methane

3.3 Carbon

SECTION THREE.

CURRENT STATE OF KNOWLEDGE ON GHG EMISSIONS

REDUCING GREENHOUSE GAS EMISSIONS FROM PEI'S AGRICULTURE SECTOR

To assess and implement Beneficial Management Practices (BMP) for the reduction of GHG emissions, it is important to understand the climatic, soil and social context of PEI, as they impact both the potential for GHG emissions and the opportunity to undertake measures to reduce those emissions. Further, it is important to consider the current state of knowledge of the processes generating GHGs, and how agriculture management can mitigate these emissions. We will begin with a consideration of the biophysical context of PEI.

CLIMATE

As climate is a major determinant of greenhouse gas (GHG) emissions, developing beneficial management practices (BMPs) to reduced GHG emissions must recognize the constraints of the agro-ecozone and agricultural production systems, and how they impact the GHG production from agriculture. The risk of GHG emissions also varies with season. It is important that GHG emissions-reduction BMPs are assessed in the context of climatic zone and season. In a recent meta-analysis, growing season precipitation was the single factor that explained the greatest amount of the variation in N2O emissions, accounting for 38% of the variation in cumulative N2O emissions (Rochette et al., 2008). While there a much more limited variation in climate in PEI than found across Canada, there are significant micro-scale variations in climate that may influence the potential for GHG emissions. At the site level, management was observed to have a greater impact on N2O emissions than climate (Congreves et al., 2016; Congreves et al., 2017).

Prince Edward Island is found within the Atlantic Maritime eco-zone (Fig. 1). In this eco-zone, proximity to the Atlantic Ocean creates a moderate, cool, and moist maritime climate. The PEI ecoregion covers all of Prince Edward Island. Moderated by the Atlantic Ocean, the summers are warm and winters mild and snowy. The mean annual temperature is approximately 5.5°C. The mean summer temperature is 15°C, and the mean winter temperature is -3.5°C. The mean annual precipitation ranges 900-1150 mm. The average annual growing season ranges from 1,500 to over 1,750 growing degree days above 5°C. Frost-free days, on average, fluctuate from 80 in the New Brunswick highlands to 180 along the coast. There is also a high storm frequency, which can impact growing conditions and extreme events during the non-growing season.

The Island is part of the Maritime Plain consisting of flat to gently dipping late Palaeozoic sandstones, siltstone, and conglomerates that rise from sea level to a high of 142 m inland.

This undulating plain is mantled with loamy glacial till, fluvioglacial deposits, and level marine sediments of varying depth. The dominant soils of the region are Humo-Ferric Podzols. Significant inclusions are Gleysols, Gray Luvisols, Mesisols on flat and bowl bogs, and Fibrisols on domed bogs and fens.

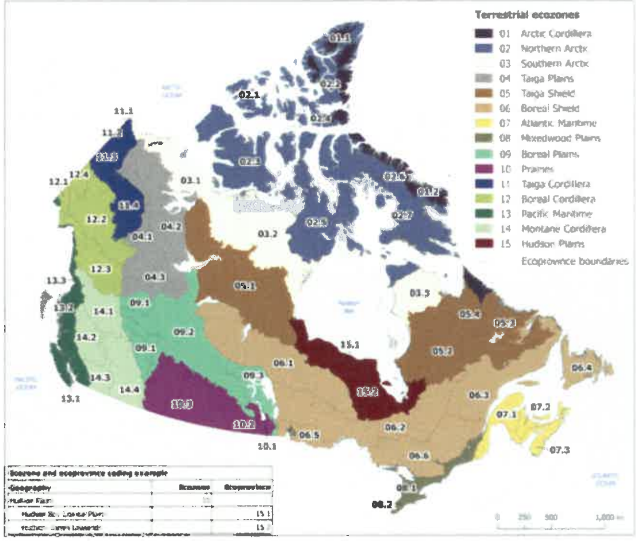


Figure 1: Eco-zones of Eastern Canada.

NITROUS OXIDE
NITROUS OXIDE EMISSIONS

The 4R Nutrient Stewardship framework has proven to be an effective means of communicating the various opportunities to increase nutrient use efficiency, agronomic efficiency and to reduce nutrient losses to the environment. In this section, we will examine source, timing, rate, and placement of nitrogen fertilizer use as a means of reducing N2O emissions.

NITROGEN SOURCE EFFECTS ON N2O EMISSIONS

Source selection provides the opportunity to use fertilizer N formulations that will result in lower N2O emissions. Over the past two decades, we have become aware that N2O is generated from a number of combinations of nitrifying and denitrifying processes, specifically nitrifier nitrification, nitrifier denitrification, nitrifier-coupled denitrification, and denitrification of fertilizer nitrate sources (Fig. 2). These pathways include oxidative processes that occur primarily under aerobic conditions (nitrification), and reductive processes under conditions of oxygen limitation (denitrification).

Despite this diversity of processes potentially producing N2O, denitrification is generally considered the process that generates the greatest amount of N2O, because of its predominance during rewetting and thawing events, and because of the relative yield of N2O from de-nitrification. (Risk et al. 2013; Rochette et al. 2018).

Aerobic pathways involve the oxidation of NH4+, and anaerobic pathways involve the reduction of NO3-. Further, NO2- and NO3- are anions, which can be much more rapidly leached from soils during periods of water movement and be involved in direct pathways of N2O production.
While multiple pathways can result in N2O production, the majority originates from oxidized forms (NO2- or NO3-) and are associated with reductive processes during periods of high water content, such as rainfall or snowmelt (Risk et al. 2013; Rochette et al. 2018). As a result, fertilizer N sources that do not contain NO3- and delay the formation of NO3- generally result in reduced amounts of N2O emissions.

FORM OF NITROGEN

Generally, there is less direct N2O production from microbial processes involving ammonia (NH4+) than those involving oxides of nitrogen (NO2- + NO3-). Over time, the predominant fate of ammonia is its oxidation to NO3- during nitrification. One of the major approaches to limiting N2O production in soil is to delay nitrification, to limit the duration of NO3- accumulation and thereby reduce the risk of N2O emissions (Rochette et al. 2018). Delaying NO3- production is particularly effective in situations where there is a high potential for denitrification following N fertilizer application, such as periods of high soil moisture early in the growing season.

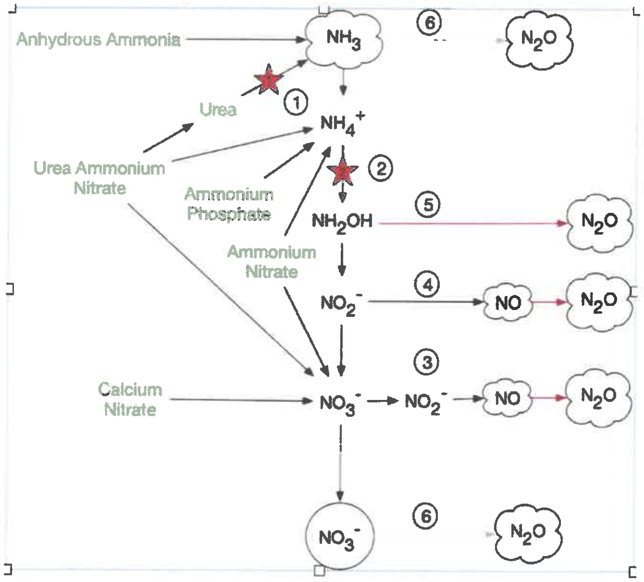


Figure 2: Pathways from fertilizer products (in green) to microbial N2O production in soil. 1) Urea hydrolysis, 2) nitrification, 3) denitrification, 4) nitrifier denitrification, 5) nitrifier nitrification, 6) in direct N2O emissions associated with NH3 and NO3- loss to the environment. The red stars indicate process inhibited by 1) urease inhibitors and 2) nitrification inhibitors.

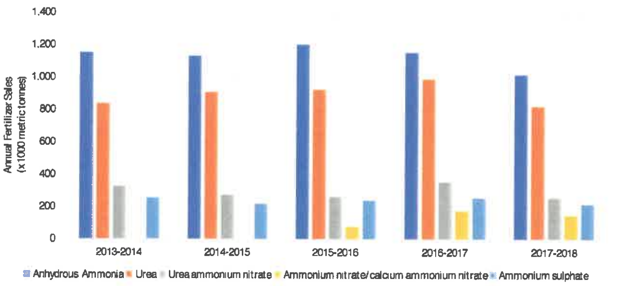


Figure 3: Forms of fertilizer nitrogen sold in Canada from 2013 to 2018. (Statistics Canada, 2018)

Ammonium-based fertilizers represent the majority of N fertilizer used in Canada (Fig. 3; Statistics Canada, 2018). The use of nitrate-based fertilizers (calcium nitrate, potassium nitrate) and fertilizers containing nitrate with other N forms (ammonium nitrate, calcium ammonium nitrate and UAN) represent less than 10% of the total N fertilizer sold in Canada, but these typs are more commonly used in Atlantic Canada (Fig. 3).

Studies examining the influence of nitrogen source on N2O emissions have produced variable results. A meta-analysis of corn cropping systems in the US Midwest, Ontario and Quebec, (Decock, 2014) reports that N source impacted fertilizer-induced emissions, and were ranked in the order: anhydrous ammonia > UAN > ammonium nitrate > urea, in terms of greatest to least N2O emissions (Fig. 4).

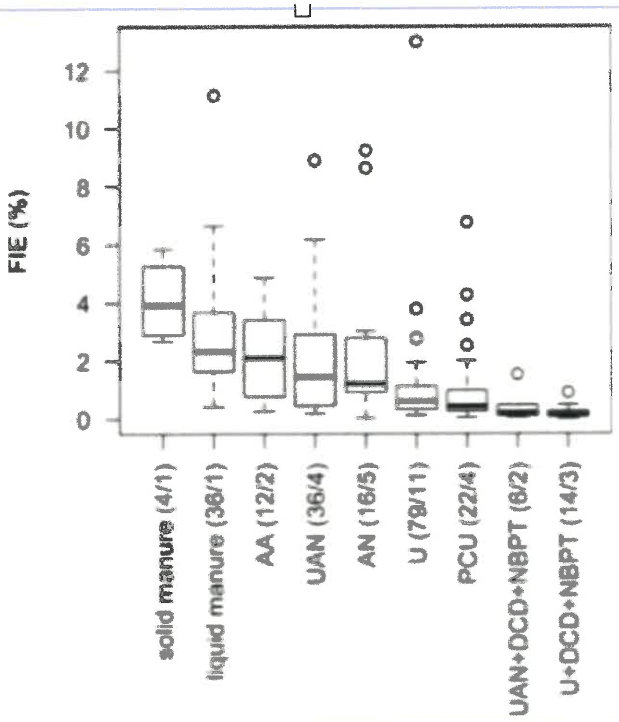


Figure 4: Influence of N source on fertilizer induced emissions (FIE) of N2O. Numbers in parentheses indicate the number of observations on which the analysis was based, and the number of different field site from which observations originated (Decock, 2014).

Abalos et al. (2016b), in examining 200 pair-wise observations from 23 studies from the same general region (US Mid-west and Eastern Canada), found no significant effect of N source (urea vs. ammonium nitrate or UAN) or time of application (fall vs. spring) on N2O emissions (Fig. 5). The use of an inhibitor did result in a 25% reduction in N2O emissions.

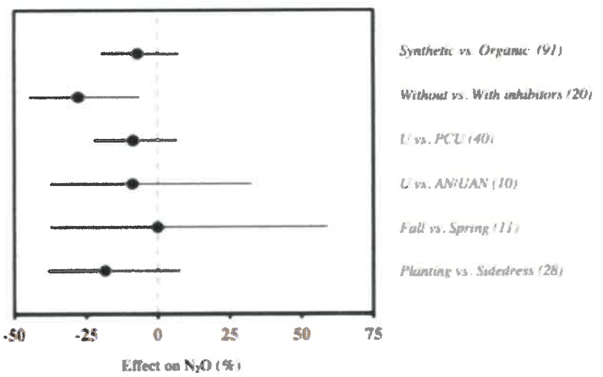


Figure 5: Influence of fertilizer management practices on N2O emissions indicating mean effect and 95% confidence intervals. Number in parentheses indicate the number of control-treatment pairs. From Abalos et al. 2016.v

ENHANCED EFFICIENCY FERTILIZERS

Emerging enhanced efficiency technologies have the promise for significant and reliable reductions in N2O emissions. The term "enhanced efficiency fertilizer" (EEF) refers to a range of technologies that use inhibitors or coatings to influence the rate of nitrate appearance in the soil. (Table 3)

The following definitions are being used in this section of this report:

Stabilized N

Stabilized nitrogen sources include urease inhibitors that inhibit enzymes in the soil which hydrolyze urea to yield ammonium (e.g. Agrotain, Limus, NYieldCX), nitrification inhibitors which inhibit ammonia-oxidizing bacteria, thereby delaying oxidation of NH4+ to NO3- (e.g. eNtrench, NBound, N-Serve), and double inhibitors (e.g. SuperU, NEON Air)

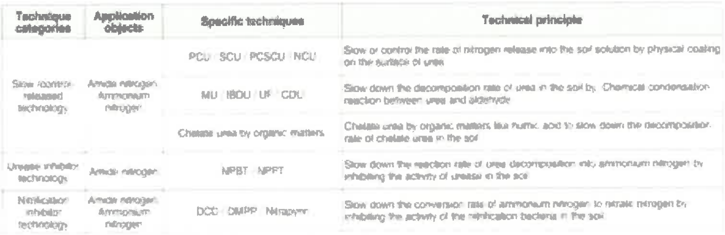
Controlled Release

A controlled-release fertilizer is a granulated form of urea that releases nutrients gradually into the soil, based on conditions such as moisture and temperature (i.e., release of urea dependent on soil conditions). An example of controlled release products is polymer coated urea, also called PCUs (e.g. ESN). The polymer membrane allows moisture to diffuse into the granule creating a solution of urea. The solution moves out through the membrane at a rate that is controlled by soil temperature.

Slow Release

A slow-release fertilizer releases nutrients to plants slowly over time. Slow-release fertilizers are usually dry blends or granular formulas (e.g. sulfur-coated urea, methylene urea, isobuylidene diurea, urea formaldehyde and urea triazone). These formulations of urea reduce the solubility and release of urea.

Table 1: Examples of enhanced efficiency fertilizer products (From: http://news.agropages.com/News/NewsDetail---19821.htm)



Technique categories	Application objects	Specific techniques	Technical principle
Slow /control-released technology	Amide nitrogen/ Ammonium nitrogen	PCU / SCU / PCSCU / NCU	Slow or control the rate of nitrogen release into the soil solution by physical coating on the surface of urea
		MU / IBDU / UF / CDU	Slow down the decomposition rate of urea in the soil by Chemical condensation reaction between urea and aldehyde
		Chelate urea by organic matters	Chelate urea by organic matters like humic acid to slow down the decomposition rate of chelate urea in the soil
Urease inhibitor technology	Amide nitrogen	NPBT / NPPT	Slow down the reaction rate of urea decomposition into ammonium nitrogen by inhibiting the activity of urease in the soil
Nitrification inhibitor technology	Amide nitrogen/ Ammonium nitrogen	DCD / DMPP / Nitrapyrin	Slow down the conversion rate of ammonium nitrogen to nitrate nitrogen by inhibiting the activity of the nitrification bacteria in the soil

Enhanced efficiency fertilizers (EFFs) have been shown to result in relatively consistent reductions in N2O emissions (Drury et al. 2012; Decock 2014;(Thapa et al., 2016); Vyn et al. 2016; Drury 201; Snyder, 2017; Eagle et al., 2017). The magnitude of the reduction is influenced by the mode of action, soil type and management factors.

In a meta-analysis of 27 studies, (Eagle et al., 2017) reported that nitrification inhibitors, side-dress timing, and broadcast placement of fertilizer N had much more significant impacts on N2O emissions than did modest (10%) decreases in rate of N application, reducing average losses by between 23 and 31%.

In a further meta-analysis of 113 data sets from 35 studies globally (Fig. 7), Akiyama et al. (2010) report an average reduction in N2O emissions of 38% and 35% from inhibitor treated products and polymer coated products, respectively.

Similarly, in their global meta-analysis, Thapa et al., (2016) reported mean reductions in N2O emissions, as a result of the use of nitrification inhibitors, of 38%, urease in combination with nitrification inhibitors of 30%, and controlled-release N fertilizers of 19% (Fig. 8). Thapa et al. (2016) found nitrification inhibitors and controlled release products to give relatively consistent reduction of 25% to 50%, whereas urease was more variable resulting in 0 to 50% reductions (Fig. 8). Urease inhibitors alone are less effective in controlling N2O emissions (Abalos et al., 2016b; Akiyama et al., 2010).

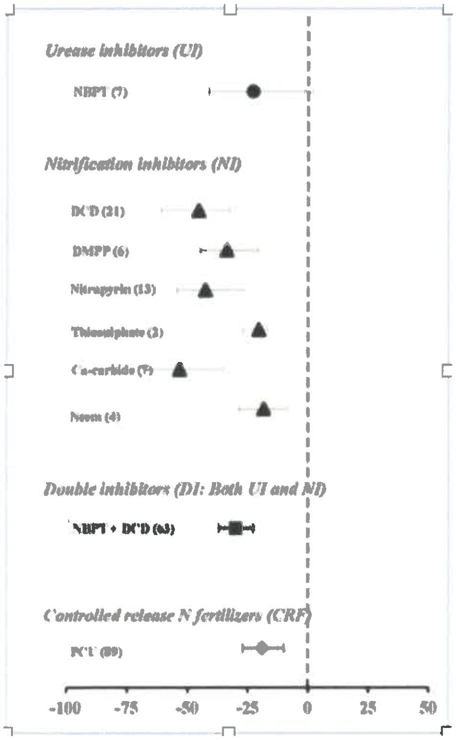


Figure 8: Effect of enhanced efficiency fertilizer products on N2O emissions relative to conventional fertilizers. Points are means; bars indicate 95% confidence intervals. Number of studies reported in parenthesis. From Thapa et al. 2016.

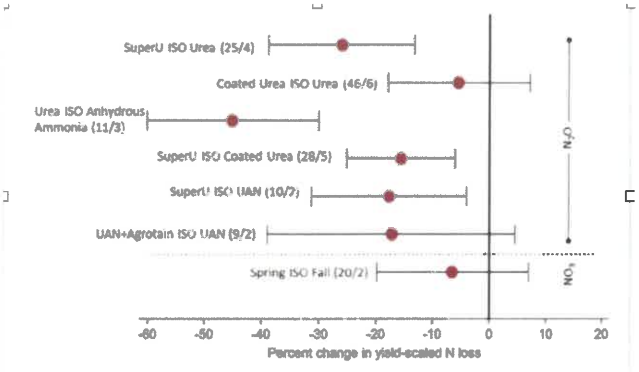


Figure 6: Effect sizes of N2O and NO3 losses from selected fertilizer management treatments, yield-scaled percent change with 95% confidence intervals. ISO = "Instead of" and values in parentheses are (number of comparisons / number of locations). from Eagle et al. (2017)

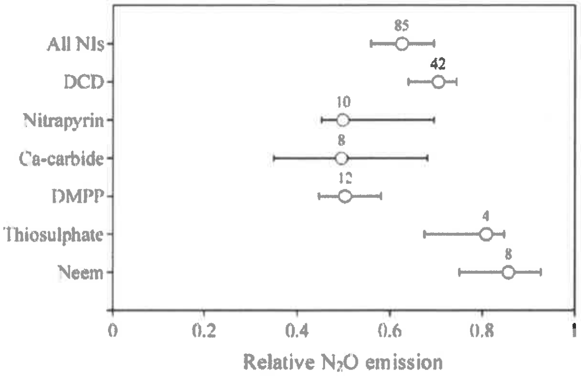
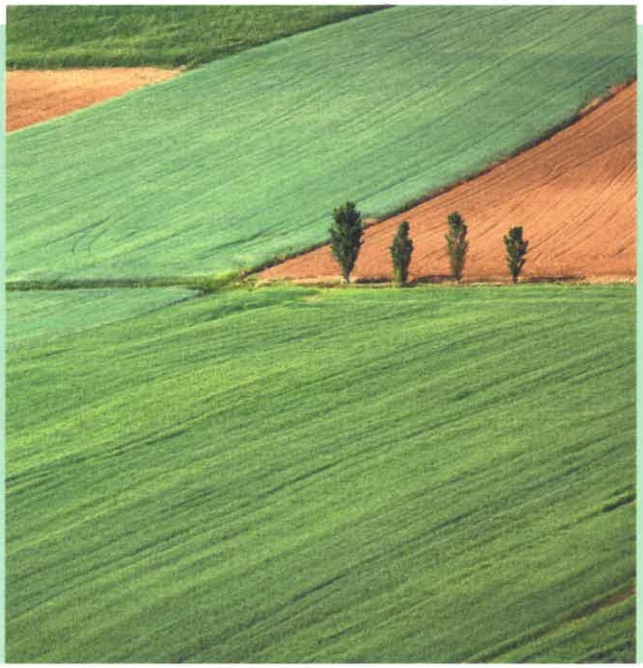


Figure 7: Influence of nitrification inhibitors on N2O emissions relative to a conventional fertilizer (without nitrification inhibitor). Points indicate mean and bars indicate 95% confidence interval. Numbers indicate number of observations. From Akiyma et al. 2010.



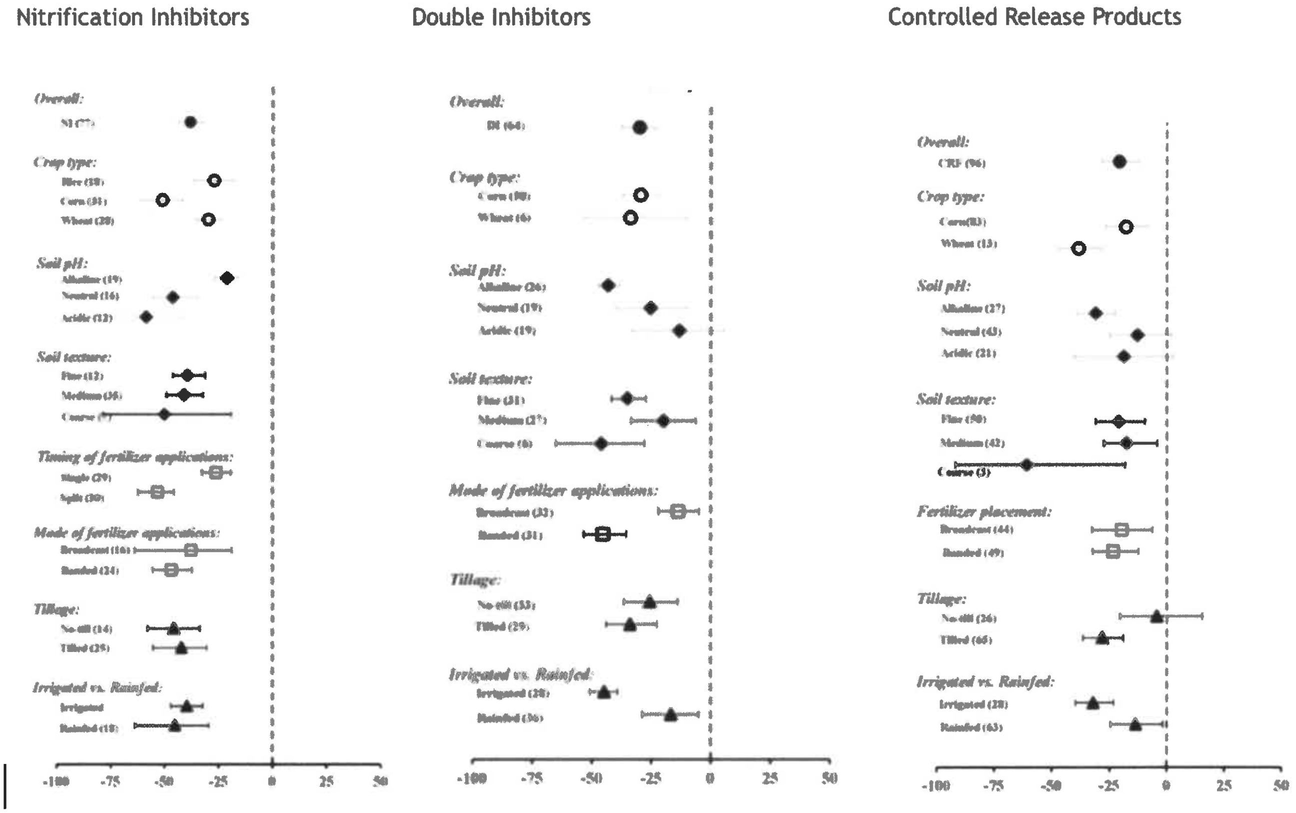


Figure 9: Effect of Nitrification inhibitors on N2O emissions as influenced by soil type and management system. (From Thapa et al. 2016)

Snyder (2017) reported the influence of EEFs on direct N2O emissions, ranging from a 466 % increase to a 100% decrease. The majority of the reported reductions in N2O emissions were between 25% and 50%, as a result of the use of nitrification inhibitors. Urease inhibitors alone were found to have resulted in either increased N2O emissions or only small reductions (Snyder 2017).

Thapa et al. (2016) examined the influence of crop type, pH, texture, and modes of application, tillage and irrigation on the effectiveness of nitrification inhibitors, urease inhibitors, a combination of urease and nitrification inhibitors and controlled release products (Fig. 9). Nitrification inhibitors were most effective in corn-based systems and when used in banded fertilizer applications (Thapa et al., 2016). The use of nitrification inhibitors alone can result in increased loss of NH3 (Drury et al., 2017; Snyder, 2017), and is generally less effective at reducing N2O loss from alkaline soils, as compared to neutral or acidic soils (Thapa et al. 2016).

The use of urease inhibitors in combination with nitrification inhibitors has been reported to result in greater reductions in N2O emissions (Decock, 2014; Abalos et al. 2016b; Drury et al., 2017; Snyder, 2017), particularly in alkaline soils, in banded systems, coarse-textured soils or in irrigated systems (Thapa et al. 2016). Drury et al. (2017) noted that, when ammonia volatilization was reduced by adding a urease inhibitor, N2O emissions were increased by 30%, when compared to a nitrification inhibitor alone. They noted that, by reducing pollution swapping (increased NH3 loss to reduce N2O loss), corn grain yields increased by 5% to 7%. The combination of a urease and a nitrification inhibitor resulted in increased yields of 19%, compared with urea without the inhibitors. Wagner-Riddle (2017), in examining corn production systems in Ontario, observed significant reduction in N2O emissions and NO3- loss, when UAN+EEF was applied as side-dress in a wet year when emissions were large. Snyder (2017) reported more consistent reductions in direct N2O emissions, as a result of the use of dual urease and nitrification inhibitor combinations, falling in the range of 17% to 46% reduction in N2O emissions. The addition of nitrogen inhibitor DCD (Dicyandiamide) to pig manure resulted in a 60% reduction in N2O emissions in a corn-wheat system in Brazil (Aita et al., 2015).

CONTROLLED RELEASE PRODUCTS

Polymer-coated urea (PCU) has been less consistent than other EEFs in reducing N2O emissions (Abalos et al. 2016b; Gao et al. 2017). Snyder (2017) reported a range of a 50% increase to a 70% decrease in direct N2O emissions associated with the use of polymer coated fertilizer products, across a range of studies globally. The majority of observations fell in the range of 20% to 40% reduction in direct N2O emissions (Snyder 2017). A single pre-plant application of PCU failed to reduce emissions, compared to conventional granular urea. However, banding the PCU resulted in a 32% reduction in emissions (Gao et al. 2017). Drury et al. (2012) found polymer coated urea only reduced N2O emissions in 1 year out of 3, whereas it delayed but did not reduce N2O emissions in the other 2 years. Polymer coated products were observed to be more effective in reducing N2O emissions in moist soil conditions, where there is a greater potential for N2O loss via denitrification (Drury et al., 2012). The use of PCU resulted in increased N2O emissions in potato production in Atlantic Canada (Zebarth et al., 2012). The authors noted that, for enhanced efficiency products to deliver reduced N2O emissions, they may have to be applied at lower rates to reflect the increased efficiency of N delivery.

INFLUENCE OF TIMING OF N APPLICATION ON N2O EMISSIONS

The objective of applying supplemental nitrogen fertilizers to crops is to meet the nitrogen requirements of the crop as efficiently as possible. Increasing nitrogen use efficiency (NUE) results in agronomic and environmental benefits. The challenge is to ensure there is sufficient nitrogen present, while minimizing exposure to loss. (Robertson and Vitousek, 2009) conclude that asynchrony between the timing of N availability and crop N demand is probably the single greatest contributor to excess N and N loss in annual cropping systems. Timing the supply of N to coincide with plant N demand minimizes the potential for N loss. Nitrate exposure, a temporally integrated measure of soil nitrate concentration (Burton et al., 2008), has been shown to be correlated with cumulative N2O emissions across a range of eco-zones and cropping systems (Aita et al., 2015; Chantigny et al., 2010; Engel et al., 2010; Gao et al., 2015; Maharjan and Venterea, 2013; Pelster et al., 2013). Management practices that reduce soil NO3- concentrations can decrease soil N2O emissions (Aita et al., 2015).

Nitrogen losses occur primarily as a result of the leaching of nitrate, volatile losses of ammonia and the production of N2O and N2. The timing of these losses is a function of climatic conditions. The leaching of NO3- and the production of N2O and N2 are related to periods of high soil water content and, therefore, coincide with periods of rainfall and/or snow melt. Ammonia volatilization occurs as a result of the presence of NH3 gas under alkaline conditions and its exchange with the atmosphere at the soil surface and, therefore, is enhanced in dry soils and during windy days, or days in which there are high evaporative losses from the soil surface. Optimizing the delivery of nitrogen to the plant and minimizing N loss requires that vulnerable forms of N are not present during the times of highest risk of loss. To minimize NO3- leaching and N2O emissions, the accumulation of NO3- should be avoided during periods of high rainfall or snowmelt. To minimized NH3 loss, NH4+ should not be allowed to accumulate in alkaline conditions at or near the soil surface.

One of the challenges in examining processes that are so dependent on climate is that results vary from year-to-year, as a result of fluctuations in weather patterns. Research on timing strategies almost always reports year-to-year variation in results based on patterns of precipitation. For example, split application of fertilizer N has been observed to result in reduced N2O emissions only when there is a potential for N2O production in the early part of the growing season (Burton et al. 2008; Wagner-Riddle 2017). These observations suggest risk-management based approaches are appropriate in assessing the role of timing in reducing N2O emissions.

Nitrogen management practices which influence the timing of N supply include the splitting of application, and a host of technologies that influence the rate of N release in the soil following application.

Split applications of N – Split applications of N involve the application of an initial amount of N early in the growing season (pre-plant or at planting), followed by applications later in the season, closer to the period of maximum plant N demand.

Split application will only result in reduced N2O emissions in situations where there is a potential for N2O loss over the time period of the split (Burton et al., 2008). Thus, the response to split application treatments can vary from year-to-year.

A study of crop production in Minnesota, (Fernandez et al., 2016) observed that split applications emitted 26% less N2O than a single pre-plant application of urea, with no differences in grain yield. Drury et al. (2012) found that, in conventional tillage treatments, N2O emissions were 49% greater, when N was applied at planting compared to a side-dress. Split applications of urea N in a corn-soybean system do not always result in reduced N2O emissions (Venterea and Coulter, 2015). In this study, the failure of the split application to reduce N2O emissions was attributed, in part, to a prolonged dry period prior to the split application, followed by a period of heavy rainfall following the split. There was a significant relationship between cumulative N2O emissions and nitrate exposure (referred to as nitrate-nitrite intensity), suggesting that the split application treatments resulted in increased availability of nitrate and nitrite loss following application.

Splitting the application of pig manure in a corn-wheat production system in Brazil resulted in a 33% reduction in N2O emissions (Aita et al., 2015). The combination of split application with the use of DCD resulted in a 41% reduction in N2O emissions. The combination of split application and DCD did not, however, result in as great an emissions reduction as did the use of DCD in a single application, which resulted in a 60% reduction in N2O emissions (Aita et al., 2015). Similarly, (Abalos et al., 2016b) observed that the combined adoption of split fertilizer application with inhibitors and a N fertilizer application rate 10% lower than the conventional application rate (i.e. 150 kg N ha−1) resulted in reduced N2O emissions, but the benefits were lower than those achieved with a single fertilizer application at side dress. In a corn production system in Ontario, Wagner-Riddle (2017) did not observe a reduction in N2O emissions as a result of split N application. A combination of UAN with inhibitors and split N application resulted in significant reduction in N2O emissions, but only in a dry year when emissions were small (Wagner-Riddle 2017).

Researchers examining potato production systems in Manitoba (Gao et al., 2017) found split urea application, with N being added both at hilling and through fertigation, resulted in reduced N2O emissions. A single split urea (2/3 pre-plant, 1/3 hilling) also reduced N2O emissions compared to single pre-plant urea application. Similarly, (Burton et al., 2008) observed that split application reduced N2O emissions by 30% in a year when there was rainfall between planting with a split application of N (hilling), but that there was no significant difference N2O emissions in drier year, where there was no risk of N loss during the period between planting and hilling.

FOLIAR APPLICATION/FERTIGATION

There is limited information on the impact of timing of N application on N2O emissions in irrigated systems in Canada. Gao et al. (2017) found that split urea application at pre-plant, and hilling and fertigation with in-season application of UAN, resulted in lowest N2O emissions, relative to a single pre-plant urea application. Farrell (2017) observed that cumulative N2O emissions in irrigated canola were significantly impacted by the timing of the fertilizer application. Emissions were lower for split N application, compared to a single application at seeding.

FALL NITRATE MANAGEMENT

Nitrate remaining in the soil after crop harvest has a high potential for N loss, under the climatic conditions of PEI. Zebarth documented the extent of carry-over of fall nitrate to the subsequent spring (Zebarth et al., 2003). Significant over-winter nitrate losses occur as a result of a combination of denitrification and nitrate leaching. Denitrification reactions occur in soil containing high concentrations of NO3- (> 10 mg N kg-1 soil), and result in considerable amounts of N2O being released as an end product (Burton et al., 2008). In addition, the over-winter period represents a period of significant NO3- loading to groundwater (Jiang et al., 2011). As result, management practices which minimize residual soil NO3- provide economic and environmental benefits to the producer and the surrounding environment. Residual soil NO3- has been proposed as an agri-environmental indicator of the risk of nitrogen contamination of water (Drury et al., 2007). It also is an indicator of the potential for direct and indirect N2O emissions (Omonode et al., 2017).

INFLUENCE OF N PLACEMENT ON N2O EMISSIONS

Nitrogen fertilizer placement attempts to place the fertilizer in an environment where its availability to the plant is maximized, and the potential for N loss in minimized. Care must be exercised to ensure placement does result in toxicity to the plant. Often sub-surface placement has a positive impact on yield, and therefore may reduce N2O emissions intensity.

The impact of placement on N2O emissions is influenced by soil water content. Sub-surface placement has been shown to increase N2O emissions in sub-humid ecosystems (Venterea et al., 2010 (Engel et al., 2010; Fujinuma et al., 2011; Venterea et al., 2010). Based on experimental observations, Farrell (2017) concludes that wetter conditions were required to induce and maintain denitrification activity in the sub-surface band. Gao et al. (2015) reported that, at two sites in Manitoba, cumulative N2O emissions were generally greater following broadcast/incorporation compared with side-banding. These differences may reflect differences in the timing of N application.

Gao et al. (2017) observed that banding of ESN, but not urea, reduced N2O emissions compared to broadcast-incorporation placement.

Depth of placement may also be a factor in determining the extent of N2O emissions. (Drury et al., 2006) observed that deeper placement of N generally results in greater N2O emissions, whereas van Kessel et al. (2013) found that when fertilizer-N was placed at >5 cm depth, in reduced tillage systems, significant reductions were observed in area-scaled N2O emissions, in particular under humid climatic conditions.

Placement is somewhat less of an issue in potato production, as fertilizer N is often either banded in the potato hill at the time of planting, or is broadcast prior to hilling, and becomes incorporated in the hill during the hilling process.

IMPACT OF FERTILIZER N APPLICATION RATE ON N20 EMISSIONS

IPCC National accounting frameworks directly reflect the impact of the rate of N fertilizer application on N2O emissions, by expressing emissions as the product of fertilizer N rate and an emission factor. The influence of the other three "Rs" is represented in changes in the magnitude of the emission factor, using an emission factor modifier. Implicit in this approach is the assumptions that N2O emissions are a linear function of fertilizer N rate (i.e., a single emission factor applies across all rates), and that other sources of N do not influence the magnitude of fertilizer N-induced emissions. Both assumptions are incorrect. Firstly, the relationship between N fertilizer application rate and N2O emissions is not linear (Fig. 10). Secondly, N2O emissions occur not only from fertilizer N sources, but are a function of total soil N supply derived from multiple sources. Thus, the magnitude of the non-fertilizer N sources influences the magnitude of fertilizer N-induced N2O emissions.

Fertilizer N application rate is also a particularly important "R", in that the yield response to N fertilizer application rate is one of the fundamental factors managed in developing agronomic production practices for a crop. Producers are keenly aware of N application rates and their implication for potential yields. Often the choice of an N rate is seen primarily through an economic lens. The maximum economic rate of N is the rate at which the value of the next increment in crop yield exceeds the cost of the fertilizer. The maximum economic rate of N does not explicitly reflect desired N recovery efficiency, or the potential for environmental impact. The use of additional "insurance" N to ensure increased yields, should climatic conditions be favourable, often result in N additions in excess of the maximum economic rate of N.

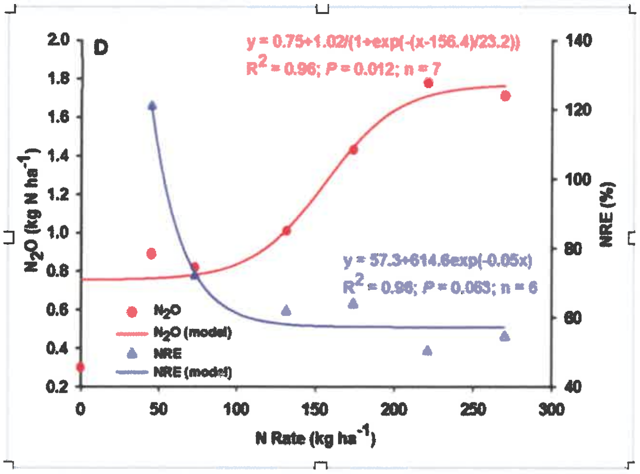


Figure 10: Relationship between fertilizer N application rate (N Rate, kg N ha-1) and cumulative growing season N2O emissions (N2O, kg N ha-1) and nitrogen recovery efficiency (NRE, %) defined as the total increase in above ground N uptake by the plant as a result of N fertilizer application. From Omonode et al. 2017.

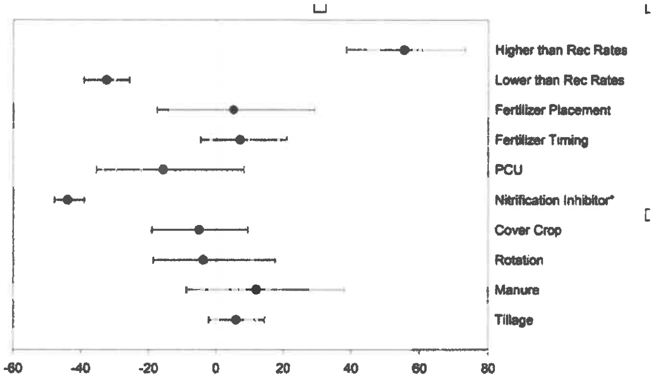


Figure 11: Effect of management practices on area-scaled N2O emissions reported as percent change from the control. Mean values and 95% confidence intervals of the back- transformed response ratios are shown. The result for nitrification inhibitors was from Qiao et al. (2015) and was shown for comparison. From Han et al., 2017.

In a meta-analysis of 597 pair-wise comparisons, Han et al. (2017) found that the rate of N application was a more significant driver of N2O emissions than was N source. They observed that applying N fertilizer at higher than recommended rates resulted in 55% greater N2O emissions than application at the recommended rate, and that application at less than recommended rate resulting in a 33% decline in N2O emissions (Fig. 11). In a study of N fertilization of barley across soil zones, Kryzanowski (2018) found reduction in emissions was greater for high N treatments, compared to low N. Eagle et al. (2017) concluded that lower fertilizer N rates resulted in lower N2O emissions and NO3- leaching. Cutting typical N fertilizer rates by as little as 10 kg N ha-1, a rate likely to be considered reasonable by producers, reduced average N2O emissions by 4%, and reduced average NO3- leaching losses by 2.9%, under average conditions (Eagle et al., 2017).

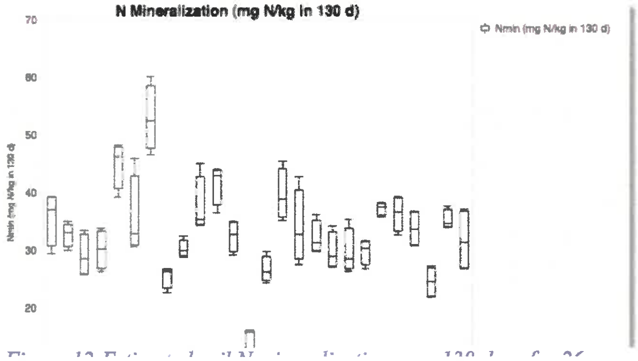


Figure 12:Estimated soil N mineralization over 130-days for 26 potato fields in Prince Edward Island (Burton, pers. comm.)

One of the most difficult aspects of determining the right rate of N fertilizer is the degree to which other N sources are quantified. Soil organic matter, crop residues and organic amendments all contribute to supply of nitrogen to the crop. The addition of fertilizer N should be based on the difference between plant N demand and other soil N sources. Often the contributions of the residue from previous crops or organic amendments are reflected in nitrogen credits, in the determination of fertilizer N requirement. The quantification of soil nitrogen mineralization is less often considered. In a study of 26 potato fields in PEI, the variation in soil N supply found variation in estimated soil N supply from 12 – 60 mg N kg-1 soil (~25 - 125 kg N ha-1), over a 130-day period (Fig. 12).

Currently there is no mechanism to account for this 100 kg N ha-1 difference in the N supplying capacity of these soils, in making right-rate fertilizer N recommendations.

There have been calls for alternate measures of agronomic, economic, and environment soundness of N management systems (Snyder et al., 2014). Omonode et al. (2017) assessed whether the impact of fertilizer N rate might better be quantified in terms of various measures of N uptake by the plant and/or residual N in the soil. Residual soil nitrate, nitrate remaining in the soil following crop harvest, is also used in Agriculture and Agri-Food Canada's Agri-Environmental Indicators as an indicator risk of water contamination by nitrogen (Clearwater et al. 2016). Omonode et al. (2017) found measures of N uptake by the plant, and/or residual N in the soil, were highly correlated with area-scaled N2O emissions. They noted that, as fertilizer N rate increased, there was a non-linear response in growing season N2O emissions and decline in N recovery efficiency (NRE) by the plant (Fig. 16). Growing season N2O emissions increased exponentially when plant N recover dropped below 60%.

To fully realize potential reductions in N2O emissions, increased nitrogen use efficiency, resulting from the implementation of 4R practices, should result in a corresponding reduction in the optimal rate of N fertilizer, and thereby a reduction in N2O emissions (Zebarth et al. 2012; Rose et al. 2018). Often, experimental designs consider various candidate 4R practices at the same rate of N fertilizer addition and, as a result, may not reflect the opportunity to reduce rate and N2O emissions while maintaining yield. Rose et al. (2018) noted that studies examining enhanced efficiency products often find decreased N2O emissions, but with no significant effect on yield. They argue that reduced N fertilizer rates should be considered to reflect the enhanced efficiency.

Weather is also an important consideration in determining yield potential. In an evaluation of the response of potato to fertilizer N rate, conducted in PEI in 2017, a period of drought in August limited plant yield and the response of the crop to fertilizer N addition (Fig. 13). The emissions of N2O were impacted by fertilizer N rate and reflected, in part, the failure of the crop to take up the additional N supplied at higher fertilize N rates (Fig. 13). This emphasizes the increased environmental risk of higher N rates, particularly in years where non-nitrogen factors limit crop yield.

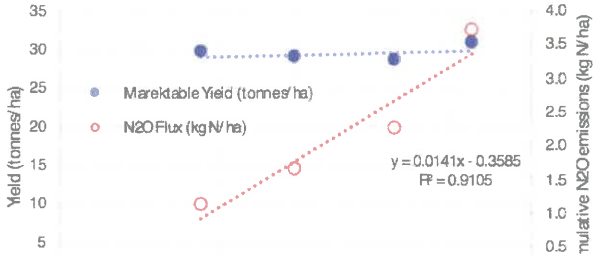


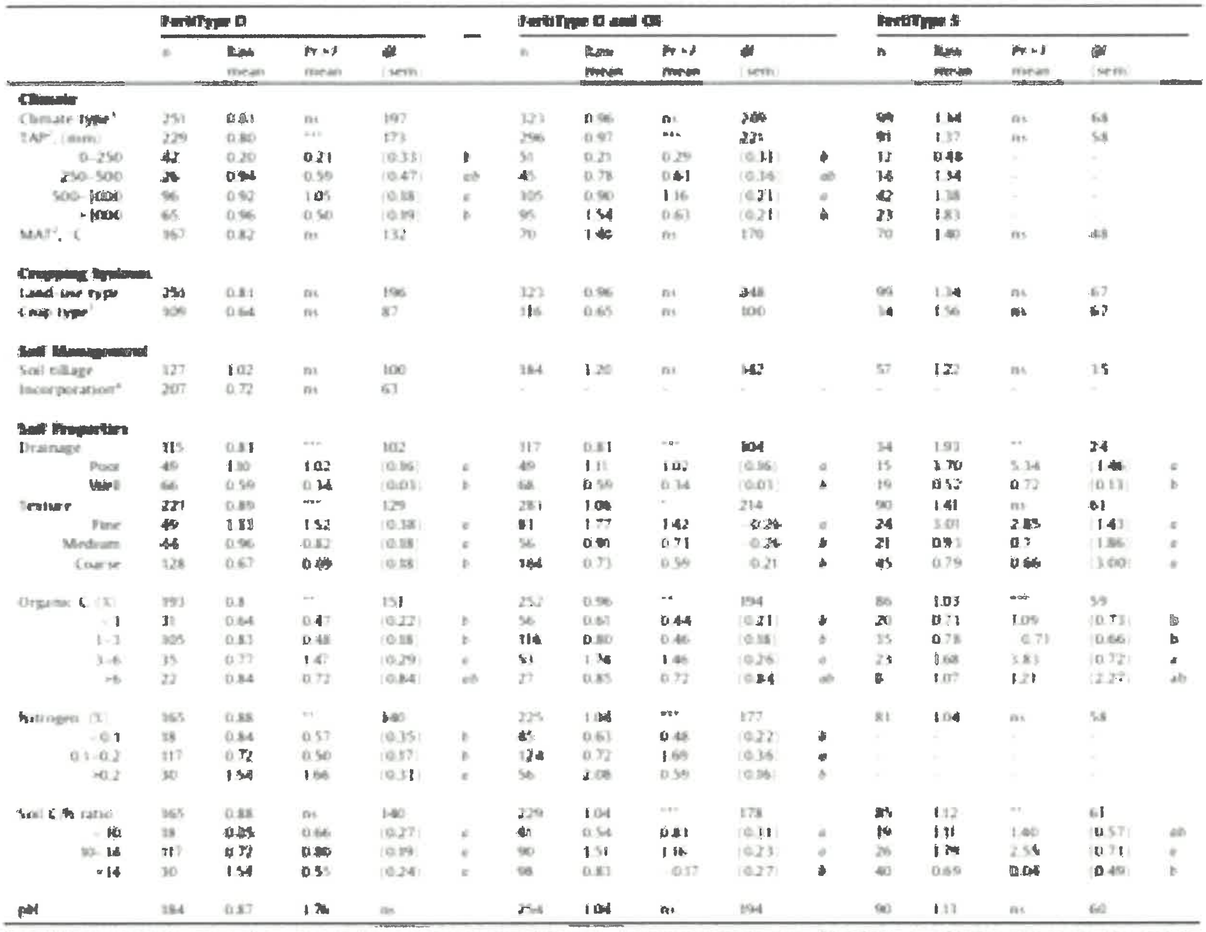
Figure 13: Influence of fertilizer N application rate on marketable yield of potato (tonnes/ha) and cumulative N2O emissions over the growing season (kg N/ha) in a potato field in PEI (Burton, personal comunication.)

NON 4R FACTORS THAT INFLUENCE N2O EMISSIONS

It is important to recognize the implications of soil management factors and conditions on N2O emissions. These factors primarily act by altering the availability of carbon, and/or the soil aeration, as influenced by water content.

SOIL TYPE/TEXTURE

In their global meta-analysis, Charles et al. (2018) identified the significance of a range of soil factors in influencing N2O emissions from both organic and inorganic fertilizers (Table 4). For both mineral and organic fertilizers, Charles et al. (2018) found poorly drained soils had greater emissions factors than did well-drained soils.



	FertiType O					FertiType O and OS					FertiType S				
	n	Raw mean	Pr > F mean	df (sem)		n	Raw mean	Pr > F mean	df (sem)		n	Raw mean	Pr > F mean	df (sem)	
Climate															
Climate type[1]	251	0.81	ns	197		323	0.96	ns	249		99	1.34	ns	68	
TAP[2], (mm)	229	0.80	***	173		296	0.97	***	221		91	1.37	ns	58	
0–250	42	0.20	0.21	(0.33)	b	51	0.23	0.29	(0.31)	b	12	0.48	-	-	
250–500	26	0.94	0.59	(0.47)	ab	45	0.78	0.41	(0.34)	ab	14	1.34	-	-	
500–1000	96	0.92	1.05	(0.18)	a	105	0.90	1.16	(0.21)	a	42	1.38	-	-	
>1000	65	0.96	0.50	(0.19)	b	95	1.54	0.63	(0.21)	b	23	1.83			
MAT[3], °C	367	0.82	ns	132		70	1.46	ns	170		70	1.40	ns	48	
Cropping Systems															
Land use type	250	0.81	ns	196		323	0.96	ns	348		99	1.34	ns	67	
Crop type[5]	109	0.64	ns	87		116	0.65	ns	100		34	1.56	ns	67	
Soil Management															
Soil tillage	127	1.02	ns	100		184	1.20	ns	142		57	1.22	ns	35	
Incorporation[6]	207	0.72	ns	63		-	-	-	-	-	-	-	-	-	
Soil Properties															
Drainage	115	0.81	***	102		117	0.81	***	104		34	1.93	**	24	
Poor	49	1.10	1.02	(0.16)	a	49	1.11	1.02	(0.16)	a	15	3.70	5.34	(1.46)	a
Well	66	0.59	0.14	(0.03)	b	68	0.59	0.34	(0.03)	b	19	0.52	0.72	(0.13)	b
Texture	221	0.89	***	129		281	1.06	*	214		90	1.41	ns	61	
Fine	49	1.33	1.52	(0.38)	a	81	1.77	1.42	(0.26)	a	24	3.01	2.85	(1.43)	a
Medium	44	0.96	0.82	(0.18)	a	56	0.91	0.71	(0.26)	b	21	0.93	0.7	(1.86)	a
Coarse	128	0.67	0.49	(0.18)	b	144	0.73	0.59	(0.21)	b	45	0.79	0.66	(3.00)	a
Organic C (%)	193	0.8	**	151		252	0.96	**	194		86	1.03	***	59	
<1	31	0.64	0.47	(0.22)	b	56	0.61	0.44	(0.21)	b	20	0.71	1.09	(0.73)	b
1–3	105	0.83	0.48	(0.18)	b	114	0.80	0.46	(0.18)	b	35	0.78	0.71	(0.66)	b
3–6	35	0.77	1.47	(0.29)	a	51	1.36	1.46	(0.26)	a	23	1.68	3.83	(0.72)	a
>6	22	0.84	0.72	(0.84)	ab	27	0.85	0.72	(0.34)	ab	8	1.07	1.21	(2.27)	ab
Nitrogen (%)	165	0.88	**	140		225	1.06	***	177		81	1.04	ns	58	
<0.1	18	0.84	0.57	(0.35)	b	45	0.63	0.48	(0.22)	b	-	-	-	-	
0.1–0.2	117	0.72	0.50	(0.17)	b	124	0.72	1.69	(0.36)	a	-	-	-	-	
>0.2	30	1.54	1.66	(0.31)	a	56	2.08	0.59	(0.36)	b	-	-	-	-	
Soil C/N ratio	165	0.88	ns	140		229	1.04	***	178		85	1.12	**	61	
<10	18	0.85	0.66	(0.27)	a	41	0.54	0.81	(0.31)	a	19	1.31	1.40	(0.57)	ab
10–14	117	0.72	0.80	(0.19)	a	90	1.51	1.16	(0.23)	a	26	1.79	2.55	(0.71)	a
>14	30	1.54	0.55	(0.24)	a	98	0.83	0.17	(0.27)	b	40	0.69	0.04	(0.49)	b
pH	184	0.87	1.76	ns		254	1.04	ns	194		90	1.13	ns	60	

[1]Climate types reported in the database: cool temperate dry/moist, tropical dry/moist, warm temperate dry/moist. [2]FertiType, type of fertilization: organic (O), synthetic fertilizers (S), organic and synthetic fertilizers (OS). [3]TAP: Total annual precipitation. [4]AMAT: Annual mean air temperature. [5]Crop type: type of crops (legume, grass, legume + grass) in grassland only. [6]Incorporation: incorporation depth (cm) of organic amendments only. n, total # of observations used in the analysis. Pr > F refers to a F-test used for comparing the soil factors of the total deviation. Df: degree of freedom. Significance of the effect: Pr < 0.001***, Pr < 0.01** and Pr < 0.05*. ns = non-significant. Means sharing a letter are not significantly different within soil factor by a LSD test (P < 0.05).

Table 2: The impact of climate, cropping system, soil management and soil properties on N2O emission factors for soil amended with organic (FertiType O), synthetic (FertiType S) and combinations of organic and synthetic (FertiType O and OS) nitrogen sources (From Charles et al. 2017).

For mineral fertilizers (FertiTyp S), the factors resulting in the greatest increases in N2O emission factor were the result of: a) difference in drainage (poor > well drained) b) organic matter content (N2O emissions were greater in soils with >3% organic C), while soils with wide C:N ratios (>14) had reduced N2O emissions. While N2O emission factors from fine textured soil were numerically greater than from medium or coarse textures, these differences were not statistically different (Table 1). For organic fertilizers (FertiType O), drainage (poor > well drained) and texture (fine = medium > coarse) were significant influences, as were organic C content (3% or less < 3-6% = greater than 6%) and nitrogen content (0.2% or greater > 0.2 % or lower; Table 4).

Abalos et al. (2016b) identified soil texture and C:N ratio as the dominant factors influencing N2O emission factors. Fine-textured soils were highly responsive to fertilizer management, in terms of both N2O emissions and crop yield. The mitigation of N2O emissions, without concurrent yield reductions, is most frequently achieved in soils with a low C/N ratio (i.e. <12.5).

IRRIGATION AND DRAINAGE

Tile drainage reduced N2O emissions during periods of excess moisture, but not in periods of adequate precipitation, in a corn production system in Minnesota (Fernandez et al., 2016). Averaged across years, the undrained soil emitted 1.8 times more N2O than the drained soil. Elmi et al. (2005) found denitrification (N2O + N2) to be greater under sub-irrigation (12.9 kg N ha-1) than in freely drained systems (5.8 kg N ha-1). The N2O emissions were greater under freely drained systems (2.2 kg N ha-1) than sub-irrigation (1.6 kg N ha-1). The reduced N2O production under sub-irrigation was attributed to a greater reduction of N2O to N2. Nangia et al. (2013) reported that there were no statistically significant differences in observed N2O fluxes between conventional tile drainage and controlled tile drainage fields, during the growing season. They report that predicted N2O fluxes, using a semi-empirical model (NEMIS-NOE), were higher for conventional tile drainage for approximately 70% of the paired-field study periods.

Thus, while tile drainage appears to reduce emissions during periods of excess moisture, it is not clear that tile drained systems consistently emit lower amounts of N2O emissions. Controlled drainage water management has the potential to reduce N2O emissions, but this appears to be the result of creating conditions conducive to complete denitrification to N2.

Vyn et al. (2016) found that fertilizer-induced emissions were greater under rain fed (0.73%), compared to irrigated, corn (0.41%) systems, in a meta-analysis of the US corn belt and Eastern Canada. Applying reduced deficit irrigation, and the nitrification inhibitor DMPP individually, slightly decreased N2O emissions, but when applied in combination, resulted in a greater reduction in N2O emissions (Jamali et al., 2016). In isolation, DMPP tended to be more efficient than optimised irrigation management in mitigating N2O emissions. Irrigation can be critical in preventing large yield decreases in rain-fed potato production systems and, thereby, reduce the risk high soil nitrate in the fall and winter period.

TILLAGE

In the drier regions of the country, greater N2O emissions are generally observed under conventional tillage, compared with reduced tillage management, due to higher rates of nitrification (Helgason et al., 2005; Kariyapperuma et al., 2011). In contrast, in the more humid regions of Canada, greater N2O emissions usually occur under reduced tillage, due to wetter soil conditions, resulting in higher rates of denitrification (Rochette et al., 2008; Smith et al., 2010).

Drury et al. (2012) observed greater N2O emissions (4.2 kg N ha-1), under conventional tillage, than under no till (3.5 kg N ha-1), or zero till management (2.4 kg N ha-1). Uzoma et al. (2015) observed no difference between tillage treatments, in a study conducted in the Red River Valley, during a period of moderate precipitation. In a meta-analysis, considering 239 direct comparisons between conventional tillage (CT) and no tillage (NT) or reduced tillage (RT), van Kessel et al. (2013) did not observe a significant impact of tillage system on N2O emissions (Fig. 15). They noted that, in long-term sites (<10 years) and dry climates, NT/RT reduced N2O emissions by 27%. In sites under NT/RT for reduced durations, N2O emissions were 57% greater than from CT counterparts.

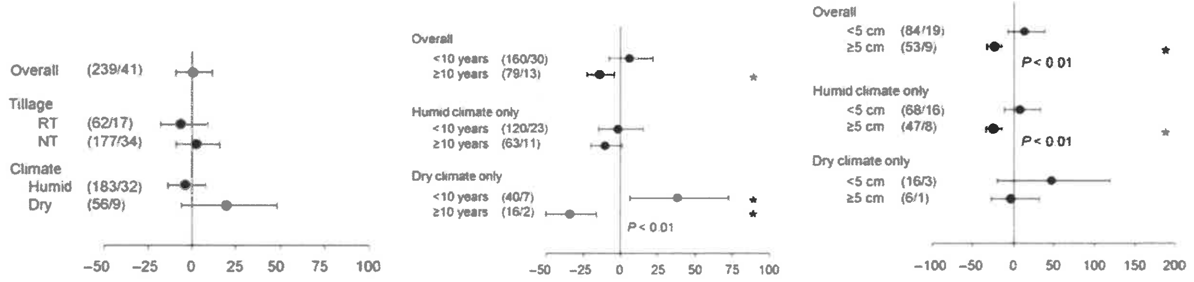


Figure 14: Effect of no till (NT) and reduced tillage (RT) relative to conventional tillage (%) on cumulative growing season N2O emission (kg N ha-1) broken out according to climate, duration of tillage treatment and depth of tillage. from van Kessel et al. (2013)

CROP ROTATION/CROPPING SYSTEM

Reflecting the role of legumes in rotation in N2O emissions has historically been complicated by apparent double accounting - emissions associated with the process of biological N fixation and emissions associated with N-rich residue decomposition. This issue has since been resolved (Rochette and Janzen, 2005). They note that there is little evidence for the use of an emission factor for biological N fixation (BNF) by legume crops, equal to that for fertilizer N. Increased N2O emissions in legume crops may result from the N release from root exudates during the growing season, and from decomposition of crop residues after harvest. As a result of this work N2O emissions induced by the growth of legume crops are estimated solely as a function of crop residue decomposition using estimates of above- and below-ground residue inputs.

Drury et al. (2014) found that growing corn in corn-oat-alfalfa-alfalfa rotations lost 6.5 kg N ha-1, 12% lower than emission under continuous corn cropping (7.3 kg N ha-1), despite the higher N input from fertilizer and legume N sources. Long-term management practices and crop rotation were attributed for the difference. Uzoma et al. (2015) observed that N2O emissions were more than 4 times higher under annual cropping than under alfalfa production. The plow down of alfalfa did not result in any significant emission events in either the fall or winter. Large emissions were observed in the year following alfalfa incorporation, despite there being only moderate amounts of additional N fertilizer application. This is consistent with the findings of Wagner- Riddle et al. (1997), who also measured high N2O emissions in the spring, following plow down of alfalfa the previous autumn. Rochette et al. (2004) found that, despite consistently higher soil N, N2O emissions were greater under alfalfa than timothy production in only 6 out of 10 field comparisons. Giweta et al. (2017) found that extended rotations involving legumes (with or without manure) resulted in greater N2O emissions than a wheat-fallow rotation. Further, they found that, in this long-term rotation experiment, N2O emissions were correlated with total soil N (Fig. 16). The rotation that did not contain a legume tended to have reduced total soil N and reduced N2O emissions. Manure addition increased total soil N and N2O emissions.

In a study of the interaction of manure application and cropping system, (Nikiema et al., 2016) found that, over two growing seasons and across manure types, the N2O emissions factor did not differ between annual cropping and perennial forage systems.

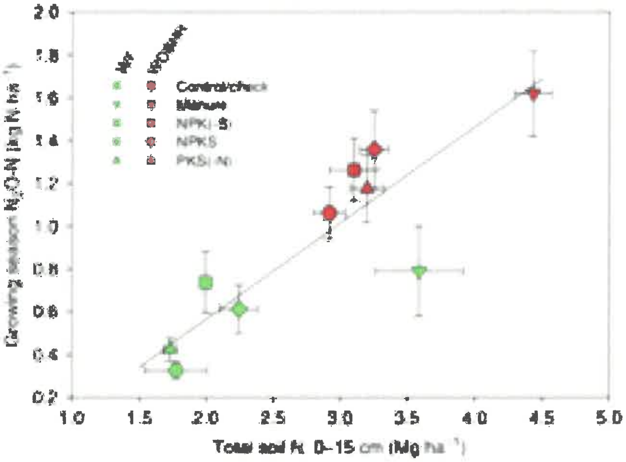


Figure 15: Relationship between cumulative growing season N2O emissions and total soil N (0-15 cm) of soils with different fertilization histories under wheat-fallow (WF) and wheat-oat-barley-alfalfa/brome hay- alfalfa/brome hay (WOBHH) crop rotations at Breton Plots, Western Canada. Symbols represent mean values, and error bars represent 1 standard error. The line represents the orthogonal regression relationship y = 0.45 x - 0.33. The slope is significantly different from zero (p<0.001), but intercept is not (p = 0.21). From Giweta et al. (2017).

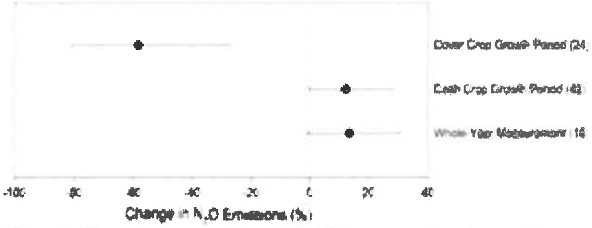


Figure 16: Effect of cover crops on area-scaled N2O emissions depending on different measurement periods. Mean values and 95% confidence intervals of the back-transformed response ratios are shown. From Han et al. (2017).

COVER CROPS

In a meta-analysis examining the role of cover crops in N2O emissions, Han et al. 2017 found that cover crops reduced N2O emissions by 58% relative to bare soils, but that the additional N supplied by the cover crop resulted in increased emissions in the subsequent crop (Fig. 17).

The magnitude of N2O emissions associated with the cover crop was inversely related to C:N ratio of the cover crop (Fig. 18). (Han et al., 2017) note that in most of the comparisons examined, the fertilizer N rate was not adjusted to reflect the additional N contribution of the cover crop.

In a meta-analysis of 26 peer-review articles, Basche et al. (2014) found that, in forty percent of the observations, a cover crop resulted in reduced N2O emissions, relative to adjacent systems not using a cover crop, and 60% indicated increased N2O emissions. Higher emissions were associated with legume cover crops and the incorporation of the cover crop into the soil.

Elevated N2O emissions appear to be associated with the decomposition of the cover crop. When examined over the entire year, cover crops were found to be closer to having a zero impact - periods of higher emissions associated with incorporation of the cover crop were offset by periods of lower emissions during the growth of the cover crop.

CROPPING SYSTEM AND N USE EFFICIENCY

Understanding the influence of the inclusion of legumes in rotation is complicated by the different ways the N associated with the legume are considered, in choosing the rate of N fertilizer to be applied. Rochette et al. (2018) found that, in land receiving animal manure, perennial cropping systems had N2O emissions that were 28% of those of annual cropping systems. This was attributed to the efficiency of N cycling in perennial cropping systems.

A study conducted in Minnesota found that corn stover removal decreased soil total CO2 and N2O emissions by 4 and 7 %, respectively, relative to no removal. Lower GHG emissions in stover removal treatments were attributed to decreased C and N inputs into soils, as well as possible microclimatic differences associated with changes in soil cover (Jin et al., 2014).

Thomas et al. (2017) found that cover crops (fall rye, oilseed radish) increased non-growing season N2O emissions. Winter N2O emissions were greater than spring or fall emissions.

In one of the two years studied, the magnitude of non-growing season N2O losses were correlated with late-fall soil NO3- concentration, with concentrations of < 6 mg N kg-1 soil limiting N2O emissions. In the second year N2O emissions were correlated with water extractable organic carbon.

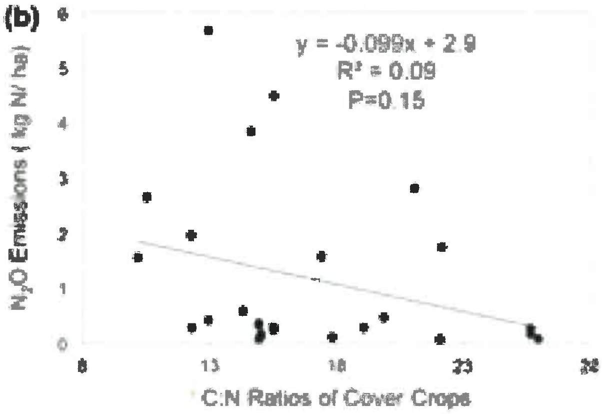


Figure 17: Relationship between N2O emissions and cover crop C:N ratios (n = 27). From Han et al. (2017)

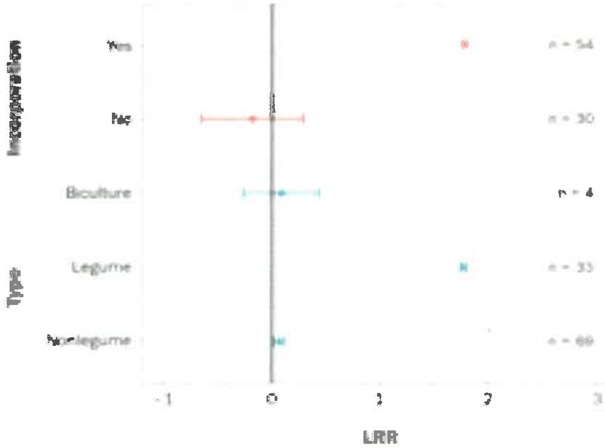


Figure 18: Meta-analysis of impact on N2O emissions associated with cover crops, incorporation of crop residues management. Positive numbers indicate increased emissions, negative decreased emissions.
(From Basche et al. 2014).

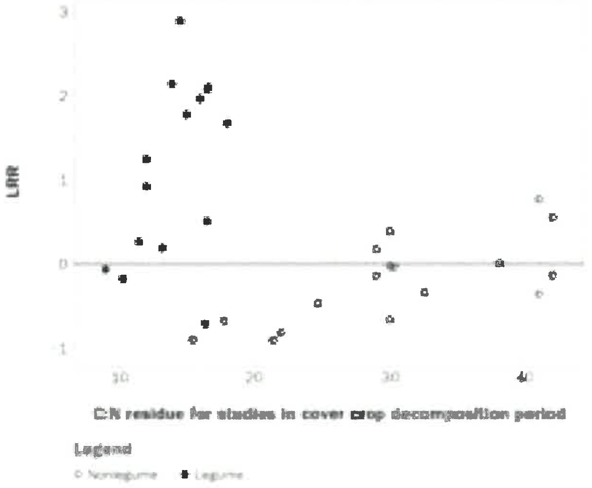
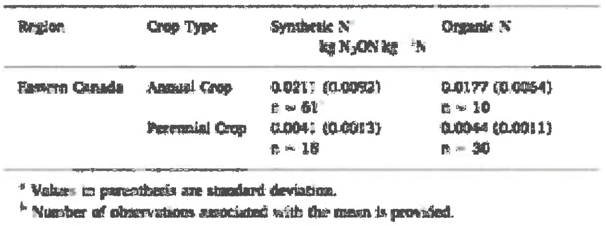


Figure 19: Meta-analysis of impact of C:N ratio of cover crop on N2O emissions during the decomposition period. (From Basche et al. 2014).



Region	Crop Type	Synthetic N[a]	Organic N
		$kg\ N_2O\text{-}N\ kg^{-1}\ N$	
Eastern Canada	Annual Crop	0.0211 (0.0092) n = 61[b]	0.0177 (0.0054) n = 10
	Perennial Crop	0.0041 (0.0013) n = 18	0.0044 (0.0011) n = 30

[a] Values in parenthesis are standard deviation.

[b] Number of observations associated with the mean is provided.

Table 3: Effect of crop type and fertilizer nitrogen type on soil nitrous oxide emission factors in Eastern Canada. From Rochette et al. (2018).

The effectiveness of including a cover crop under reduced tillage, to lower net GHG balance relative to conventional tillage, is dependent on increased soil organic carbon to compensate for higher N2O emissions (Abdalla et al., 2014). The use of non-legume cover crops that are not incorporated in the soil show the greatest potential for N2O emissions reduction.

CONCLUSIONS RELATING TO N2O EMISSIONS REDUCTION

There is now a considerable body of scientific evidence supporting the ability of 4R N fertilizer management to reduce N2O emissions. It is clear that developing a 4R program is, at the very least, region- and crop-specific and, in many cases, site-specific. The overall program must consider the interaction of source, rate, time and place.

The impact of N fertilizer management on N2O emissions is highly dependent on climate and soil type. The timing of precipitation remains an important determinant of the potential for N2O loss. Open winters result in greater non-growing season emissions. Fall nitrate accumulation is an important strategy in reducing N2O emissions, and fall N applications should be avoided.

Fertilizer products/practices that delay the formation of nitrate are consistent in their ability to reduce N2O emissions. Urease and nitrification inhibitors are particularly consistent in this regard. Products and placements that influence the solubilization of the fertilizer product are influenced by the pattern of precipitation and, as a result, produce more variable results. Similarly, timing of fertilizer N application interacts with the pattern of precipitation in determining the magnitude of reduction in N2O emissions.

Determining the right rate of N fertilizer still remains one of the greatest challenges establishing a 4R program. The need to consider all N sources and non-linear nature of N2O emissions to soil N availability complicate the determination of the right rate. The emergence of tools to provide site specific measures, soil N supply and plant N response would greatly assist the determinate of right rate.

There is a greater realization and understanding emerging as to the role of other soil management and cropping practices in determining the potential for N2O emissions. The choice of the most appropriate 4R practices should consider the impact of these factors in determining the magnitude and timing of the potential for N2O losses.

While this review has primarily focused on the potential for N2O emissions, the potential for pollution swapping must also be considered. Practices that decrease N2O emissions, but result in increased NH3 or NO3- loss, do not result in increased N use efficiency. While the indirect emissions from these compounds may not be as great as direct emissions of N2O, the overall impact on the ecosystem should be considered.

NITROUS OXIDE EMISSIONS REDUCTION PROTOCOL (NERP)

Fertilizer Canada is leading the development of a Nitrous Oxide Emissions Reduction Protocol (NERP) fashioned after the protocol developed by the province of Alberta.

Table 4: Suggested emissions reduction modifiers for 4R nitrogen fertilizer management in rain-fed potato production in Eastern Canada.

Right Source	**Right Rate**	**Right Time**	**Right Place**	**Emissions Reduction Modifier**
Any N fertilizer with guaranteed analysis.	Apply based on nitrogen balance or provincial guidelines for yield goals. Set field specific rates based on previous yield history and soil types. Adjust for variety following provincial guidelines.	Apply nitrogen in spring before or at seeding. No N application on frozen soil and/or snow-covered ground.	Broadcast and incorporate. Consider using enhanced efficiency fertilizer in cases where incorporation is not possible following surface application	1.0 (no reduction)
Same as Basic, plus Use of enhanced efficiency fertilizers (nitrification inhibitors, urease inhibitors, or controlled release) should account for at least 33% of total N budget	Same as Basic, plus Adjust N rates based on estimates of residual nitrogen in combination with estimates of other soil supply sources (mineralization, previous pulse or other legume crops). Build N rate strategy based on well -developed field management zones adjusting N rates according to estimates of field variability.	Same as Basic. Split nitrogen between before or at seeding and one or more in-season applications.	Same as Basic	0.85
Same as Intermediate, plus Use of enhanced efficiency fertilizers (nitrification inhibitors, urease inhibitors, or controlled release) should account for at least 50% of total N budget	Same as Intermediate, plus Monitor in-season and/or post season N use using technologies such as crop sensors, satellite or UAV imagery, crop nitrogen demand modelling, field scouting, and petiole testing. Apply Nitrogen according to quantified field variability usine digitized soil maps (advanced variable rate)	Same as Intermediate	Same as Intermediate	0.85

METHANE

Methane is a greenhouse gas that is produced by biological degradation of various organic carbon-containing materials, when those materials are in low-oxygen or anaerobic conditions.

Methane as a greenhouse gas has 23 times the effect of carbon dioxide in the atmosphere. As methane rises into the air, it naturally reacts with hydroxyl radicals (OH-) to create water vapour and carbon dioxide. As a result, the lifespan of methane in the atmosphere was estimated to be 9.6 years as of 2001. Below is a chart of global total methane emissions from 1988 to 2016(1).

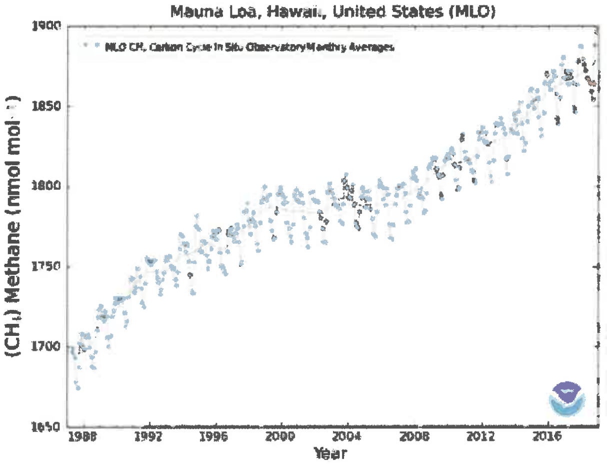


Fig. 20. Global total methane emissions, 1988-2016 (1)

As seen in the above chart, since the 2001 estimate, methane has continued to accumulate in the atmosphere globally. Because methane is increasing faster than it degrades, the lifetime of methane in the atmosphere is likely now longer than 10 years.

Besides being an important greenhouse gas, methane is also flammable and toxic if inhaled. This creates a hazard in low-oxygen environments such as sewers and enclosed manure pits.

Examples of methane generation in farm environments include breakdown of manure in high-moisture storage piles or pits and fermentation of feed contents by bacteria in the rumen stomachs of ruminant livestock (sheep, dairy cattle, beef cattle).

Methane gas is a potent greenhouse gas produced in the rumen of cattle during the normal process of feed digestion and represents a significant loss of feed energy that increases feed costs. For example, a lactating dairy cow produces about 400 grams of methane each day. These methane losses quickly add up. In one year, the amount of methane a dairy cow produces is equivalent to the greenhouse gas emissions from a mid-sized vehicle driven 20,000 kilometres.

Agriculture and Agri-Food Canada (AAFC) scientists at the Lethbridge Research Centre in Alberta are developing methane mitigation strategies for the beef and dairy industries.

Dr. Karen Beauchemin, a livestock specialist with AAFC, is finding ways to measure and curb methane gas emissions. She believes that since approximately 40% of agricultural emissions in Canada come directly from methane, with 90% from cattle and sheep as a result of feed digestion, agricultural methane emissions can be best reduced through livestock feeding and management systems.

"We have conducted feeding trials to determine how various diets can lower methane emissions from cows," explains Dr. Beauchemin. The team used specialized instrumented rooms at the Lethbridge Research Centre to measure methane losses from the animals and also recorded effects of the various diets on milk and meat production and feed efficiency.

FEEDING STRATEGIES

So far, several feeding strategies show promise. For example, increasing the level of dietary fat by feeding a diet of crushed oilseeds (sunflower seed, canola seed or flaxseed) or dried corn distillers grain reduced the energy lost as methane by up to twenty percent. Similar reductions in methane were also seen when other fat sources, such as whole cottonseed, plant oils, and some ethanol byproducts were added to the diet. Overall methane was lowered by 5 percentage units for each percentage of crude fat added to the dietary dry matter.

Adding more grain in the ration also reduced methane emissions, but the scope for increasing the amount of grain fed to ruminants is fairly limited as this ignores the importance of ruminants in converting fibrous feeds, unsuitable for direct human consumption, to the high quality protein sources milk and meat. Diets based on corn grain, compared with barley grain, reduce methane emissions, as does feeding high quality forages such as corn silage and alfalfa. Ionophores, antimicrobials that target the ruminal bacterial population and increase production efficiency, also reduce methane emissions at least for a short time.

FEED ADDITIVES

The team is also examining feed additives, including plant extracts (condensed tannins, saponins, essential oils) and rumen modifiers (yeast, bacterial direct fed microbials, and enzymes). In a recent study, they supplemented the cattle diet with commercial active dried yeast products including a new product selected on its ability to improve fiber digestion in the rumen.

This combination was found to reduce methane by six percent and demonstrates the possibility of developing yeast products to improve cattle digestion.

Other research teams in New Zealand and in Australia are also exploring innovative ways of eliminating the microbes in the rumen that produce the methane, such as vaccines. This research is expected to lead to practical solutions that can be used to reduce methane from beef and dairy cattle in the future.

FEED CONVERSION EFFICIENCY

Because methane production increases as the animal eats more feed, improving feed conversion efficiency, the amount of feed consumed per kilogram of milk produced or weight gained, decreases methane output. Diets that are more highly digestible lower the amount of methane emitted per product produced. It may also be possible to breed more efficient cattle that produce less methane. Researchers in Canada, Australia and New Zealand are currently evaluating methane production in beef and dairy cattle selected for high- versus low-feed conversion efficiency.

MANAGEMENT PRACTICES

Management practices that reduce animal numbers on beef and dairy farms also help reduce methane production. For example, improving reproductive performance of cows leads to fewer replacement heifers, which helps reduce methane emissions.

MODELING EMISSIONS USING HOLOS SOFTWARE

Livestock producers wanting to gain a better understanding of the greenhouse gas emissions from their farms can use the Holos greenhouse gas calculator developed by Agriculture and Agri-Food Canada. Holos estimates carbon dioxide, nitrous oxide and methane emissions from rumen fermentation, manure management, cropping systems and energy use. However, this software relies on a database generated from Western Canadian data, which poorly relates to Atlantic Canada due to different soil types and climates. Work is required to obtain reliable data from Atlantic Canada farms to update the software.

The program was designed to help farmers envision and test possible ways of reducing greenhouse gas emissions on their farms and has been evaluated across Canada by the Soil Conservation Council of Canada's (SCCC) Taking Charge Teams. These teams, located in every province, tested the program by plugging in real data provided by farmers.

The program allows farmers to select farm management practices that best describe their operation. It then allows the user to enter options that might reduce emissions and estimate how those options would affect whole-farm emissions.

"Livestock operations are complex ecosystems because of the various components that interact, including the soils, crops, feeds, animals and manure," explains Dr. Beauchemin. On a typical beef or dairy farm methane from the animals and their manure accounts for more than half of greenhouse gas emissions, nitrous oxide from cropping and soils accounts about a third, and carbon dioxide from on-farm energy use accounts for the rest.

"It is important to ensure that a reduction in methane resonates throughout the farm to decrease total greenhouse gas emissions. In some instances, reducing methane emissions from cows can lead to an undesirable increase in the other greenhouse gases emitted by the farm." There are already a number of options for livestock producers wanting to take advantage of methane reduction and more solutions are expected in the future (see table 5). The bottom line is that controlling the loss of feed energy as methane helps improve efficiency of cattle production and is an environmentally sound goal for the livestock industry.

Table 5. Methods for reducing methane e missions from dairy cows and expected timeline

Timeline for development	**Mitigation practice for the dairy industry**	**Expected reduction in methane**
	Feeding oils and oilseeds.	5 to 20%
	Higher grain diets.	5 to 10%
	Using legumes rather than grasses.	5 to 15%
Intermediate	Using corn silage or small grain silage rather than grass silage or grass hay.	5 to 10%
	Lonophores	5 to 10%
	Herd management to reduce animale numbers.	5 to 20%
	Best management practices that increase milk production per cow.	5 to 20%
	Rumen modifers (yeast, enzymes, directly fed microbials).	5 to 15%
5 Years	Plant extracts (tannins, saponins, oils).	5 to 20%
	Animal selection for increased feed conversion efficiency.	10 to 20%
	Vaccines	10 to 20%
10 Years	Strategies that alter rumen microbial populations.	30 to 60%

MEASURING RUMINANT METHANE EMISSIONS ON-FARM

Measuring methane production from ruminant animals is historically difficult, costly and unreliable. However, as the issue gains more importance, new technologies are evolving to address this unmet need.

One of the methods, called GreenFeed, is basically a breathalyzer for cows. The device was designed by C-Lock Inc., a scientific company specializing in livestock measurement tools, according to Richard Todd, a research scientist with USDA.

"Cattle are trained to put their head into an open hood (with food), and while they're there munching on the little treat the device is sampling their breath," Todd said. "Then we can calculate the methane emissions while they're inside."

These new technologies also include laser interferometry, which can measure the methane rising from cows as they feed or graze, as well as the methane emerging from manure pits and field applications.

While it is beyond the scope of this project, it is suggested that the research needed on PEI to generate local GHG-related data and create tools for GHG reduction be incorporated into Federal and Provincial research plans in the near future.

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CARBON

CARBON STORAGE

One of the opportunities for reducing the carbon footprint of agriculture in PEI is to increase the storage of carbon in agricultural soils, by increasing their soil organic matter content. In recent decades the soil organic matter content of agricultural soils in PEI has been in decline (Nyiraneza et al., 2017). The average decline of 1% has resulted in a release of 0.673 Mt of CO2. This decline has also resulted in a decline in the health and productivity of these soils. There is the opportunity to reverse this trend and sequester carbon in agricultural soil (Carter et al., 2009a; Peters et al., 2006; VandenBygaart et al., 2010), as well as increase the health and productivity of these soils (Carter et al., 2009a). In addition, the accumulation of carbon in soil as soil organic matter results in multiple enhanced ecosystem services, ranging from the protection of groundwater to resiliency against the impacts of climate change (Janzen et al., 2006). From an agricultural perspective, soils with increased soil organic matter content result in increased soil fertility, reduced susceptibility to erosion and increased water holding capacity (Janzen, 2006).

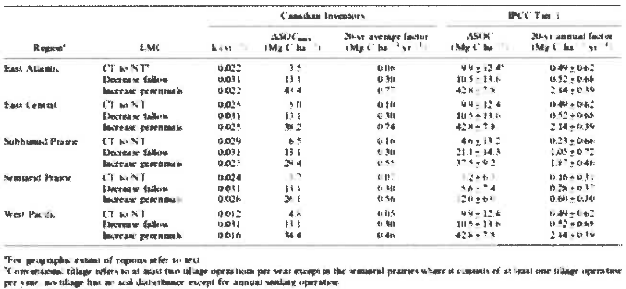
Beneficial management practices for increasing the soil organic matter content of soils generally involve increased diversity and duration of plant cover, and decreased soil disturbance (Carter et al., 2009b; Peters et al., 2006). The addition of organic materials to soil have also been proposed as a means of increasing soil organic matter content, but the success of these measures often depends on the associated soil management. It is also important to note that the organic matter content of soil also influences general microbial activity and, therefore, has implications for soil fertility and the potential for N2O emissions (Carter et al., 2009a; Gregorich et al., 2005). This is particularly true of soils receiving organic amendments or crop residues, as the added carbon is often far more bioactive than is soil organic matter (Charles et al., 2017).

REDUCED INTENSITY, DEPTH AND FREQUENCY OF TILLAGE

In general, the potential to sequester carbon as a result of reduced tillage has been assumed to be limited in Atlantic Canada (VandenBygaart, 2016a, b). It has been suggested that current Tier I carbon storage coefficients presented by the IPCC may actually overestimate the carbon storage capacity of Eastern Canadian soils, particularly in the short-term (5-10 years) (Angers et al. 1997). VandenBygaart et al. (2008) reported that simulation modeling indicates that the potential for the conversion of tilled system to no till results in a potential for carbon storage of 3.5 Mg C ha-1 , whereas the IPCC Tier I coefficient assumes this value to be 9.9 Mg C ha-1 (Table 1).

These conclusions are primarily based on estimates of storage capacity. Nyiraneza et al. (2017) observed that, over an 18-year period, 56% of the total land base in PEI area shifted from class 3 (3.1%-4% SOM) to class 2 (2%-3% SOM), equivalent to an approximate SOM decline of 1%. This amount corresponds to the loss of 0.05% SOM yr-1 or 570 kg C ha-1 y-1. A 1% decrease in SOM over 56% of the total land area resulted in the emissions of 3.3 Mt of C or 12.1 Mt of CO2e over an 18-year period.

Table 6. Rate constants (k), maximum carbon exchange (ASOC max) and 20-yr average C change factors for Canadian soils, for converting from conventional tillage (CT) to no-till (NT) (VandenBygaart, et.al., 2008)



		Canadian Inventory			IPCC Tier 1	
Region^a	LMC	k (yr^{-1})	ΔSOC$_{max}$ (Mg C ha^{-1})	20-yr average factor (Mg C ha^{-1} yr^{-1})	ΔSOC (Mg C ha^{-1})	20-yr annual factor (Mg C ha^{-1} yr^{-1})
East Atlantic	CT to NT^b	0.022	3.5	0.16	9.9 ± 12.4^c	0.49 ± 0.62
	Decrease fallow	0.031	13.1	0.30	10.5 ± 13.6	0.52 ± 0.68
	Increase perennials	0.022	44.4	0.77	42.8 ± 7.8	2.14 ± 0.39
East Central	CT to NT	0.025	5.0	0.10	9.9 ± 12.4	0.49 ± 0.62
	Decrease fallow	0.031	13.1	0.30	10.5 ± 13.6	0.52 ± 0.68
	Increase perennials	0.025	38.2	0.74	42.8 ± 7.8	2.14 ± 0.39
Subhumid Prairie	CT to NT	0.029	6.5	0.16	4.6 ± 13.2	0.23 ± 0.66
	Decrease fallow	0.031	13.1	0.30	21.1 ± 14.3	1.05 ± 0.72
	Increase perennials	0.025	29.4	0.55	37.5 ± 9.2	1.87 ± 0.46
Semiarid Prairie	CT to NT	0.024	3.7	0.07	7.2 ± 6.3	0.36 ± 0.31
	Decrease fallow	0.031	13.1	0.30	5.6 ± 7.4	0.28 ± 0.37
	Increase perennials	0.026	29.1	0.56	12.0 ± 6.0	0.60 ± 0.30
West Pacific	CT to NT	0.012	4.8	0.05	9.9 ± 12.4	0.49 ± 0.62
	Decrease fallow	0.031	13.1	0.30	10.5 ± 13.6	0.52 ± 0.68
	Increase perennials	0.016	34.4	0.46	42.8 ± 7.8	2.14 ± 0.39

^{a}For geographic extent of regions refer to text.
^{b}Conventional tillage refers to at least two tillage operations per year except in the semiarid prairies where it consists of at least one tillage operation per year; no-tillage has no soil disturbance except for annual seeding operation.
^{c} Mean ± 95% confidence limits.

Carter and Sanderson (2001) advocated a shift in primary tillage of the crop, preceding potato, from the fall to the spring, and reducing the intensity of tillage (mouldboard to a chisel plow). They demonstrated, in an 18-year long trial, that switch from fall to spring tillage resulted in improved soil cover and water retention over the winter period. The use of the less intensive chisel plow resulted in less soil disruption, and the burying of less residue, than does traditional moldboard inversion tillage.

The conservation tillage system, when compared to conventional tillage, increased soil organic C, large water-stable macro-aggregates, and soil particulate C and N in the potato year. After the potato phase, rotation crops were associated with the further restoration of all soil C and N fractions and soil structural stability indices (Carter et al., 2009a).

EXTENDED ROTATIONS

Use of forage increased stored C and N by 55% and 35%, respectively. The ability of the forage sites to maintain greater levels of organic matter, relative to adjacent cultivated sites, underlines the importance of continuous vegetation growth and associated C and N inputs for sustaining organic matter storage in Podzolic soils (Carter et al., 1998).

USE OF COVER CROPS

Cover crops, especially sorghum-sudangrass, have been shown to have the potential to increase potato tuber yield and quality (Essah et al., 2012). Potatoes grown after cover crops produced 13-25% more tubers, compared to no cover crop (Jahanzad et al., 2017b). Potatoes grown after cover crops often produced highest yield at lower rates of nitrogen fertilizer. Potatoes after winter pea or forage radish produced the same or higher yields (10-25%) at 75 or 150 kg N ha-1, relative to those without a cover crop fertilized at 225 kg N ha-1(Jahanzad et al., 2017b). Forage radish or winter pea improved nitrogen use efficiency, as a result of greater synchrony between N release from cover crop residues and potato N demand, than that of cereal rye (Jahanzad et al., 2017a). Rye provided less N to a succeeding potato crop than forage radish or winter pea. Overall, forage radish and winter pea were better alternatives to rye, as indicated by less N fertilizer application, sustained tuber yield, and tuber mineral nutrient concentration (Jahanzad et al., 2017b).

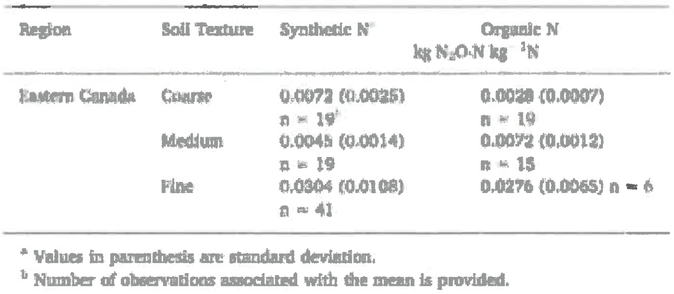
Cover crops also show promise to increase SOC cycling (Ghimire et al., 2018), reduce N requirements (Guardia et al., 2016; Jahanzad et al., 2017b), and potentially reduce N losses (Jahanzad et al., 2017b). One of the challenges in this type of research is that longer cropping periods are needed to detect the influence of cropping system and the use of cover crops on SOC (Bavin et al., 2009; Beehler et al., 2017). What is clear is that roots and rhizodeposition are critical elements in assessing the ability of cover crops to cause increased SOC (Austin et al., 2017). Shoot and root biomass contribute to SOC but, since the majority of both root and shoot inputs are eventually mineralized, cover crops will likely need to be included every year in rotations to accumulate soil C (Austin et al., 2017).

Daryato et al. (2018) argue for a detailed economic analysis to calculate the direct (e.g., reduction in the amount of chemical fertilizer) and indirect monetary benefits (e.g., GHG emissions, the improvement of soil health) of cover crops. Such a comprehensive analysis could serve as incentive for producers to integrate cover crops into their management practices (Daryanto et al., 2018).

SOIL TYPE

Soil characteristics influence the environment of the soil microorganisms that are producing N2O. Relevant characteristics include soil physical characteristics (texture, bulk density), which influence the soil water content and aeration status; chemical characteristics (pH), which influence chemical speciation and the microbial environment; and, biological characteristics (organic matter content, microbial community) which impact the nature and extent of microbial activity.

Soil texture influences the water-holding capacity of the soil and, therefore, interacts with precipitation in influencing N2O emissions. Rochette et al. (2018) examined the impact of soil texture on N2O emissions from synthetic and organic N sources in Eastern Canada (Table 7). They found that emission factors increased in finer-textured soils. In addition, organic N sources had lower emission factors in coarse-textured soils, but had emission factors that were equal to or greater than those for synthetic nitrogen sources in medium- and fine-textured soils. Table 8.

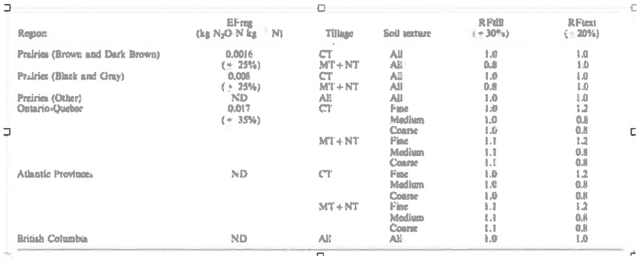


Region	Soil Texture	Synthetic N[a]	Organic N
		kg N_2O-N kg^{-1}N	
Eastern Canada	Coarse	0.0072 (0.0025) n = 19[b]	0.0028 (0.0007) n = 19
	Medium	0.0045 (0.0014) n = 19	0.0072 (0.0012) n = 15
	Fine	0.0304 (0.0108) n = 41	0.0276 (0.0065) n = 6

[a] Values in parenthesis are standard deviation.

[b] Number of observations associated with the mean is provided.

Table 7: Effect of texture and fertilizer nitrogen type on soil nitrous oxide emissions factors in Eastern Canada (Rochette et al. 2018).



Region	EFreg (kg N_2O-N kg^{-1} N)	Tillage	Soil texture	RFtill (± 30%)	RFtext (± 20%)
Prairies (Brown and Dark Brown)	0.0016 (± 25%)	CT	All	1.0	1.0
		MT + NT	All	0.8	1.0
Prairies (Black and Gray)	0.006 (± 25%)	CT	All	1.0	1.0
		MT + NT	All	0.8	1.0
Prairies (Other)	ND	All	All	1.0	1.0
Ontario-Quebec	0.017 (± 35%)	CT	Fine	1.0	1.2
			Medium	1.0	0.8
			Coarse	1.0	0.8
		MT + NT	Fine	1.1	1.2
			Medium	1.1	0.8
			Coarse	1.1	0.8
Atlantic Provinces	ND	CT	Fine	1.0	1.2
			Medium	1.0	0.8
			Coarse	1.0	0.8
		MT + NT	Fine	1.1	1.2
			Medium	1.1	0.8
			Coarse	1.1	0.8
British Columbia	ND	All	All	1.0	1.0

Table 8: Regional emission factors (EFreg) for the estimation of direct N2O emissions. RFtill is the ratio factor accounting for the effect of tillage; RFtext is the ratio factor accounting for the effect of soil texture on emissions (from Rochette et al. 2008b).

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SECTION FOUR.

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SECTOR AWARENESS OF GHG MITIGATION OPPORTUNITIES

Awareness of the sources of GHG emissions, the current practices that contribute to them, and the current or potential practices that could mitigate emissions, will have an impact on the ability to embrace GHG-mitigating Beneficial Management Practices in the future.

In order to determine the awareness of PEI producer groups and farmers, within the timeframe of this project, the following groups were contacted:

- PEI Department of Agriculture commodity experts
- PEI Federation of Agriculture Commodity Board leaders
- Agriculture & Agri-Food Canada research staff at AAFC Charlottetown
- Individual Producers (as time and availability allowed)

The following abbreviations are used throughout this section:

- AAFC – Agriculture and Agri-Food Canada
- EFPEI – Egg farmers of PEI
- PEIDAF – Prince Edward Island Department of Agriculture and Fisheries
- PEIFA – Prince Edward Island Federation of Agriculture

As well, secondary research was conducted online, to determine past and current PEI farm-based activities as disclosed on pertinent web sites, such as government sites and news releases on PEI farm-related project activities.

This information served as a portion of the basis for drafting the Beneficial Management Practices defined in this report, by providing the authors some knowledge of the types of producers who might be willing to participate in future projects based on these Practices.

Following are the results of these engagements and inquiries, grouped by commodity, including sources of information. The information is complete, within bounds of privacy and government confidentiality.

ANIMAL PRODUCERS

BEEF PRODUCERS

ENGAGEMENT

- John Annema, owner,
  Oyster Bed Compost and beef farmer
- Barb Enman, former beef farmer
- Les Halliday, PEI DAF
- Roger Henry, composting expert, AAFC

Current Size (2016)
9,319 beef cows + 8126 steers
~ 25% more than in 1991

Beef production in the region is currently reasonably steady. However, according to the Maritime Beef Council (2016 AGM), the future plan for the region is to expand Maritime beef herd numbers by 20,000 in the next 5 years (ie: by 2021) However, it is uncertain how much PEI herds will be able to expand, based on feed costs and market realities.

MAJOR PRODUCTION CONCERNS

All beef manure on PEI, and largely across Canada, is stored and handled in solid form, including the bedding, which usually consists of straw or sawdust/wood chips. Manure is removed from feedlots every two weeks on average, and either stored in an open-sided storage barn or trucked directly to a nearby field. There, it is stored in uncovered windrows, where it is allowed to crust over and "cure" until spread in the spring or, less commonly, in the fall. Due to difficulty of access to fields in the, winter, field storage areas tend to be very close to the barns.

Due to presence of straw in the piles, the Carbon to Nitrogen (C:N) ratio is conducive to composting, assuming the pile is neither too wet (anaerobic, creating methane) or dry (preventing compost bacteria and fungi to grow).

Because the heaps not covered, wet conditions create a leachate into surrounding soil from excess moisture. This results in a loss of nutrients from the unspread manure to the soil, which can result in groundwater pollution and/or N2O release at warmer soil temperatures.

While manure may be spread in the fall or winter, most is spread in the spring. Because few producers test the nutrient content of their manure, the amount applied to fields may be in excess or too low, for the field and crop requirements in the coming year. As well, depending on the user, manure may not be spread at the optimum time.

AWARENESS OF OPPORTUNITIES

Based on nutrient needs on-farm, many producers swap manure for land or straw with nearby potato farms. The distance between partnering farms restricts the effective use of manure. Many crop producers would like to obtain more manure, as it is seen as in short supply, oftem because of the distance between the beef producer and the purchasing farm. This suggests that manure is very under-valued, compared to equivalent value of chemical fertilizer, if the soil organic matter and health benefits are factored in. At the same time, many beef producers report utilizing the majority (at least 70%) of their manure on their own fields.

Beef producers need a more effective and inexpensive way to truck manure to where it is most needed, but cost, labor and time is a barrier to improving this. There is an opportunity to look for a better way to swap manure for straw/grain, etc (eg: a Manure Exchange based on one of the custom manure trucking and spreading companies, as practiced in some parts of the USA).

Also, there is a resistance to the practice of covering beef manure windrows, based on cost of coverings, time and equipment. Compost experts, such as Oyster Bed Compost, suggest turning the pile at least two times a week during the spring and summer, using a commercial compost turner. These opportunities are dealt with in detail in the BPP section of this report.

LIKELY TO ADOPT

Beef producers would consider improvements, such as covering the manure in storage areas until spreading, or composting the piles, if some government pilot program could assist with extra time & labour costs. Producers would need to see more information on the format of a Manure Exchange before considering that, but generally those consulted see it as a good idea.

DAIRY PRODUCERS

Engagement

- Doug Thompson, PEIDAF
- Fred VanderKloot, PEDAF
- Dairy Farmers of PEI
- Vernon Campbell, Producer
- Oyster Bed Compost, Inc.

MAJOR PRODUCTION CONCERNS AND ACTIONS

MANURE MANAGEMENT/STORAGE

Because of early access to government support, as well as a trend toward in-barn animal management, the past decade has seen a sector-wide implementation of concrete manure storage facilities, both as new builds, as well as expansions of earlier adoptions of that manure management tool. The sector sees this as an improvement in the cost of manure management. After those capital cost expenditures, it would be difficult to return to an outdoor

COST OF BEDDING

The cost of bedding is steadily increasing, as straw continues to be in short supply. Many partnering farmers are chosing to grpow straw for themselves, as residue cropping. Producers are therefore moving to other bedding options, such as sawdust, peat and sand, each of which creates its own positive or negative GHG issues. Sand can be used longer as a bedding, lowering the inputs from crop material and manure removal from barns, but creates more sediment in the manure pits, making removal and spreading more difficult.

COST/AVAILABILITY OF FEED

The cost of producing or growing hay feed is increasing (due to lowering yields and competition for use, such as potato growers using hay crops as cover and residue crops), to the point that more corn is now being grown and added to the ration.

LABOUR ISSUES

Lack of skilled (or any) labor locally, paired with increasing difficulty obtaining seasonal immigrant workers, as well as herd health and efficiency issues, is powering the trend towards automated milking and feeding equipment.

AWARE OF OPPORTUNITIES

The awareness of manure management, specifically the need for environmentally (GHG) better storage and usage is evident by the number of manure pits constructed in the past 5-6 years. Beyond the PEI requirements defined under the Manure Management Guidelines, a thorough review of the environmental assessments of these projects (numbering 17 or more), shows growing awareness of innovations such as:

Separation of liquid and solid components of manure for separate treatment
(eg: liquids to septic, solids to composting or spreading)

Avoiding inclusion of dairy parlor and milk room wash water to manure
Given that spreading manure has a GHG-related cost, for best management, manure should be in either a solid form (aerobically store-able and spreadable by traditional means) or liquid form (easy pit storage, removal and injection field application).

Custom manure removal, transport and field application services
Two PEI companies currently provide these services, one in Eastern PEI (Oyster Bed Bridge) and one in Western PEI (near Summerside). This has been proven sufficiently effective that there is a need for more services such as this. It also may support a Public-Private plan to create a Manure Exchange for all types of PEI manure sources, as has been successful in the USA.

From discussions with growers, it is apparent that the majority of dairy manure is utilized on-farm, although sme is removed from the farm by commercial services, such as Oyster Bed Compost, or sold/swapped to potato and other growers in exchange for bedding of forage, from partnering farmers' rotation cropping (usually nearby potato farms).

Animal producers also manage substantial amounts of land for production of forage and bedding crop. Those practices include spreading of manure. However the awareness of the GHG effect of manure utilization is much lower than that of manure storage, which structures and practices (especially composting) undergo Provincial environmental review and oversight.

The awareness of the manure application portions of PEI's Manure Management Guidelines is a barrier to adoption by dairy farms of potentially more costly practices/BMPs, such as:

Dewatered manure storage in-field with covers and appropriate carbon content for successful composting

Soil-testing cropland such as hay or corn for actual manure-based nutrient requirements, prior to manure application schedules being set, to fine-tune the use of manure as a nutrient, which has a shelf-life.

Pasture management planning, involving pasture soil testing, and choosing the best time to apply and till-in manure to fields. This will reduce CH3 and N2O emissions due to not tilling in in a timely manner and/or over-application

Manure injection, which would be most possible if the manure was of the correct moisture content for existing equipment

Willingness to work with the two custom manure application services in PEI, who currently under-serve Eastern & Western PEI respectively, and perha[ps stimulate fureth service companies to become involved.

LIKELY TO ADOPT

As farm infrastructure modernizes and herd sizes grow, many PEI dairy farms have implemented or expanded concrete manure storage pits in the past 5-6 years, as evidenced from environmental assessment applications. These recent capital costs may be a barrier to further storage improvements, such as manure pit covers, biofuel usage or composting/stabilization options.

However, with minimal incentives, some producers are willing to revisit the covering of manure storage pits, which have a negative historic image, and perhaps manure composting.

If dairy producers are willing to manage manure liquids and solids separately, they may adopt a practice of composting the solids in windrows (or having a service site do this as part of the removal services), as is standard in the beef industry. This would require ensuring that the bedding or other post-removal materials were sufficient to create te correct C:N ratio for effective composting, as well as the willingness of the farmer to incur the equipment and labor costs of managing composted manure.

4.1.2 PORK

Engagement

Tim Seeber, PEI Hog Commodity Marketing Board

Producers (not disclosed)

This sector runs an average of 1000 live hogs/wk to the Larsons slaughterhouse in Quebec.

Hog producers regularly also grow grains & soybeans as rotation, and lease land to potato growers. Some (5 producers reported) grow corn as feed., Corn is a high N feeder to absorb over-manured nearby fields (due to lack of manure market and cost of hauling beyond certain distance)

MAJOR PRODUCTION CONCERNS

MANURE MANAGEMENT/UTILIZATION

50% of hog producers utilize all their manure, spreading it in the most nearby fields, due to transport costs

Potato growers who lease hog producer land do not want manure applied the year before potatoes, due to high phosphorus content and a claimed risk of scab disease

Hog manure pits fill faster in rainy seasons, requiring higher cost of more frequent emptying and spreading, and can also overflow if leftover manure is present in the spring

Often there is insufficient nearby land affordably available to dispose of/spread manure, meaning the more nearby fields are over-fertilized, lending to N2O emissions

LAND USE

Field crop industry pressure (especially potato sector, which is struggling to obtain additional land for rotation crops) on land use through leasing land from other sectors, including hag farms, translates into loss of ~170K ac grain production as rotation crops (crop rotations force hog producers to be price takers in purchasing feed)

Leased rotation to potato pressure decreases hog producer land OM b/s causes grain plow-down pre-potato, less pasture

Potato rotation crops such as soy returns no OM, causes nematodes

AWARENESS OF OPPORTUNITIES

Reported innovation projects involving PEI hog producer, mostly funded by PEI government programs, include hog barn ventilation upgrades (Energy Efficiency), and construction or expansion of concrete liquid manure pits.

As well, an increasing numbers of Amish producers are seen as low-impact leaders, due to organic-style and low-energy inputs from non-fossil-fuel machinery and transport.

The authors have identified the following further innovations, which, if implemented, could result in GHG mitigation effects.

COVERING MANURE STORAGE PITS

In the early 2000's, projects supported by the Province assisted in covers for hog manure pits, to control odor and potentially prevent methane out-gassing. Failures in these early applications, due to covers blowing off in winter wind, etc., are a current barrier to re-introduction of new and improved materials and technologies (such as marketed in Canada by GORE Technologies). There is a need to revisit this as a methane capture opportunity, including potentially "flaring" or burning off contained methane in safe legal ways.

A second option to inert covers is to add a "floating solids" cap on manure tanks, consisting of 1-2 feet of wood chips, that form a semi-anaerobic cover as well as a space for methane-producing bacteria to live, may be an affordable solution.

MANURE INJECTION

Randall De Boer (DeBoer Ag, Earnscliff) hauls and spreads dairy and/hog manure in the Spring. He would consider injection technology if can get a fair price for their manure. Hog manure increases Organic Matter and & is an early nitrogen boost to keep new crops ahead of wireworm, weeds and other challenges.

PROGRAMS

Awareness of programs that would assist hog farmers include the Swine Innovation part of the National Research Cluster, under the Canadian Agricultural Partnership program (CAP), which funds environmental projects, such as hog feeding projects which show an opportunity to decrease phosphorus in hog manure, and a decreased feed particle size, which results in increased digestibility. The latter practice has potential to decreased GHG effects of manure.

LIKELIHOOD TO ADOPT INNOVATIONS

The hog industry in PEI must ship live hogs to Quebec for processing at about 20/hog vs $2/hog when Garden Province Meats slaughter plant was operational. This "margin squeeze" means that the hog producers are reluctant to engage in the expense of any GHG mitigating improvements to their manure storage or management processes. Any improvement changes would need to show clear short-term results.

The pork sector's low margins make innovation money scarce; adoption needs near 100% funding or a clear return on investment in a BMP such as covering manure pits to capture methane.

At the same time, there is a perceived need to determine how to improve the profile of hog manure injection; early lack of adoption due to odor, groundwater issues easily avoidable with current knowledge, technology. Randall De Boer (DeBoer Ag, Earnscliff) hauls/spreads dairy/hog manure in Spring, and would be a potential partner with a producer to enact a project for wide adoption of manure injection of hog manure.

POULTRY

Engagement

- Mike Cummiskey, Manager, Egg Producers of PEI (EPPEI)
- Janet Murphy, Chicken Farmers of PEI
- Ian Simmonds, Kool Breeze farms (producer)
- Nathan Burns, Burns Poultry (producer)

Current Size (2016)

PEI produces 461,734 total hens & chickens (layers & broilers), with a less than 10% variance in these numbers between 1991 and 2016. There are 8 eggs (layers) producers, producing over 3.3 million eggs annually (EPPEI web stats).

MAJOR PRODUCTION CONCERNS

While the PEI poultry/egg production size is similar over the past two decades, the trend is towards far fewer producers with more birds per farm, raising an increasing on-site manure management issue, with related increases in management costs, as well as utilization issues.

Feed costs continue to increasing faster than the proportional value of eggs and meat. As a result more producers are using more land to grow corn, grain and other feed crops.

As farm sizes increase and more automated equipment is used, lighting, ventilation, heating, water pumping, conveyors and other electrical based equipment is rapidly increasing the farms' electric bills. In some cases, a poultry or egg farm will incur costs of over $2,000 per month.

AWARE OF OPPORTUNITIES

On larger farms, "Layer" manure is being dehydrated, both passively on the conveyors, as well as forced-air drying in storage barn, and, in some cases, being bagged and sold as an ammonia nitrogen source. This is a relatively inexpensive way to capture large amount of sustainable manure nutrients from this sector. Further study is needed to determine the energy inputs needed for this option, and the GHG mitigation effects of quickly stabilizing this type of manure.

On the energy side, most barns are increasingly adopting lower-cost LED lighting, but energy costs remain high for other electric machinery, especially conveyors and watering.. Alternate energy sources have already being adopted at Kool-Breeze farms (Summerside), which powers its poultry facility and greenhouses with two older but effective-sized wind turbines, creating a total of 55kW of electric power.

LIKELIHOOD OF ADOPTION

Based on the cost of a pilot project's implementation, producers would like to see better value from manure, considering perhaps improved efficiency of the cost of handling & dehydration/bagging.

Poultry producers would like to see programs for producers to increase energy efficiency, lower costs. With the ability of small solar or wind power producers (<100Kw) to obtain credits on future electricity usage from Maritime Electric, a set of strategic farm energy audits would be welcome on PEI's poultry farms, which incur substantial electricity costs. With the availability of modern versions of wind turbines and incremental, low-cost solar panels, an energy audit would determine the PEI poultry farms tat would most benefit from this option.

4.2 FIELD CROPS

4.2.1 FORAGES

Engagement

Joanne Driscoll, PEI Horticultural Association

Tyler Wright, PEI Soil & Crop Association

Kyra Stiles, Nutrient Management Officer, PEI DAF

Various producers' testimonials,
via the PEI Horticultural Assn (Joanne Driscoll)

Current Size (2016)

tame hay	120,319 ac
silage corn	7,825 ac

Major Production Concerns

- Soil health
- Pressure from potato producers to do contract growing
- Nutrient management and costs

AWARENESS OF OPPORTUNITIES

Few farms produce only grains or forages. As a result, farmers who are already aware of soil health issues for their main money crops have a good general awareness of the need to practice reduced tillage, cover cropping and nutrient management practices.

Most growers are aware of soil, and participate in Environmental Farm Plans, ALUS, and other government-sponsored innovation programs.

Most producers grow some forages as rotation or cover crops, or under contract to animal producers, such as beef and dairy, in exchange for manure. Potato growers regularly grow forages, both for trading with other growers, as a rotation necessity, and most recently, as a cover or plow-down residue crop.

That being said, this sub-sector requires the same outreach for improved nutrient management practices as other farms, including the BMPs presented in this report.

LIKELIHOOD FOR 0 ADOPTION

Growers consulted are interested in adopting low-till practices, but cost of equipment is a barrier.

4.2.2 GRAINS & PULSES

Current Size (2016)

	acres
Wheat	33,592
Oats	10,481
Barley	61,467
Mixed grain	3,171
Rye	2,392
Soybeans	44,932

MAJOR PRODUCTION CONCERNS

As wireworm continues to spread in PEI, crops previously free of wireworm infestation have begun to show signs of damage, including soybeans. This shifts crop choices to more fumigant crops, including research trials at AAFC Charlottetown.

Potato producers, such as Farm Boys Inc and Red Soil Organics, who currently run three combines for grains, along with their combined 3,000+ acres of potato land, would like to "get out of grains" on their land, and instead grow grains on leased rotation land, allowing them to focus on-farm efforts on maximizing potato production.

This indicates that there may be a trend away from potato producers growing grains. Other farms would need to take up this deficit in some way.

AWARENESS OF OPPORTUNITIES

Low tillage and nutrient management practices are being more and more incorporated, especially where a grain crop is grown before potatoes.

LIKELINESS FOR ADOPTION

Growers would likely incorporate more low-till practices if government subsidies were available for appropriate equipment.

POTATOES

Engagement

Ryan Barrett, PEI Potato Board

Steven Watts, Agricultural Researcher

John MacQuarrie, Environmental Officer, Cavendish Farms

Current Size (2016)
83,326 acres in 2018

MAJOR PRODUCTION CONCERNS

Land availability is a growing issue. Producers in this sector are tapped out on the ability to increase acreage of their own land, and cannot buy more under current conditions, and cannot find any more land on other farms to swap or lease

Nutrient management is well-recognized within the sector, with multiple resources to address this, and market pressures as well. This sector seems to be a leader I nnutrient management and has the resources and market pressures to continue to improve. Producers growing under contract are aepecially aware of n dintersted in initiatives to improve nutrient management

AWARE OF OPPORTUNITIES

The potato industry has a robust R&D capacity through the PEI Potato Board, Cavendish Farms R&D programs, the Fertilizer Institute and other service industry partners and government programs (PEIDAF, AAFC. This fact, plus the growing awareness of the need to preserve soil health and pressure from buyers to brand the sector's product as "green" and "sustainable', makes this production sector current leaders in soil conservation and nutrient management innovations.

Sector producers are proactively partnering with other sectors (beef, dairy, vegetable, grain/pulse, etc) for access to land, making them high-probability partners in BMP pilot studies. This is seen in the current widespread partnering with watershed groups for several R&D projects, including the Living Lab project.

LIKELIHOOD FOR ADOPTION

This sector has the highest likelihood to adopt evidence-based BMPs of any other commodity sector, due to early adoption of soil and nutrient management practices through regulations, programs, funding, etc. The PEI Potato Board and individual growers continue to lead in this trend by their contracts with buyers.

Several producers identified during this project have expressed strong interest in being potential BMP pilot sites.

VEGETABLES AND FRUITS

Engagement

Joanne Driscoll, Director, PEI Horticultural Association

Matthew Compton, PEI Strawberry Growers Association

JoAnn Pineau, PEI Wild Blueberry Growers Association

Nancy MacKay, PEI Fruit Tree Growers Association (and PEI Apple Growers Association, a new marketing group)

Current Size, Vegetables (2016)
This sector grew 2,244 acres of vegetable crops in 2016. 30+ varieties are grown historically, some not is any one year.

Area planted in vegetables by type (>50ac)
(from PEI Farm Stats 2017)

Broccoli	55
Cabbage	205
Carrots	850
Cauliflower	150
Corn, Sweet	55
Lettuce	**confidential**
Onions	**confidential**
Pumpkin	95
Spinach	2000
Rutabaga/Turnip	420

Current Size, Fruits (2016)
14,390 ac. total fruit crop acrage,
mostly blueberries (PEI Ag Stats 2017)

41 hectares of commercial strawberry crops
(down from 79 hectares in 2011.)

45 hectares of apple orchards operated
by 6 producers on PEI

MAJOR PRODUCTION CONCERN (VEGETABLES)

The vegetable sector is under pressure with very low margins on costs/sale value. This is an increasing negative trend, which makes building-in costs for GHG reduction very challenging without some form of government program support. The average grower practices a 3-4 year crop rotation.

Integration within the general field crop sector is a challenge. Vegetable growers desire more cooperation between Commodity Groups/farms to provide shared costs and information for shared problems (eg: wireworm, nematodes), including better fumigant crop choices.

AWARENESS OF OPPORTUNITIES (VEGETABLES)

The sector wants more rotation crops with benefits, such as fumigant crops against wireworm, soil building crops for improvement or soil nutrient capacity, water retention, etc. eg: Current: timothy/rye, buckwheat/sorghum; Developing: pearl millet, sorghum, sudan grass

LIKELIHOOD TO ADOPT (VEGETABLES)

Joanne Driscoll, Director of PEI Vegetable Growers, is historically very active in attracting funding for her producers, especially against wireworm spreading to historically clean crops, which she says is the greatest threat to the industry. Anything that would relieve that pressure, as well as give them more control over crop choices (vs growing rotation crops for potato producers) is welcome.

MAJOR PRODUCTION CONCERNS FRUITS

Strawberries are becoming a rarer crop on PEI. The acreage has plummeted in recent years as has the number of growers. (Matthew Compton, president, PEI Strawberry Growers Association) About a dozen commercial growers remain, down from 20 a few years ago.

PEI's strawberry growers are getting old and retiring. To meet demand, remaining growers are doubling new field sizes. New fields take a year to establish. As well, pollinators (bees) for strawberries remains a challenge, as most commercial pollination hives are used on blueberry fields. (CBC Charlottetown, 12 June, 2017)

Blueberry growers utilize the minimum amount of applications, including nitrogen. However, their Association does not know the actual Nitrogen application rate. More field testing should be done.

Apple growers are becoming fewer and the remainder are consolidating as marketing groups in a regionally growing industry, but costs to market are increasingly challenging, coupled with increased climate threats (late frosts, freeze-thaw winters, etc.)

AWARENESS OF OPPORTUNITIES (FRUITS)

C-Sequestration
Because they maintain agricultural land in a no-till, long-term low input form, the sector would like to see credit for their carbon sequestration effects.

Soil and Nutrient Testing
The sector would like to see better data on soil nutrients and the effect of current amendment application rates.

LIKELIHOOD OF ADOPTION (FRUITS)

Based on costs, there are no current strong drivers to adopt new practices. However, this is a direct-to-market, small commodity sector that is very willing to engage in dialogue about improvements, especially based on the market pressure to diversify their product as "green".

REFERENCES

PEI DAF and AAFC online commodity statistics.
In-person or telephone interviews with commodity experts as listed above.

SECTION
FIVE.

SECTION FIVE.

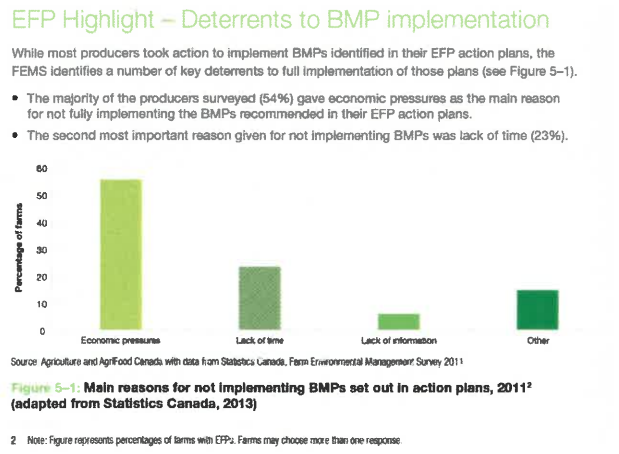
BENEFICIAL MANAGEMENT PRACTICES TO REDUCE GREENHOUSE GAS EMISSIONS

PURPOSE OF BMP'S

Beneficial Management Practices (BMPs) are intended to improve the overall performance of agronomic systems. They are intended to not only sustain crop yields but also to enhance environmental performance. The BMPs presented here were developed to decrease the greenhouse gas (GHG) emissions of agricultural operations in Prince Edward Island. These reductions are achieved through the reduction of N2O or CH4 emissions or as a result of enhanced carbon sequestration.

One of the challenges of BMPs of this nature is they are often not primarily directed at the economic returns of the production system and therefore may not be a high priority for adoption by producers or the supply chain. Most BMPs also represent additional costs in inputs, operations and time. As a result, their adoption is not justified in terms of economic returns alone and have often depended on government programs, the promotion of co-benefits or a direct marketing to consumers of their enhanced sustainability. The supply chain is increasingly becoming aware of the marketability of more sustainable production practices. Initiatives such as Field to Market attempt to quantify and market these practices to consumers.

In its Farm Environmental Management Survey (FEMS), Agriculture and Agri-Food Canada examined the barriers to BMP implementation across Canada (Fig 1). The greatest barrier to adoption was economic, with over 54% of farms reporting this as the major barrier. Lack of time (23%) and lack of information (8%) were also commonly identified barriers.



EFP Highlight – Deterrents to BMP implementation

While most producers took action to implement BMPs identified in their EFP action plans, the FEMS identifies a number of key deterrents to full implementation of those plans (see Figure 5–1).

- The majority of the producers surveyed (54%) gave economic pressures as the main reason for not fully implementing the BMPs recommended in their EFP action plans.
- The second most important reason given for not implementing BMPs was lack of time (23%).

Source: Agriculture and AgriFood Canada with data from Statistics Canada, Farm Environmental Management Survey 2011

Figure 5–1: **Main reasons for not implementing BMPs set out in action plans, 2011[2] (adapted from Statistics Canada, 2013)**

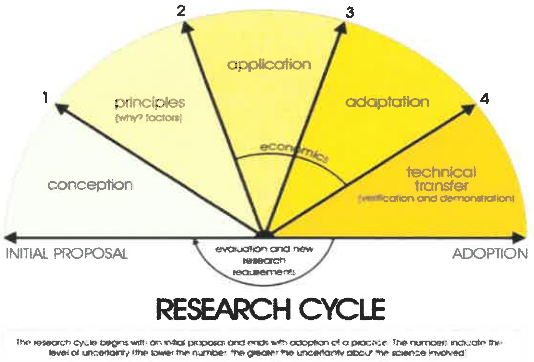
[2] Note: Figure represents percentages of farms with EFPs. Farms may choose more than one response.

Figure 1: Barriers to implemendation of Beneficial Management Practices identified in the Farm Environmental Management Survey (source Clearwater et al., 2016).

In terms of environmental measures, in the 2006 Agricultural Census, 40% of producers in the Atlantic Provinces had a completed Environmental Farm Plan (EFP), another 10% had plans under development. Many producers in the Atlantic region were implementing BMPs on their operations to reduce risk to the environment and improve environmental performance. For example, 45% of producers established a riparian buffer along waterways in the Atlantic provinces, and 43% established a setback distance. Annual soil cover days have remained relatively constant over the past 20 years with 98% of PEI's cropland in the moderate category at approximately ~190 days of over.

IDENTIFYING BARRIERS TO ADOPTION

To be able to assess the suitability of BMPs and their potential for adoption involves not only an assessment of the magnitude of reduction but also the certainty of achieving that reduction, the cost of implementation, timeframe over which implementation could occur and any co-benefits which should also be considered. In doing this assessment it is important to highlight any barriers to adoption that may exist in any of these areas. In assessing the potential for adoption and impact of GHG reduction practices in PEI's agriculture sector we have identified where the BMPs lies research cycle from early stage conception to late stage technical transfer (Fig. 3) Assessing the scientific evidence supporting the likelihood of the practice to realizing reduced GHG emissions through to the technical and economic challenges to the adoption of the practice are critical in understanding the likelihood of adoption.



The research cycle begins with an initial proposal and ends with adoption of a practice. The numbers indicate the level of uncertainty (the lower the number, the greater the uncertainty about the science involved)

Figure 2: Diagrammatic representation of the research cycle and the five stages of research (From Burton and Sauvé, 2005)

Table 1 describes the type of information acquired at each stage of the research cycle and is the basis of the stage of development of each of the BMPs examined in this report. It is important to note that barriers can range from a lack of clear understanding of the mechanisms creating the GHG reduction and uncertainty whether the reduction will be realized, an understanding of the economics of implementation, and finally, demonstration and transfer of knowledge to the producer. This process is cyclical in that the development and delivery of BMPs informs the opportunity to conceive and develop future BMPs.

TABLE 1:
FIVE STAGES OF RESEARCH
(FROM BURTON AND SAUVE, 2005)

Research Stage	Definition	Example
Conception	Describes and tests the concept or hypothesis	This stage predicts "what", i.e. what GHG are emitted.
Principles	Describes the principles of action and/or controlling factors as a basis for predictability	This stage answers questions about "why" GHG emissions are emitted.
Application	Applies the theoretical findings to actual field situations (measuring actual results in the field)	This stage addresses the interaction of factors in an applied setting and tests initial assumptions about economic feasibility.
Adaptation	Describes how the findings can be adapted to various settings	This stage adapts the findings to variances such as scale, landscape, farming practices, and climatic variables. Identifies barriers to implementation (including economic analysis).
Tech Transfer	Supports transfer of the technology onto the farm	Includes demonstration projects, education, verification of results.

In many cases the information needed to adequately assess the potential impact of BMPs in PEI was limited by lack of detailed information about the nature of the sector in PEI. In other cases, Atlantic Canada is the finest level of reporting by Statistics Canada.

In its Climate Change Action Plant 2018-2023, the government of PEI highlights that in agriculture there are barriers that prevent widespread adoption of solutions such as nutrient stewardship, conservation cropping, and livestock feeding strategies. We need to understand the nature of these barrier and how they can be overcome if we are going to be successful in having beneficial management strategies adopted.

One of the important tools in identifying opportunities to implement environmental BMPs is the completion of an Environmental Farm Plan (EFP). From the 2006 Agricultural Census, 40% of producers in the Atlantic Provinces had a completed Environmental Farm Plan, and another 10% had plans under development. Other producers in Atlantic Canada are implementing BMPs to reduce risk to the environment and improve environmental performance. For example, 45% of producers established a riparian buffer along waterways in the Atlantic provinces, and 43% established a setback distance.

Annual soil cover days have remained relatively constant over the past 20 years, with 98% of PEI's cropland in the moderate category at approximately ~190 days of cover. The challenge now is to facilitate development and implementation of BMPs to address environmental risks. As indicated earlier, cost of implementation is a primary barrier to adoption (Fig. 1). This is particularly true for environmental concerns that do not return economic benefits to the producer, such as greenhouse gas emissions. There is an unmet need for government policy and financial support to support these future public-good outcomes.

Industry and producer engagement are important at all stages of the research cycle. PEI is fortunate in there are excellent examples of industry and producer engagement in achieving GHG emissions reductions. Fertilizer Canada has introduced the 4R Nutrient Stewardship program to optimize the efficiency of nutrient use in agriculture.

The program highlights the opportunity to use the Right Source of fertilizer applied at the Right Rate in the Right Place at the Right Time. The application of 4R Nutrient Stewardship principles to nitrogen fertilizer can result in reductions in N2O emissions and reduced NO3- leaching (and in-direct source of N2O). These principles form the basis of the Nitrous Oxide Emissions Reduction Protocol (NERP) which has been implemented in Alberta and is being considered for national implementation. Protocols of this nature provide incentive to producers to adopt GHG mitigating practices by allowing them to be quantified and used as carbon offsets in carbon trading mechanisms.

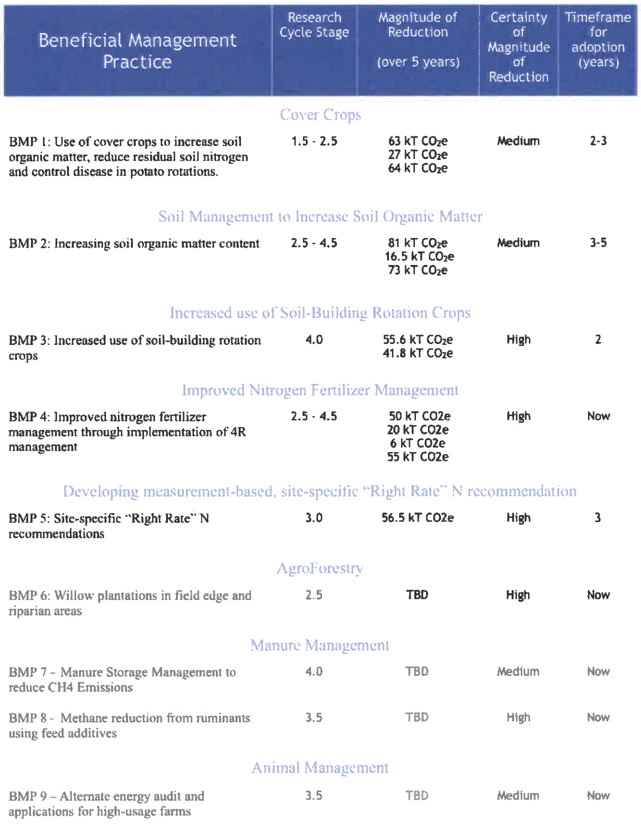
The implementation of 4R Nutrient Stewardship principles also results in other environmental benefits, such as reduced risk of NO3- leaching. Cavendish and McCain have demonstrated interest in developing soil management practices that increase nutrient use efficiency and improve soil organic matter content. Several producer-lead environmental groups, in particular the East Prince Agri-Environment Association and partners have taken the lead in supporting on-farm research in this area. Agriculture and Agri-Food Canada has funded the Agricultural Greenhouse Gas Program, supporting research into reduction of GHG emissions from agriculture and have announced the Living Labs Initiative that establishes a collaboration with industry to support research in nutrient use efficiency and the maintenance of soil health.

Much of the reporting of GHG emissions and carbon sinks is based not on direct measurement but rather related agricultural activities. For example, agricultural N2O emissions from PEI are estimated using an emission factor and the amount of fertilizer N applied (actually fertilizer N sales). So, despite uncertainties in the control of actual N2O emission processes in agricultural landscapes, BMPs that reduce the amount of fertilizer N use or the N2O emission factor will result in a reduced reporting of N2O emissions. Thus, a focus on BMPs that increase the efficiency of fertilizer N use (lower N2O emission factor) and/or lower fertilizer N applications, while sustaining productivity, will result in reduced reported N2O emissions.

PROPOSED BMP'S

In developing a short list of promising BMPs, the authors focused on practices that enhance carbon storage in agricultural soils, decrease fossil fuel use, reduce N2O emissions from soil and manure management, and reduce CH4 emissions from ruminant animal production and manure storage. This list is not exhaustive, but reflects what we consider to be the most promising management practices that could result in sizable reductions in GHG emissions from PEIs agriculture sector in the near term (5 years). Table 2 summarizes the BMPs that are described in greater detail in the remainder of this chapter.

Table 2: Listing of Beneficial Management Practices examined to reduce greenhouse gas emissions from the agriculture sector in Prince Edward Island.



Beneficial Management Practice	Research Cycle Stage	Magnitude of Reduction (over 5 years)	Certainty of Magnitude of Reduction	Timeframe for adoption (years)
Cover Crops				
BMP 1: Use of cover crops to increase soil organic matter, reduce residual soil nitrogen and control disease in potato rotations.	1.5 - 2.5	63 kT CO$_2$e 27 kT CO$_2$e 64 kT CO$_2$e	Medium	2-3
Soil Management to Increase Soil Organic Matter				
BMP 2: Increasing soil organic matter content	2.5 - 4.5	81 kT CO$_2$e 16.5 kT CO$_2$e 73 kT CO$_2$e	Medium	3-5
Increased use of Soil-Building Rotation Crops				
BMP 3: Increased use of soil-building rotation crops	4.0	55.6 kT CO$_2$e 41.8 kT CO$_2$e	High	2
Improved Nitrogen Fertilizer Management				
BMP 4: Improved nitrogen fertilizer management through implementation of 4R management	2.5 - 4.5	50 kT CO2e 20 kT CO2e 6 kT CO2e 55 kT CO2e	High	Now
Developing measurement-based, site-specific "Right Rate" N recommendation				
BMP 5: Site-specific "Right Rate" N recommendations	3.0	56.5 kT CO2e	High	3
AgroForestry				
BMP 6: Willow plantations in field edge and riparian areas	2.5	TBD	High	Now
Manure Management				
BMP 7 - Manure Storage Management to reduce CH4 Emissions	4.0	TBD	Medium	Now
BMP 8 - Methane reduction from ruminants using feed additives	3.5	TBD	High	Now
Animal Management				
BMP 9 – Alternate energy audit and applications for high-usage farms	3.5	TBD	Medium	Now

REFERENCES

Field to Market (https://fieldtomarket.org)

PEI Climate Change Action Plan (https://www.princeedwardisland.ca/en/information/communities-land-and-environment/climate-change-action-plan-2018-2023)

Fertilizer Canada (https://fertilizercanada.ca)
4R Nutrient Stewardship (https://fertilizercanada.ca/nutrient-stewardship/)

NERP (https://discovernerp.ca/4r-nutrient-stewardship-to-reduce-nitrous-oxide-emission)

Cavendish Agri. (https://www.cavagri.com/cavendish-agri-aboutus-sustainability.aspx)

McCain (https://www.mccain.com/sustainability/smart-sustainable-farming/)

PEI Canada Story on East Prince Agri-Environmental Club (http://www.peicanada.com/island_farmer/article_cab40384-ccd7-11e4-99af-3b7b914bb49e.html)

AAFC Agricultural Greenhouse Gas Program (http://www.agr.gc.ca/eng/programs-and-services/agricultural-greenhouse-gases-program/approved-projects/?id=1508423883267)

AAFC Living Labs (http://www.agr.gc.ca/eng/science-and-innovation/living-laboratories-initiative/?id=1551383721157)

BMP 1

USE OF COVER CROPS TO INCREASE SOIL ORGANIC MATTER, REDUCE RESIDUAL SOIL NITROGEN AND CONTROL DISEASE IN POTATO ROTATIONS.

DESCRIPTION

The use of cover crops to increase the productivity and sustainability of intensive production systems such as potatoes and vegetable production systems is gaining increasing attention. Potato growers have long recognized the role of rotational crops in controlling disease (Peters et al., 2003) and in the use of extended rotations to reduce nitrogen impacts on groundwater (Jiang et al., 2011). The use of crops to increase the nutrient content of the soil or "green manures" are common practices in organic production systems. Recently "cover crops" and full season forage crops are gaining increased attention for their ability to control disease, retain nutrients, reduce erosion, and build soil organic matter. Cover crops are defined as crops which are not sown to be harvested but rather to be incorporated in the soil at some point in their growth. In addition to opportunities to control disease and improve soil health, the potential exists for these cropping approaches to result in reduced N2O emissions and increased soil carbon storage.

There are several points in the production system where cover crops can play a role. Cover crops, or full season forage crops, can be used in years prior potato or vegetable production in the rotation as a soil building and/or disease sanitation crop (biofumigant). In this case, the goal is to cover the soil, build organic matter, and reduce disease pressure. Candidate crops include sorghum-sudangrass, forage pearl millet, buckwheat, brown mustard and multi-species mixes.

Cover crops can also be used late in the fall following crop harvest as a "catch crop" to take up nutrients remaining in the soil and prevent their loss via leaching, erosion or gaseous loss (N2O). In this case, the role of the cover crop is to immobilize fall NO3-, reducing the potential for fall and overwinter N2O production. The growth of a cover crop also increases soil organic matter, resulting in removal of CO2 from the atmosphere. The term "catch crop" refers to a crop grown in the same year as the main crop but after the main crop. In this case, the goal is to cover the soil, immobilize residual nutrients (especially nitrate) and build soil organic matter. Candidate crops that have been examined for use in PEI production systems include fall rye, winter wheat, spring oats, spring barley, tillage radish and brown mustard. Cover crops can also impact in-direct N2O emissions (those emissions resulting from nitrate leached). In a corn-soybean rotation, Parkin et al. (2016) found that while cover crops did not have a significant impact on direct N2O emissions during the growing season, in-direct emissions were reduced by 50%.

GHG Reduction Potential

Much of the research in PEI has focused on the use of cover crops in potato production. Cover crops, especially sorghum-sudangrass, have been shown to have the potential to increase potato tuber yield and quality (Essah et al., 2012). Potatoes grown after cover crops produced 13 to 25% more tubers compared to no cover crop (Jahanzad et al., 2017b). Potatoes grown after cover crops often produced highest yield at lower rates of nitrogen fertilizer than in the absence of the cover crop. Potatoes after winter pea or forage radish produced the same or higher yields (10-25%) at 75 or 150 kg N ha-1, relative to those without a cover crop fertilized at 225 kg N ha-1 (Jahanzad et al., 2017b). Forage radish or winter pea improved nitrogen use efficiency as a result of greater synchrony between N release from cover crop residues and potato N demand than that of cereal rye (Jahanzad et al., 2017a). Rye provided less N to a succeeding potato crop than forage radish or winter pea. Overall, forage radish and winter pea were better alternatives to rye as indicated by less N fertilizer application, sustained tuber yield, and tuber mineral nutrient concentration (Jahanzad et al., 2017b).

There are also other positive impacts of the use of cover crops in potato rotations. In Maine, Larkin has looked extensively at potential disease-suppressive rotation crops, such as Brassica (canola, rapeseed, and mustard) and Sudan grass cover crops (Bernard et al., 2014; Bernard et al., 2012; Larkin, 2008; Larkin et al., 2010). When mustard was grown as cover crop, it reduced the incidence of powdery scab, common scab, and Verticillium wilt. Brassica cover crops planted in the fall prior to potato planting the following spring reduced the incidence and severity of black scurf on tubers by 30 to 80 percent and reduced the incidence of common scab up to 50 percent. Rapeseed provided the highest reductions in black scurf.

In a meta-analysis examining the role of cover crops in N2O emissions, Han et al. 2017 found that cover crops reduced N2O emissions by 58% relative to bare soils, but that the additional N supplied by the cover crop resulted in increased emissions in the subsequent crop (Fig. 1). The magnitude of N2O emissions associated with the cover crop was inversely related to C:N ratio of the cover crop (Fig. 2). (Han et al., 2017) noted that, in most of the comparisons examined, the fertilizer N rate was not adjusted to reflect the additional N contribution of the cover crop. Adjusting N fertilizer N rates in the subsequent crop to reflect N supply from the cover crop may eliminate the increased N2O associate with the crop following the cover crop. In a meta-analysis of 26 peer-review articles, Basche et al. (2014) found that in forty percent of the observations, a cover crop resulted in reduced N2O emissions relative to adjacent systems not using a cover crop and 60% resulted increased N2O emissions. Higher emissions were primarily associated with legume cover crops following their incorporation into the soil (Basche et al., 2014). Elevated N2O emissions associated with cover crop use appear to be associated with the decomposition of the cover crop and its management. The incorporation of cover crops into the soil was associated with increased N2O emissions (Fig. 3) and the use of cover crops with a narrow C:N ratio (Figs. 3 & 4). When examined over the entire year, cover crops were found to be closer to having a zero impact - periods of higher emissions associated with incorporation of the cover crop were offset by periods of lower emissions during the growth of the cover crop. The use of non-legume cover crops is especially important when being seeded following the plowing down of a legume forage crop as significant N mineralization is anticipated as the legume forage begins to decompose.

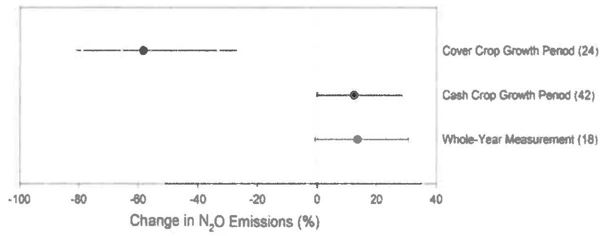


Figure 1: Effect of cover crops on area-scaled N2O emissions depending on different measurement periods. Mean values and 95% confidence intervals of the back-transformed response ratios are shown. From Han et al. (2017).

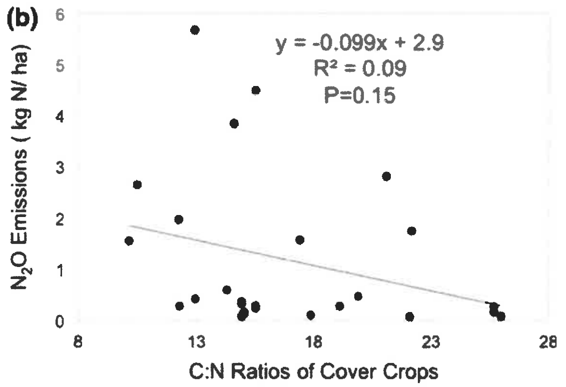


Figure 2: Relationship between N2O emissions and cover crop C:N ratios (n = 27). From Han et al. (2017)

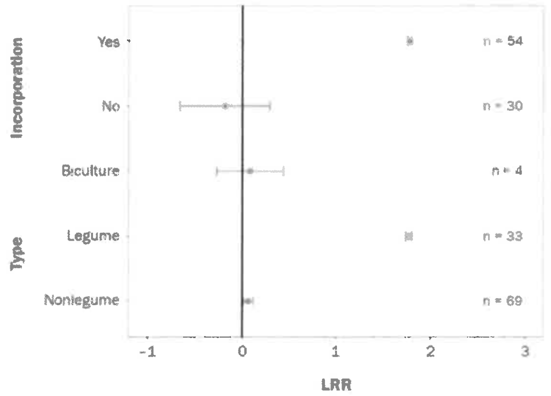


Figure 3: Mean response ratios (cover crop/no cover crop) for management factors included in the meta-analysis. (From Basche et al., 2014)

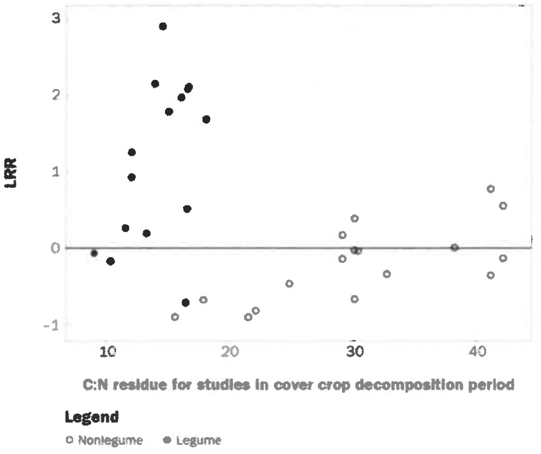


Figure 4: Mean response rations (cover crop/no cover crop) measured during the cover crop decomposition period as a function of the residue carbon:nitrogen ratio. (From Basche et la. 2014).

(Parkin et al., 2016) observed that a rye cover crop did not reduce direct N2O emissions but did reduce estimated indirect emissions by approximately 50%.

THE ROLE OF COVER CROPS IN CARBON STORAGE

Cover crops also show promise as a means of increasing soil organic matter (Ghimire et al., 2018), reducing N requirements (Guardia et al., 2016); Jahanzad et al., 2017b), and reducing N losses (Han et al. 2017). One of the challenges in documenting soil carbon gains is that longer cropping periods are needed to detect the influence of cropping system and the use of cover crops ((Bavin et al., 2009; Beehler et al., 2017). What is clear is that roots and rhizodeposition are critical elements in assessing the ability of cover crops to result in increased soil organic matter (Austin et al., 2017). Shoot and root biomass contribute to soil organic matter but since the majority of both root and shoot inputs are eventually mineralized, cover crops will likely need to be included frequently in rotations to accumulate significant amounts of soil C (Austin et al., 2017). A global meta-analysis of research at 139 plots at 37 different sites demonstrated an average annual rate of change in SOC of 0.32 ± 0.08 Mg C ha-1 y-1 (~300 kg C ha-1 y-1) as a result of the inclusion of a cover crop (Poeplau and Don, 2015). This estimate is with the range of estimates of the potential for carbon sequestration as a result of the inclusion of a cover crop in cropping systems in the US range from −0.07 to +3.22 Mg CO2e ha-1 y-1, with higher values being observed in warmer climates where plant growth continues over the winter period(Eagle and Olander, 2012).

IMPLEMENTATION

If the objective in including a cover crop is to reduce N2O emissions, then a few principles can be drawn from the literature. The use non-legume cover crops as catch crops will result in a reduction of soil nitrate and less N mineralization and therefore reduce the potential for N2O emissions. This is particularly true for the potential to reduce N2O emissions during the non-growing period, which is a major period of loss in PEI. Cover crops which result in C:N ratios greater than 20:1 such as grasses have greater potential to reduce N2O emissions. If legume cover crops are to be used, the supply of nitrogen from the cover crop should be considered and the rate of N fertilizer applied to subsequent crop be reduced accordingly. Guardia et al. (2016) demonstrated that both legume and nonlegume cover crops could be used to maximize agronomic efficiency (lowering synthetic N requirements for the subsequent cash crop) without increasing cumulative or yield-scaled N2O losses as long as they were combined with integrated soil fertility management to avoid excess N applications.

Another important principle is to avoid incorporation as much as is possible. The incorporation of the cover crop into the soil stimulates increased microbial activity and often results in increased N2O emissions and less soil organic matter system. Systems which minimize the disturbance of the cover crop until the spring period prior to potato cropping will result in greater carbon storage and reduced N2O emissions.

The use of cover crops with wide C:N ratios will necessarily reduce the potential for these crops to supply nitrogen to subsequent crops. The growth of leguminous crops as a green manure, that is to supply nitrogen to subsequent crops, results in increased N2O emissions potential.

The agronomic, economic, and environmental advantages to the use of cover crops are not always apparent to producers. Daryato et al. (2018) argue for the need for a detailed economic analysis to calculate the direct (e.g., reduction in the amount of chemical fertilizer) and indirect monetary benefits (e.g., GHG emissions, the improvement of soil health) of cover crops. Such a comprehensive analysis could serve as incentive for producers to integrate cover crops into their management practices (Daryanto et al., 2018).

GHG REDUCTION MODELLING AND MEASUREMENT

There are three major means by which cover crops are used in annual crop production in PEI

.

1. The use of fall-seeded cover crops following primary tillage of forages

2. Use of Fall-Seeded Cover Crops following Potato Production

3. Nurse Cropping Demonstration Trials within Potato and Corn Production Systems

The potato production system represents the greatest opportunity for the implementation of cover crops, but many of the same principles apply to high input low soil coverage crops such as corn. We will base our estimates of the reduction potential based on implementation in potato production in PEI.

FALL-SEEDED COVER CROPS FOLLOWING FALL PRIMARY TILLAGE OF FORAGES

It is common for potato producers in PEI to plow in the forage crops that precede the potato year in the fall prior to the potato year. This leaves the soil exposed over the winter period increasing the potential for wind and water erosion, allows nutrient accumulation in the soil in the fall increasing the potential for over-winter nutrient loss, particularly nitrate. This issue can be particularly severe in situations where warm fall and early winter conditions promote nutrient accumulation. The planting of a fall-seeded non-leguminous cover crop following fall plowing would allow for at least some degree of soil coverage and nutrient uptake prior to soil freezing. These crops would stabilize the soil against erosion and would provide an input of soil organic matter. A range of cover crops are currently being evaluated in the province by various research groups to perform this role.

POTENTIAL GHG REDUCTIONS

The model assumption is the adoption of planting a non-leguminous cover crop, following fall tillage of a forage crop on 1/3 of PEI producers' land area that will be planted to potato in the following year. This amounts to approximately 10,000 ha. The following reductions in GHG emissions would be associated with the adoption of that practice:

Soil carbon sequestration - assuming that the use of a cover crop on average results in the sequestration of 300 kg C ha-1 y-1 or 1.1 Mg CO2e ha-1 y-1 (Poeplau and Don, 2015) This translates into:

10,000 ha x 1.1 Mg CO2e ha-1 y-1 = 11,000 Mg CO2e ha-1 = 11 kt CO2e y-1

Reduction in direct N2O emissions associated with leguminous forage (mainly red clover) plowed in the fall. Assume a 10% decrease in GHG emissions associated with the leguminous forage when followed by a non-legume cover crops on 1/3 of the land area going into potatoes each year.

Using the methodology presented by (Rochette et al., 2008) the N2O emissions associated with a red clover crop are estimated to be.

$$N_{Res} = \left(\left(R_{ag/y}\ x\ N_{ag}\right) + \left(R_{bg/y}\ x\ N_{bg}\right)\right)\ x\ P_{norm}$$

Where:

Nres = N content of returned residue (kg N ha-1 y-1)

Rag/y = Above ground crop residue as a fraction of crop yield (kg residue/ kg crop yield)

Rbg/y = Blow ground crop residue as a fraction of crop yield (kg residue/ kg crop yield)

Nag = Nitrogen content of above ground residue (kg N/kg residue)

Nbg = Nitrogen content of below ground residue (kg N/kg residue)

Pnorm = the normal yield of crop (kg crop ha-1 y-1)

Based on data presented by Bolinder et al., (2002) and Warembougs et al. (1997) we have assumed a total above ground plant production of 6000 kg ha-1 and that 4500 kg ha-1 is removed from the field in a single cut of hay, 2000 kg ha-1 is left in the field as above ground residue and that there 8000 kg ha-1 of root residues remaining at the end of the growing season. The nitrogen concentration of the shoot tissue was assume to be 0.05 kg N/kg crop (C:N = 20:1) and the root tissue to be 0.04 kg N/kg crop (C:N = 25:1). The calculation becomes

$$N_{Res} = \left(\left(\frac{2000}{14500}\ x\ 0.05\right) + \left(\frac{8000}{14500}\ x\ 0.04\right)\right) x\ 4500 = 130 \text{ kg N ha}^{-1} \text{ y}^{-1}$$

The N2O emissions associated with the decomposition of this residue N would be 1.61% of the total N content or 2.1 kg N2O-N ha-1 y-1 which is equivalent to 0.95 Mg of CO2e ha-1 y-1.

10,000 ha in non-legume cover crops x 0.10 x 0.95 Mg CO2e y-1= 0.95 kt CO2e y-1

Assuming an increased retention of nitrogen by the non-leguminous cover crop results increased soil N supply to the following potato crop and this allows reduces the N fertilizer requirement for the potato crop - assume opportunity to reduce fertilizer N by 5%

10,000 ha non-legume cover crops x 0.05 x 180 kg N ha-1 = 90,000 kg N

90,000 kg N x 0.0161 x 44 kg N20/28 kg N20-N x 298 = 0.68 kt of CO2e y-1

In total the adoption of a non-legume cover crop following the fall plowing of a legume forage on 10,000 ha (1/3 of land going into potatoes each year) would result in an annual GHG reduction of 11 kt of CO2e resulting from increase SOC, 0.95 kt of CO2e from reduced GHG losses associated with the legume forage and a reduction 0.68 kt of CO2e associated with decreased fertilizer N use in the following potato crop. The total reduction would be 12.6 kt CO2e y-1 or 63 kt CO2e over 5 years.

USE OF FALL-SEEDED COVER CROPS FOLLOWING POTATO PRODUCTION

Following potato production, soils are particularly sensitive to soil erosion and generally have residual soil nitrate concentration vulnerable to leaching over the fall and winter months. The establishment of a cover crop following potato harvest would result in the immobilization of residual nitrogen, an increase in the shoot and root biomass in the soil and therefore increased SOC content and finally the cover crop will provide soil cover and reduce the risk of soil and water erosion.

There is uncertainty as to which crops can be used to establish an effective fall cover in view of the late dates of harvest of the major potato variety grown in PEI. Winter cereals have been proposed as candidate crops although there is concern over the use of winter cereals related to the termination of the crop in the following spring and the potential for volunteer growth in their next year's grain crop, which will contaminate what they are selling to the grain elevator.

To estimate the potential GHG reduction of this BMP, one must assume the adoption of cover crops on 1/3 of land cropped to potato each year, or approximately 10,000 ha. Since there is often a much shorter time period for the cover crop to grow, we assume only 100 kg C ha-1 y-1 of sequestered soil carbon as a result of the use of the cover crop. This number would be higher for the use of cover crops in earlier season varieties and/or establishment of the cover crop prior to potato harvest.

Soil carbon sequestration - assume
100 kg C ha-1 y-1 = 367 kg CO2e ha-1 y-1

10,000 ha x 367 kg CO2e ha-1 y-1 = 3,667 Mg CO2e ha-1 = 3.67 kT CO2e y-1

Direct N2O emissions - assume 10% decrease in N2O emissions associated with the uptake of nitrate in the soil as a result of the planting of a non-leguminous cover crop

10,000 ha cover crops x 0.10 x 200 kg N ha-1 = 200,000 kg N

200,000 kg N x 0.0161 x 44 kg N20/28 kg N20-N x 298 = 1.51 kT of CO2e

IPCC estimates indirect in-direct N2O emissions by assuming 30% of the N from the crop is leached and of that 0.75% (EF = 0.0075) is converted to N2O. Therefore, in the absence of a cover crop the indirect N2O emissions from the potato crop

10,000 ha x 200 kg N ha-1 x 0.3 x 0.0075 = 4,500 kg N2O

4,500 kg N20 x 44 kg N20/28 kg N20-N x 298 = 2.1 kT of CO2e

If we assume the cover crop reduces NO3- leaching and the resulting N2O emissions by 10% this is equivalent to 0.21 kT of CO2e.

In total, the use of a non-legume cover crop following the harvest of a potato crop on 10,000 ha (1/3 of land in potatoes each year) would result in an annual GHG reduction of 3.67 kT of CO2e resulting from increase SOC, 1.51 kT of CO2e from reduced GHG losses associated residual soil nitrate following the potato and 0.21 kT of CO2e associated with lower in-direct N2O emissions resulting from reduced nitrate leaching. The total reduction would be 5.39 kT of CO2e y-1 or 27 kT of CO2e over five years.

NURSE CROPPING DEMONSTRATION TRIALS WITHIN POTATO AND CORN PRODUCTION SYSTEMS

A crop which is planted into an existing crop is referred to as a nurse crop. Another strategy for increasing the duration of the year over which the soil is covered with a living crop is the use of nurse crops. For many row crops, such as potatoes and corn, the soil surface area is left bare throughout large parts of the season, relative to forage or broadcast seeded crops. The practice of including a nurse crop, which is defined as a companion crop alongside or inter-rowed between main cash crops during the growing season, could be an opportunity to provide soil cover throughout parts of the growing season or following harvest, immobilizing nutrients after the primary growing period for the main crop, increasing root biomass and therefore SOC and finally reducing soil loss due to erosion.

The province of New Brunswick has been conducting trials documenting the use of a nurse crop within potato hills using fall rye. Fall rye is broadcast following planting, established, and then terminated with glyphosate prior to hilling. This management practice has been assessed in a few fields on PEI and has shown potential benefits to the potato crop, by increasing water moisture within the hill. However, the benefits and limitations of this practice on PEI should be further expanded, to understand the best timing and cropping strategies associated with this practice, and whether there are other crops that may be beneficial as nurse crops. For example, the use of fall rye specifically has been found to be difficult to terminate with glyphosate and has proven to be competition to the potato crop. The use of other crops such as barley, oats or perhaps mustard, could be advantageous to try at differing rates on a field scale.

The use of ryegrass nurse crop into corn stands in Quebec has been proven as a beneficial winter cover crop, and potential yield booster in the following year's crops such as soybean and grains. Following the 6-leaf stage of corn, ryegrass seeds are broadcast across the field and will establish but be outcompeted by the corn crop. Following corn harvest, the ryegrass has already fully established, and will act as a winter cover to reduce nutrient loss and erosion throughout the winter season. This practice has been assessed on a very small scale on PEI.

This BMP involves the use of nurse crops within two major crops grown on PEI, and the effect on yield and moisture holding capacity of the soil. Due to the harvest dates of corn production systems, it is difficult to establish winter cover crops following harvest, however with the addition of a nurse crop during the growing season, a winter cover crop could be established and provide erosion, nutrient and soil health benefits over the long term.

The effect of a nurse crop on potato production may potentially boost yields if it can influence greater water availability to the potato crop, as it acts as a mulch cover throughout the growing season. The continued growth of the nurse crop following the harvest of the main crop would result in nitrate immobilization and therefore reduced direct and in-direct N2O emissions, increased above and below ground plant residue and therefore increased SOC and over-winter ground cover reducing wind and water erosion.

Assume the adoption of cover crops on 1/3 of land area going into potato production each year or approximately 10,000 ha.

Soil carbon sequestration - assume
300 kg C ha-1 y-1 = 1100 kg CO2e ha-1 y-1

10,000 ha x 1.1 Mg CO2e ha-1 y-1 = 11,000 Mg CO2e ha-1 = 11 kT CO2e y-1

Direct N2O emissions – assume 10% decrease in N2O emissions associated with the uptake of nitrate in the soil as a result of the planting of a non-leguminous cover crop

10,000 ha cover crops x 0.10 x 200 kg N ha-1 = 200,000 kg N

200,000 kg N x 0.0161 x 44 kg N20/28 kg N20-N x 298 = 1.51 kT of CO2e

IPCC estimates indirect in-direct N2O emissions by assuming 30% of the N from the crop is leached and of that 0.75% (EF = 0.0075) is converted to N2O. Therefore, in the absence of a nurse crop the indirect N2O emissions from the potato crop

10,000 ha x 200 kg N ha-1 x 0.3 x 0.0075 = 4,500 kg N20
4,500 kg N20 x 44 kg N20/28 kg N20-N x 298 = 2.1 kT of CO2e

If we assume the nurse crop reduces NO3- leaching and the resulting N2O emissions by 10% this is equivalent to 0.21 kT of CO2e.

In total the use of a non-legume cover crop following the harvest of a potato crop on 10,000 ha (1/3 of land in potatoes each year) would result in an annual GHG reduction of 11 kT of CO2e resulting from increase SOC, 1.51 kT of CO2e from reduced GHG losses associated residual soil nitrate following the potato and 0.21 kT of CO2e associated with lower in-direct N2O emissions resulting from reduced nitrate leaching. The total reduction would be 12.72 kT of CO2e. over 5 years this would represent 64 kT of CO2e.

COSTS

The primary costs associated with the implementation of this BMP relate to the cost of seed for the cover crop and the addition field passes required to manage the cover crop.

This BMP is currently being implemented by a number of producers across the province. Agriculture and Agri-Food Canada, PEI Department of Agriculture and Fisheries, and several industry groups are conducting trials with cover crops. While the most appropriate crop selections and agronomic practices will evolve, there is currently sufficient information available to implement this BMP immediately.

In addition to increasing soil organic matter content, greater nutrient retention and decreased soil erosion, the co-benefits associated with these BMPs include increased soil health and benefits related to plant disease suppression depending on the cover crop chosen.

BARRIERS TO ADOPTION

There is large industry interest in the inclusion of cover crops in potato rotations. There is also currently considerable awareness and uptake of this opportunity in the producer community. More and more producers have been experimenting with cover cropping systems in PEI. McCain Foods, through its contracted growers, has been conducting trials of full season cover crop mixtures, and this has been an area research by AAFC in PEI and through the PEIDAF. This BMP has also been included in a pending proposal under the Living Labs program.

Major barriers lie in understanding the agronomics of management of the cover crop and the potential for impacts on potato crop (competition, increased disease, reduced nutrient supply). There are also barriers in the application/adaptation of these practices as a result of limited awareness of the potential of these practices and their agronomic and economic implications.

One of the major barriers to broader adoption of this BMP is the knowledge as to which crops should be grown, as well as agronomic management of these crops, within the context of the current primary production system.

POLICY DRIVERS

The PEIDAF Agriculture Stewardship program has supported projects considering the use of winter cereals as cover crops (fall rye and winter wheat), and there has been good uptake by producers for this program. The program plans to include spring cereals as a winter cover next year in their programing but will encourage high seeding rates to ensure a denser stand and greater residue production to help control erosion.

In terms of soil management, the Tillage Timing of Forages (with cover crop) BMP program provides $25/acre up to a max of $500 per field and $2,000 per year for eligible expenses to assist with establishing a cover crop following tillage of a forage crop, provided that the cover crop can adequately establish before winter.

Also, the PEIDAF still has a program to assist with use of winter cereals following potato harvest as a winter cover crop. $25/acre up to a max of $500 per field (and $1,000/year) is available for this program. Again, contact Kyra Stiles for more details. Past studies have shown that winter rye will establish up to October 15th, and other cereals like oats and barley can serve as effective cover crops for potato fields harvested in September.

MODELLING AND MEASURING EMISSIONS REDUCTION AND/OR SEQUESTRATION

The adoption of this BMP is best measured as the number of acres receiving cover crop or nurse crop treatments, increased soil cover days or reduced residual soil nitrogen. This could be documented via program participation, or in the Agricultural Census. Baseline data on these metrics would first need to be established. There are Agri-Environmental indicators for both soil cover days and residual soil nitrogen.

Various national model and inventory approaches (e.g., Holos or Daycent) would allow quantification of the impact of the implementation of these BMPs. Direct measurement of decreased GHG emissions or increased soil organic carbon concentration would not be practical.

SUCCESS METRICS

In addition to documenting adoption of this BMP as the number of hectares receiving cover crop or nurse crop treatments, the success of this BMP would be documented as an increase in the number of soil cover days, a decrease in residual soil nitrogen or decreased NO3- loading to groundwater.

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BMP 2

INCREASING SOIL ORGANIC MATTER CONTENT

BEST PRACTICE DESCRIPTION

Soil has the capacity to store significant amounts of carbon.

Globally, soil stores 2,300 billion tonnes (Gt) of carbon as soil organic matter (SOM) with annual fluxes of ~60 Gt of carbon as photosynthetic inputs and an equal amount lost via decomposition (Fig. 1). Agriculture has exacerbated the loss of SOM as a result of the cultivation of arable crops. Increasingly we are exploring methods by which we can manage annual cropping systems with less soil disturbance to reduce the rate of loss of SOM. Ideally practices could be adopted that would increase SOM and thereby sequester carbon dioxide removed from the atmosphere as stable SOM.

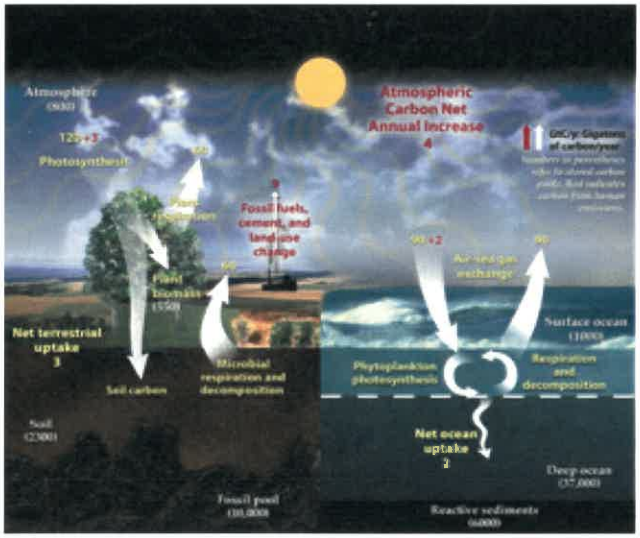

Figure 1: Global carbon cycle reflecting the annual fluxes in billions of tonnes of carbon. Yellow numbers are natural fluxes, red are human contributions, white is stored carbon. The effects of volcanic and tectonic activity are not included. Source Wikipedia

Project Drawdown has estimated that the implementation of conservation agriculture, where cultivation is minimized and cover cropping and extended rotations are adopted, could result in the removal of 17.4 Gt on CO2 (4.7 Gt C) from the atmosphere.

There are significant co-benefits of increasing SOM as it not only represents a removal of CO2 from the atmosphere it also has multiple co-benefits to agricultural soils. Soil organic matter plays a critical role in the function of soil. It is responsible for the formation of soil structure, the storage of soil nutrients and is substrate for soil organisms. Agronomically SOM is important in maintaining soil structure which enables the soil to store plant available water, resist soil erosion and drain water in a timely fashion. SOM is also an important source of nutrients and thus increasing SOM improves the fertility of soil. Building soil organic matter in soil is therefore not only a GHG mitigation strategy it is also a climate change adaptation strategy as it enhances the resiliency of soil and its ability to withstand more extreme climatic fluctuations.

This BMP presents three management practices that can be implemented independently or in combination to build SOM - reduced intensity, depth and timing of tillage, the used of extended rotations, and the addition of carbon amendments.

REDUCED INTENSITY, DEPTH AND TIMING OF TILLAGE

The cultivation of agricultural soils is one of the primary management practices that has resulted in the decline in soil organic matter in agricultural soils in Canada (Clearwater et al., 2016). In Prairie Canada, the adoption of reduced tillage practices has resulted in a reversal of this trend. Reducing the amount of soil disturbance has allowed the recovery of soil organic matter levels and significant storage of carbon in agricultural soils. At a national level this represents a storage of approximately 1.6 Mt C y-1 (5.7 Mt of CO2e y-1).

There is a considerable body of research to support the potential for changes the tillage operations in potato production systems to build SOM in PEI. Carter and Sanderson (2001) advocated a shift in primary tillage of the crop preceding potato from the fall to the spring (Fig. 2). In a Long-term (18-year) evaluation of this approach they compared a conservation tillage approach to conventional methods. The conservation tillage approach involved altering the timing and intensity of tillage to affect a conservation of soil organic matter and an increase spring soil water content. The conservation tillage (MT) system consisting of spring tillage using a chisel plow and was compared to a conventional tillage (CT) system involving the fall plowing of the forage crop preceding potato using a mouldboard plow (Fig 2). These we evaluated both in 2-year and 3-year potato production systems. The switch from fall to spring tillage results in improved soil cover and water retention over the winter period. The use of the less intensive chisel plow resulted in less soil disruption and the burying of less residue than does traditional moldboard inversion tillage. There was no adverse impact of the conservation tillage system on potato yield (Carter et al., 1998).

Tillage practices significantly affected soil water content (at both the 0- to 15-cm and 15- to 30-cm soil depths) with CT generally showing a greater soil water content prior to spring tillage in comparison to the other treatments (Carter et al. 2005). Surface residue levels were higher with reduced tillage systems such as CT and autumn chisel plowing, in comparison to conventional tillage systems. Soil organic carbon and soil structural stability were significantly increased at the 0-10 cm soil depth in the CT, compared to the conventional system (Carter et al., 2010). The conservation tillage system, when compared to conventional tillage, increased soil organic C, large water-stable macro-aggregates, and soil particulate C and N in the potato year only. The increase in SOC stabilized after 5 years in the rotation at approximately 200 g C m-2 (2,000 kg C ha-1) in each of three years reported. After the potato phase, rotation crops were associated with the further restoration of all soil C and N fractions and soil structural stability indices (Carter et al., 2009a). Comparisons with earlier studies indicated that soil organic C had reached an equilibrium level at the 0- to 10-cm soil depth (Carter et al., 2009b). Soil-borne diseases of potato were significantly reduced in 3-year rotations compared to 2-year rotations but were mainly unaffected by tillage practice. Overall, use of CT in 3-year potato systems has the potential to maintain crop productivity and protect the soil resource (Carter et al., 1998).

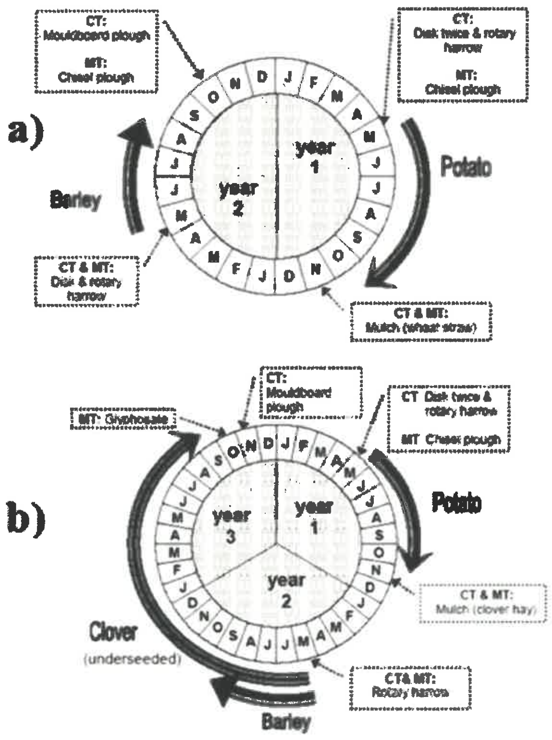

Figure 2: Conceptual outline of tillage and management practices for conventional (CT) and conservation (MT) tillage in the (a) 2-year and (b) 3-year potato rotation (from Carter et al. 2010).

The observations of Carter in PEI are consistent with work being conducted on diversified potato rotations in Maine (Griffin et al., 2009). Delaying primary tillage until spring, immediately before planting potato, resulted in higher soil water content early in the growing season (before or immediately after planting). Delaying fall tillage until the spring also provided nearly complete ground cover during potentially erosive periods in fall and early spring. The inclusion of clover or ryegrass cover crops had small, positive effects on the proportion of the soil surface covered by crop residue in both fall and spring tillage systems. A significant tillage effect on total tuber yield was seen in only one rotation cycle, when delaying tillage until spring reduced yield by about 12% (Griffin et al., 2009).

The results of the 14-yr study confirm the conclusions of previous short-term studies that a reduction in depth and intensity of tillage for potato culture is yield neutral, and a viable alternative to conventional tillage systems for potato production on sandy loams in eastern Canada (Carter et al., 2009c). In order to minimize tillage erosion, both the frequency and intensity of all field activities that disturb the soil must be reduced. Simply leaving crop residue at the surface does not control tillage erosion. (Tiessen et al. 2007 a,b).

This BMP proposes the adoption of the conservation tillage system advocated by Carter including the shift from the use of a mouldboard plow in the fall to a chisel plow in the spring.

POTENTIAL GHG REDUCTIONS

Carter's work documented that a ~ 2 tonne C ha-1 (200 g C m-2) increase in SOC could be achieved over a three year rotation with a transition to a conservation tillage system (Carter et al., 2010). This would also represent a reversal of the 0.05% y-1 (~1 tonne C ha-1) loss currently occurring (Nyiraneza et al., 2017) and therefore a net change of 1.67 tonnes C ha-1 y-1. The adoption of these practices on 10,000 ha would represent a 17 kt C y-1 (62 kt CO2e y-1) of carbon sequestration.

Assume the adoption of cover crops on 1/3 of land area going into potato production each year or approximately 10,000 ha.

Soil carbon sequestration - assume
2000 kg C ha-1 = 7.3 tonne CO2e ha-1 y-1

10,000 ha x 7.3 tonne CO2e ha-1 = 73,000 tonne CO2e ha-1 = 73 kT CO2e

To estimate the impact on direct N2O emissions, assume that not plowing the fall crop will result in a decrease in N2O emissions associated with residue decomposition. The N2O emissions associated with the decomposition of this residue N would be 1.61% of the total N content or 2.1 kg N2O-N ha-1 y-1 which is equivalent to 0.95 tonnes of CO2e ha-1 y-1.

10,000 ha x 0.10 x 0.95 tonnes CO2e y-1= 0.95 kt CO2e y-1

Assuming an increased retention of nitrogen by delaying the incorporation of the forage crop results increased soil N supply to the following potato crop and this allows reduces the N fertilizer requirement for the potato crop – assume opportunity to reduce fertilizer N by 5%

10,000 ha x 0.05 x 200 kg N ha-1 = 100,000 kg N

100,000 kg N x 0.0161 x 44 kg N20/28 kg N20-N x 298 = 0.75 kt of CO2e

Thus, the adoption of the conservation tillage approach on 10,000 ha (1/3 of land going into potatoes each year) would result in an increase in SOC over 5 years equivalent to 73 kt CO2e an annual GHG reductions of 0.95 kt of CO2e from reduced GHG losses associated with reduced fall decomposition of the legume forage and a reduction 0.75 kt of CO2e associated with decreased fertilizer N use in the following potato crop. The total reduction would be a one-time 73 kt CO2e and annual reductions of 1.7 kt CO2e y-1. Over a 5-year timeframe this would represent a total reduction of 81 kt CO2e.

Here we base our estimation of the impact of implementing this BMP based solely on its use in potato production in PEI. There is additional opportunity to build SOM through reduced tillage in other phases of the potato production system as well as in other cropping systems in PEI. This estimate should be viewed as a conservative estimate of the total potential.

COSTS AND POTENTIAL CO-BENEFITS

Cost associated with implanting the element of the BMP primarily relate to the purchase of new equipment (tillage equipment, no till seeders). A government programs to assist with the cost of purchasing this equipment would reduce this barrier.

There are significant co-benefits associated with the adoption related to reduced fuel cost, increased soil health, and reduced soil erosion. Long-term field studies conducted in PEI have also demonstrated that potato production systems could be modified through lengthening the rotation (2 to 3-year) and the implementation of conservation tillage practices would improve disease suppression (Peters et al., 2003).

MODELLING AND MEASURING EMISSIONS REDUCTION AND/OR SEQUESTRATION

The adoption of this practice would be most effectively documented by producer surveys and/or self-reporting as part of program participation. In addition, surveys of soil coverage in the fall might be undertaken to confirm reduced fall tillage. The magnitude of carbon storage would be could be captured in national-scale soil carbon modelling tools (daycent, Holos). The impact of this practice would also be anticipated to appear in the routine soil quality monitoring being undertaken by the PEI Department of Agriculture and Fisheries as well as in routine measurements of soil carbon/soil health being done by the PEI Analytical Lab.

THE USE OF EXTENDED ROTATIONS

The PEI potato industry have moved from a 2-year rotation (potato 1 in 2 years) to a 3-year rotation (potato 1 in three years), in part, in response to the Agricultural Crop Rotation Act of 1988, to control nitrate loading to groundwater, surface water and to protect soil quality. This transition was supported by extensive research that had demonstrated the positive impacts of the longer rotations. The move to a 3-year rotation is expected to result in an increase in SOC content (Fig. 3), or at least a decrease in the rate of decline.

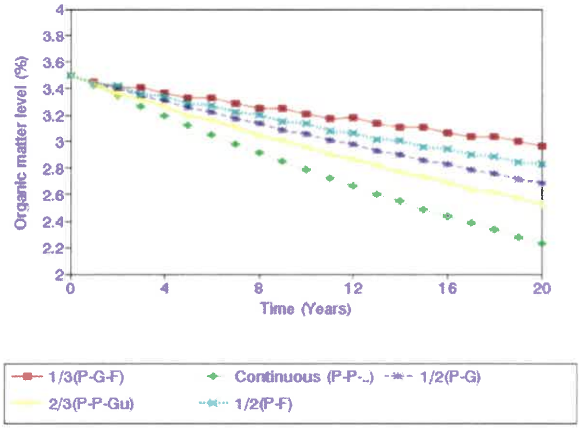

Figure 3: Influence of the frequency of potato inclusion in rotation on soil organic matter content. (Source: Eastern Soil and Water Conservation Centre).

Peters et al. (2003) demonstrated that potato tubers harvested from 3-year rotational soils had less diseased than those from 2-year rotation, supporting the view that soil agroecosystems can be modified through rotation and conservation tillage practices to improve disease suppression (Peters et al., 2003). Carter and Sanderson demonstrated the interaction between conservation tillage and extended crop rotation increased soil organic carbon content an addition 15% above the 8% realized from the implementation of conservation tillage. (Carter and Sanderson, 2001).

There are few studies which have examined the potential for rotations longer than 3-years on SOC. Preliminary data from a study soil health in PEI demonstrated a weak but significant relationship between SOC and frequency of potato in rotation (Fig. 4; Burton, pers. comm.). This data suggests that SOC content was 13% greater in a 3-year rotation than a 2-year rotation and that extending the rotation to 4 years would result in an additional 19% increase in SOC and to 5 years a 23% increase relative to a 2-year rotation.

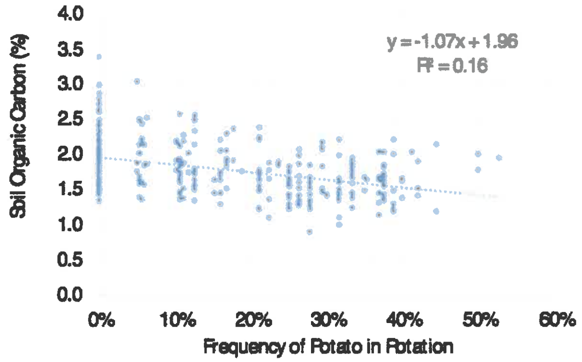

Figure 4: The relationship between soil organic carbon (%) and the frequency of potato crops in ten years of crop history for soils sampled as part of PEI Soil Health Survey (Burton, pers. comm.)

POTENTIAL GHG REDUCTIONS

SHIFT FROM 2-YEAR TO 3-YEAR ROTATION

Based on the assumption that a shift from a 2-year rotation to a 3-year rotation resulted in an increase in SOC of 0.18% and assuming that this shift occurs in most of the area in potato production (30,000 ha).

2,000,000 kg soil/ha x 0.0018 kg additional C/kg soil = 3,600 kg additional C/ha

3,600 kg C/ha x 44 kg CO2e/12 kg C x 30,000 ha = 396,000,000 kg CO2e = 396 kt CO2e

This is the expected new equilibrium concentration and it is reasonable to suggest that establishing this new equilibrium would take 20 years (5 rotations) and thus would represent an annual increase in carbon storage of 19.8 kt CO2e y-1. Since the crop rotation act has been in place since 1988 this 20-year period has passed and therefore this could be considered as a benefit that has already been realized.

SHIFT FROM 3-YEAR TO 4-YEAR ROTATION

Based on the assumption that a shift from a 3-year rotation to a 4-year rotation would result in an increase in SOC of 0.09% and assuming that this shift occurs in 1/3 of the area in potato production (10,000 ha).

2,000,000 kg soil/ha x 0.0009 kg additional C/kg soil = 1,800 kg additional C/ha

1,800 kg C/ha x 44 kg CO2e/12 kg C x 10,000 ha = 66,000,000 kg CO2e = 66 kt CO2e

This is the expected new equilibrium concentration and it is reasonable to suggest that establishing this new equilibrium would take 20 years (5 rotations) and thus would represent an annual increase in carbon storage of 3.3 kt CO2e y-1.

COSTS AND BENEFITS

The primary costs associated with the implementation of this BMP relate to the reduced return associated with the reduced frequency of the potato crop. A study conducted by the Eastern Canada Soil and Crop Improvement Centre indicated that, while a 3-year potato rotation was resulted in similar net income relative to a 2-year rotation (Fig 5), a 5-year rotation resulted in a significant decline in revenue. This assumes there is not another high value crop in the rotation. To make extended rotation more attractive to producers there would to be another revenue generating crop included in the rotation.

The effect of the frequency of potato in rotation influences the potential for disease impacts. In a study conducted in Washington State, the incidence of black dot (Colletotrichum coccodes) was related to the frequency of potato in rotation while incidence, silver scurf (Helminthosporium solani) was found to relate to the number of previous potato crops, and incidence of Verticillium dahliae was not related to years between potato crops or number of previous potato crops (Johnson and Cummings, 2015).

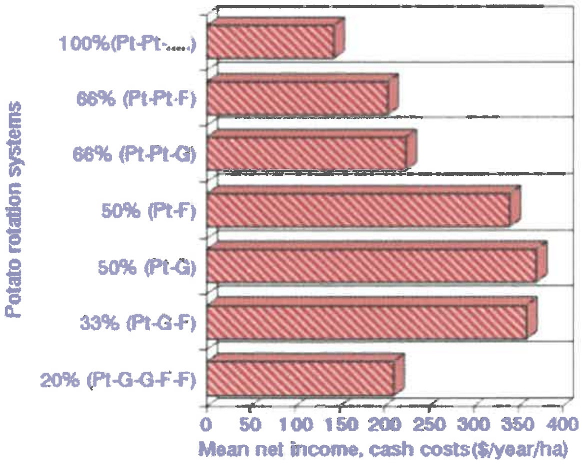

Figure 5: Influence of frequency of potato in rotation on the mean net income from the rotation. (Source: Eastern Canada Soil and Water Conservation Centre).

Land availability may also represent a significant barrier to adoption. The availability of land for potato production is often cited by producers as a challenge in considering alternate management. This BMP would require a 33% increase in the land base required to sustain the production of potatoes on the operation.

MODELLING AND MEASURING EMISSIONS REDUCTION AND/OR SEQUESTRATION

The adoption of this practice would be most effectively documented by producer surveys and/or self-reporting as part of program participation. In addition, surveys of soil coverage in the fall might be undertaken to confirm reduced fall tillage. The magnitude of carbon storage would be could be captured in national-scale soil carbon modelling tools (daycent, Holos). The impact of this practice would also be anticipated to appear in the routine soil quality monitoring being undertaken by the PEI Department of Agriculture and Fisheries as well as in routine measurements of soil carbon/soil health being done by the PEI Analytical Lab.

ADDITION OF CARBON AMENDMENTS

In intensive cropping systems in eastern Canada, such as potatoes, soils are suffering from declining SOM (Carter et al. 2004; Gagnon et al. 2001). Resulting losses in productivity and soil functioning has led to the pursuit of SOM conserving and enhancing practices (Carter et al. 2004; Gagnon et al. 2001). Applying compost is one option for rapidly increasing SOM (Wilson et al., 2018a).

In Eastern Canada, several studies have demonstrated increases in SOC following compost application (Carter et al. 2004; Gagnon et al. 2001; Lynch et al. 2005(Alam et al., 2016; Sharifi et al., 2014; Wilson et al., 2018a). Gagnon et al. (2001) observed a statistically significant increase in SOC after one-time application of either 10.4 tonnes C ha-1 or 20.7 Mg C ha-1 of pulp compost resulting in ~5 g C kg-1 soil and ~10 g C kg-1 soil increases in soil carbon. Increases were observed three years after application. The application of three compost products at rates of 300 and/or 600 kg N ha-1 y-1 (equivalent to total application rates of 4.6 to 10.9 tonnes C ha-1) for two years resulted in significant increases in SOC in 0-5 cm depth (Lynch et al. 2005). However, not all compost products behaved the same: different carbon gains were observed for different composts despite similar application rate of ~10 tonnes C ha-1. The biggest gains in the second year were attributed to the corn silage compost (Lynch et al. 2005). This compost had the slowest rate of mineralization (k ~ 0.05 yr-1) with 89% of compost-C retained in the soil two years after the last application. The low C:N ratio of the corn silage compost product (9.8) suggests that this compost is highly mature and more recalcitrant than the two other products with C:N ratios of 23.4 and 20.3 (Lynch et al. 2004; Lynch et al. 2005).

Carter et al. (2004) observed statistically significant increases in soil organic C following compost addition (potato: sawdust: manure, 3:3:1, C:N = 4) at a cumulative rate of ~5 tonnes C ha-1 in a potato rotation that included potato, barley and red clover. However, a significant increase in SOC following compost addition was not observed during the red clover phase of the experiment. This is likely due to high annual C input from red clover (240-600 g C m-2). Had higher rates of compost been applied, it is likely that a significant increase in SOC would have been observed. The average increase in SOC was 2 g C kg-1 soil (4 tonnes C ha-1). Sharifi et al. (2014) observed that the addition of 12 Mg ha-1 of municipal solid waste compost resulted in an increase of 0.3 tonnes C ha-1 in SOC. Wilson et al. (2019) observed that the addition of 45 Mg ha-1 composts of diverse origin resulted in increases in SOC ranging from 1.1 to 4.5 g C kg-1 with an average of 2.2 g C kg-1 (4.4 tonnes C ha-1)

The use compost amendments to control of soil-borne diseases has also been demonstrated to be an effective means of reducing soil-borne disease pressure (Bernard et al., 2012; Larkin, 2008; Wilson et al., 2018b) and thus represents a significant co-benefit.

Here we consider the addition of compost at ~ 45 tonnes ha-1 on 5,000 ha over a 5-year period.

Assume the application of ~ **45 tonnes ha-1 of compost on 5,000 ha of land.**

Soil carbon sequestration - assume 4 tonnes C ha-1 = 14.7 tonne CO2e ha-1

5,000 ha x 14.7 tonne CO2e ha-1 = 73,000 tonne CO2e ha-1 = 73 kT CO2e

These gains due to carbon sequestration may be offset to some degree by increased N2O emissions associated with the addition of a carbon substrate.

MODELLING AND MEASURING EMISSIONS REDUCTION AND/OR SEQUESTRATION

The adoption of this BMP could be documented as the measured increase in soil organic carbon over time in land receiving organic amendment. The limitation being that it will take 5+ years before measurable differences would be detected. Inclusion of soil organic carbon determination in routine soil testing as is the current practice and increased use of soil health assessments would further enhance the documentation of these soil organic matter building practices.

SUCCESS METRICS

The primary success metric for this BMP is the number of hectares that are under one of the three practices described. In all cases the increase in SOC could either be documented through direct measurement or modeled output using national scale carbon models (daycent, Holos).

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BMP 3
INCREASED USE OF SOIL-BUILDING CROPS AND PERENNIAL CROPPING SYSTEMS

DESCRIPTION

One of the practices that has resulted in a significant decline in organic matter in PEI is the shift from perennial plant cover (forest, pasture, orchard) to annual cropping systems. This BMP examines opportunities to integrate more multi-year and perennial cropping systems into agricultural land use in PEI.

Plant growth sustains and enhances soil function. It is cropping systems with limited duration of plant cover and high amounts of soil disturbance to establish, maintain and harvest the crop that result in soil degradation. The potential to use a cover crop to extend the period of plant cover was demonstrated in BMP 1. In this BMP we examine the full season and perennial use of plant cover as a means of increasing soil organic matter, reducing the need for nitrogen fertilizer inputs, and in disease suppression. The general concept is to increase the length of time a plant is actively growing in the soil, choosing plant species that have fibrous roots, preferably legumes and minimizing soil disturbance increase the potential to build soil organic matter and soil health.

USE OF FULL-SEASON SOIL-BUILDING ROTATION CROPS

Prince Edward Island soils in potato production have seen a declining trend for soil organic matter percentage (Nyiraneza et al., 2017). Higher soil organic matter is generally associated with improved water holding capacity, soil structure, and soil nutrient levels. Soils with higher organic matter sequester atmospheric carbon and are more resilient to climate change, particularly periods of low rainfall in the summer months that have become more common in recent years. Due to a lack of available and economically viable sources of organic soil amendments, building soil organic matter through rotation crops is a growing practice in Prince Edward Island. However, there is a lack of scientific evidence demonstrating the effect that particular crops have on soil organic matter and soil structure as well as levels of certain soil-borne diseases.

Rather than simply establish the crop as fall catch or cover crop this BMP proposes the growth the crop for the entire season to enhance soil function. This type of management is not without precedence in PEI. The introduction of the 3-year rotation was legislated to address issues of nutrient impacts on water as a result of leaching and soil erosion. The third year of the rotation was most commonly a red clover crop that had been under-seeded into the previous barley crop.

This is an example of a full-season soil building crop. The red clover phase of the crop rotation not only helps to restore SOC but also contributes nitrogen to the subsequent potato crop, reducing the amount of fertilizer N that needs to be added and thus reducing N2O emissions.

In a 6-year trial conducted in PEI, (Carter and Sanderson, 2001) demonstrated that a 3-year potato-barely-red clover rotation resulted in 3 g C kg-1 (6 tonnes C ha-1; 22 Mg CO2e ha-1) soil more SOC than did a 2-year potato-barley rotation. Grandy et al. (2002) found that a green manure crop (oat, pea and hairy vetch) grown in 2-year rotation with potatoes resulted in 2 g C kg-1 (4 tonnes C ha-1; 15 Mg CO2e ha-1) soil increase in SOC (Grandy et al., 2002). In contrast, in a 3-year trial Nyiraneza did not detect a significant effect of the inclusion of soil building crop (red clover, sorgum sudan grass/winter rape, canola/winter rape) on SOC (Nyiraneza et al., 2015).

Soil carbon sequestration - assume that the adoption of a full season on 10,000 ha (1/3 of all potato rotations in PEI), and that the soil building crop would result in the sequestration of at least 10 Mg CO2e ha-1 over a 10 year period, this translates into:

100,000 ha x 5 Mg CO2e ha-1 = 10,000 Mg CO2e ha-1 = 100 kt CO2e

Assuming an increased soil N supply to the following potato crop when the soil building crop is a legume, this practice would reduce the N fertilizer requirement for the potato crop by 30 kg N ha-1 (current credit for legume plowdown). Assume 50% of the soil building crops are legumes.

5,000 ha legume soil building crops x 30 kg N ha-1 = 150,000 kg N

150,000 kg N x 0.0161 x 44 kg N20/28 kg N20-N x 298 = 1.13 kt of CO2e y-1

Over a five-year period this
translates into a total reduction of

50 + 5.7 kt of CO2e = 55.6 kt of CO2e

A co-benefit of this BMP proposes is the use of full season soil building crops to address soil health issues including disease pressure. Extending rotations beyond five years has been shown to decrease severity of a number of soil-borne diseases (Johnson and Cummings, 2015). The inclusion of biofumigant crops as full season crops has been shown to be more effective in controlling soil-borne disease (Larkin and Halloran, 2014). There is considerable interest in using crops such as brown mustard to not only act as a biofumigant but also to supply increased amounts of organic matter. One of the challenges in assessing the potential for carbon storage with this practice is that the brown mustard requires incorporation into the soil to become active and thus the increased degree of disturbance may negate any SOC building role of this crop.

In total the use of full-season soil-building cover crops on 10,000 ha (1/3 of land in potatoes each year) would result in a GHG reduction of 55.6 kT of CO2e over a 5-year period resulting from increase SOC and reduced N fertilizer use in the potato crop. We have not attributed any reduction associated with N2O emissions during the growth of the soil building crop but assume this crop would have relatively low fertilizer N requirements and therefore would have low associated N2O emissions.

CO-BENEFITS

The anticipated improvements in soil health and reduced disease pressure would be significant co-benefits of this BMP. Increased soil organic matter content would result in increased aggregation and soil water holding capacity which would increase the resiliency of the soil to the impacts of climate change and drought.

BARRIERS TO ADOPTION

One of the major barriers to adoption is knowledge of which crops to grow and how to work them into existing rotations. There is active research at AAFC in PEI and by industry. McCain has been examining an annual (one-year) cover crop mix featuring 13 species, including pearl millet, sorghum-sudangrass, spring oats, dwarf Essex rape, Austrian winter peas, fababeans, chickling vetch, balansa clover, buckwheat, sunflower, phacelia, Winter Hawk ryegrass and Ethiopian cabbage (Pearce, 2018). They are also considering a perennial (two-year) blend has 12 species, with pearl millet, sorghum Sudan grass, spring oats, Austrian winter peas, fababeans, balansa clover and sunflower – all annuals. Those die off after the first year leaving a second-year crop of Winter Hawk ryegrass, perennial ryegrass, alfalfa, double-cut red clover and timothy. McCain launched the one-year multi-species blend in 2017 and the two-year mix in 2018 by conducting trials in grower fields. The company expects to modify the blends based on observations on the on-going trials.

SHIFT FROM ANNUAL CROPS TO PERENNIAL CROPS

One of the major factors causing the decline in SOC levels in PEI has been the conversion of land in annual crops (pasture/hay) into annual crops. This BMP considers the impact of reversing that trend and converting land that is marginal for annual crop production into permanent cover. Examples would be re-establishing land currently cropped to annual crops (potatoes, field crops, vegetables) to permanent pasture, berries, tree fruits or similar low disturbance systems. The conversion to permanent cover results in greater carbon inputs, particularly root carbon, as well as less disturbance. The result is significant increases in soil organic matter contents.

For the purposes of evaluation, the potential sequestration related to the conversion of land in annual cropping to perennial cover we have assumed that a 1% increase in SOM could be achieved over 5 years. We have also assumed a rather modest conversion of only 1,000 ha of land area in total would be converted.

1% SOM x 57% C = 0.0057 kg C kg-1 soil x 2,000,000 kg soil ha-1 = 11,400 kg C ha-1

11,400 kg C ha-1 x 44 kg CO2e/12 kg C x 1,000 ha = 41,800,000 kg CO2e = 41.8 kt CO2e

Thus, the conversion of 1,000 ha of land from annual cropping to perennial cropping would result in a 41.8 kT CO2e sequestration of carbon in the first 5-years of conversion. There might be further increases at lower rates of accumulation over additional years, but they have not been considered in this assessment. Also, perennial cropping systems also often involve lower rates of N fertilizer application which also has not been considered in this scenario.

COSTS AND BENEFITS

The economic returns from annual cropping systems are generally much greater than perennial cropping systems and this has been one of the major factors driving the conversion or lands under perennial cover to annual cropping over the past three decades. The increase in the number of high value perennial crops (fruit trees, vineyards) may help to reverse this trend. In the US government programs such as the set aside reserve program have been used to take marginal land for annual cropping out of production.

MODELLING AND MEASURING EMISSIONS REDUCTION AND/OR SEQUESTRATION

Producers could be asked to report of the establishing of soil-building crops within rotation and/or conversion of land for permanent cover. The magnitude of SOC accumulation can be estimated using nationally accepted modelling platforms (daycent, Holos). Reduced N fertilizer sales provide direct evidence of reduce N2O emissions associated with increased use of legumes in rotation.

Measurements of SOC as part soil fertility or soil health testing by producers or changes in SOC documented in PEI Department of Agriculture and Fisheries Soil Quality Monitoring program could also be used to support emissions reductions.

SUCCESS METRICS

The number of hectare adopting this BMP would be the most direct success metric.

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BMP 4

IMPROVED NITROGEN FERTILIZER MANAGEMENT THROUGH IMPLEMENTATION OF 4R MANAGEMENT

DESCRIPTION

The potential for reducing N2O emissions from improved N fertilizer management is large. While there has been a decline in N fertilizer use in Atlantic Canada, peaking in 2002 (Fig. 1), the decline has been primarily associated with a decrease in area cropped and not to a decline rate of N fertilizer use per hectare.

There is a considerable body of scientific evidence supporting the ability of 4R N fertilizer management to reduce N2O emissions. It is clear that developing a 4R program is, at the very least, region and crop specific and, in many cases, site-specific. The overall program must consider the interaction of source, rate, time and place.

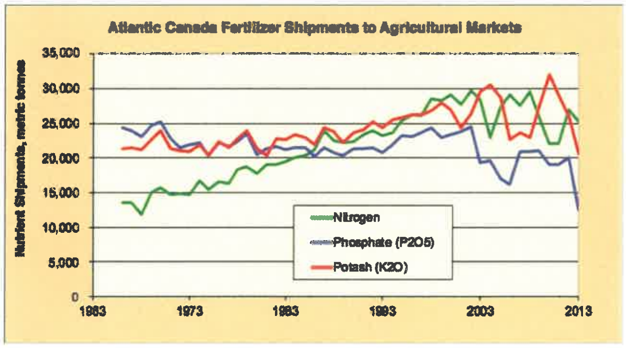

Figure 1: Sales of fertilizer macronutrients in Atlantic Canada from 1966 to 2013 (IPNI based on Fertilizer Canada and Statistics Canada data).

4R MANAGEMENT AND THE NITROUS OXIDE EMISSIONS REDUCTION PROTOCOL (NERP)

Fertilizer Canada has introduced the 4R Nutrient Stewardship program to optimize the efficiency of nutrient use in agriculture. The program highlights the opportunity to use the Right Source of fertilizer applied at the Right Rate in the Right Place at the Right Time. The application of 4R Nutrient Stewardship principles to nitrogen fertilizer can result in reductions in N2O emissions and reduced NO3- leaching (and in-direct source of N2O). These principles form the basis of the Nitrous Oxide Emissions Reduction Protocol (NERP) which has been implemented in Alberta and is being considered for national implementation. Protocols of this nature provide incentive to producers to adopt GHG mitigating practices by allowing them to be quantified and used as carbon offsets in carbon trading mechanisms. The implementation of 4R Nutrient Stewardship principles also result in other environmental benefits as reduced risk of NO3- leaching.

The impact of N fertilizer management on N2O emissions is highly dependent on climate and soil type. The timing of precipitation remains an important determinant of the potential for N2O loss, open winters result in greater non-growing season emissions. Fall nitrate accumulation is an important strategy in reducing N2O emissions and fall N applications should be avoided.

Fertilizer products/practices that delay the formation of nitrate are consistent in their ability to reduce N2O emissions. Urease and nitrification inhibitors are particularly consistent in this regard. Products and placements that influence the solubilization of the fertilizer product are influenced by the pattern of precipitation and as a result produce more variable result. Similarly, timing of fertilizer N application interacts with the pattern of precipitation in determining the magnitude of reduction in N2O emissions. Determining the right rate of N fertilizer still remains one of the greatest challenges establishing a 4R program. The need to consider all N sources and non-linear nature of N2O emissions to soil N availability complicate the determination of the right rate. The emergence of tools to provide site specific measures soil N supply and plant N response would greatly assist the determinate of right rate. This will be the subject of a separate BMP (BMP 5).

There is a greater realization and understanding emerging as to the role of other soil management and cropping practices in determining the potential for N2O emissions. The choice of the most appropriate 4R practices should consider the impact of these factors in determining the magnitude and timing of the potential for N2O losses.

The potential for pollution swapping must also be considered. Practices that decrease N2O emissions but result in increased NH3 or NO3- loss do not result in increased N use efficiency. While the indirect emissions from these compounds may not be as great as direct emissions of N2O, the overall impact on the ecosystem should be considered.

The following chart summarizes the 4R nitrogen fertilizer management practices that have been recommended by Fertilizer Canada's Metrics and Adoption Working Group to increase fertilizer nitrogen use efficiency and decrease direct and indirect N2O emissions.

Table 1: Suggested emissions reduction modifiers for 4R nitrogen fertilizer management in rain-fed potato production in Eastern Canada (Fertilizer Canada Metrics and Adoption Working Group, 2018).

	Right Source	**Right Rate**	**Right Time**	**Right Place**	**Emissions Reduction Modifier**
Basic	Any N fertilizer with guaranteed analysis.	Apply based on nitrogen balance or provincial guidelines for yield goals. Set field specific rates based on previous yield history and soil types. Adjust for variety following provincial guidelines.	Apply nitrogen in spring before or at seeding. No N application on frozen soil and/or snow-covered ground.	Broadcast and incorporate. Consider using enhanced efficiency fertilizer in cases where incorporation is not possible following surface application	1.0 (no reduction)
Intermediate	Same as Basic, plus Use of enhanced efficiency fertilizers (nitrification inhibitors, urease inhibitors, or controlled release) should account for at least 33% of total N budget	Same as Basic, plus Adjust N rates based on estimates of residual nitrogen in combination with estimates of other soil supply sources (mineralization, previous pulse or other legume crops). Build N rate strategy based on well -developed field management zones adjusting N rates according to estimates of field variability.	Same as Basic. Split nitrogen between before or at seeding and one or more in-season applications.	Same as Basic	0.85
	Same as Intermediate, plus Use of enhanced efficiency fertilizers (nitrification inhibitors, urease inhibitors, or controlled release) should account for at least 50% of total N budget	Same as Intermediate, plus Apply N according to quantified field variability using digitized soil maps (advanced variable rate). Monitor in-season and/or post season N use using technologies such as crop sensors, satellite or UAV imagery, crop nitrogen demand modelling, field scouting, and petiole testing.	Same as Intermediate	Same as Intermediate	0.85

USE OF ENHANCED EFFICIENCY FERTILIZERS

The use of enhanced efficiency fertilizers (EEF) permits a reduction in the amount of N fertilizer to reflect the higher efficiency of N delivery as well as improving the synchrony of the formation of nitrate with plant N demand. Together these principles allow for reduced N2O emissions and NO3- leaching while maintaining plant N supply. Substituting a EEF for a standard N source such as urea without the corresponding reduction in N rate seldom results in reduced N2O emissions(Zebarth et al., 2012). The science supporting the impact of EEFs on N2O emissions is summarized in the State of Knowledge chapter.

This BMP proposes the substitution of 33% of the recommended N fertilizer rate with an EFF further it is assumed that the EFF is applied a rate 15% less than the recommended rate to reflect the higher efficiency of N use with the EFF.

THE MAGNITUDE OF THE POTENTIAL REDUCTION

We were unable to locate statistics for the amount of fertilizer used in potato fields in PEI each year. Here we estimate that number

Assume 35,000 ha in potato production each year

Assume an average N fertilizer application rate of 200 kg N ha-1 (180 lb N ac-1)

35,000 ha x 200 kg N/ha = 7,000,000 kg N

Further we can estimate the amount of direct N2O emissions from this fertilizer using the IPCC Tier 1 emission coefficient of 0.01

7,000,000 kg N x 0.0161 = 112,700 kg N2O-N x 44 kg N2O/28 kg N2O-N x 298 CO2e/N2O =53 kT of CO2e

Expressed on a per hectare basis for the 35,000 hectares considered in this example it is equivalent to ~ 1,500 kg CO2e ha-1 y-1.

It has been estimated as part of Fertilizer Canada's development of a Nitrous Oxide Emissions Reduction Protocol (NERP) that the replacement of 33% of N fertilizer used in potato crops with EEFs would result in a 15% reduction in N2OEFmin and a 50% replacement of N fertilizer used with EEFs would result in a 25% reduction in N2OEFmin. Adoption of the BMP in 25% of the farms using

Assume 7,000 tonnes of fertilizer N used annually

Assume 25% of potato producers replace 33% of their N fertilizer use with EEFs

Assume that the use of the EFF results in a 15% reduction in N fertilizer rate.

Assume the N2OEFmin = 1.61 x 0.85 = 0.0137

The 25% of farms adoption this practice would be applying **7,000,000 kg N x 0.25 x 0.85 = 1,487,500 kg N**

For this fertilizer N, a reduced N2O emission coefficient of 0.0085 would apply resulting in a further reduction equivalent to

1,487,500 kg N y-1 x 0.0137 = 20,379 kg N2O-N y-1
20,379 kg N2O-N x 44 kg N2O/28 kg N2O-N x 298 = 9.54 kT of CO2e y-1

This is 3.71 kT CO2e less than the 13.25 kT CO2e (53 kt CO2e x 25%) that would be emitted from these fields had the BMP not been implemented and represents a 10 kT CO2e reduction per year or 50 kT CO2e over five years.

One of the barriers to adoption is the increased cost of EFF products. They are typically 20 -50% higher in cost. This cost can, at least partially, be offset by decreased rate of application. A clear documentation of the economics of including an EFF in the N fertilization program would increase the likelihood of adoption.

Another barrier to adoption is a lack of familiarity with these products and the number of new products that are becoming available. Field trials demonstrating specific products at reduced rates of application would increase the adoption of these practices. Fertilizer Canada through the 4R Island program has been conducting field-scale demonstrations of 4R practices that have included the use of EEFs. Often these side-by-side trials have featured a comparison between the grower's standard practice and a 4R suite that may involve several of the 4Rs. These demonstrations might be more effective in demonstrating the importance of EEFs if that was the only difference between the field comparisons.

SPLIT APPLICATION OF NITROGEN FERTILIZERS TO INCREASE N USE EFFICIENCY

The splitting of the application of nitrogen between planting and hilling would reduce the risk of loss of N to either N2O emissions, denitrification or NO3- leaching in years where there is significant rain fall during that period (Burton et al., 2008). This BMP assumes that at least 33% of the application of nitrogen is delayed until just prior to hilling.

It has been estimated as part of Fertilizer Canada's development of a Nitrous Oxide Emissions Reduction Protocol (NERP) that split application of N fertilizer would result in a 15% reduction in N2OEFmin. Since this is a relatively modest change in practice, with limited additional costs we assumed the adoption of the BMP on 50% of potato fields in PEI. We estimate the reduction of GHG emissions on the following basis.

Assume 7,000 tonnes of fertilizer N used annually

Assume 50% of potato producers split at least 33% of their N fertilizer

Assume the N2OEFmin = 0.0161 x 0.85 = 0.0137

For this fertilizer N, a reduced N2O emission coefficient of 0.0137 (0.0161 x 0.85) would apply resulting in a further reduction equivalent to

3,500,000 kg N y-1 x 0.0137 = 47,950 kg N2O-N y-1

47,950 kg N2O-N x 44 kg N2O/28 kg N2O-N x 298 = 22.5 kT of CO2e y-1

This is 4.0 kT CO2e less than the 16.4 kT CO2e (53 kT CO2e x 50% = 26.5 kT CO2e y-1) that would be emitted from these fields had the BMP not been implemented. Over five years this represents 20 kT CO2e.

Note that this BMP could also be implement in field crop systems, but this has not been included in the estimate of emissions reduction presented here.

There are number of producers that are currently using split N applications. The biggest barrier is there has not been a demonstrated yield advantage to split application. This may be in part because few potato production systems are N limited and therefore increased efficiency of N use is seldom reflected in yield.

USE OF IRRIGATION TO MITIGATE DROUGHT STRESS AND INCREASE NUTRIENT USE EFFICIENCY

Crop failure as a result of drought is not only a severe economic risk for the grower, but also has a major environmental impact. Each season growers fertilize to meet an anticipated yield goal. If drought prevents the crop from achieving that goal, then nutrients are in excess. Some nutrients are retained in the soil for future crops, but nitrogen has a very high probability of being lost as N2O or NO3- leaching. The use irrigation to mitigate drought would not only save the crop in terms of an economic harvest but would also reduce the accumulation of unused nitrogen.

Assume that the use of irrigation results in the prevention of drought induced yield reductions 1 in 5 years. Assume that 33% of the area cropped to potatoes installs irrigation to prevent these drought impacts.

Assume that in drought years the emissions of N2O associated with N fertilizer are 40% higher (Emission Factor associated with direct emissions from fertilizer is increased from 1.61% to 2.25%) and that in-direct emissions are increased as a result of the greater carryover of soil N into the fall winter period.

10,000 ha x 200 kg N ha-1 y-1 x 0.0064 x 0.2 = 2,560 kg N2O-N y-1

2,560 kg N2O-N x 44 kg N2O/28 kg N2O-N x 298 = 1.20 kT of CO2e y-1

Over a 5-year period this would result in 6 kT of CO2e reduction.

ADOPTION OF HIGHER EFFICIENCY, SHORTER SEASON POTATO CULTIVARS

DESCRIPTION

Russet Burbank is the dominant potato variety grown in PEI. It is both a long-season variety and one that is a high demanding and not particularly efficient at N utilization (Zebarth et al., 2004). The long season means there is limited opportunity to establish a cover crop to provide soil cover and immobilize nutrients. The high N demand means that there is a high rate of N application that is at risk of N loss during adverse climatic conditions. Switching to a shorter season less N demanding potato variety would reduce the amount of N fertilizer applied and allow for greater fall management of N remaining in the soil.

Assume the adoption of a shorter season variety on 1/3 of land cropped to potato each year or approximately 10,000 ha. Assume that adoption of a shorter season variety would result in a 25% reduction (150 kg N ha-1 rather than 200 kg N ha-1) therefore a decrease in the rate of N fertilizer applied 50 kg N ha-1.

10,000 ha x 50 kg N ha-1 = 500,000 kg N reduction

500,000 kg N x 0.0161 = 8,050 kg N2O-N
8,050 kg N2O-N x 44 kg N2O/28 kg N2O-N x 298 = 3.77 kT of CO2e

This is 3.77 kT CO2e less N2O emitted.

The use of a shorter season potato variety would also provide more time for a cover crop to grow, therefore we assume only 200 kg C ha-1 y-1 of sequestered soil carbon as a result of the use of the cover crop.

Soil carbon sequestration - assume 200 kg C ha-1 y-1 = 733 kg CO2e ha-1 y-1

10,000 ha x 733 kg CO2e ha-1 y-1 = 7,333 Mg CO2e ha-1 = 7.33 kT CO2e y-1

The total reduction would be 11.10 kT CO2e y-1 over a 5-year period this would represent 55 kT CO2e.

The greatest barrier for the adoption of this BMP is a market for the shorter season varieties. The major buyers of potatoes in PEI still demand Russet Burbank. Consumer demand for more environmentally sustainable production may change this situation, but until it does there is little likelihood that this BMP will be widely adoption. The other option is the development of a short season variety that would meet the specifications of buyers.

COSTS AND BENEFITS

The primary costs associated with the implementation of Enhanced Efficiency Fertilizers is the increased cost (20 to 50%) of the product. The increased efficiency of N supply to the crop should result in a corresponding decrease in N fertilizer application to offset some of these costs. It is also anticipated that as the market for these products increased the cost differential will decline. Agriculture and Agri-Food Canada, PEI Department of Agriculture and Fisheries, and several industry groups are conducting trials with enhanced N management practices and products. While the documentation of the success of these approaches and the more widespread dissemination of their potential remains to be done (Stages 3&4 in the Research Cycle), there is currently sufficient information available to implement this BMP immediately.

MODELLING AND MEASURING EMISSIONS REDUCTION AND/OR SEQUESTRATION

In addition to documenting the effect of the more efficient use of nitrogen fertilizer on crop yield and quality, the effectiveness in reducing N2O emissions and NO3- leaching could be demonstrated in several ways:

1. Documentation of reduced amount N fertilizer used (kg N ha-1)
2. Documentation if increased implementation of 4R N management practices
3. Documenting a reduction in residual soil nitrogen in the fall.
4. Modelling of N2O emissions as a result of increased N efficiency N management.
5. The measurement of nitrate exposure using PRS Probe technology in producer fields implementing enhanced N efficiency practices
6. The measurement of N2O emissions from field trials implementing enhanced N efficiency practices.

The cost of monitoring increase dramatically from 1-6. The reporting of reduced N fertilizer use is the easiest and most direct method of documenting reduced N2O emissions as N2O emissions are calculated as a fraction of N fertilizer sales. Fertilizer Canada is also rolling out a program to certify 4R compliance of fertilizer retailers in PEI. This would help to document the number of hectares over which 4R management practices are being adopted. This approach does not allow for direct site-specific assessment of the efficiency of N use. To do this the measurement of residual soil nitrogen is the most practical approach.

Nitrate remaining in the soil after crop harvest has a high potential for N loss under the climatic conditions of PEI. Zebarth documented the extent of carry-over of fall nitrate to the subsequent spring (Zebarth et al., 2003). Significant over-winter nitrate losses occur as a result of a combination of denitrification and nitrate leaching. Denitrification reactions occurring in soil containing high concentrations of NO3- (> 10 mg N kg-1 soil) result in considerable amounts of N2O being released as an end product (Burton et al., 2008). In addition the over-winter period represents a period of significant NO3- loading to groundwater(Jiang et al., 2011). As result management practices which minimize residual soil NO3- provide economic and environmental benefits to the producer and the surrounding environment.

Residual soil nitrogen (RSN) is used as an agri-environmental indicator of the risk of nitrogen contamination of water (Drury et al., 2007), it also is an indicator of the potential for direct and in-direct N2O emissions (Omonode et al., 2017).

SUCCESS METRICS

The number of hectares under 4R management and a decrease in the rate N fertilizer application would be potential success metrics. In addition, the decreased impacts on N loading groundwater could be measured and reported.

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Web Links
Fertilizer Canada (https://fertilizercanada.ca)
4R Nutrient Stewardship (https://fertilizercanada.ca/nutrient-stewardship/)
NERP (https://discovernerp.ca/4r-nutrient-stewardship-to-reduce-nitrous-oxide-emission)

BMP 5

SITE-SPECIFIC "RIGHT RATE" N RECOMMENDATIONS

DESCRIPTION

Determining the right rate for fertilizer N additions is one of the most critical decisions in determining the potential for N2O emissions and NO3- leaching. Currently N fertilizer recommendation are generalized for the entire province. For potato production differences in N fertilizer recommendations reflect different potato cultivars. There are only rudementary means of reflecting nitrogen supplying capabilities of the soil as influenced by soil type and management. Fertilizer N recommendations should not only reflect the needs of the plant but also relfect the supply of N from other sources such as soil organic matter, crop residues and organic amendments such as manure (Fig. 1).

The 4R approach to fertilizer management emphasizes the use of the Right Product, at the Right Rate, applied in the Right Place at the Right Time. There are several approaches by which Right Rate N recommendations can be developed including a nitrogen budget approach, the use of software-based estimates of N demand and measurement-based assessment of soil N supply. The latter approach is the most robust as it involves the fewest assumptions.

The measurement of soil N supply (Sharifi et al., 2006; Sharifi et al., 2007a; Sharifi et al., 2007b; Zebarth et al., 2005) and the role of soil climate in influencing soil N mineralization (Dessureault-Rompre et al., 2015; Dessureault-Rompre et al., 2016; Dessureault-Rompre et al., 2013; Dessureault-Rompre et al., 2010; Dessureault-Rompre et al., 2011a; Dessureault-Rompre et al., 2011b; Dessureault-Rompre et al., 2012; Georgallas et al., 2012) have provided effective tools for the measurement of the soil N supplying capacity of soils in Atlantic Canada. We have demonstrated significant variation in soil N supply in the soils of PEI with an average soil N supply of 60 kg N ha-1 (Burton et al., 2018).

The site specific quanitification of soil N supply and its use to adust fertilizer N recommendation rates could result in significant improvements in fertilizer N use efficiency and reduced N2O and NO3- leaching.

This BMP proposes the adjustment of fertilizer N rate used in potato production to reflect a realistic estimate of plant N demand and measured soil N supply. This could be achieved by direct measurement of soil nitrogen supply, the PEI Analytical Lab is piloting this soil test in 2019, or through regional estimates of soil N supply.

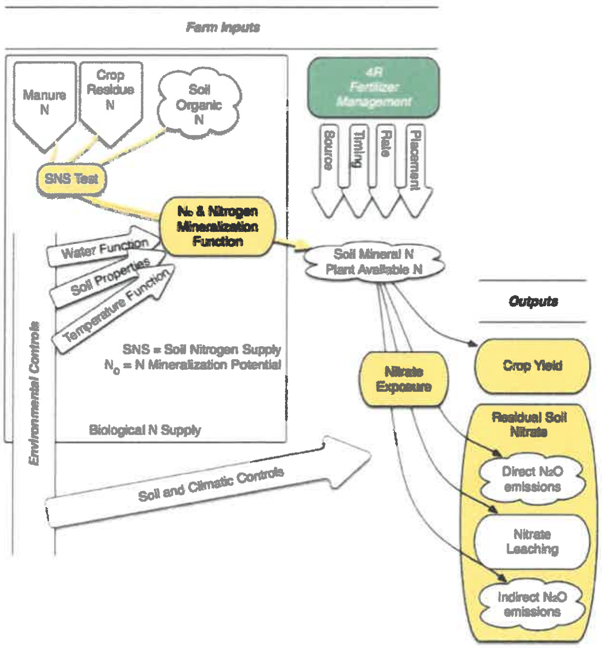

Figure 1: Approach to estimating soil nitrogen supply and assessing the efficiency of nitrogen management (Burton, 2012).

A survey of the soil nitogen supplying capacity of 26 potato production systems distributed across PEI (Burton et al., 2016) found that there was significant variation in the N supplying capacity of the fields survey and on average 65 kg N ha-1 would be mineralized during a 130-day growing season with values ranging from 29 to 103 kg N ha-1, a 70 kg N ha-1 difference (Fig. 2). All of these fields currently receive the same fertilizer N recommendation (200 kg N ha-1 for Russet Burbank).

There were significant differences between regions with the Central West having the greatest average (77 kg N ha-1) and the East having the least (68 kg N ha-1). It is noteworthy that the Central West region is the region with highest groundwater nitrate values.

There is greater variation between individual producer fields than between regions pointing to the importance of management in determining soil N supply and the opportunity to use a measure of soil N supply to improve N use efficiency and decrease environmental N impacts such as N2O emissions and NO3- leaching.

On average, we are assuming this may result in a decrease in fertilizer N use in potato production of 25%. While there are sites that increased fertilizer N application might be recommended, these are sites that are currently N defficient and therefore are not contributing to N losses. It is the sites that are currently over fertilizing where the largest reductions would be recommended and are currently resulting in disproportionate contribution to both N2O emissions and NO3- leaching.

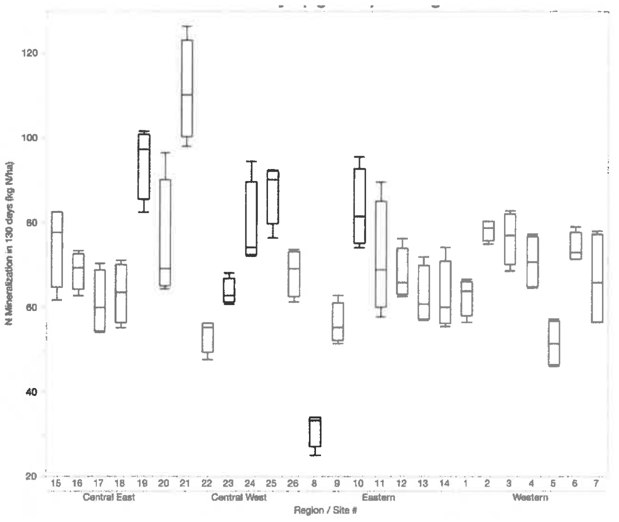

Figure 2: Variation in estimated nitrogen mineralized during a 130-day growing period based on measured variation in soil N supply on 26 farms in PEI in the fall of 2014 (Burton et al.2016).

MAGNITUDE OF THE POTENTIAL REDUCTION

It is assumed that the use of measured soil N supply would allow for more precise N applications, and result in a 50 kg N ha-1 reduction in the rate of N fertilizer applied across all hectares planted to potato in PEI (30,000 ha).

50 kg N ha-1y-1 x 30,000 ha = 1,500,000 kg N y-1
1,500,000 kg N x 0.0161 = 24,150 kg N2O-N y-1
24,150 kg N2O-N x 44 kg N2O/28 kg N2O-N x 298 CO2e/N2O =11.3 kT of CO2e y-1

This emission reduction would occur yearly and, over a 5-year period, would result in a 56.5 kT CO2e reduction. Note that this BMP could also be implement in field crop systems, but this has not been included in the estimate of emissions reduction presented here.

COSTS AND BENEFITS

The major cost associated with this BMP would be the measurement of soil N supply. The PEI Analytical Lab is currently piloting this analysis but has yet to determine a cost per sample. If this measurement resulted in a decrease in N fertilizer application in sites with high soil N supply the reduced fertilizer cost would offset the cost of soil testing. In fields where the soil N test results in higher N fertilizer application the cost of the test would likely be offset by the increased yield of the crop.

The largest barrier to adoption is uncertainty as to the effectiveness of the soil N test procedure and the potential implications of a reduction of N fertilizer application rate on marketable yield. This uncertainty can only be addressed by field-scale demonstration of this approach. Other barriers might include the cost of the test, availability of the test, and the dissemination of information as to use the test and its reliability.

During the early stages of adoption one of the policy tools that might increase adoption would be a program of sharing the risk (or perceived risk) of reducing N fertilizer application rate. A policy relating to reduced costs of crop insurance on fields implementing this approach would in effect share the risk and encourage adoption.

MODELLING AND MEASURING EMISSIONS REDUCTION AND/OR SEQUESTRATION

Since direct N2O emissions are calculated based of N fertilizer sales then any reduction in N fertilizer use will translate directly in reduced estimates and reporting of N2O emissions in the national inventory.

SUCCESS METRICS

The number of soil N supply tests conducted by the PEI Analytical Lab would be a good measure of the adoption of this BMP. In addition, the overall reduction in N fertilizer application would be another success metric.

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BMP 6

WILLOW PLANTATIONS IN FIELD EDGE AND RIPARIAN AREAS

DESCRIPTION

Planting Salix (Willow) bioenergy buffer strips on downslope field edges and/or riparian zones can reduce agriculturally derived N2O emissions, sequester carbon, and improve the nutrient use efficiency of agricultural systems. Willow plantations recycle nitrate from upland fertilizer application, as it is lost through leaching or surface runoff. In this way, strategically placed bioenergy willow can complement the sustainable intensification objectives of agriculture.

Bioenergy willow is managed for maximum nutrient uptake and biomass accumulation, through regular coppicing on a 3-year cycle. This will maximize N2O reductions and soil carbon storage. Salix species have a long growing season, rapid growth, extensive root systems, continuous soil cover, and a 25-year lifespan. This makes them good candidates for preventing soil nitrate accumulation and subsequent N2O loss, by maximizing and sustaining plant uptake (Borjesson, 1999; Bressler et al., 2017; Dimitriou et al., 2012).

By intercepting fertilizer derived nitrate (NO3-) as it is transported from agricultural fields, downslope/riparian willow buffer strips remove NO3- via biological plant root uptake. This thereby reduces the amount of denitrification and subsequent N2O loss from the soil system.

The effectiveness of Salix at reducing soil NO3- is well documented, even when large N and P inputs are occurring, and willow biomass production is directly impacted by NO3- supply. This indicates that plant uptake is a major removal pathway. Harvested biomass N removal in Salix averages around 25 kg N ha-1yr-1 (Amichev, 2014). It is estimated that Salix buffer strips planted between annual cropped fields and streams can retain N at a rate of 70kg N ha-1yr-1, when nitrate inputs are greater than 15 kg N ha-1yr-1, and that 2/3 of this is due to plant uptake. The remaining 1/3 is lost to denitrification (Borjesson, 1999). Of this 1/3 denitrified N, approximately 3% is thought to be released as N2O, representing 1% of nitrate retained by Salix buffers (Styles et al., 2016). In contrast, NO3- that is transported to waterways has a 75% risk of being lost as N2O (Styles et al., 2016).

Studies show that N2O emissions in Salix are lower than annual cropping systems (Bressler et al., 2017; Gauder et al., 2012; Borjesson, 1999). The magnitude of reduction depends on factors such as nitrate input, buffer width and soil characteristics. Kavdir et al. (2007) observed that N2O fluxes were 3.2 kg ha-1 lower in Salix than in rape/rye, when both were fertilized at a rate of 150 kg N ha-1. Mean N2O emissions in willow plantation soil have been observed to be 6.4 mg N2O-N m-2 d-1 lower than corn, representing a ten-fold decrease in N2O emissions (Bressler et al., 2017).

A factsheet for the establishment of Willow Riparian Buffers has been published by Agriculture and Agri-Food Canada based on field trials conducted in PEI from 2006 to 2012 (AAFC, 2014).

POTENTIAL REDUCTIONS ON PEI FARMS

Salix bioenergy crops are considered carbon neutral (Volk et al., 2004) or slight net sequesters of carbon. (Pacaldo et al., 2014). Willow are capable of rapid biomass accumulation and, when grown in 3-year coppicing rotations, are capable of sequestering between 4.9 and 6.6 metric tonnes C ha-1yr-1 (Amichev et al., 2014).

Recent studies indicate that Salix bioenergy crops achieve carbon neutrality within 5 years post-establishment, and that, through carbon storage, they are capable of reducing GHG emissions by 36.3 tonnes CO2 eq ha-1 over 21 years (Pacaldo et al., 2014).

Previous research on Prince Edward Island found that willow species Salix viminalis was effective at carbon and nutrient sequestration on field edges bordering riparian zones on PEI. It produced higher above-ground biomass yield, with greater N concentration, than other Salix varieties studied. Coppiced (perennially trimmed) Salix viminalis were found to sequester carbon at an average rate of 17 t C ha-1 yr-1, while accumulating N at a rate of 160 kg C ha-1 yr-1, when both above- and below-ground biomass was considered (Shroeder et al., pers. comm.). N in harvested aboveground biomass was removed at a rate of 236 kg N ha-1yr-1 (Schroeder et al., 2013). Research is currently underway to specifically assess the effectiveness of Salix viminalis at reducing N2O emissions on PEI (Island Farmer, 2019.).

To assess the magnitude of the potential reduction associated with this BMP, we have assumed that a total of 50 ha of riparian area (or area immediately adjacent to the riparian area) are planted to willow each year for the next 5 years. Further we conservatively assume that establishing a willow plantation in the field edge would result in the sequestration of 10 tonnes C ha-1 yr-1 and a reduction in N2O emissions by 90% as a result of displacing land that would have otherwise been fertilized and by reducing indirect N2O emissions associated with nitrate leaching from the cropped portion of the field.

250 ha x 10 tonnes C ha-1 y-1 = 2,500 tonnes C y-1
2,500 tonnes C y-1 x 44 kg CO2/12 kg CO2-C = 9.2 kt CO2e y-1

The reduced N2O emissions would result in an additional

200 kg N ha-1 y-1 x 0.0161 = 3.2 kg N2O ha-1 y-1 x 0.9 = 2.9 kg N2O ha-1 y-1

Since potato is typically grown 1 in 3 years, this reduction would only apply 1/3 of the time.

2.9 kg N2O ha-1 y-1 x 0.33 x 44 kg N2O/28 kg N2O-N x 298 CO2e/N2O =0.45 kT of CO2e y-1

Therefore, total reduction for the implementation of this BMP over 50 ha y-1 for 5 years would be 9.2 kt CO2e y-1 due to carbon sequestration and 0.45 kT of CO2e y-1 in reduced N2O emissions for a total of 9.7 kt CO2e y-1

CO-BENEFITS

The anticipated improvements in soil health, as well as reduced disease pressure, would be significant co-benefits of this BMP. Increased soil organic matter content would result in increased aggregation and soil water holding capacity, which would increase the resiliency of the soil to the impacts of climate change and drought.

As well, the substantial amount of trimmed willow material, available every three years after planting, could be utilized as biomass for energy production in applicable on-farm furnaces or boilers, or applied to the soil in other areas of the farm as an organic matter (carbon) builder.

DRIVERS AND BARRIERS TO ADOPTION

An increasing number of PEI farmers are aware of the importance of soil protection and nitrate management, and are developing riparian zone, buffer zone and headland stabilization, mainly as grassed waterways, terraces, etc. These existing areas, as well as those to be developed in the future, would be easy targets for establishing willow plantations.

The major barriers to the adoption of this BMP would be the cost of implementation and the amount of land taken out of crop production.

To counter these realities, drivers to adoption would include the amount of agricultural land already set aside to the ALUS (Alternative Land Use System) program over the past decade. This otherwise unproductive land, which serves currently as a carbon sink and potential erosion control site, would be an easy site for adoption of this BMP on a wide-scale pilot trial of this BMP, with little impact on the landowner's current practices.

The PEI Alternative Land Use Services (ALUS) program has increasing uptake by producers, especially in the potato industry. These retired lands, if near a watercourse or erosion area, would be easy targets for willow or other plantation (including trees/woodlots) development. As of 2017, about 425 farmers and landowners are participating in the ALUS program, including carbon sequestration efforts.

However, there is resistance, as well as regulatory barriers, to doing work on ALUS set-aside land. Although some ALUS land planted in grasses is mowed for animal feed (eg: dairy), current regulations in PEI do not permit crop management of the riparian area adjacent to crop fields (Barrett, 2019). Unless legislation is amended to allow mechanical coppicing on ALUS and other regulated lands (eg: riparian zones), this BMP would establish willow plantations in the area between the field edge and the legislated riparian area.

Other co-benefits of establishing treed buffers include providing food and habitat for wildlife, lower local water temperatures in shaded areas, slower flood event flows, and potential to produce energy from coppiced (trimmed) plantations. Increasing vegetation in previously degraded areas also improves carbon storage.

COSTS

Costs associated with establishing and maintaining a buffer or riparian zone plantation varies greatly, depending on the size, type and density of the buffer. A 2000 study in Maryland found that costs range from $218/ac to over $700/ac (prices in y2000 USD). Pennsylvania data showed similar costs, with tree/shrub buffers starting at ~$400/ac., including labour, with planting density being the largest cost variable.

The following cost approximation was developed for the establishment, maintenance and harvest of willow riparian buffers in PEI by Brian Murray, associated with AAFC demonstration of willow plantations in PEI. It considers the total cost of planting and harvesting 5333 willows. This would cover 1 ha, which is the design described in the above-mentioned AAFC factsheet.

COST OF MATERIALS YEAR 1

5333 cuttings/ha	$0.35/cutting	$1,866.55
12 Rolls of plastic/ha	$140.00/roll	$1,680.00
6 boxes staples/ha	$90.00/1000	$540.00
30 lbs Grass seed/ha	$3.00/lb	$90.00

Materials for Year 1 **$4,176.55/ha**

Labour and rental of machinery (tractor, mulch applicator, harvester & wagon)

Manual Planting and installation of plastic mulch – Year 1
$1740.00/ha

Weed Control - Year 2
$500.00/ha

Harvest - Year 3
$4000.00/ha

Assuming the willow plantations are trimmed every three years, the Total Cost for the 3 years of the Willow Management project is approximately $10,500.00/ha.

Note that there could also be income generated from these areas as a result of the harvested willow biomass, if a suitable biomass market is identified (eg: wood pellet manufacturers).

POLICY DRIVERS

The PEI Land use regulations should be revisited and amended, to allow controlled harvest of willow cuttings, on a three-year rotation basis. ALUS lands would be the first target for this amendment, and perhaps riparian zones could be included in eth future, if no negative effects of coppicing are seen.

In concert with ALUS, the PEI Forest Enhancement Program could be further developed to expand carbon sequestration opportunities, including willow plantations. As well, the J. Frank Goudet forestry nursery has mass-produced woody plants and trees for farm use in the past, and a program to mass-produce willow at the nursery should be considered, on a cost-sharing basis.

As a supporting database, the PEI Government, through PEI Forestry, is planning to model and report Province-wide carbon sequestration data in future State of the Forest reports, including a recommendation that those reports increase in frequency to every 5 years.

As part of implementation of this BMP, it should also be recommended that participating producers become involved in the PEI Woodlot Owners Association, as a means of involving more producers to become involved in this organization of over 1400 woodlot owners. The PEIWA would be capable of acting as a high-percentage funding receptor for its members, if a suitable program is developed for willow plantation development on PEI farms.

According to John Rowe, PEI Woodlot Owners Association, few of his 400+ members are farmers, although the PEIWA is an associate member of the PEI Federation of Agriculture, underlining the low awareness of farm woodlot value, especially potential for GHG reduction.

SUCCESS METRICS

The most obvious measure of adoption will be the area of land planted to willow and/or the length of stream bank protected. Also, the growth rate and survival rate of plantation trees should be monitored, and any dead or diseased trees replaced annually. The tonnage of cuttings on a 3-year rotation basis should be monitored, to determine the variation in growth rate from site to site.

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Also preliminary Schroeder results of willow plantations are online: https://vergepermaculture.ca/wp-content/uploads/Buffer-strips-for-biomass-production-and-riparian-protection_Schroeder_A....pdf

BMP 7

IMPROVED MANURE MANAGEMENT AND UTILIZATION

DESCRIPTION

Livestock manure is a valuable resource for organic nutrients that are valuable as an excellent soil amendment to improve soil quality, tilth and productivity. Improper management, including storage and field applications, can contribute substantial amounts of GHGs to the atmosphere. The major sources of animal manure from PEI production are beef cattle, dairy cattle, poultry and sheep. Each type has its own physical characteristics and management challenges.

Manure management is an essential practice in minimizing GHG emissions caused by microbial activities during manure decomposition, both in storage and as it decomposes in the soil after field applications.

The main GHGs emitted by manure are methane (CH4), which is emitted during the anaerobic (without oxygen) decomposition of organic matter during storage, and nitrous oxide (N2O), which is emitted after soil application. Additional gases emitted from manure include ammonia (NH3) and nitrogen oxides (NOX), which contributes to odour and are indirect sources of nitrous oxide, due to biological processes in the soil.

Roughly 80% of manure management emissions come from CH4 and 20% from N2O.

Factors that affect GHG emissions from manure include: temperature, oxygen level (aeration), moisture content, and sources of nutrients for decomposition-causing bacteria.

These factors are affected, in turn, by manure type (livestock type), diet, storage and handling of manure (pile, anaerobic lagoon, etc), and manure field application methods (injected, spread then incorporated by plowing-in). This BMP aims to increase awareness among producers of the It is important to note that proper manure management is essential for any agricultural operation, as improper management of manure can lead release of large amounts of GHGs.

As well, there are other impacts on the environment, including strong odors that spread to nearby properties, and leaching of field manure to waterways and groundwater. This leachate can create hyper-nutrient conditions in the water, which can lead to anaerobic conditions and release of other GHGs.

IMPLEMENTATION

Solid manure management systems are generally used for poultry and beef production. Beef cattle are usually housed on relatively dry bedded manure packs of straw or sawdust, which have lower CH4 emissions in storage. Poultry manure is quite dry, dries easily in the barns (meat birds or broilers) and egg conveyors (egg producers or layers). Thus, poultry manure on PEI is the least likely to emit CH4 .

In comparison, dairy manure is higher in moisture (75%-90%, ASABE, 2006), depending on amount of urine and milk parlor wash-water included), and swine manures are highest in moisture (over 90%). Both these types are usually handled and stored using liquid or slurry handling systems, and stored in concrete pits.

Emissions from manure storage systems are released when favourable conditions are met for gas creation. Warm, wet conditions tend to create higher amounts of CH4 and N2O. Thus, the major sources of CH4 in stored manure are from swine and dairy manure pits.

More aerobic (high oxygen) manure management conditions, such as daily spreading or composting solids, prevent CH4 production. a portion of those solids being carbon compounds called volatile solids (VS), and also various nitrogen (N) compounds. Some of the VS are precursors for CH4 and some of the nitrogen compounds are precursors for N2O. The opposite pattern is true for N2O: when manure-N is stored more anaerobically, N will not convert to N2O (and has great benefit for reducing synthetic N fertilizer needs during spring planting); when manure-N is stored under aerobic conditions (e.g. composted solids), more N2O is released.

Based on proven reduction of methane, as well as to retain the greatest available nutrients in the manure, the following manure storage management practices have been proven to be effective:

Avoid disturbing liquid manures in manure storage lagoons (eg: dairy, swine). Stirring or aerating lagoons increases oxygen, and can eliminate CH4 emissions, but at the expense of increasing N2O emissions, due to biological processes in the storage lagoon favoring release of N2O. N2O is nearly 10 times higher CO2 equivalents than CH4.

Avoid straw covers in manure pits without replacing the straw regularly before it sinks. Using a straw cover may be an effective odour barrier, but when the straw sinks into the liquid manure it adds Carbon, which can substantially increase CH4 production.

Avoid stockpiling manure for long periods, either in the barn or in field windrows. Unless the pile is regularly turned, kept at a moderate moisture level and/or kept covered, stock-piling can lead to anaerobic decomposition, resulting in both CH4 and N2O emissions.

Prior to removal for field spreading, manure testing should be done routinely to determine the amount of plant-available nutrients, particularly N and P. Manure application should be based on soil nutrient levels.

Complete emptying of liquid manure storage tanks in the spring eliminates the inoculums (aged manure containing bacteria) remaining in the tank and reduces the CH4 emissions from the newly loaded manure in the following months.

In terms of field applications, when soil Olsen-P levels (phosphorus as measured by soil testing) are between 60 and 180 ppm, manure can be applied no more than five times the annual crop removal rate of phosphate (P2O5). Additionally, nitrate-N levels can be no more than 140 lbs per acre (157.1 kg/ha) of soil class 1 to 3.

Because both nutrient levels are important in terms of the amount of applied manure, manure testing prior to spreading, as stated above, is a cost-effective farming practice, and should be an integral part of a manure management BMP.

Following is a general manure application calendar, which applies to field application of all manure types.

November to mid-April;
Manure should be going into
covered storage, not on fields, if possible.

Do not spread on frozen, bare, or snow-covered land.

Mid-April to mid-June;
Apply to land growing annual crops before planting.

Mid-June to August;
Inject liquid manure between rows of growing row crops.

Apply manure to cereal land immediately after harvest and prior to conservation tillage.

September to October;
Apply manure to grassland.
Avoid applications in areas subject to concentrated runoff and avoid tillage until after October 15.

Apply to annual crop lands that will be planted with winter cover crops.

In terms of dairy manure management, it is recommended that the producer consider avoiding addition of liquid milk house waste and milking parlor wash water to the manure storage pit, and, instead dispose of these liquids in a separate lagoon or septic pit.

The average daily production of wash water on a per-milking-cow basis is 14.1 litres (3.1 gals). The disposal of this wash water has become a major environmental concern. Wastewater contains milk solids, fat, detergents, acid cleaners and sanitizers, manure, soil particles, and other substances. In a manure pit, these act as nutrients for methanogenic (CH4 producing) bacteria. Not incorporating them into dairy manure pits would reduce the volume and GHG potential of the manure in storage, as well as reduce the frequency and cost of manure removal.

Following are a number of ways these liquids can be beneficially managed.

Reduce:
Manual washing and prepping of cows uses less water than automated systems.

Mechanically removing manure and wasted feed from the parlour prior to wash down reduces waste volume and strength.

Manually check water hardness and iron content, and calibrate cleaning equipment annually. Adjust chemical cleanser concentrations based on the quality of the washwater.

Design the milking parlour to minimize washwater requirements. Drain locations and floor slopes are important.

Reuse:
Feed the first rinse of milking equipment to calves. This will reduce the amount of milking parlor wash water by 15-20%.

Feed pre-cooler water to livestock. Pre-coolers are used to lower milk temperature before it enters the bulk tank.

Many new dairy operations have underground tanks to store wash water. Use this water to wash parlor floors and drain to manure storage.

Recycling wash water reduces the amount of chemical cleansers required. Wash water can be used from one cleaning cycle to the next.

Make sure that reused water does not increase bacterial counts.

Composting manure is rarely practiced on PEI, but is an effective way to lock up nitrogen nutrients and reduce N2O emissions.

In terms of swine manure and higher moisture dairy manure (eg: including wash water) separating solids from the liquid manure (or avoiding adding wash water) and composting the solid fraction is a possible strategy, assuming the producer is willing to purchase composting equipment and create a suitable composting site on-farm.

Beef manure is easier to compost, due to its high carbon content (straw and other high C bedding), and a certain amount of composting activity does occur in beef manure field windrows, if good conditions are present. This would be aided greatly by covering the piles, something producers are currently unwilling to do.

MANURE STORAGE COVERS

Covering manure storage pits prevents water from entering the manure and reduces gaseous losses. Preventing water from being added to the storage reduces the volume of manure that has to be spread, reducing cost, as well as increasing the nutrient concentration of the manure being spread.

Covers for liquid manure storages significantly reduce odour and gas emissions by creating a physical barrier between the liquid and the air. Zhang and Gaakeer (1998) include covers in their list of methods to effectively reduce odour emissions from storages.

Covers are classified as either impermeable or permeable. Impermeable covers do not allow any gases coming from the manure to be emitted to the atmosphere. On the other hand, permeable covers permit transmission of some gases. Various types of covers have been tried and each has its own advantages and disadvantages.

Following is a detailed discussion of the various types of manure cover practices that have been tested and/or applied elsewhere in livestock production systems.

Table 1 -Types of covers, effectiveness, life expectancy, and capital costs.

Material	Reduction Effectiveness (%)			Life Expectancy	Capital Cost (US$/m2)
	Odour	H2S	NH3		
Permeable Covers					
Straw	40 to 90a	80 to 95a, b	25 to 85a	<6monthsa	0.2 to 0.8 a
Geotextile	40 to 65a	30 to 90a	0 to 45a, c	3 to 5 years a	1to2.4a, c
Geotextile/straw	50 to 80a	60 to 98a	8 to 85 a	N/A	1.3 to 2.2 a
Leca®	90 a	N/A	65to95a	10 years a	13 a
Macrolite®	60 a	64 to 84a	N/A	10 years a	13 a
Perlite	30 to 93d	N/A	63 to 91d	10 years d	1.3 to 2d
Rigid Foam	70 to 82e	N/A	N/A	10 to 20 years e	N/A
Oil	0d	N/A	85 d	N/A	N/A
Natural crust	10 to 90b	10 to 90b	10 to 90b	2to4monthsb	0b
Impermeable Covers					
Inflatable plastic	95 a	95 a	95 a	10 years a	5.8 to15 a, f
Floating plastic (neg. pressure)	95 b	95 b	95 b	5 to 10 yearsb	N/A
Floating plastic	60 to 95a, b	90 to 95a, b	95 b	10 years a	2.5 to 4a
Concrete lid	95 a	N/A	N/A	30 to 50 yearsg	(CDN) 108g
Wood/Steel lid	95 a	N/A	95 a	10 to15 years a	48 f

(Nicolai et al., 2002) b (Bicudo et al., 2003) c (Bicudo et al., 2004) d (Hornig et al., 1999) e (Miner et al., 2003) f (Zhang and Gaakeer, 1998) g (Johnson, 2006)

Table 2 - Summary of advantages and disadvantages of various manure storage covers

From:
www.ridgetownc.com/research/documents/fleming_Liquid_manure_storage_covers.pdf

Type of Cover	**Advantages**	**Disadvantages**
Permeable Covers		
Straw	- very low cost - effective odour and gas reduction	- very short lifetime - requires a manure pump that can chop straw - difficult to spread evenly and measure thickness - deteriorates with intense rainfall and wind
Straw and Oil	- low cost - stays afloat longer than straw alone - effective odour and gas reduction	- short lifetime - requires a manure pump that can chop straw - difficult to spread evenly and measure thickness
Geotextile	- low cost - relatively effective odour and gas reduction - resistant to rot, moisture, and chemical attack	- short lifetime - effectiveness at reducing odour and gases decreases over time - disposal is costly - can be submerged (e.g. intense rainfall, snow melt) - safety an issue during agitation and pumping
Clay Balls	- effective odour and gas reduction - relatively long lifetime	- when they sink, they form clumps and can plug the pumping equipment - relatively expensive
Perlite	- low cost - relatively effective odour and gas reduction - floats quickly to surface after application, compared to straw - relatively long lifetime	- relatively little performance information available - effectiveness varies significantly
Rigid Foam	- relatively low cost - relatively effective odour and gas reduction - survives intense storms - long lifetime	- complicated installation - good electrical insulator - may cause sparks - can be ignited, producing poisonous gases
Oil	- low cost	- short lifetime - produces a distinctive offensive odour
Natural Crust	- no cost	- very short lifetime - does not always form (especially on swine manure) - poor odour and gas reduction
Cornstalks, Sawdust, Wood Shavings, Rice Hulls, Ground Corncobs, Grass Clippings	- low cost	- very short lifetime - poor odour and gas reduction
Impermeable Covers		
Inflatable Plastic (positive pressure)	- long lifetime - tarp never touches manure - very effective odour and gas reduction with biofilter - prevents precipitation accumulation on top and in manure storage	- high cost - more wind resistance - must be deactivated to pump or agitate - not appropriate for earthen basins
Floating Plastic (negative pressure)	- relatively long lifetime - very effective odour and gas reduction with biofilter - prevents precipitation accumulation in manure storage	- relatively high cost - collects precipitation - bunches up when manure level fluctuates - potential for damage due to ice
Floating Plastic	- long lifetime - relatively effective odour and gas reduction with biofilter - prevents precipitation accumulation in manure storage	- relatively high cost - gas bubbles in cover - potential for wind damage - collects precipitation - bunches up when manure level fluctuates
Suspended Plastic	- effective odour and gas reduction - prevents precipitation accumulation in manure storage	- no cost information available may not be available in North America
Concrete	- very long lifetime - very effective odour and gas reduction - very low maintenance - prevents precipitation accumulation in manure storage	- very high cost
Wood/Steel	- long lifetime - very effective odour and gas reduction - low maintenance - prevents precipitation accumulation in manure storage	- very high cost

Table 3 - Comparison of the common liquid manure storage covers considered by livestock producers in southern Ontario

	Straw	Geotextile	Inflatable Plastic	Floating Plastic (negative pressure)	Floating Plastic	Concrete
Odour Control	poor	very poor	good	good	good	very good
Reduced Gas Emissions	good	poor	very good	very good	good	very good
Excludes Precipitation	no	no	yes	yes	yes	yes
Labour/ Maintenance	very high	high	low	medium	medium	very low
Ease of Agitation	easy	hard	easy	hard	hard	very easy
Life Expectancy	< 6 months	< 5 years	< 10 years	<10 years	<10 years	>30 years
Cost	low	medium	medium	high	high	very high

Natural Crust - Natural floating covers are those formed by the fibrous material contained in the manure, such as bedding straw. (Bicudo et al., 2003). Dairy manure usually contains high amounts of such material and therefore a natural crust is common on the surface of dairy manure. Stored swine manure can sometimes develop a natural crust but its consistency is much different from dairy manure (Bicudo et al., 2003). Sommer et al. (2000) found that a 7 to 10 cm thick cover developed naturally over the cattle manure in a concrete tank. Bicudo, et al. (2004) found that natural crust can be at least as effective as a geotextile cover in reducing emissions of hydrogen sulfide. There was no indication of the effectiveness of natural crusts at reducing odours. Bicudo et al. (2003) concluded that the effectiveness of natural crust at reducing odours and gases was difficult to quantify.

Much depends on the thickness and other physical properties of the crust. The effectiveness varied in the range of 10 to 90%. A natural crust only has a life expectancy of two to four months (Bicudo et al., 2003).

Straw - Straw covers reduce CH4 emissions by providing an environment with enough oxygen for the microbes that break down CH4 and by reducing transport of gas produced in the bottom of the tank to the atmosphere.

Applying a straw cover comes with many other benefits; they are simple to put into practice, inexpensive, adaptable and immediately usable, decrease ammonia emissions, and reduce odour and hydrogen sulfide production. However, straw covers are susceptible to wind and rain damage. Although straw has limited buoyancy time, it can be made more durable by providing floating supports.

Odour reduction with straw covers will vary from 90% for a thick, newly applied cover to 40% or less depending on straw thickness and uniformity (Nicolai et al., 2002). University of Minnesota researchers (Clanton et al., 2001) have shown that a 10 cm thick layer of straw reduces odours by 47%, a 20 cm layer by 69% and a 30 cm layer by 76%. Another study showed that a straw cover varying in depth between five and 15 cm reduced odour emissions by about 84% (Hornig et al., 1999).

Straw covers reduce hydrogen sulfide emissions by 80 to 95% (Bicudo et al., 2003). Xue et al. (1999) found that a five to 10 cm thick layer of straw, along with a naturally forming crust on dairy manure, suppressed hydrogen sulfide emissions by 95%.

The effectiveness of straw at reducing ammonia emissions varies widely - between 25 and 85% (Nicolai et al., 2002). With a straw depth of 5 to 15 cm, ammonia emission was shown to reduce by 80% (Hornig et al., 1999). A different study using the same thickness, along with a natural crust, showed a 95% reduction (Xue et al., 1999).

Sommer et al. (2000) found that a straw cover was more effective than a natural crust or Leca® pebbles at reducing the emissions of methane. This would also be the least expensive option.

Geotextiles - The performance of geotextile covers (eg: GORE Industries, available in Canada), while relatively inexpensive and long-lasting, is variable at reducing emissions. Nicolai et al. (2002) have documented odour reductions of 40 to 65%, hydrogen sulfide reductions of 30 to 90%, and ineffectiveness at removing ammonia.

Bicudo, et al. (2004) showed that a geotextile cover reduced odours by 50%, hydrogen sulfide by 72%, and ammonia by 30 to 45%. Any effectiveness in reducing odours and gases decreases over time compared to straw, because the fabric becomes plugged with biomass growth. This creates an impermeable barrier that allows gases to build up and move to open spaces along sidewalls, where they are vented (Bicudo, et al., 2004). Geotextile thickness has no impact on odour and gas emissions (Clanton et al., 2001).

A geotextile cover can be made more effective if combined with a floating barrier. Miner et al. (2003) evaluated the effectiveness of a 5 cm thick composite cover made from recycled closed-cell polyethylene foam chips topped with a geotextile layer containing zeolite particles. Under field conditions, the cover survived severe storms and

Inflatable Plastic (positively pressurized) Impermeable covers (see Figure 5) are more expensive than permeable covers but they have a longer life expectancy and are more effective at reducing odours and gases. An inflatable plastic cover is 95% effective at reducing odours, hydrogen sulfide, and ammonia concentrations (Nicolai et al., 2002). Suspended plastic is a type of cover that is popular in northern of Europe consists of a solid vertical support post in the centre of a circular concrete tank, strips of material from the support to the walls and a plastic cover laid on top and stretched tight to the walls, as shown in Figure 12. This cover excludes all precipitation, reduces ammonia losses and reduces odour emissions (Holm-Nielsen, 2006).

Concrete - Concrete lids are very reliable and capture 95% of odours, but are very capital intensive (Nicolai et al., 2002).

Wood/Steel - Wood or steel lids are also reliable but even more capital-intensive, and would increase management costs dramatically, due to difficulty in removal for pumping or stirring. Also, it is unknown how they would stand up under frozen winter conditions (freeze-thaw) A steel or wooden lid is estimated to cost US$20,000 for a 23 m diameter concrete manure tank (i.e. US$48/m2) (Zhang and Gaakeer, 1998).

Wooden lids are 95% effective at reducing odours and gases and have a life expectancy of 10 to 15 years (Nicolai

THE MAGNITUDE OF THE POTENTIAL REDUCTION IN PEI

Applying a straw cover on the liquid manure surface has the potential to reduce CH4 emissions during storage by up to 15%. The thickness of the cover should be at least 15 cm to achieve this suggested reduction as thin straw covers have been found to increase CH4 emissions.
Natural crust manure covers, such as in beef manure windrows, can reduce methane emissions by 38%.
Other potential reduction estimates are discussed in eth details of cover types seen above.
Complete emptying of liquid manure storage tanks in the spring eliminates the inoculums (aged manure containing bacteria) remaining in the tank and reduces the CH4 emissions from the newly loaded manure in the following months by up to 40%. Benefits can also be realized when a small amount (5%) of manure is left in the tank compared to leaving 15%. Downstream effects on field manure application with complete emptying have to be taken into account, but overall this is a practice with a lot of potential for GHG reduction at the dairy farm level.
Composting dewatered manure solids shows the potential to reduce overall CH4 emissions by about 30%. Emissions from the liquid portion are reduced because volatile solids, the substrate for methane-producing microbes, are reduced by 60-80%. Caution has to be exerted because storage of the solid fraction could increase ammonia emissions; however, by supplying sufficient oxygen in manure heaps and implementing good composting practices, these emissions can be reduced and lower overall emissions can be achieved.

BARRIERS TO ADOPTION

PRODUCER AWARENESS OF THE NUTRIENT ISSUE

Producers generally receive low value from their manure if sold or swapped for other inputs such as forage and bedding crops. However, those who largely use their own manure on-farm would be more interested in seeing the nutrient benefit of covering open manure pits (ie: dairy and hog producers).

Awareness of the value and management costs of manure in all animal sectors is high, especially with producers who regularly sell or swap manure. The hog producers would benefit most from manure pit covers, as their high-moisture manure is most liable to outgas methane under the anaerobic conditions in the pit. That being said, a farm trial that shows the beneficial changes in manure nutrient quality would go far to improve awareness of the benefit of this BMP.

While it is difficult to measure methane emissions directly, measuring the nutrient content of hog manure at various times across several farms would improve awareness and uptake of this BMP.

Dairy producers experience high costs for pumping out manure pits, due to the density of the manure, and its stratification into surface water and floating organic matter (eg: bedding). Either decreasing the density by adding more water, which increases shipping and handling costs, or increasing density by ceasing to include milk room and milking parlour wash water to the pit (which may lower transport costs and bio-degradation) are options.

PEI animal producers, especially in terms of beef and sheep, report experiencing low returns from their products and increasing feed costs. As these animal sectors are least probable to benefit from covers, they are not the first target for this BMP.

COMPATIBILITY WITH CURRENT PRACTICE

Beef producers would benefit least from manure covers, as they report having natural dry crusts form over the field storage windrows which they claim act as barriers to over-moisture from rain and snow. Beef producers on PEI do not generally store manure inside for any length of time.

Dairy and hog producers are probably more amenable to covering their manure pits, as they mostly all have concrete pits in-place. However, some have installed pits in the past, only to have them fil in the winter due to snow load and/or wind.

An awareness campaign and pilot trial on 2-3 larger farms would go far to encourage others to adopt the practice, especially if it is seen that the covers created a co-benefit, such as improved manure quality in terms of nutrient value.

POTENTIAL FOR ADOPTION AND POLICY TOOLS

It would help standardize the form, storage and quality of manure across all liquid manure species (ie: dairy, swine) through pre-spreading treatments, including removing moisture or, in the case of high-moisture manure (hog) by encouraging methane production by use of covers or any type. See below the relative effectiveness of various types of covers on nitrous oxide groduction.

Aerating the manure (eg: hog manure) to discourage anaerobic generation of methane is a possible strategy, but research suggests that this would in turn increase the outgassing of nitrous oxide, which is a much more powerful GHG.

One policy tool would be to encourage methane generation, capture and burning off of methane under covered pits. The technology, safety and regulatory environment would need to be developed to allow and encourage such a pre-treatment.

FUTURE RESEARCH NEEDED

The majority of research on liquid manure storage covers has involved earthen basins and the main manure type has been swine manure. Less information is available on concrete tanks and on cattle manure, both of which are the normal current types on PEI. More research is needed especially in the area of covers for concrete tanks (a very common storage option in many areas).

Impermeable covers offer the opportunity for collecting and using methane gas for firing water boilers for barn, shop, or home heating needs, an on-farm incinerator, or simply flaring the gas (MacLeod, 2006).

A more advanced methane treatment option is the production of electricity using a methane-fired engine and matched power generation unit. Increased on-farm income through energy generation and the sale of greenhouse gas emission reduction credits are becoming a feasible option through the advancement of manure storage cover technology (MacLeod, 2006). No research results could be found where an attempt had been made to cash in on the trapped methane gas. It is considered unlikely that such a process would be applicable to the relatively small amounts of manure available in PEI.

Adapting this manure cover BMP to existing dairy and hog farm manure pits would be the most likely chance of successful adoption of this BMP. At least six farms should be recruited for pilot testing, with half using covers and the other half not. Assuming that any cover type would be 50% effective in reducing methane release to the atmosphere, the benefits would be at least a 50% decrease in methane for dairy and even more for hog manure.

Methane is easily combusted to CO2, greatly reducing its effect on climate, and some farms have covered their manure storage units to capture and flare the methane gas. The authors found that covering and flaring methane from most storage units would reduce GHG emissions by 62% at a cost of $13 Mg CO2e⇹1, which is within the range currently paid in carbon markets.

Frequent removal of manure, anaerobic submerged) digestion in terms of hog and dairy manure with a carbon source added (eg: molasses), and manure acidification (addition of an inexpensive organic acid such as sulfuric) reduced ammonia (3–60%), nitrous oxide (21–55%), and methane (29–74%) emissions simultaneously
In order to properly test his BMP, a reliable way to measure the methane that accumulates under the cover, vs that released must be obtained.

It is estimated that, in the case of hog manure pit cover applications, without flaring off trapped methane, the methane release to the atmosphere would be reduced by 35-50%, while including flaring has a methane reduction potential for 90%. Reductions would be lower for dairy applications, unless the pit can be rendered more anaerobic.

ON-FARM COMPOSTING OF MANURE

Composting is the aerobic decomposition of organic materials by microorganisms under controlled conditions. During decomposition, the microorganisms consume oxygen while feeding on organic matter. Composting reduces both the volume and mass of the raw materials while transforming them into a valuable soil conditioner. The benefits and limitations of composting manure on PEI include:

- Compost adds organic matter, improves soil structure, reduces fertilizer requirements and reduces the potential for soil erosion.

- composting involves an increase in expenditure, however the increased market potential and soil conditioning properties offer substantial offset benefits.

- markets for compost are readily available. Potential buyers include home gardeners, landscapers, vegetable farmers, operators of golf courses, etc. However, on PEI, relatively small amounts of manure spaced unevenly across PEI limits the affordability of transport to farm or off-farm markets.

- composting reduces the weight and moisture content and increases stability of manure. Uncomposted manure exposed to air can lose 30-40% of its nitrogen value over the time between storage and allpication. Compost is easier to handle than manure and stores well without odors or fly problems, thus lowering the risk of pollution and nuisance complaints.

- composted manure is less susceptible to leaching and further ammonia losses. Composting high-carbon manure/bedding mixtures lowers the carbon/nitrogen ratio to acceptable levels for land application.

- proper temperatures within the compost pile will reduce pathogens.

- potential reduction in soil-borne plant diseases.

ON-FARM COMPOSTING, USING A COMMERCIAL COMPOST TURNER

TYPES OF FARM COMPOST SYSTEMS & APPLICATION TO PEI

Passive composting involves simply stacking the materials in piles to decompose over a long period of time with little or no agitation and minimal management. This is the method preferred by PEI beef producers. In fact, other types of producers (dairy, swine, poultry) generally do not compost their manure by this or any other method. The common reasons given for this are expense of equipment and labour., as well as a lack of awareness of the benefits of composting their manure, from a standpoint of its value as a fertilizer.

Windrow composting - the materials are formed into long narrow windrows which are mechanically turned. This process is used successfully by Oyster Bed Compost, which operates on a 300-head beef farm in PEI. They produce soil-quality compost in 1.5-2 years, using their beef manure, manure from other farms (dairy), wood chips, sawdust and other bedding materials rich in carbon.

Also producing compost in this way is Steven Cousins or The Shepherd's Farm, who has been producing low-cost high-quality compost on his organic farm for over a decade. Besides his own farm's manure, Cousins also utilizes local waste streams high in nitrogen and minerals (mussel farm waste) as well as carbon and minerals (seaweeds such as Zostera or eel-grass). The operation avoids transport costs by focusing on raw materials that are considered a costly waste by the odors, which the generators of those wastes are happy to deliver to the composting farm free of charge.

This is an innovative, affordable way to introduce composting of manure to a farm, with the majority of expenses being the capital cost of a compost turner, estimated by Oyster Bed Compost at about $15,000.

Aerated static pile, the most common approach for outdoor composting of municipal organic waste, uses blowers to force air though pipes and into the pile. This does not appear to be used on PEI farms to compost manure, due to cost and difficulty of using blower machinery out of doors.

In-vessel composting - the materials are contained within bins, reactors, or buildings where a high level of control of moisture and oxygen is provided. In terms of cost, labour, management and process speed.

The windrow and aerated static pile systems are comparable. In-vessel composting is generally more expensive but results in better control over the process, a higher quality product, and less odor.

The location of a composting site should provide:

- easy access with a minimum of travel and materials handling.

- a firm surface to support vehicles under varying weather conditions.

- appropriate separation distance from wells, watercourses and neighbours.

- minimal risk of groundwater contamination.

- good surface drainage.

- grading for containment of surface runoff.

Composting solid manure produces a stabilized product that can be stored or spread on agricultural land with minimal odor, pathogens and weed seeds. Composted manure applications to land should be based on soil test results and crop needs. This is to prevent a nutrient imbalance from occurring and to make efficient use of compost.

Exposure to oxygen during composting will reduce manure methane emissions; however, it can lead to increased nitrous oxide emissions. Many factors determine this balance: diet, type of animal, and, most importantly, temperature, moisture and oxygen levels in storage. On-farm research is needed to determine whether the process of composting emits more GHGs than the application of fresh manure. This BMP project is an ideal opportunity to determine the effectiveness of composting manure on PEI farms.

RECENT ON-FARM COMPOSTING RESEARCH

A host of studies have shown the benefits of farm composting of manure, specifically dairy and beef manure, including detailed cost analyses. Following is one such study by Center for Integrated Agricultural Systems (CIAS). And the University of Wisconsin-River Falls. Note that all prices are in US dollars, as of 2015.

The researchers calculated the costs of various composting systems that use either specialized composting machinery or common farm equipment and compared this to existing research on the economics of long-term manure storage systems. Their research suggests composting can spare farmers from expensive long-term storage systems that require high structure and upkeep costs, especially if farmers are willing to share compost equipment or use existing farm machinery.

Bob Butler, of the UW-RF agricultural engineering technology department, Bill Connolly, assistant director of the UW-RF research farm, and Vern Elefson, a UW-RF ag economist, estimated composting costs by measuring the labor required and by calculating equipment and operating costs for four composting methods. Butler said the cost analysis may be useful to farmers who are thinking of switching to composting rather than investing in long-term liquid or solid storage systems.

WINDROW COMPOSTING

Composting using the windrow method requires some management to set up windrow piles, turn them periodically, and monitor the composting process. Compost forms as microbes in the manure decompose the organic wastes. This rrequires a moist environment containing oxygen, and farmers must aerate the material by turning the piles two to four times during the process.

The researchers estimated the costs of managing compost piles that were 50 feet long, 12 feet wide, and 3 feet high, using manure and bedding from the UW-RF farm. The team considered four scenarios for composting: investing in a tractor-drawn compost turner; hiring custom help with a compost turner; using an existing front-end loader; and renting a bulldozer.

The team examined both the labor costs of composting and the equipment investment for a 60-cow dairy farm. They based these values on an economics model developed by Brian Holmes of the UW-Madison ag engineering department, and Rick Klemme, a CIAS ag-economist. This format allowed the River Falls researchers to compare the economics of composting to several other manure management methods, from daily haul to higher-investment, long-term storage systems.

ESTIMATING THE COSTS OF COMPOSTING

TIME REQUIRED

In their on-farm demonstration, the researchers measured several elements of composting time management, including the time required to form the windrow pile (loading, traveling, and unloading time using a tractor and manure spreader); the time needed to turn the pile for the first time and for subsequent times (using either a compost turner and tractor, a front-end loader, or a bulldozer); and the time required to reload the compost (using a tractor, spreader, and front-end loader). When calculating the time required, the researchers assumed two turnings were adequate for the compost turner methods, while four turnings were necessary for the bulldozer and front-end loader methods.

The researchers estimated that the time required to form the windrow pile takes about 6.8 minutes per ton of manure, with 20 minutes' setup time. The time needed to turn the piles for the first time varies, depending on the equipment used. A bulldozer takes the least time at 0.2 minutes per ton, followed by the compost turner at 0.8 minutes per ton, and the front-end loader at 1.5 minutes per ton. Although the bulldozer takes the least amount of time to turn the piles, this method is also the least efficient and requires more turning times, the researchers found. Additional turnings require about half the time compared to the first turning. Again, the researchers found the bulldozer was the quickest method, followed by the compost turner and the front-end loader. Reloading the compost for field spreading using a tractor/spreader/front-end loader combination took about 2.2 minutes per ton, with about 20 minutes for setup.

ANNUAL OPERATING COSTS

Based on these time estimates, the researchers calculated annual operating costs for each composting method, including electricity and fuel, labor (at $5/hour), annual land cost for the compost site (for 2.1 acres), and costs of straw to mix with the manure (at $2,450 per year for 60-cows at 4 pounds/cow/day).
The bulldozer method required an additional $1,420 annually for renting equipment, while custom hire using a compost turner required $3,055 (for labor at $65/hour). Annual operating costs per cow were the lowest for the front-end loader and the bulldozer methods at $142/cow each, followed by the custom-hire compost turner scenario at $170/cow, and investing in a compost turner at $185/cow.

EQUIPMENT COSTS

The researchers estimated equipment costs for composting. Regardless of the method, composting requires about a $12,600 equipment investment for using a tractor (calculated by assuming 40 percent of its use is loading and hauling) and for buying a solid manure spreader, based on a 60-cow farm.

Composting using a turner and tractor requires another $16,600 equipment investment, for a total of $29,200. The front end loader requires an additional $2,750 investment (for costs of a front-end loader at 15 percent of its use), for a total investment of $15,350. Using a bulldozer or hiring custom help with a compost turner would require no additional equipment investment beyond the $12,600 tractor and spreader costs, according to the study.

The total investment costs per cow are $487/cow for the compost turner, $256/cow for the front-end loader, and $210/cow for both the bulldozer and custom hire compost turner methods.

Although compost turner methods require the highest investment, they are also the most efficient way to make compost. Farmers who share equipment or hire custom help could significantly reduce this investment. Using a front-end loader or bulldozer would require little, if any, additional equipment investment, although these methods would require more windrow turning.
An interesting result of this study is to compare the cost of manure composting to that of traditional manure storage and handling methods, as used in PEI. Following is the result of that analysis.

Figure 1: Cost comparisons of seven manure handling methods

Type	**Investment/cow**	**Annual cost/cow**
Concrete*	$1,426	$266
Picket dam*	$1,030	$194
Remote slab*	$697	$148
Tractor turner (compost)	$487	$185
Front end loader (compost)	$256	$142
Bulldozer (compost)	$210	$142
Tractor turner (custom hire)	$210	$170
Daily haul*	$150	$54

*Data from "The economics of dairy cow manure long-term storage," by Richard Klemme and Brian Holmes; other data, UW-RF study; all data based on 60-cow herd.

Figure 1 shows that the total investment for composting methods is between those of daily haul (at $150/cow) and a remote stacking slab (at $697/cow). Composting costs are far below high-investment systems, such as a concrete tank system. Annual costs of composting are similar to those of remote slab methods ($148/cow) and picket dam ($194/cow), according to Figure 1.

A commercial compost turner would cost in the order of CDN$18,000-25,000, with the opportunity of several farms nearby to each other sharing that cost and the equipment's usage.

The main negative GHG effect of this process would be usage of fossil fuels in equipment usage for management of the windrows (CO2).

The perceived GHG mitigation effects would include:

Decreased GHG effects of storing manure in pits, both in terms of fossil fuel usage for manure handling and removal (CO2) and generation of GHG gasses in storage (methane, nitrous oxide)

Decreased (perceived) GHG emissions from application of raw or uncomposted manure on farm fields, through nutrient loss (N2O)

Increased health effects on the soil, including carbon capture (CO2), and possibly providing low-cost soil building that would reduce N2) emissions.
GHG reductions of this method must be actually measured on-farm by implementation of this BMP and Program assistance for the purchase or lease of a commercial windrow compost turner.

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BMP 8

ANIMAL MANAGEMENT FOR GHG REDUCTION

DESCRIPTION

Animal production is a significant source of greenhouse gas (GHG) emissions worldwide. This is represented mainly by methane (CH4), and includes methane released from ruminant digestion (about 65%), and animal manure management (35%), such as storage and field application practices.

On average, dairy cattle produce 185 to 271 pounds of methane per animal per year, depending on size, feed intake and age. As methane is 23 times the GHG effect of CO2, this translates to at least 4,255 kg CO2 equivalents (CO2-eq) per animal per year. Based on the above percentages, this represents an average of 228 lbs CH4 from rumen digestion, and 148lbs CH4 potential in manure.

Another standard model for estimating the rate of total methane emission in terms of carbon footprint for dairy cattle is 2.8 kg CO2-eq/kg milk.
For beef cattle, that rate is expressed as 46.2 kg CO2-eq/kg meat. The majority of those emissions (65-75%) are from rumen methane.
As manure management and GHG mitigation is dealt with in a later BMP of this report, this BMP will focus on the potential to reduce methane emissions from the eructation (or belching) of CH4, produced in the rumen during digestion. These ruminant livestock include, in decreasing order of amount of CH4 produced, beef cattle, dairy cattle and sheep. Due to the level of interest from PEI's dairy and beef industries, this BMP will focus on those species.

In comparison, hog manure produces 10.5 pounds of methane per animal per year (Monteny, Groenestein, & Hilhorst, 2001). In the case of hogs, methane is generated from manure pits.

Following are average emissions, including methane, from PEI's major animal sources.

Table 1. Daily Waste & Methane Production by Dairy, Beef and Swine per 1000 lbs Animal Weight

Item	**Dairy**	**Beef**	**Swine**
Raw manure (lb.)	82.0	60.0	65.0
Total solids (lb.)	10.4	6.9	6.0
Volatile solids (lb.)	8.6	5.9	4.8
Methane potential (ft3)*	28.4	19.4	18.6

* Based on 65 percent of gas being methane.

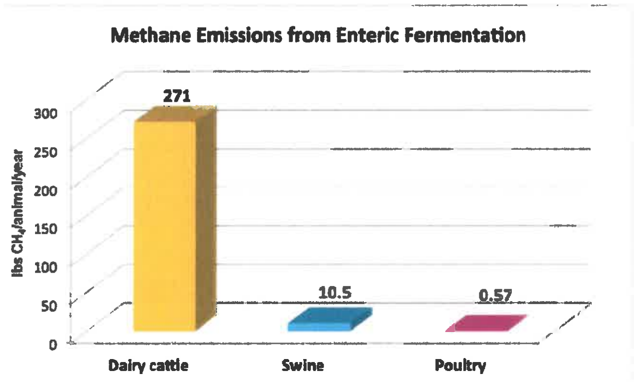


Table 2. Methane Emissions from Enteric Fermentation

IMPLEMENYTATION

PASTURE MANAGEMENT

Grass/pasture management is defined as the practices involved in growing healthy grass and related plants to profitably sustain forage availability and livestock production while ensuring soil and environmental health. ... Many ranchers now assert that their primary activity is growing grass, not beef.

Grass/pasture management practices provide strategies for conserving and enhancing native grass, improving forage production, restoring soil quality and quantity (for example, more organic matter), improving plant communities and reducing overall operational costs.

Well managed pastures have healthier plants that produce more biomass and therefore take up more CO2. More digestible feed grown in these pastures in the form of grasses, or in forage fields, also decreases methane production in livestock. Improved pasture has the potential to increase feeding efficiency, reduce feed and reseeding costs and increase animal productivity.

Feeding high quality grass and legume forages that meet animal nutrient requirements will improve production, shorten the time to reach a target weight or body condition score and lower feed costs. Specific to GHG emissions, high quality forage is also more digestible, meaning less energy in the feed is converted to methane reducing the animal's GHG footprint.

Different forages are suited to different micro-environments. Selecting the best plant composition for pastures will improve their productivity and long-term sustainability.

GRAZING MANAGEMENT

Rotational grazing consists of erecting moveable fencing around successive field areas, to ensure closely controlled feeding in each area. While requiring more planning, field records of pasture growth stages and labor, this method ensures pastures are kept at the most digestible stage, thus reducing methane emissions associated with enteric fermentation, and prevents overgrazing. Allowing vegetation to recover improves carbon sequestration potential, prevents erosion and improves pasture productivity.

Intensive grazing can be incorporated into rotational grazing practices, whereby large numbers of cattle are fenced in each successive area, requiring more diligence in timing for each area, to avoid over-grazing damage to that pasture area.

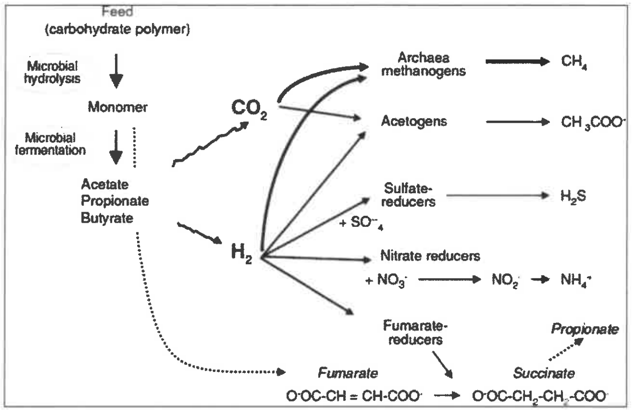
Both these practices could easily be incorporated into current PEI production practices. It should be noted, however, that the trend in the dairy industry is to feed the cattle in the barn and/or milking parlour. Therefore, any attempt to pilot these grazing practices on-farm should focus initially on the beef industry.

RUMINANT METHANE REDUCTION WITH FEED ADDITIVES

Rumen methane mitigation practices are categorized as enteric CH4 mitigation practices, dietary and animal management mitigation practices.

Recent research on rumen production of methane has focussed on evaluating the potential use of nutritional and animal management practices to mitigate methane from enteric fermentation. The majority of methane is produced by methanogenic bacteria, which comprise a relatively small component of the total rumen microbes.

See below the pathways of rumen fermentation, including methane generation.



Dietary manipulation can reduce CH4 emission up to 40% depending the degree of change and the nature of the intervention [22]. Another study also indicated that CH4 emissions can possibly be reduced up to 75% through better nutrition [23].

However, dietary manipulation is the most commonly practiced approach. Dietary strategies can be divided into two main categories: i) improving the forage quality and changing the proportion of the diet and ii) dietary supplementation of feed additives that either directly inhibit methanogens or altering the metabolic pathways leading to a reduction of the substrate for methanogenesis.

Following is a detailed overview of the more promising methods of dietary rumen manipulation for methane reduction, and their positive and negative properties. Many of these may be more suitable to beef and non-dairy sheep methane mitigations, as the dairy industry is more sensitive to the effects on milk production and quality.

FORAGE

Forage quality has influences CH4 production in the rumen [24]. High-quality forage, e.g., young plants, can reduce CH4 production by altering the fermentation pathway because this forage contains higher amounts of easily fermentable carbohydrates and less NDF, leading to a higher digestibility and passage rate [25]. In contrast, more mature forage induces a higher CH4 yield mainly due to an increased C:N ratio, which decreases the digestibility [18]. Different types of forage can also affect CH4 emission due to the differences in their chemical composition [22].

However, Hammond, Burke [26] found an inconsistent effect of the chemical composition of white clover and ryegrass on CH4 production. Legume forage has a lower CH4 yield, which is explained by the presence of condensed tannins, a low fibre content, a high dry matter intake and a fast passage rate [19]. Generally, C4 grasses yield more CH4 than the C3 plants [27]. Forage processing and preservation also affect CH4 emission [21].

For instance chopping or pelleting forages can reduce the CH4 emission per kg of DMI, as smaller particles require less degradation in the rumen [28]. Methanogenesis tends to be lower in the ensiled forages [28], presumably because the ensiled forages are already partially fermented during the ensiling process. Feeding improves the forage quality by feeding young forage with a lower fibre content and a higher soluble carbohydrate content; supplementing a small amount of grain with forage is a promising mitigation approach.

REPLACEMENT OF GRASS SILAGE BY MAIZE SILAGE

Grass silage is usually harvested at a later stage of maturity, resulting in a lower content of digestible organic matter, lower sugar and nitrogen contents and a fraction of lactate as a result of the ensiling process [29]. Consequently, the CH4 emission from animals that are fed grass silage is likely to be higher. In contrast, maize silage or other whole-crop small-grain silage typically provides higher contents of dry matter with readily digestible carbohydrates, e.g., starch, increasing the DMI and animal performance [19] and ultimately resulting in a lower CH4 yield from animals. There are three possible ways by which maize silage or whole-crop silage can reduce CH4 production in the rumen. First, the higher starch content favours propionate production rather than acetate. Second, the increased total DMI and passage rate reduce the ruminal residence time, thereby reducing ruminal fermentation and promoting post-ruminal digestion. Third, replacing grass silage with maize silage improves animal performance, resulting in fewer CH4 emissions per unit of animal product [30]. Several recent studies have indicated the positive effects of replacing grass silage with maize silage. Hassanat, Gervais [31] reported lower CH4 emission when alfalfa silage is replaced by 100% corn silage. Maize silage that is harvested during the later stage of maturity has also claimed to reduce CH4 [29].

CONCENTRATES

High-producing dairy cows have a higher requirement that exceeds their capacity to ingest nutrients from forage only. Therefore, forages must be supplemented with concentrates with a higher density of nutrients and less fibre. Due to less cell walls and readily fermentable carbohydrates (starch and sugar), concentrates favour propionic acid production, decreasing CH4 emission [21]. The CH4 reduction effect of concentrates can be described in two ways as below.

PROPORTION OF CONCENTRATE

The increased dietary level of concentrate reduces CH4 production as the energy proportion is mostly utilised by the animal products, such as milk and meat [21]. This effect is independent of genetic merit [32]. Decreased CH4 emission was observed at 80 and 90% concentrate supplementation, whereas no effect was found at 35 or 60% concentrate supplementation [33]. Most energy-rich concentrates are associated with increased DMI, rate of rumen fermentation and feed-turnover rate, causing a greater change in the rumen environment and microbial composition [21]. An extremely low CH4 loss of 2–3% of the gross energy intake was reported for feedlot cattle that were fed diet a 90% concentrate [34].

However, high-concentrate diets are low in structural fibre and in the long term disturb rumen function by leading to sub-acute or acute acidosis; therefore, these diets are not sustainable for ruminant production. Feeding concentrate with a suitable F:C ration would obviously be effective in methane mitigation as well as animal productivity.

CONCENTRATE COMPOSITION

Concentrates that are composed of different ingredients have variable carbohydrate compositions, ranging from structural (cellulose and hemicellulose) to non-structural (starch and sugar) carbohydrates. The degradable rate of both of these types of carbohydrates also varies widely according to the volatile fatty acid profile and CH4 loss. In beef cattle [34], the digestion of the cell wall leads to a higher acetate: propionate ratio and CH4 loss compared to other carbohydrate fraction; within non-structural components, sugar is more methanogenic than starch. All of the carbohydrate fractions contribute to CH4 loss, of which the least contribution is that from starch, probably due to the maintenance of a propionate-dominating VFA profile [29].

Feeding more starch to ruminants reduces enteric CH4 energy losses compared to feeding a forage diet [35]. Starch fermentation promotes propionate production in the rumen by creating an alternative H2 sink [36], a lower rumen pH, inhibiting the growth of methanogens [37], decreasing the rumen protozoan numbers and limiting the interspecies H2 transfer between methanogens and protozoa [38]. In addition, feeding starch, which can escape rumen fermentation, could potentially supply energy to the host animals while avoiding methanogenesis in the rumen.

Up to 30% of the starch from corn can escape rumen fermentation and be digested in the small intestine [39]. However, the bypass starch has limited digestibility (up to 60%) in the small intestine [40]. Very limited results are available on the effects of bypass starch on methane mitigation. Further investigation is required for detailed information.

In contrast, sugar as a water-soluble carbohydrate is rapidly and completely degradable in the rumen, enhancing butyrate production at the expense of propionate, thereby making sugar concentrates more methanogenic than starch [41]. Sugars enhance butyrate production at a higher H2 partial pressure and higher rumen pH, as confirmed by Hindrichsen and Kreuzer [42], who reported a 40% higher CH4 production with sucrose at a high pH compared to starch, while the opposite result was observed at a low pH with a significantly lower pH for sucrose.

FAT SUPPLEMENTATION

The addition of fat to the diet has traditionally been used to increase the dietary energy content to meet the energy demand of high-producing dairy cows. More recently, fat has been used for CH4 mitigation. If the energy supplementation in a ruminant's diet is changed from carbohydrate to fat, then less fermentation and CH4 production will occur.

The CH4-suppressing mechanism of fat is induced by reducing organic matter fermentation, fibre digestibility and consequently the methanogenic pathway and by the direct inhibition of methanogens in the rumen via the hydrogenation of unsaturated fatty acids [34].

The greatest reduction comes from the unsaturated fatty acids, which act as an H2 sink in the rumen through dehydrogenation [43], although other studies have reported that hydrogenation contributes only 1% of the H2 in the rumen [44]. Among fatty acids, the medium-chain C8:C14 from coconut or palm oil is the most effective in CH4 mitigation. Furthermore, fats are not metabolised in the rumen [45] and therefore do not contribute to methanogenesis [34]. Grainger and Beauchemin [46] also reported that fat supplementation often reduces carbohydrate fermentation due to the toxic effects of fat on cellulolytic bacteria and protozoa, while starch fermentation remains unaffected. Consequently, fat depresses CH4 emission [47]. However, fat supplementation to the ruminant diet is a persistent mitigation strategy [46].

ORGANIC ACIDS

The addition of organic acids, the intermediates of carbohydrate degradation, to the rumen has been suggested as potential feed additives for CH4 mitigation. Organic acids probably stimulate propionic acid production in the rumen by acting as an H2 sink, thereby reducing the amount of CH4 [48]. Newbold, Lopez [49] tested 15 propionate precursors in vitro and concluded that the structure appears to be more effective as an H2 sink that can reduce CH4 up to 17%. Fumarate and acrylate produce the most consistent reductions in CH4 formation in batch cultures, while fumarate is more effective than acrylate in artificial rumens [50].

Furthermore, fumarate (3.5 g/L) reduces the CH4 output by 38% in continuous fermenters using forage as a substrate [51]. However, a meta-analysis [52] reported a lower CH4 reduction effect in a continuous batch culture. Including multiple forms of propionate precursors in the diet yielded an additive inhibition of CH4 emissions as the reductive pathways differ among organic acid sources [50]. In contrast, an in vivo study with growing beef cattle reported a potential beneficial change in rumen fermentation by fumarate, although CH4 reduction was unaffected [53]. Organic acid supplementation has mostly been tested for CH4 production in vitro, producing inconsistent results. Therefore, there is the potential to invest more research in farm animals.

ESSENTIAL OILS

Essential oils are plant secondary metabolites, volatile components [29] and aromatic lipophilic compounds [54] with very strong antimicrobial properties [55], which inhibit the growth and survival of most of microorganisms in rumen [56]. The mode of action varies in individual essential oils [57]. However, all essential oils contain chemical constituents and functional groups, such as terpenoids, phenolic and phenols, which have strong antimicrobial properties. Because of their lipophilic nature, essential oils have a high affinity for microbial cell membranes, and functional groups interact with the microbial cell membrane [58]. Methanogenesis decreases with the application of essential oil, especially by reducing microbial populations.

However, no effect has been observed so far on the major aspects of rumen fermentation [59]. Limited studies have investigated the effect on CH4 reduction in vivo. However, methanogenesis is inhibited by altering protein degradation and amino acid determination [59]. Further research needs to investigate the potential use of essential oils in mainstream livestock farming.

IONOPHORES

Antibiotics, such as monensin, are antimicrobial compounds that are typically used in beef and dairy cattle production to modulate feed intake and improve feed efficiency and animal productivity [60]. Monensin increases the acetate: propionate ratio in rumen fermentation by increasing reducing equivalents that help to form propionate [19]. Monensin may also decrease ruminal protozoa. This antibiotic is typically added to the diet as premix or via a slow-releasing capsule and has an anti-methanogenic effect [19].

Ionophores do not alter the diversity of methanogens [61] but change the bacterial population from Gram-positive to Gram-negative with a consequent change in the fermentation from acetate to propionate, thereby reducing CH4 [62]. A high dose of monensin reduces CH4 production (g/d) by 4–10% in dairy and beef cattle [63, 64]. Furthermore, Guan, Wittenberg [65] reported a 30% CH4 reduction in beef cattle that were fed monensin (33 mg/kg), which was related to the number of ciliated protozoa.

The inhibitory effects of ionophores on CH4 production may not persist over time, and microorganisms adapt to ionophores [19, 34, 65]. However, the possible transient effect of ionophores and increasing public pressure to reduce the use of antimicrobial feed additives in agricultural production will obviously limit the scope for a long-term solution to CH4 mitigation [19].

PROBIOTICS

The use of probiotics for CH4 mitigation has recently been described [66]; [43]. The specific CH4 reduction potential of probiotics has not been well documented due to the unsuccessful introduction of acetogens to the rumen as competitors of methanogens [67]. Probiotics, such as lactic acid producers (Lactobacillus plantarum, L. casei, L. acidophilus and Enterococcus faecium), acetate and propionate producers (Selenomonas ruminantium and Megasphaera elsdenii) and yeast (Saccharomyces cerevisiae and Aspergillus oryzae) are widely used for the health of both human and animals [68]. Probiotics based on Saccharomyces cerevisiae are increasingly used in ruminant diets to improve rumen fermentation, dry matter intake and milk yield [19].

The underlying mechanism is probably the alteration of H2 production by the increased number of bacteria due to the partitioning of degraded carbohydrates between the microbial cells and fermented products [69]. Due to their modest price and wide use in ruminant production, the acceptance of CH4-reducing probiotics has a high probability in CH4 abatement. However, further research is needed to investigate the best possible products [19].

EXOGENOUS ENZYMES

Enzymes, such as cellulase and hemicellulase, are currently being used in ruminant diets. When properly formulated, enzymes can improve fibre digestibility and animal productivity [70]. Enzymes that improve fibre digestibility typically lower the acetate: propionate ratio in the rumen, ultimately reducing CH4 production [71]. Subsequently, in a recent review, Beauchemin, Kreuzer [19] suggested the possibility of developing a commercial enzyme additive to reduce CH4. However, searching for potential enzymes for methane abatement warrants future research.

ALTERNATIVE H2 SINK

Alternative H2 sinks, for example, nitrate and sulphate, are used at lower concentrations in the basic diets of ruminants. As alternative electron acceptors, nitrate and sulphate have a greater reduction potential and are thermodynamically highly favourable for some rumen microbes [72].

Regarding methane mitigation, Leng [73] described the potential of nitrate supplementation in the ruminant diet. Furthermore, van Zijderveld, Gerrits [74] demonstrated that the reduction effect of nitrate and sulphate is electronically more favourable than is CH4 production, which can potentially change the competitiveness of H2 scavengers.

In recent years, nitrate and sulphate have been increasingly tested for CH4 abatement. A 32% methane reduction was reported for nitrate, 16% for sulphate and 47% for a combination of nitrate and sulphate fed to lambs [74]. The same author in a subsequent study indicated an approximately 16% CH4 (g/d and g/kg DMI) reduction in dairy cows [75]. However, nitrate supplementation has not been established in many countries (e.g., in Denmark) due to toxic effects that could lead to animal death. One potential toxic effect occurs via the reduction of nitrate to nitrite, which causes methemoglobinemia, a condition in which blood haemoglobin cannot carry oxygen [74].

Because a lower amount of nitrate in the diet is safe for the animal [76], nitrate supplementation can be an effective CH4 mitigation measure. However, more research is needed to determine the inclusion levels for different ruminant species.

PLANT SECONDARY METABOLITES

The potential effect of plant secondary metabolites (PSM) in CH4 reduction has been recently recognised [19]. The CH4-suppressing effect of PSM is mainly associated with antimicrobial properties that kill the bacteria [77], protozoa [78] and fungi [79] in the rumen. Plant secondary metabolites contain phenolic compounds the main active components that have antimicrobial activity [80]. Plants produce a variety of secondary compounds, among which condensed tannins [81] and saponins [82] have received much attention.

CONDENSED TANNINS

An interesting development in CH4 mitigation research is the development of forages with higher levels of tannins, such as clover and other legumes, including trefoil, vetch, sulla and chicory [29]. The anti-methanogenic activity of tannins has recently been investigated in vitro and in vivo [83]. The CH4-suppressing mechanism of tannins has not been described clearly; however, this mechanism may inhibit ruminal microorganisms [77].

Tannins may inhibit, through bactericidal or bacteriostatic activities, the growth or activity of rumen methanogens and protozoa [84]. Methane production was reduced (up to 55%) when ruminants were fed tannin-rich forages, such as lucerne, sulla, red clover, chicory and lotus [81].

Although tannins appear promising for CH4 mitigation, these impede forage digestibility and animal productivity when fed at a higher concentration, limiting their future wide-scale use in CH4 abatement [19]. However, more research may identify the balance between CH4 reduction and possible anti-nutritional side effects as associated with tannin supplementation.

SAPONINS

Saponins are naturally occurring surface-active glycosides that are found in a wide variety of cultivated and wild plant species that reduce CH4 production in the rumen [29, 79]. Saponins have a potent antiprotozoal activity by forming complex sterols in protozoan cell membranes [83] and, to some extent, exhibit bacteriolytic activity in the rumen [66]. Saponins are antiprotozoal at lower concentrations [85], whereas higher concentrations can suppress methanogens [77]. Saponins inhibit ruminal bacterial and fungal species [79] and limit the H2 availability for methanogenesis in the rumen, thereby reducing CH4 production [77].

Methane reduction of up to 50% has been reported with the addition of saponins [86]. However, a wider range of CH4 reduction (14–96% depending on the plant and the solvent that was used for extraction) has been reported [62].

RUMEN MANIPULATION

Manipulating the microbial diversity in the rumen through chemical means (e.g., halogenated compounds such as bromine and iodine); by introducing competitive or predatory microbes or through direct immunisation can reduce methanogenesis in ruminants [20].

A preliminary study suggested that vaccination against methanogens can reduce CH4 emission up to 8% [87]. However, the long-term effect of vaccination on CH4 reduction is still uncertain [88]. Furthermore, methanogen populations in the rumen are influenced by diet and geographic location (Wright et al., 2007); therefore, it is challenging to develop a broad-spectrum vaccine against all methanogens. Instead, the development of a vaccine against the cell-surface proteins of methanogens may improve the efficacy of vaccination for CH4 mitigation [50].

Biological control bacteriophages or bacteriocins could be effective in the direct inhibition of methanogens and in redirecting H2 to other reductive rumen microbes, such as propionate producers or acetogens [50]. However, most of these options are still conceptual, and significant research is required. They are therefore not considered in this review of potential BMPs.

Halogenated compounds, such as bromochloromethane and chloroform, are potent inhibitors of CH4 production in ruminants. Methane reduction has been reported with bromochloromethane mainly due to the reduction of methanogen abundance [89].

An approximately 26% CH4 reduction was reported by McAllister and Newbold [50] through the chemical inhibition of protozoa because the methanogens are often attached to the surface or endosymbionts within ciliated protozoa [50]. This effect of halogens, Iodine being one, may explain why seaweeds are known to reduce methanogenic bacteria. Seaweeds are high in Iodine.

Inclusion of concentrate feeds in the diet of ruminants will likely decrease enteric CH4 emission per unit of product, particularly when inclusion is above 35 to 40% of dry matter intake, but the effect will depend on inclusion level, production response, effect on fiber digestibility, plane of nutrition, feed type, feed processing, and likely animal species.

Increased forage digestibility is expected to increase production and decrease enteric CH4 production per unit of product. It appears that the introduction of legumes in warm weather offers a mitigation opportunity. Increasing forage digestibility, intake, and animal production reduces overall GHG emission from rumen fermentation and are highly-recommended mitigation practices.

Processing of grain to increase its digestibility likely reduces enteric CH4 production per unit of animal product, but caution should be exercised that fiber digestibility is not decreased. Minimal processing is highly recommended, so grain energy is better utilized for animal production.

Improving the nutritive value of low quality feeds in ruminant diets can have a considerable benefit on herd productivity while keeping the herd CH4 output constant. Consequentially, CH4 emission per unit of product is reduced.

Feeding protein close to animal requirements, including varying protein concentration with stage of lactation or growth, is recommended as an effective manure ammonia and N2O emission mitigation practice.

Chemical treatment of low quality feeds, supplementation, selective breeding, and selection for straw quality are easily applied solutions with varying positive and few negative effects, but there has been little adoption of these technologies on farms.

It is recommended that the use of seaplants be revisited, as there has been positive effects seen in their usage in PEI in the past, and there is a substantial supply of seaweeds available here.

In conclusion, no single option appears to provide a simple and enduring solution. Selection and breeding of low methane emitter animals is an attractive solution, but a requires longer time frame than can be tested as a BMP in the timeframe of this project. Use of chemicals, ionophors, plant secondary metabolites have shown transitory effects on methane reduction.

However, overall dietary manipulation by selecting and utilizing high quality forages, strategic supplementation of forages, changing concentrate proportion with special emphasis on changing carbohydrate composition should be considered as an immediate and sustainable methane mitigation approach of enteric CH4 emitted from ruminant livestock.

Feeding a diet with more starch and less fibres not only produce less methane per kg feed DM but also form a basis for higher feed intake and higher production per animal and hence will be the most efficient way to reduce the methane production per kg of meat or milk produced.

SPECIFIC FEED SUPPLEMENTATION

For the purposes of this report, the use of two unique, low-impact, affordable and proven effective feed supplements are described. Each should be pilot tested separately and together, to determine the maximum methane reduction possible without affecting animal or milk production and quality.

SEAWEEDS

Both research-based and commercial sources of seaeweed feed supplements, specifically aimed at reducing ruminant methane production, have been identified.

North Atlantic Organics, Joe Dorgan, Seacow Pond http://naorganics.com/
North Atlantic Organics Ltd (NAO) is a producer and distributor of organic sea plant (seaweed) products that serve as mineral supplements to animals and plants. The product is Certified Organic and its production has a very low carbon footprint.

Using traditional methods of hand and horse raking seaweeds from PEI shores, as well as solar drying, fossil fuels are not burned while the quality of the product is preserved through gentle drying. Sold under the trade name Atlantic-Gro® products are made from Kelp and Rockweed seaweeds and are certified free of artificial additives, preservatives, fertilizers, pesticides, hormones, antibodies and genetically modified organisms (GMO).

Products have been farm-tested on PEI dairy and beef cattle and are considered suitable for feeding to cattle, horses, hogs, hens and sheep. They are also in the process of diversifying their product as a natural plant enhancement supplement that can be used as fertilizer for crops such as potatoes, cranberries, strawberries, soybeans and more.

The agricultural scientist Rob Kiley, while a researcher at the Dalhousie Department of Agriculture in Truro, NS, helpedtest NAO's seaweed mix, and discovered it reduced the cows' methane production by about 20 per cent, using a 5% feed inclusion rate. Higher reductions may be realized at higher inclusion rates.

Mr Dorgan states that he would be happy to provide sufficient seaweed product to assist in farm feeding trials with PEI cattle.

FutureFeed, Inc. c/o Rob Kinley, CSIOR, Australia

UNIVERSITY OF CALIFORNIA- DAVIS

University of California researchers have ongoing research on feeding seaweed to dairy and beef cows, to measure the effect on rumen methane production. In a study over the spring of 2017, researchers found methane emissions were reduced by more than 30 per cent in a dozen Holstein cows that ate the ocean algae, which was mixed into their feed and sweetened with molasses to disguise the salty taste. Ermias Kebreab, the UC Davis animal scientist who led the study, is now conducting a six-month study of a seaweed-infused diet in beef cattle.

More studies will be needed to determine its safety and efficacy, and seaweed harvesters would have to ramp up production to make it an economical option for farmers. If successful, adding seaweed to cattle feed could help California dairy farms comply with a state law requiring livestock operators to cut emissions by 40 per cent from 2013 levels by 2030.

There's nothing novel about cows eating seaweed. Joan Salwen, an environmental science fellow at Stanford University who introduced UC Davis scientists to their seaweed solution, and formed a nonprofit, Elm Innovations, to help focus and fund research, says, "Cows eat what's available. In California, they eat almond hulls; in Georgia, they eat cottonseeds. Documented evidence attests to farmers in ancient Greece and 18th-century Iceland deliberately grazing their cows on beaches, where they had access to seaweeds, such as rockweed.

Rockweed (Fucus vesiculosis) is the same species used by Acadian Seaplants (Nova Scotia)for their products. Acadian has commercialized their seaweed products to a high degree, selling specialized supplements for animal and human use. To ensure control over their raw materials, they have licenses with the Nova Scotia government to lease tidal waters for sustainable harvest of the seaweeds, and are researching the possibility of culturing the sea plants on water leases.

This method has been applied commercially by Dr Thierry Chopin, University de Moncton, as a "multitroophic aquaculture" application, where long-lines of seaweeds are cultured among salmon and shellfish aquaculture sites, where the plants hyper-accumulate nitrogen and phosphorous form the growing animals. While it is beyond the scope of this report, such forms of seaweed culture are of growing interest in the Maritimes and worldwide, suggesting that there would be more affordable amounts of seaweed in the future.

Generally, as seen in previous sections of this report, methanoenic bacteria are reduced by the presence of halogens, a class of metallic chemicals that include Indine and Bromine. It is interesting that the two products above contain high amounts of halogens: iodine and bromine. It is unknown why some seaweeds show 30% methane reduction, while others show up to 90% reduction of rumen methane.

CARINATA GRAIN EXTRACTS

Agrisoma Biosciences Inc., an agriculture technology company, has developed and commercialized Brassica carinata, and oilseed crop originally intended for commercial production of oil for biodiesel and advanced biofuels production.

The company currently sells its carinata seed to farmers for growing carinata as a rotation crop or on their fallow land for the production of renewable biodiesel oil. It serves customers in North America. The company was founded in 2001 and is based in Gatineau, Canada.

Discussions with the company, based on researching a press release, revealed that Agrisoma is also completing research and farm trials on carinata as a feed supplement. Research using fermenters and artificial rumens showed that carinata reduced methanogenic bacteria by 70% or more, and early feeding trials on beef cattle in the EU showed a 45-50% methane reduction.

The company suggests a 10-20% inclusion rate, either top-dressed or included in the feed mix. Regulatory work is underway, and the product is regarded as GRAS (Generally regarded as safe in food) by agri-food regulators, including the CFIA. Research is needed now to show the effect of carinata in dairy animals, specifically milk quality, due to the existence of glucosinolates and erucuc acids. The company is developing inexpensive methods of processing the carinata to remove these compounds or reduce them to acceptable levels.

Meanwhile, it should be noted that carinata (being a Brassica) is very effective as a fumigant crop against Wireworm, a currently devastating crop pest in PEI. It should be explored whether this species of brassica is more effective than current ones grown in PEI.

INCLUSION RATES OF SUPPLEMENTS

The daily dry matter intake of a 550 kg beef animal, eating an average-quality hay, is about 11kg per head at 88% dry matter, or about 12-13kg per day on an as-fed basis. Therefore, specific to dairy, a 20% or higher inclusion rate of carinata (recommended rate by the company) would require over 2kg per animal per day, and a 10% inclusion rate of seaweed requires more than a kilogram per animal per day.

Drivers to adoption of this practice on PEI farms are:

The relatively low cost of the
supplement at 10% inclusion rate

Ease of handling and application

Availability of the raw material across PEI

Evidence that the product positively affects animal production and health (eg: dairy cattle have been seen to have substantially reduced somatic cell counts in their milk and udders)

Widespread awareness of supplementation, specifically in the beef and dairy industry, and knowledge among these producers of the earlier work using seaweeds on PEI farms.

The main barriers to adoption of this practice in PEI are:

the reluctance of dairy producers to alter their carefully formulated feeding regimen

fears that a supplement will negatively affect milt production, quality and taste/smell

lack of knowledge of the long-term effects of unusual compounds in the natural supplement materials (eg: iodine content of seaweeds, glucosinloates and erucic acid in carinata)

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BMP 9

ALTERNATIVE ENERGY SOURCES FOR PEI FARMS

DESCRIPTION

Electrical energy is a large and increasingly costly portion of the cost of operations on many PEI farms.
This BMP focuses on the two most available and proven alternate sources of electrical energy: wind and solar power. As part of this practice, it is essential that the interested farm perform an electrical energy audit, to determine the cost-benefit of adopting either of these alternative sources of energy. The final section of this BMP provides detailed information on what such an audit entails, and an example of public programs to assist in the cost of audits.

As of 2017, there were 203 MW of installed wind capacity on PEI. Approximately 25% of the energy distributed by Maritime Electric comes from on-Island wind generation. The remaining 75% of electricity consumed in PEI comes from New Brunswick, which generates electricity from a mix of nuclear, fossil fuels, and hydroelectricity.

In 2017, approximately 30% of New Brunswick's electricity generation was from nuclear, 40% was from fossil fuels (natural gas, coal, and petroleum), and 21% was from hydroelectricity. The remainder was produced from wind and biomass.

Assuming this New Brunswick electric power mix is evenly distributed to PEI, it is assumed that approximately 50% of electricity used on PEI farms comes from a non-renewable source, and has a proportional GHG footprint.

In discussions with PEI farmers and alternative energy systems suppliers in Eastern Canada, it is apparent that some PEI farms have adopted some form of alternate energy systems over the past decade, with very mixed results.

For example, while wind energy farms have become an increasingly substantial part of PEI's provincial energy platform, small, private wind generation by households and farms has decreased over time, due mainly to a combination of poorly performing or failed earlier technology and a current lack of public incentives for small-scale wind energy adoption.

Solar technology enjoys a slightly more successful record of implementation, with several companies supplying increasingly efficient and affordable systems to businesses, governments and households, including some PEI farm operations.

Once a small energy generating source is installed, a "Net Metering" option is available to all Maritime Electric customers who are served from the distribution system and are billed under one of the metered service rates, and who install a renewable energy generator of less than 100 kW capacity, which meets the requirements of the Renewable Energy Act.

The customer is credited at the retail price for energy supplied to the utility that is surplus to his load at the time, up to a maximum of what the customer can use during the following 12 months, during times when his load is greater than his generation.

However, an initial government program (Renewable Energy Incentive) to stimulate adoption of alternate energy technologies by Islanders in no longer available. See a description of this program at the end of this section. It is recommended that, to aid in implementation of this BMP, a similar incentive is offered to PEI farmers interested in implementing alternate, low-GHG energy technologies on their farms.

Due to the lack of provincial financial incentives, initial capital costs, poor awareness of the sustainable long-term financial benefits of these technologies, and negative optics of earlier farm implementation attempts, PEI farmers are reluctant to revisit these energy options, even while farm energy usage and costs are on the rise.

IMPLEMENTATION TARGETS

Generally, the larger the electric demand on-farm, the more suitable these alternate energy options will be. From consultations with current wind and solar power users, Maritime Electric, alternate energy equipment supply companies and government experts, as well as review of the types of farm operations that use the most power, the following types of farms are considered as best potential adopters of this BMP.

POULTRY FACILITIES

Poultry production is an intensive production farm that utilizes a relatively large amount of energy for lighting, ventilation, manure conveyors, etc. Recent trends in dehydration of poultry manure on-farm further increases the electricity demand.

DAIRY FARMS

The trend on PEI is for larger dairy herds on fewer farms, thus centralizing the energy demand on fewer sites. A second more recent trend, driven also by a lack of available farm workers, is to incorporate robotic milking and feeding operations, where the cows are fed, washed and milked, managed on a cow-by-cow needs basis, using sophisticated computer-based management programs.

This shows an increased electricity demand on dairy farms, including milk room refrigeration and washing equipment, milking parlor automated equipment, lighting, ventilation fans, etc.

POTATO STORAGE WAREHOUSES

Both on-farm and off, the larger, highly-automated potato storage facilities have maximum electrical demand in the fall, when newly-stored potatoes must be in high-energy artificial environments that include humidity, refrigeration and ventilation electrical demands. This coupled with the fact that the roofs of these facilities could support substantial solar panels, and the bordering properties would have room to accommodate a small wind turbine, makes a targeted energy audit around such options feasible.

A PEI-based solar technology company has installed such systems on at least two such warehouses.

POTATO WASHING FACILITIES

At least one recent solar installation on the roof of a Prince County potato grower's farm, where potatoes are washed for the table market, is an example of recent willingness to adopt such opportunities to reduce energy costs, while, perhaps not intentionally, reduce GHG emissions from purchasing electricity from non-renewable sources.

WIND ENERGY

PEI has abundant wind for energy production, evidenced by the fact that over 25% of our provincial energy is produced on PEI through wind farms. As seen in the maps below, some parts of PEI have a more reliable amount of wind per year than others, depending partly on elevation. This Wind Atlas is used by engineers to determine best sites for wind turbines.

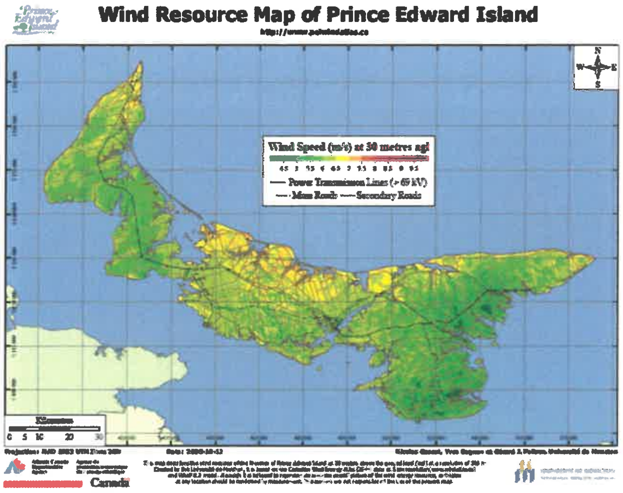


Fig. 1. Average wind speed available on PEI at an elevation of 30 meters above ground level

These maps (Fig. 1-3) show the average amount of wind available in PEI at three different elevations above ground-level. Note that the largest amount of wind at all elevations occurs on the North shore of PEI, with more inland wind available above 50 meters, and most farmland in Central Queens County showing adequate wind above 80 meters. This informs the minimum windmill tower height must be at least 50 meters above ground.

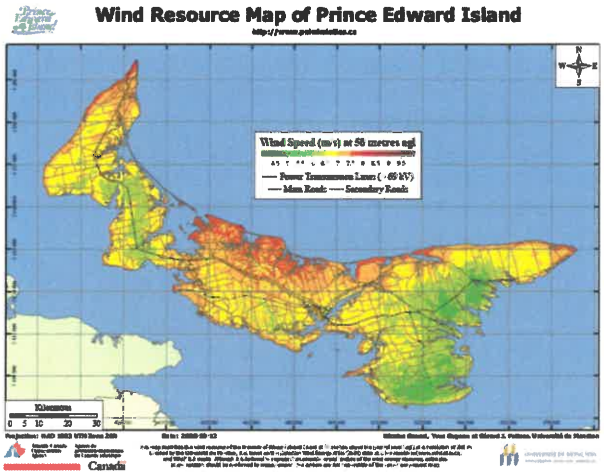
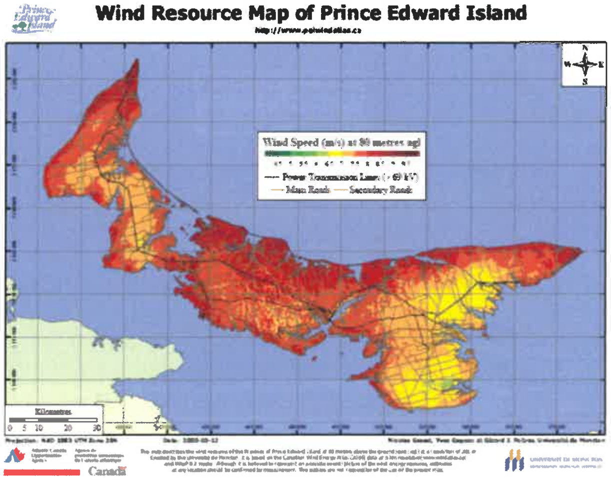


Fig. 2. Average wind speed available on PEI at an elevation of 50 meters above ground level.

Fig. 3. Average wind speed available on PEI at an elevation of 80 meters above ground level



An early adopter of farm wind energy is Kool-Breeze Farms in Summerside, which offsets its energy demand for a poultry facility and several greenhouses with two relatively old 55kW wind turbines. The owners claim that, using Maritime Electric's Demand Metering system, where on-farm power generation up to 100kW can be returned to the PEI power grid for electricity credits, their electricity bells are often below $100/month. The strategy is to have adequate generation capacity to provide at least 50% of the on-farm demand (this also applies to solar or a mix of solar and wind), thus ensuring that high-generation times (windy days, most frequent in the fall and winter) offset the cost of electricity in low-generation times (less wind, especially in the summer).
Most wind turbines available on the market are too large for the demand of most PEI farms, as well as for applicability to the Maritime Electric demand metering system (ie: larger than 100kW).

A recent exception is EO Cycle, a Quebec company that produces 25kW turbines, specifically aimed at the farm market. Since 2013, EO Cycle has acquired international certification for their long-life, low-maintenance turbines. A typical dairy farm of 300 animals, according to Maritime Electric, has a demand of 25,500kWh annually, meaning that a 25kW turbine, producing 80,000kW annually, would supply all of the farm's electricity demand, as well as produce demand metering credits. Poultry farms and potato warehouses would be within the same range of demand.

COSTS

According to EO Cycle CEO Richard Legault, they have sold their 25Kw wind turbine systems throughout the USA and EU, and always start with a free online energy audit. Their 25Kw turbine, installed, costs CDN$175,000, which they claim will retrieve cost at 50% of that demand within 7 years. EO Cycle also provides investment-style financing for their turbines at 10-12% for the duration of the turbine's life, estimated at 20 years.
EO Cycle has expressed firm interest in participating in the farm audit portion of this BMP in Phase I of the Project.

POTENTIAL GHG REDUCTIONS

According to Natural resources Canada data, it is estimated that a 25kW wind system would remediate on-farm almost all of the 25g CO2 equivalent/kWh "generation intensity" of PEI's GHG electric power usage footprint. For an annual farm usage of 20,000-30,000 kWh, this equates to a GHG reduction of 500kg CO2 equivalents per year.

BARRIERS TO ADOPTION

Wind energy was introduced to PEI many years ago, when turbine technology was still relatively low-efficiency, high cost and was seen within a few years to have even higher maintenance costs. Government incentives at the time resulted in a dozen or so farms installing these early turbines, often with no maintenance service backup, as early companies went out of business.

The result is seen on the PEI landscape today, with many empty towers and non-functioning turbines still standing. This has solidified PEI producers' negative attitudes against wind as a farm energy option to this day.

A robust effort of "show-me" outreach and pilot installations will be needed to overcome this understandable, but outdated vision of farm wind power. Of course, for smaller operations, capital cost will remain the major barrier.

POLICY DRIVERS

Overcoming the negative perception of farm wind solutions on PEI could start with a program to facilitate installation of today's high-efficiency, low cost (relatively), low maintenance small turbines, on 2-3 high electrical usage farm operations that are of sufficient size to gain maximum cost savings in a short time. It is recommended that the largest dairy and poultry operations be approached to do a 3-year trial of a 25Kw rotor, following a detailed energy audit.

It is worth noting that, if individual farms wish to cooperatively purchase and operate a larger turbine (>100kw), such as those supplied on PEI by Frontier Power, they must be registered as a Commercial Energy Producer, under current Maritime Electric and PEI government policies around energy generation. The appropriate bodies in government should be approached to determine interest in legally exempting cooperative, nearby clusters of high-usage farms from current regulations, to allow a co-op farm cluster to, in the future, deploy a commercial sized turbine to supply the cluster.

SOLAR ENERGY

DESCRIPTION

PEI enjoys an average of 1,841 hours of sunshine per year, or 40% of an average daytime period. This varies by month considerable, from a low of 70 hours per month in November-December, to a high of 200-210 hours per month in May-September. Coincidentally, this is relatively opposite to the seasonal wind availability in PEI, making wind-solar options the best, albeit, highest capital cost, alternate energy solutions for PEI high electricity-use farms.

The table below lists yearly and monthly averages for the number of sunny days and hours of sunshine for Prince Edward Island. The number for % Sun is the usual percentage of daylight hours with bright sunshine. Hours gives the total hours of bright sunshine that's normal during a year or month. Days statistics are for the typical number of days annually with any amount of measurable sunshine.

All the data are averages for the years 1981 to 2010.

Average total sunshine in Charlottetown, PEI

% Sun		**Hours**	**Days**
39	January	109	22
38	February	109	22
38	March	141	22
37	April	148	22
43	May	197	26
47	June	220	27
53	July	254	28
50	August	219	28
48	September	181	26
36	October	124	26
22	November	63	19
28	December	76	19
40	Annual	1841	286

Solar energy production on-farm, unlike wind power generation, requires large horizontal surface areas, either on rooftops or on the ground. However, and partly because of this fact, solar energy technology is more easily adapted to the average PEI farm, both because it can be added as incremental low-wattage units, compared to the Megawatt-sized units available for wind energy, and due to the large rooftop surfaces available on large-usage farms.

From research on the larger farm electricity users, coupled with knowledge those farms with the most building rooftop areas, it is apparent that the three PEI farm operation types most likely to easily adapt solar power options are poultry operations, dairy operations and potato storage warehouses.

Unlike wind power options, farms need not bear a large one-time capital installment cost for solar power equipment, and can incrementally add solar panels as individual farm economics allow.

IMPLEMENTATION

Potato storage warehouses and larger animal barns (eg: poultry) have large roof areas that could hold sufficient solar panels to supply most of the facility's power needs during the sunny months (Spring, Summer), while a small wind turbine could supply the bulk of demand in the Winter and Fall, when wind supply is greatest. This would be buffered by the demand metering system that would flatten out the small drops or excess of demand and generation seasonally. Potato warehouses would have peak demand in the fall, when the newly stored potatoes require chilling and drying ventilation as well as throughout the winter.

Modern potato warehouses typically have roof areas of 800-1,600 sq.ft. per side. Assuming barns are usually oriented east-west to minimize snow collection, solar collectors could be placed on both roof surfaces, providing sufficient power for the majority of the facility's needs. Otherwise, ground-based systems would benefit by being orientable to the best sun angle.

Technology providers advise that dairy and poultry farms would also benefit from solar or, in the case of larger facilities over 100kW demand, a dual solar/wind system. The benefit of solar technology is that it can be incrementally added to as demand becomes greater, or to spread out the initial capital cost of installation.

For example, Steve Howard of Solar Island Electric has been targeting specific farm applications for the past several years, including to two different sized potato warehouses, where a 20kW and 6kW system was custom-installed based on electric demand in each case.

COST

With this type of system, the cost is about $2.40/W power, installed. For the above examples, this translates to costs of $48,000 for the 20kW installation and $14,400 for the 6kW system.

POTENTIAL GHG REDUCTION

A 50 kW system produces thousands of kWh per month. The GHG reduction would be identical at 25g CO2 equivalents per kWh. As an example, a farm with an annual draw of 10,000 kWh would see a reduction in non-green electricity usage of at least 50%, as seen on other currently operating systems, if not more. This represents a reduction of 250 kg CO2eq yearly per farm.

Again, a strategic energy audit would be completed prior to defining what type(s) of systems (wind at x kW, solar at x kW, or a mix of both) should be considered, to implement this BMP.

PEI FARM GHG ENERGY AUDITS

Any opportunity to implement alternate energy BMPs to PEI farms should first be in the form of an on-farm Energy Audit. Following is an overview of such audits successfully applied to farms elsewhere.

Specific to this BMP, a farm energy audit should primarily focus on the opportunity to reduce electrical energy usage, based on whether the farm has sufficiently high electricity usage to warrant installation of technology, the capital cost of which may require 5-7 years to write down.

It is assumed that prior to implementation of the following section's BMP, this GHG-related energy audit be completed.

The audit report identifies and describes major energy consuming systems within the operation. A farm operational overview would include the type and size of the operation. A site plan or aerial view can be useful for describing the facilities. A building summary should include all the structures in the operation, including their square footage, primary uses, details of construction and energy-using systems.

In terms of an electrical farm energy audit, an infrastructure summary will describe the facilities for receiving, storing (where applicable) and distributing energy. This would include electrical supply, includes the electrical phase (single, three-phase), voltage and amperage of main panels. Farms may have more than one metering location for electricity, and may have multiple fuel storage facilities.

Rather than simply knowing the average monthly farm electricity usage, monitoring seasonal electrical usage is the essential starting point of identifying the size and cost effectiveness of alternate energy installations.

A table of the characteristics of larger equipment can be created and used to compare alternatives when it is time for the equipment to be replaced. Just because a piece of equipment is relatively inefficient does not always justify its replacement with a more efficient model. For example, replacing motors that are rarely used will often have a very long payback period.

TYPES AND COSTS OF ON-FARM ENERGY AUDITS

A Level 1 (walk-through) audit is a tour of a facility where each energy-using system is visually inspected. The auditor evaluates energy consumption data, sometimes compares this to industry averages or benchmarks for similar facilities, and creates a list of low-cost energy saving opportunities, with preliminary estimates of possible dollar savings. When these changes are merely possible or hypothetical they are called energy conservation opportunities or ECOs. Once they are implemented, they are called an energy conservation measure or ECMs.

A Level 2 (standard) audit "goes on to quantify energy uses and losses through a more detailed review and analysis of equipment, systems, and operational characteristics." (Thumann, p. 2) This may include on-site energy measurements and testing, standard engineering calculations, and an economic analysis of the recommended conservation measures.

A Level 3 audit includes some computer simulation and a more comprehensive evaluation of energy use patterns. The computer simulation creates an accurate baseline of current consumption, allowing for weather and other variables. By changing variables, the auditor can look at a great number of possible changes and estimate their effect on energy consumption and cost.

Here are some other terms and distinctions commonly used to describe audits:
A do-it-yourself audit is conducted by the owner of the facility. The options for agricultural producers to conduct their own energy audits have recently exploded, with the appearance of many dozens of free do-it-yourself energy analysis tools on the Internet.

A whole-farm audit (also known as a comprehensive or holistic audit) looks at all the energy consuming systems of a farm, and may be contrasted with operation- or technology-specific audits (also known as single-purpose or targeted audits). For example, a common technology-specific audit is an irrigation efficiency audit, one that simply looks at the energy efficiency of the irrigation pump, motor (or engine), and distribution system. But in principle, an audit could focus its attention on lighting, heating, cooling, ventilation, or any other individual energy-consuming system or process.

Likewise, some audit programs target a specific farm type (such as dairies, greenhouses, or poultry farms), and may be contrasted with general programs that audit any type of farm.

According to the USDA, a basic farm energy audit—suitable for the REAP Renewable Energy for America Program (REAP)—would typically cost USD $1,000 to $2,000 in 2013. Based on this estimate, it is probable that a farm energy audit for a mid- to high-demand farm would be CDN $2500-4000.

POLICY DRIVERS

No current PEI government programs exist to address the costs of implementing this BMP, including the cost of an energy audit. The PEI Department of Communities, Lands and Environment should be approached, along with the PEI Department of Agriculture, to determine interest in cooperating on a program to at least buffer the costs of an on-farm audit. This would both gauge the level of interest from producers to invest in wind or solar power options, as well as minimize the public cost of this first phase of the BMP. Federal partnering dollars should be sought to maximize the program capacity.

Following is an overview of a previous Federal/Provincial PEI government program, with a similar goal.

RENEWABLE ENERGY INITIATIVE

The Renewable Energy Initiative on PEI was a 7 million-dollar program offered through the Agricultural Flexibility Fund, a cost-sharing agreement between the Government of Canada and the Province of Prince Edward Island. The program was delivered by the P.E.I. Department of Agriculture in cooperation with the Office of Energy Efficiency.

PROGRAM DESCRIPTION

Renewable energy sources can provide farmers with a degree of energy independence while improving both the individual farm's and the agriculture sector's environmental footprint. Renewable energy is perceived as a major opportunity for farms on Prince Edward Island to reduce their input costs. This initiative is part of the overall effort to increase the competitiveness of the agriculture sector.

The Renewable Energy Initiative provides financial assistance towards farm energy audits and the implementation of on-farm renewable energy system(s). The purpose of the REI is to demonstrate the potential for on-farm renewable energy to improve farm net income while enhancing environmental sustainability.

PROGRAM ELIGIBILITY

Applicants must be a bona fide farmer, and the maximum contribution for eligible expenses is $1,500 for audits and $50,000 for implementation, per farm unit. The Initiative will accept applications from a group wishing to act in a joint venture for the purposes of developing an on-farm renewable energy system. In a joint venture proposal, each participating operation must individually qualify as a bona fide farmer.

The maximum contribution of $1,500 for audits and $50,000 for implementation per participating farm unit will apply to each participant in the joint venture. Each participant in the joint venture must equally share in the eligible expenses and benefits.

A bona fide farmer is defined in the Revenue Tax Act and the status is granted through the Taxation and Property Records Division of the Department of Finance and Municipal Affairs. Proof of status will be a valid Farmers Revenue Tax Exemption Permit Number issued in the name of the applicant.

In determining a 'farm unit', the Administration will evaluate each operation's respective degree of legal, financial, and operational independence.

ELIGIBLE RENEWABLE ENERGY CATEGORIES

- Solar: The use of solar-energy through photo-voltaic panels for the production of electricity or solar panels for the production of space-heat, crop drying and/or hot water.

- Biogas: The use of methane gas produced from the anaerobic digestion of crop, manure and/or other material that is primarily of agricultural origin, for the production of electricity and/or heat.

- Wind: The use of wind that is captured by turbine(s) and generates electricity to off-set the cost of electrical energy for farm lighting, refrigeration or electrical equipment operation.

- Biomass: The combustion of agricultural biomass to replace fossil fuel use for the production of space-heat, crop drying and/or hot water.

- Geothermal: The use of a central heat exchange system to extract the stored energy of the earth for heating and/or cooling.

PROGRAM COMPONENTS

There are three components to the program:

1) Initial Application
a. Complete and submit a program application form

b. Receive acceptance letter and complete the On-Farm Energy Audit (a prerequisite for Component 2)

c. Claim eligible costs on the audit and submit a copy of the audit for evaluation

2) System Implementation
a. Develop and submit an Implementation of Renewable Energy System(s) application

b. Sign Implementation Agreement and commence action on renewable energy system

c. Claim eligible costs by completing either partial or final claims for the project described in the Agreement

3) Post Energy Audit (compulsory for those that receive funding under Component 2)
a. Approximately one-year after the system is implemented a second energy audit will be performed to evaluate the impact of the renewable energy system

1) APPLICATION, AUDIT AND CLAIM

Applications are available from the Department of Agriculture's website at: http://www.gov.pe.ca/agriculture/REI, from the P.E.I. Department of Agriculture Information Desk 1-866-PEI-FARM (734-3276) or from the Office of Energy Efficiency. A completed application should be returned to the Office of Energy Efficiency at the address provided at the end of this document.

The audit requires a site visit by an energy auditor who will assess the farm energy consumption to identify the main areas of energy usage and establish a baseline for the operation's energy consumption. Based on the audit and an analysis of energy consumption records, recommendations are expected to be made on ways to increase energy efficiency on the farm and potential energy management options. The information derived from the energy audit will assist the producer in determining whether a renewable energy system would be viable for their operation and in selecting the optimal renewable energy system. A detailed list of the criteria to be met in the energy audit is available from the program contacts or at: http://www.gov.pe.ca/agriculture/REI.

Approved applicants must choose an energy auditor from a list of Natural Resources Canada (NRCan) approved energy management service providers that have agreed to perform farm energy audits through this program. A list of the companies servicing P.E.I. can be obtained from the Department of Agriculture and will be forwarded to applicants with their letter of acceptance.

The on-farm energy audit component is a prerequisite to be eligible for the Implementation of Renewable Energy System(s) component. For the program the audit is valid for a twelve month period from the date of completion.

Rate of assistance: Funding for the on-farm energy audit will be provided at 75%, to a maximum contribution of $1,500 per farm unit. The per farm unit limits will apply to each individual member of a joint venture proposal on an equal basis. For audits performed on large and complex operations that exceed the funding cap, there may be an exception made to increase the maximum contribution dollar level. Assistance may be claimed once the audit is finished by completing and submitting the Audit Claim Form to the Office of Energy Efficiency along with a copy of the completed audit. This component will provide assistance for the purchase and installation of new infrastructure/equipment that will enable agricultural producers to produce renewable energy for their on-farm energy requirements from one of the eligible renewable energy sources.

It is at the discretion of each applicant, subject to the Department of Agriculture's approval, to select which renewable energy system(s) to implement. A combination of renewable energy systems is permissible; however, the funding level offered is on a per farm unit basis and will not be increased for multiple systems.

Joint venture applications must, in their applications for assistance concerning the implementation of a renewable energy system, identify each bona fide farmer applicant that is a party to the joint venture and indicate the individual contact responsible for the application to the Renewable Energy Initiative administration.

Rate of assistance: Funding will be provided up to 50% of the eligible costs for the purchase and installation of a renewable energy system(s), to a maximum of $50,000 contribution per farm unit. The per farm unit limits will apply to each individual member of a joint venture proposal on an equal basis.

Eligible expenses: Eligible expenses will include but may not be limited to:
- Renewable energy system(s) and materials required for system installation, delivery included.
- Installation of system(s)

Claims:
- Once significant expenses have been incurred to implement a proposal proponents are eligible to complete and submit a claim using the appropriate form.

The Department will determine which items are eligible upon application review.
Detailed quotes are required for this purpose. In-kind contributions by the applicant are not eligible.
It is advised that you check with your insurance coverage provider prior to installing a renewable energy system to ensure that you meet any and all insurance requirements.

3) POST ENERGY AUDIT

A post energy audit will be performed on operations that receive funding for implementation of a renewable energy system. The purpose of the audit is to review the application of the renewable energy system and its impact on the energy consumption of the operation. The data from the initial on-farm energy audit will be used for comparative purposes. The audit will be planned for approximately one year after the installation and activation of the renewable energy system and will involve an on-site visit of the operation where the renewable energy system is installed. The applicant is required to be cooperative in providing a site inspection and utility records to the auditor.

Information gathered from this component will be used by the Department of Agriculture to develop a conclusion on program results and to share findings with the public.

Rate of assistance: Funding of the post energy audit will be provided at 100% with no cost to the producer.

TERMS AND CONDITIONS

Applicants must submit a completed application form for Component 1) On-farm Energy Audit and Component 2) Implementation of Renewable Energy System and meet the eligibility criteria. An approved applicant for Component 1 is not automatically considered for Component 2. Program guidelines and application forms may be revised at any time throughout the life of the program.

Program funds are allocated annually and distributed on a first come first served basis. Expenses incurred prior to application approval are not eligible for assistance.

The applicant is responsible for obtaining required licenses, permits, approvals and authorizations, and for complying with all applicable municipal, provincial and federal legislation.

To be eligible for the program component, Implementation of Renewable Energy System, the on-farm energy audit must have been performed within the past 12 months.

Where possible, renewable energy projects should be completed and operational by March 1st of the fiscal year in which the implementation contract is concluded. Where more time is required, project proponents must request a contract amendment, and such a request must be made within a reasonable period of time. Final claims for a project must be submitted, at the latest, by March 1 in the fiscal year of the contract end date.

All materials must be purchased new to qualify for funding assistance. Project costs must be representative of fair market value. Costs in excess of fair market value will not be eligible for funding. Installation costs must be an arm's length transaction. Non-arm's length costs will not be eligible for funding.

For the initial audit, eligible expenses will be reimbursed upon the Department's receipt and approval of a claim form accompanied by invoices and proof of payment from the applicant.

For the implementation of a renewable energy system(s), eligible expenses such as down payments may be reimbursed upon the Department's receipt and approval of a claim form accompanied by invoices and proof of payment. All approved projects are subject to an on-site and financial audit after project completion.

Biomass combustion systems funded through this program must be a model that achieves comparable emission levels to the CAN/CSA-B415.1 or the EPA outdoor Wood-fired Hydronic Heater (OWHH Method 28) Program, Phase 1 or 2.

Geothermal systems are to meet the requirements of CAN/CSA-C448 earth energy system.

Successful applicants will be expected to share key results of their project. The Department may request organized tours or site visits of the project, with permission, to promote renewable energy opportunities.

This program commenced on April 1, 2010, terminated March 31, 2014 and has not been renewed.

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SECTION
SIX.

SECTION SIX.

POTENTIAL BMP TEST PRODUCERS

6.1 Throughout this project, the authors have reached out to PEI producers across commodity groups, first to determine their current practices related to GHG emissions sources, then to determine their level of interest in the Beneficial Management Practices (BMPs) presented here.
In all, 26 producers expressed moderate to high interest in participating on at least one of the BMPs, and most of these were interested in several of the BMPs. It should be noted that he producers were not supplied with the full text of each BMP. However, interviewers did discuss details of each BMP, where the producer requested more information, especially in the case of the more unfamiliar BMPs.
Most PEI producers, including animal producers, grow at least one field crops annually, either for sale, as animal feed, as a cover of residue crop, and/or as a requirement of their rotation plan.

For this reason, most producers were very aware of the BMPs relating to nitrogen management

Reasons for producer interest fell into three categories:

1. Producers are already applying practices similar to one or more of the BMPs, and would do more, if a program was available to further buffer those costs.

2. Producers who know that a practice would benefit them, but were not currently able to afford the cost of implementation, especially if that required new equipment purchases

3. Producers who see benefit in a BMP practice in theory, but have knowledge of past experiences by other producers, where the technology or methodology was insufficient, and eventually failed.

Following is a summary of interested producers by BMP, their commodity sector(s), the level of interest (low, medium, high), and the specific drivers of their interests. The numbers in brackets represent the number of producers in each commodity group that expressed at least moderate interest in that specific BMP.

BMP 1

COVER CROPPING WITHIN POTATO AND CORN PRODUCTION SYSTEMS

(HIGH INTEREST)

Potato (8) and vegetable (2) producers alike showed high knowledge and interest in this BMP. Many potato growers produce more corn than in the past, both as an effective post-harvest cover crop, as well as to swap for manure or land with local animal producers. Growers were also interested in the co-benefit of future cover crops that would more effectively help prevent wireworm infestations (fumigant crops). Animal producers had moderate interest in this BMP.

BMP 2

REDUCED INTENSITY, DEPTH AND FREQUENCY OF TILLAGE

(HIGH INTEREST)

Potato growers (9) and vegetable growers (2), as well as animal producers growing forage crops (5) expressed high interest in reducing the amount of tillage on their land. Many growers across sectors, especially potato growers, have been steadily moving away from the older moldboard plows toward less-intense chisel plows and other more modern designs. More growers would incorporate this practice, if there was a one-time assistance with retiring old equipment and buying new, low-intensity tillage equipment. One potato producer has recently purchased the required equipment, and would be interested in a per-acre subsidy for application of this BMP. This was a common request across sectors and field-related BMPs in general.

Among animal producers, the mixed-farmers (2) (ie: those with animals and cash crops), although the exception on PEI, were also very interested.

BMP 3

USE OF FULL-SEASON SOIL-BUILDING ROTATION CROPS

(MODERATE INTEREST)

Not all growers are aware of the benefits or costs of this practice, while others, especially potato farmers (3), have reported having been using this practice for several years. Vegetable producers, according to Joanne Driscoll, PEI Horticultural Association, would welcome availability of better fumigant cover crops against wireworm and other diseases, as it is reported that some current fumigant crops are no longer effective. Potato growers express a similar concern over their own disease management with cover crops.

BMP 4

SITE-SPECIFIC "RIGHT RATE" N RECOMMENDATIONS

(MODERATE INTEREST)

The potato industry (7) has high awareness and participation in the 4R Program, as are some vegetable (1) and animal (2) producers. 4R participants were interested in the potential to apply 4R to more land, if a program would assist with costs.

BMP 5

USE OF ENHANCED EFFICIENCY FERTILIZERS

BMP 6

WILLOW PLANTATIONS IN FIELD EDGE AND RIPARIAN AREAS

(HIGH INTEREST)

All participants contacted who are also participants in the ALUS set-aside land program (6) have high interest in this BMP, assuming ALUS land is allowed to receive a willow plantation. It is probable that all ALUS participants would embrace this BMP, if funding was available for establishment of willow plantations.

Once regulatory issues of working ALUS and other set-aside lands (eg: riparian zones, buffer zones), the interest and uptake of this BMP would probably be very large.

As well, participants in the ongoing Living Labs Program are already having willow plantations experimentally placed on their land, making partnering with the current ALUS and Living Lab growers an excellent launching point for the first year of this BMP.

BMP 7

MANURE STORAGE MANAGEMENT TO REDUCE CH4 EMISSIONS

(LOW TO MODERATE INTEREST)

All animal producers with manure pits (dairy (5), pork (3) would benefit from this BMP. Of those contacted, the use of manure covers was seen as beneficial but expensive and labor-intensive, based on earlier experiences with the use of covers several years ago. These earlier efforts experienced failures in winter and windy weather, however, more and better options are now available to replace the earlier tarpaulin covers, including in-pit floating coverings (see full text of BMP 7).

Once made aware of these facts, growers are willing to look at these options, once the BMP full text is available to growers as a public document.

Beef (4) producers are currently unwilling to cover their in-field manure windrows at this time, due mainly to the interference with handling, especially the cost of labor to remove and replace the covers. However, some beef producers are either already composting their manure (2), or would consider the practice, given program incentives for equipment, such as a compost turner machine. Such a machine is in the range of $18,000 and can be shared among nearby farms. Both beef and dairy farms on PEI tend to geographically cluster, making this possible.

Poultry producers (2) report that they are already stabilizing that type of, arguably, more-easily handled manure, including adding to compost heaps.

Most organic producers report using composting, including crop waste and manure, on their farms, and would be excellent receptors for any manure management BMPs, as well as acting as models of the positive co-benefits and affordability of this BMP.

BMP 8

METHANE REDUCTION FROM RUMINANTS USING FEED ADDITIVES

[LOW TO MODERATE INTEREST]

With the past inclusion of PEI seaweed into ruminant diets (mainly diary), acceptance of this BMP will rely on having off-the-shelf, proven additives to test. Beef (3) producers will more easily accept this practice, while dairy (1) would only consider additives that are shown to not have a negative effect on their milk production/quality and animal productivity. This may require some early work with the dairy group in Dalhousie agriculture, Truro, or a similar service at the Atlantic Veterinary College, to show dairy producers that the products are not only safe, but show co-benefits, such as improved animal health.

Early adopters would be producers who have previously used the seaweed product from beef producer (1) Joe Dorgan in PEI (North Atlantic Organics). Mr Dorgan is very interested in participating in this BMP, and feels he can recruit other beef producers to adopt the BMP.

BMP 9

ALTERNATE ENERGY AUDITS AND APPLICATIONS FOR HIGH-USAGE FARMS

All producers with high electrical energy demands would welcome a program that assists in incorporating solar power onto the rooftops of their production buildings, including potato storage facilities (3), dairy parlors (2), beef feedlots (3) and poultry/egg production facilities (2). With the first step of offering low-cost energy audits, this BMP should see several more early adopters, aided by the existence of several solar arrays in-place.

Wind power, despite the availability of lower-cost, high-efficiency, low-maintenance wind generators, has lower interest. This is due to the need to install the equipment all at once, as compared to the opportunity to add solar panels incrementally, as can be afforded, each year or so. This in spite of the existence of at least one early adopter (Kool Breeze Farms), who has shown huge reductions in power bills over the past several years. Wind energy adoption will take longer time, and a more robust set of policies and incentives, including a loans program, availability of test windmills, and changes to the Maritime Electric regulations restricting the size of wind generators to 100kW.

Overall, none of the BMPs were flatly rejected, and all should be widely accepted in some form, if producers can see both affordability and co-benefits to their implementation.