GROUPE AGÉCO

THE POWER OF SOIL:

AN ASSESSMENT OF BEST APPROACHES TO IMPROVING AGRICULTURAL SOIL HEALTH IN CANADA

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FINAL REPORT

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SUMMARY

Soil health is vital to long-term, sustainable crop production in Canada. In addition to contributing to reducing the GHG footprint of crop production (and some animal production), maintaining healthy soils also contributes to increasing on-farm resilience (water management, nutrient management, etc.) and help farmers maintain yields, harvests and farm profitability over time. For this reason, there are many opportunities for climate and agricultural policies in Canada to improve their focus on soil health, notably through encouraging the adoption of beneficial soil health management practices on the farm.

However, improving soil health is no easy task. Soil health is the result of a complex interplay of various factors – geographic, economic, social, political, ecological, demographic, and psychological. Therefore, improving soil health requires a comprehensive, systems-wide approach to production and soils, considering all aspects of the production system and agroecosystem.

In this context the goal of this report is to provide a holistic review of the different factors affecting soil health management practices and assess how policies can enhance their adoption in Canada. Specifically, using a systems approach, this technical report looks at the agronomic, psychological, social, economic, and political dimensions of soil health by answering the following questions:

1. What are the main agricultural practices benefiting soil health?
2. What are the key factors influencing BMP adoption by farmers?
3. What are the existing and innovative policies supporting BMP adoption in Canada?

To answer each of these questions, an extensive review of the literature was performed as well as interviews with key informants and advisors from a variety of backgrounds.

Specifically, **chapter 1** reviews and summarizes the available science and knowledge on soil health practices in Canada. This chapter shows that soil health is a complex state involving several physical, biological, and chemical characteristics and processes. In other words, what defines a healthy soil depends on regional factors as well as on the soil's intended use and function. Therefore, improving soil health requires a comprehensive, systems approach to production and soils that consider all aspects of the production system and agroecosystem.

This chapter defines four interconnected perspectives that can be used to evaluate the benefits of BMPs to soil health: soil health principles, soil degradations, soil functions, and soil characteristics. Any management practice (or set of practices) consistent with these perspectives could be considered beneficial to soil health. It also identifies 11 beneficial management practices (BMPs) considered beneficial to soil health in the Canadian context.

However, based on a review of the characteristics, strengths and limitations of these BMPs, the section suggests that it is critical to first identify the soil health objectives being prioritized and the current producers situation in order to determine the appropriate BMPs in a given situation.

Chapter 2 identifies and summarizes the key factors influencing the adoption of soil health practices. More specifically, this chapter looks at the psychological, social, and economic dimensions affecting soil health. Results show that farmers' decision to adopt a BMP or not is an individual one, significantly influenced by a person's distinctive behavioural factors. In turn, these factors are influenced by many other considerations (farmer profile, farmer attitude and behavior, farm characteristics, awareness and access to information, and economic factors). All these factors are interrelated, making the understanding of the decision-making process complex.

Given this, it is essential to understand the individual person behind the decision-making process leading to BMP adoption, especially in the context of a systems approach. Yet, three core factors contributing to successful BMP adoption and implementation are identified: a strong business case that relates to the perceived benefits, costs, and risks of adopting new BMPs, access to information and expertise, and the ability to track progress over time. Better understanding these factors is an important step in designing better policies to foster BMP adoption.

Lastly, **chapter 3** focuses on the policy dimension of soil health in Canada. The chapter presents and reviews current policies, programs, projects and initiatives targeting soil health in Canada and other jurisdictions. Indeed, to improve BMP adoption rate and foster system changes at the production level, farmers need to operate in a business environment offering the appropriate support and signals through successful policy proposals. If designed properly, a variety of public policy tools can help create a policy system that will make soil health systems more attractive and accessible to farmers.

This chapter documents 7 policy tool categories used in Canada and the provinces under the federal-provincial-territorial Canadian Agricultural Partnership (CAP). The chapter also presents some inspirational programs used here and abroad, along with their respective strengths, limitations, and gaps, as well as suggestions as to how they could be enhanced. Based on these observations, many different innovative, improved or new approaches can address some of the limitations faced by any type of farmers across the country. There are thus many inspiring examples in Canada and around the world deserving to be tested on a larger scale, for the benefit of soil health.

The insights provided here offer a foundation for rethinking some of our agricultural and climate change policies and programs. More specifically, the findings are aimed at supporting program-level recommendations related to improvements to current program interventions in Canada. The content can assist in the development of soil health strategies and program instruments for Canada to meet its global climate change commitments and support the agricultural sector's ongoing adaptation to climate change. The content can also be informative in the development of the new federal climate plan and the new FPT agricultural policy framework expected in 2023.

A comprehensive set of draft recommendations for changes in federal and provincial climate and agri-environmental policy, awareness building, easily accessible information and advice, farmer-to-farmer learning, technology, and better financial incentives for soil health are presented in a companion report, "The Power of Soil: An Agenda for Change to Benefit Farmers and Climate Resilience". That report also summarizes the extensive material in this volume in a simpler format and more accessible language. The recommendations are inter-related forming a system to support change, addressing known barriers to adoption of better soil management and constitute a roadmap for soil health in Canada.

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LIST OF ABBREVIATIONS:

AA: Anhydrous Ammonia
AAID: Automatic Air Inflation Deflation
AMF: Arbuscular Mycorrhizal Fungi
AWC: Available Water Capacity
BMP: Best Management Practices
BRM: Business Risk Management
CASH: Cornell Comprehensive Assessment of Soil Health
CC: Cover Crops
CSPM: Climate-Smart Pest Management
CRSC: Canadian Roundtable for Sustainable Crops
CT: Conventional Tillage
CTF: Controlled Traffic Farming
ECCC: Environment and Climate Change Canada
EGS: Ecological Goods and Services
EF: Emission Factor
EFP: Environmental Farm Plan
FEMS: Farm Environmental Management Survey
FTP: Federal-Provincial-Territorial
GHG: Greenhouse Gas
GMO: Genetically Modified Organism
IPCC: Intergovernmental Panel on Climate Change
IPM: Integrated Pest Management Strategy
LCA: Life Cycle Assessment
MWDA: Mean Weight Diameter of Aggregates
NI: Nitrification Inhibitor
NIR: National Inventory Report
NT: No-Till
OSCIA: Ontario Soil and Crop Improvement Association
PCU: Polymer Coated Urea
PLFA: Phospholipid-Derived Fatty Acids Profile
SMAF: Soil Management Assessment Framework
SOC: Soil Organic Carbon
SOM: Soil Organic Matter
ST: Systems Thinking
UI: Urease Inhibitor
VBS: Vegetated Buffer Strip
WFPS: Soil Water-Filled Pore Space
WSA: Wet Stable Aggregates

INTRODUCTION

BACKGROUND

One of humanity's major challenges for the 21st century is how to produce food for a growing population in the face of a changing climate and environmental degradation (Bowles et al., 2020). Extreme weather events and long-term change in climate conditions will exacerbate agroecosystems' vulnerability to those variations (Gaudin et al., 2015). Sustainable food production will require building resilient agricultural systems in the face of climate change. Heavy rainfall, drought or changing pest conditions may also challenge productivity, unless adaptive measures are taken. Indeed, the Intergovernmental Panel on Climate Change (2013) suggests that year-to-year variations will increase along with wetter spring conditions, drier summer months and greater frequency of abnormal precipitation events.[1]

In addition to the agronomic and economic value of maintaining and improving soil health, it is now recognized that healthy soils can improve climate change adaptation and contribute to reducing climate change impacts in different ways (c.f. side box below). For instance, well-managed soils capture and store soil organic carbon (SOC) through a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool (Ontl and Schulte, 2012).[2] Healthy soil also stores and supplies nutrients, thus reducing the need for farm inputs, such as mineral fertilizers, whose production and volatilization contribute to greenhouse gas (GHG) emissions (CRSC, 2020).

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

Over time, the structure and function of a healthy soil should remain relatively stable, even in the face of disturbances such as climate change.[3] Therefore, in addition to contributing to reducing the GHG footprint of crop production (and some animal production), maintaining healthy soils also contributes to increase on-farm resilience (water management, nutrient management, etc.) and help farmers maintain yields, harvests and farm profitability over time.

[1] The impacts of these changes are already being experienced, with significant financial costs. For instance, according to the Insurance Institute of Canada, severe weather damage claims have averaged $2.1 billion a year since 2013, or 20 times the insurance claims paid in the early 1980s, after adjustment for inflation. Over the next decade, the average annual severe weather claims paid by insurers in Canada could more than double, reaching $5 billion a year (Insurance Institute of Canada, 2020).

[2] Mostly due to soil organic matter, agricultural ecosystems hold large carbon reserves. Improved management practices that increase the photosynthetic input of carbon and/or slow the return of stored carbon to CO2 will increase carbon reserves (IPCC, 2007).

[3] Agroecosystems vulnerability includes various concepts such as resilience, persistence and resistance. The concept of improving the level of resilience has been studied in diverse natural ecosystems, communities and food systems. However, it has not been well studied at the field scale where stability and resilience are often used interchangeably to describe fluctuations in final crop yields after perturbance (Gaudin et al., 2015).

As stewards of the land, many farmers understand soil health and, in many instances, there has been a shift in farm practices to increase soil health and long-term productivity. Some government and industry policies and programs encourage soil health practices like crop rotation and cover crops. However, there are many opportunities for climate and agricultural policies in Canada to improve their focus on soil health through encouraging the adoption of beneficial soil health management practices on the farm. Canada faced another crisis in soil conservation in the 1980s when the Senate of Canada held nation-wide hearings and issued "Soil at Risk: Canada's Eroding Future" and governments responded with new policies and programs (Senate of Canada, 1984).

SIDE BOX: SOIL HEALTH AND CLIMATE CHANGE

According to Agriculture and Agri-Food Canada (AAFC), improvements to soil quality has been seen over the last 30 years in Canada, primarily attributable to improvements in land management practices, such as increased adoption of reduced tillage and no-till practices, and the reduction in area under summer fallow in the Prairie Region (Clearwater et al., 2016). However, many issues remain as many of Canada's soils are still losing organic matter and degrading.[4]

In addition, the latest National Inventory Report (NIR) shows that emissions from the agriculture sector accounted in 2018 for 59 Mt or 8.1% of total GHG emissions in Canada,[5] a decrease of 0.5 Mt or 1% from 2005 levels, but corresponding to an increase of 12 Mt or 27% since 1999. They are projected to increase to 73 MT of CO_2 equivalent in 2030 (Environment and Climate Change Canada, 2020). The report also states that the current net removal from cropland is lower than in 2005,[6] mainly as a result of increased conversion of perennial to annual crops on the Prairies and the declining effect of the adoption of conservation tillage on cropland.

While GHGs associated with animal production (CH_4 and N_2O, from manure management and enteric fermentation) will continue to remain the largest source in Canadian agriculture, emissions from crop production are rising. In fact, in 2018 the NIR reported an "unprecedented shift" with the total agricultural emissions now consisting of slightly higher proportions of N_2O (nitrous oxide, mainly from crop production) than CH_4 (methane, from livestock production).[7] This situation is mainly due to an increase in the use of inorganic nitrogen fertilizers (+72% since 2005).

By enhancing soil health, the biology of the soil creates fertility for plants, which reduces the need for fertility from high GHG fertilizers. There is therefore a significant untapped potential to improve soil health, not only as a mean to sequester more carbon but also to use nutrients more efficiently and reduce overall emissions from the sector (Clearwater et al., 2016; FAO, 2015).

[4] For instance, in Ontario results from the same report indicate that 82% of agricultural soils in Ontario were losing more CO_2 to the atmosphere than storing organic carbon. Sixty-eight percent of farmlands were at risk of unsustainable erosion, and 53% of soil had low or shallow soil cover (Agricultural Soil Health and Conservation Working Group, 2018).

[5] Current agriculture sector emissions calculations from crop production do not account for the additional elements of agriculture's GHG footprint inherent in Canada's crop production today including, for instance, the manufacture of mineral fertilizers in Canada and fluxes in soil carbon, which are both accounted for under other Canadian inventories.

[6] The net flux is calculated as the sum of CO_2 and non- CO_2 emissions to the atmosphere and CO_2 removals from the atmosphere (Environment and Climate Change Canada, 2020).

[7] Specifically, emissions increased from 17 Mt in 1990 to 25 Mt in 2018, an increase of 45%, due mainly to an increase in inorganic nitrogen fertilizer use. Total emissions from the application of inorganic nitrogen fertilizers increased from 6.8 Mt in 1990 to 14 Mt in 2018, an increase of 101%, as inorganic nitrogen fertilizer consumption increased steadily from 1.2 Mt N to 2.6 Mt N over the same period.

Encouraging the adoption of beneficial soil health management practices first requires understanding which agricultural practices can benefit soil health and maximize the associated environmental outcomes. Several organizations and initiatives in Canada have already developed an interest in this question. These include:

- Government-driven approaches, e.g., Environmental Farm Plans (EFPs), the Farm Environmental Management Survey (FEMS).
- Industry-led efforts, e.g., Canadian Roundtable for Sustainable Crops (CRSC), 4R Nutrient Stewardship initiative, Field to Market Canada.
- Assessments and research projects carried out by organizations and research centres.

There is thus a wealth of information, data and knowledge available. Yet, while knowledge on the environmental benefits of adopting sound agri-environmental practices is rapidly expanding, promoting and scaling up BMP adoption among producers remains a challenge.

Policies that encourage better management practices for soil health are a vital aspect of Canada's transition to a lower GHG and more sustainable agricultural sector. Federal and provincial governments have been promoting and funding the adoption of soil health practices for a long time, including under the current Canadian Agricultural Partnership (CAP). The Pan-Canadian Framework on Clean Growth and Climate Change also considers agricultural soils and forests as important carbon sinks that need to be protected and enhanced to reduce emissions (2017). And the current government has promised a new and more ambitious climate plan to go beyond the Pan Canadian Framework, expected in late 2020 or early 2021.

OBJECTIVE AND METHODOLOGY

Soil health is the result of a complex interplay of various factors – geographic, economic, social, political, ecological, demographic, and psychological. It is closely tied to individual farmers and shared beliefs in farming communities, as well as to policies at various levels of government. Therefore, improving soil health requires a comprehensive, systems-wide approach to production and soils that consider all aspects of the production system and agroecosystem (c.f. A systems approach).

Using a systems approach, this technical report looks at the agronomic, psychological, social, economic, and political dimensions of soil health. The goal of this report is to present a holistic review of the different factors affecting soil health management practices and assess how policies can enhance their adoption in Canada. More specifically, the report seeks to answer three questions:

1. What are the main agricultural practices benefiting soil health?
2. What are the key factors influencing BMP adoption by farmers?
3. What are the existing and innovative policies supporting BMP adoption in Canada?

To answer each of these questions, an extensive review of the literature was performed as well as interviews with key informants and advisors from a variety of backgrounds.[8] The report is structured as follows:

[8] List of key informants interviewed as part of this project is available in Appendix 1.

- Chapter 1 reviews and summarizes the available science and knowledge on soil health practices and identifies 11 beneficial management practices (BMPs) for soil health in Canada. This chapter provides the **agronomic** perspective associated with soil health.
- Chapter 2 identifies and summarizes the key factors influencing the adoption of soil health practices. More specifically, this chapter looks at the **psychological**, **social**, and **economic** dimensions affecting soil health.
- Chapter 3 focuses on the **policy** dimension of soil health in Canada. The chapter presents and reviews current policies, programs, projects and initiatives targeting soil health in Canada and other jurisdictions.

Healthy soils represent an opportunity to build prosperous and resilient farms that can sustain us into the future. To fully leverage this opportunity, this report provides some foundation for rethinking some of our agricultural and climate change policies and programs. More specifically, the findings are aimed at supporting program-level recommendations related to improvements to current program interventions in Canada. The content can assist in the development of soil health strategies and program instruments for Canada to meet its global climate change commitments and support the agricultural sector's ongoing adaptation to climate change. The content can also be informative in the development of the new federal climate plan and the new FPT agricultural policy framework expected in 2023.

SIDE BOX: A SYSTEMS APPROACH

Commonly, scientists and policy specialists look at components or subsystems of the agri-food system using linear, narrow and logical analytic processes. This 'silos' type of analysis limits a comprehensive understanding of the complexity of the system as a whole. Soil health is a complex subject in and of itself. To understand how to improve it, we need to also look at economic, social and political factors.

In the context of this report, we have sought to understand soil health system functions within natural systems (soil functions and characteristics in the biophysical environment and accounting for regional differences) and social and economic systems (barriers to adoption of better management practices) and how they are or could be impacted by different policy approaches. These factors are dynamic and evolve over time.

Many of the interactions, both within and across these different systems, also involve trade-offs (also called feedbacks or externalities) (TEEB 2018). As a result, a given policy intervention or practice may not have the anticipated effect if all the different factors and levers are not considered. Therefore, the multiple dimensions of the system create complex analytical and policy challenges (EEA 2017). Policies that seem to be effective to counter some barriers to adoption in a region can also cause unintended adverse effects over a different subsystem level [may actually be counterproductive to improve soil health in particular conditions], in other region, or over a different time horizon (TEEB 2018).

1. REVIEW OF AGRICULTURAL PRACTICES THAT BENEFIT SOIL HEALTH

Chapter highlights

- Soil health is a complex state involving several physical, biological, and chemical characteristics and processes. In other words, what defines a healthy soil depends on regional factors as well as on the soil's intended use and function.
- Improving soil health therefore requires a comprehensive, systems approach to production, and soils that consider all aspects of the production system and agroecosystem.
- Four interconnected perspectives can be used to evaluate the benefits of BMPs to soil health: soil health principles, soil degradations, soil functions, and soil characteristics. Any management practice (or set of practices) consistent with these perspectives could be considered beneficial to soil health.
- 11 BMPs were identified as being beneficial to soil health in the Canadian context.
- Given the existence of trade-offs and feedback loops, identifying appropriate BMPs in a given situation requires an understanding of producers' unique situation as well as an understanding of the soil health objectives being prioritized.

Improving soil health requires a comprehensive, systems approach to production and soils that consider all aspects of the production system and agroecosystem. For each farm, a customized, holistic approach is needed, integrating a suite of beneficial practices that take into account the regional climate, soil characteristics, technology and many other parameters that influence the size of effect practices can have on soil health.

Yet, a range of farm and cropping best or beneficial management practices (BMPs) are commonly identified for improving soil health and increasing soil organic matter, including no-till, strip tillage, diverse crop rotations, cover crops, nutrient management, organic amendments, and others (Agricultural Soil Health and Conservation Working Group, 2018). Extensive scientific literature and syntheses of research also exist on many of these practices and their impact on soil health.

This chapter reviews and summarizes the available science and knowledge on soil health practices to identify the most beneficial practices for soil health in Canada.[9] Section 1.1 defines soil health and soil health benefits through the lenses of four different perspectives. Then, based on a thorough review of over 40 reports including policy approaches documents, governmental publications, as well as academic and scientific papers, a list of 11 key BMPs was identified, which are presented in section 1.2. Lastly, section 1.3 then summarizes the benefits, risks and limitations of each BMP, through the lenses of the different perspectives discussed in section 1.1.

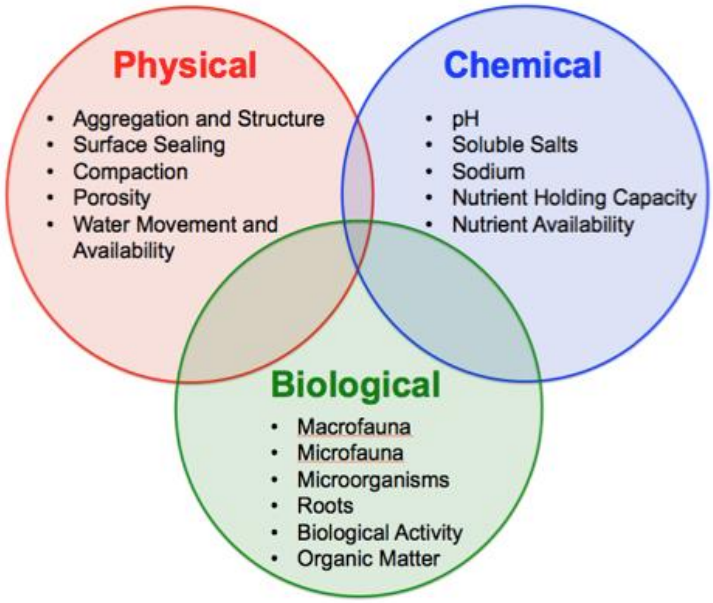
[9] The focus of this review is on practices used on working land in a Canadian context (e.g., pertaining to cropping and soil management, including practices related to rangeland, perennial forage, pasture and hay crops, as well as manure management, given their importance in building soil health). More specific livestock systems and technologies such as feedlots, manure storage, anaerobic digestion and others are out of scope. Similarly, land conversion (e.g. wetland drainage, conversion of perennial to annual crops) is not considered as part of the review.

1.1 DEFINING SOIL HEALTH AND SOIL HEALTH BENEFITS

Understanding and evaluating the benefits of BMPs to soil health first require considering the different components and dimensions defining healthy soils. However, there is no single agreed upon definition of soil health and different concepts are frequently used to refer to the importance of preserving and improving this resource.[10,11] For instance, the definition used by AAFC and some provincial jurisdictions define soil health as the soil's capacity to support crop growth without resulting in soil degradation or otherwise harming the environment. Based on this definition, a healthy soil consists of a non-degraded soil that can achieve its purpose (e.g. support crop growth).

In contrast, the USDA, other provincial jurisdictions, as well as national and international organizations define soil health through its capacity to function as a vital living ecosystem that sustains plants, animals, and humans. According to this definition soil functions can be defined as any service, role, or task that soil performs (NRCS, N.D.a). As the latter definition suggests, soil health is a complex state involving several physical, biological and chemical characteristics and processes.

Figure 1.1
Physical, Chemical and Biological aspects of soil health



Source: North Dakota State University, n.d.

[10] According to key informants interviewed as part of this project, the lack of consistent definition of what soil health is, is a source of confusion, affecting the research agenda (as well as the public policy one), as priorities vary depending on the perspective used. The growing popularity of the 'soil health' concept creates even more noise around this topic and its different components.

[11] In addition to the concepts of soil quality and soil fertility, other soil health-related concepts include the ones of regenerative agriculture, organic production, living soils and permaculture.

In other words, what defines a healthy soil depends on regional factors (e.g., soil types, crops, climate, etc.) as well as on the soil's intended use (e.g., growing trees, grain, grass, etc.) and function (e.g., control water flow, transport solute, retain and cycle nutrients, offer habitats for biodiversity). Therefore, there is no unique way of defining what a healthy soil is as it depends on various factors and perspectives. That being said, the fundamental concept of a soil's continued capacity to function and sustain living organisms over long period of time remains.

Based on the literature, four key perspectives were identified to describe and assess soil health: soil health principles, soil degradations, soil functions, and soil characteristics (see Table 1.1).[12] In turn, these four perspectives can be used to evaluate the benefits of BMPs to soil health.

Table 1.1
Four perspectives on soil health

Soil Health Principles	Soil Degradation	Soil Functions	Soil Characteristics
Build soil organic matter	Erosion (water, tillage and wind erosion)	Water flow and retention	Soil Composition (texture)
Minimize soil disturbance and compaction	Salinity	Solute transport and retention	Soil structure (aggregates)
Keep the soil covered as much as possible	Loss of SOM	Physical stability and support	Soil organic matter (SOM)
Diversify crops to increase diversity in the soil	Decline in soil fertility or Saturation/contamination with nutrients	Retention and cycling of nutrients (incl. carbon sequestration)	Soil chemical composition and fertility (Nitrogen, Phosphorus, Potassium, macro and micronutrients)
Keep living roots throughout the year as much as possible	Soil acidity and/or alkalinity	Buffering and filtering of toxic materials	Soil water holding capacity
	Decline of soil structure (compaction, bulk density and surface sealing)	Maintenance of soil biodiversity and habitat	Color
	Soil and water pollution	Cation exchange capacity	Texture
		Crop productivity[13]	Microbial activity and diversity

Source: Groupe AGÉCO.

Note: Definitions and the supporting literature are available in Appendix 2.

[12] The definitions and characteristics for each perspective can be found in Appendix 2.

[13] Compared to the other soil functions, crop productivity is less of an agronomic function but more of an outcome of a healthy soil. Nonetheless, crop productivity is the capacity of a soil to produce plant biomass for human use, providing food, feed, fiber and fuel within natural or managed ecosystem boundaries (LandMark 2020).

The first perspective is based on the five **soil health principles**. These principles are designed to guide action towards stopping soil degradation and restoring and maintaining soil health so that soils can fulfill their functions. These principles are useful to identify and sort the BMPs that should be implemented to support soil health.[14]

The **soil degradation** perspective focuses on the problems and issues related to soil functions and characteristics. This perspective follows an approach where healthy soil is defined as being a soil that is not degraded or that does not contribute to degrading the surrounding environment (Acton and Gregorich 1995). This particular dimension is critical as soil degradations are usually issues associated with specific causes that can be observed and managed at the farm level through practices consistent with the five principles of soil health. They are problems that can also be the most directly associated with yields and revenues, and thus that producers experience firsthand.

Perspectives based on soil **functions** and soil **characteristics** offer a more agronomic approach to soil health. While it is possible to look at soil health characteristics and functions separately, it is their interactions that create and sustain a healthy soil (NDSU, n. d.). The soil characteristics are usually measurable and manageable by farmers. Soil functions, on the other hand, refer to soil-based ecosystem services that contribute to the generation of goods and services (Landmark, 2020) and are therefore more challenging to measure and manage at the farm level.

Distinguishing these four perspectives is helpful in defining:

- specific farm-level objectives to attain (e.g., reduce erosion).
- ways of achieving them (e.g., by minimizing soil disturbance).
- how to measure improvements (e.g., level of soil organic matter).
- how to measure environmental benefits induced by the above improvements (e.g., better retention and cycling of nutrients).

Nonetheless, the four approaches are complementary and interrelated. For instance, for soils to have the continued capacity to function as a vital living ecosystem that sustains plants, animals, and humans, degradations must be managed and soil characteristics improved through a soil health management system that is consistent with the five soil health principles.

Incorporating the four perspectives allows for developing narratives that can speak to different audiences, from farmers to scientists and policy makers. It also helps identifying policy approaches to support farmers in protecting soil health (cf. section 3).

[14] For instance, General Mills' Regenerative Agriculture strategy is based on six core principles that are similar to those defined based on the literature. These are: understand context; minimize soil disturbance; maximize crop diversity; keep the soil covered; maintain living root year-round; integrate livestock. BMPs are associated with one or more of these principles (General Mills', 2020).

1.2 IDENTIFYING THE KEY BMPS FOR SOIL HEALTH

A beneficial management practice (BMP) refers to any management practice that reduces or eliminates an environmental risk (Alberta's ministry of Agriculture, Food and Rural Development, N. D.). Based on this definition, any management practice (or set of practices) consistent with the five soil health principles, supporting soil functions, stopping soil degradation, or improving degraded soil characteristics could be considered beneficial to soil health.

To identify the key BMPs for soil health, we performed a thorough review of over 40 reports in the literature on soil health (cf. Appendix 3). These reports include policy approaches documents, governmental publications, as well as academic and scientific papers. For each document reviewed, we identified the practices being considered the most effective or practical to implement to improve soil health.

Based on the literature review, we found a strong level of convergence among the BMPs associated to soil health. Irrespective of the types and objectives of the publications reviewed, the same set of BMPs was identified in the various reports reviewed. By selecting only those BMPs relevant to Canadian farmers, we developed a list of 11 BMPs recommended in the literature. These are:

- Conservation tillage
- Prevention of soil compaction
- Cover crops
- Integrated pest management
- Organic amendments
- Conservation buffers
- Pasture management
- Nutrient management
- Land retirement
- Diverse crop rotation
- Soil information collection

For each BMP, Table 1.2 provides a short description and, whenever appropriate, a list of related practices and considerations. A couple of observations are worth noting. First, most BMPs have been known for years for being beneficial to both the environment and soil health. As such, many agri-environmental tools and sustainability standards have identified practices including conservation tillage, cover crops, organic amendments, nutrient management, diverse crop rotation, conservation buffers, integrated pest management, and prevention of soil compaction (cf. section 3). As to land retirement and pasture management, they are also well-established and have been promoted for years for their environmental benefits.[15]

Second, the key BMPs are associated with a wide range of practices, techniques, and methods. For instance, conservation tillage includes different techniques such as no-till, strip-till, direct seeding and strip cropping. Although these techniques differ from one another, they all minimize soil movement and leave crop residue cover on the soil surface. In other words, the practical implementation of BMPs at the farm level can vary widely depending on the region, soil type and production system in place.

[15] For instance, the 1985 Farm Bill established the Conservation Reserve Program (CRP) which is a voluntary land retirement program offering yearly rental payment in exchange for farmers removing environmentally sensitive land from agricultural production and planting species that will improve environmental quality.

Third, the identified BMPs are interconnected. For instance, cover crops can be an organic amendment if incorporated to soil. Similarly, a cover crop can be part of a crop rotation or be used in strip-cropping to reduce erosion. Land retirement is usually associated to the establishment of conservations buffers, while sound nutrient management requires sufficient data from soil tests. In other words, while each BMP can be considered individually, their implementation needs to be considered as part of the broader production system in which they interact.

Lastly, all but one BMP directly impact farm operations and production techniques. For instance, conservation tillage, the use of organic amendments and pasture management all have an impact on the production system. The exception is the BMP 'Soil information collection', which refers to the activity of measuring and monitoring soil information over time. Such information can include field notes, soil profile and landscape descriptions, soil test data, drawings and photographs, descriptions of soil maps units and map unit components. New soil digital technologies (soil sensing, telemetry, digital mapping, big data analysis and precision agriculture) are also important soil information used by farmers.[16]

This specific BMP is not part of most of the reports listed in Appendix 3. However, it is considered crucial given that the comprehensive, systems approach to production needed to promote soil health starts with the establishment of a baseline of the current soil health status on farms. Not only that, but such information is also essential to identify and understand what soil types are cultivated and how they influence cropping practices.

Soil information collection is instrumental in identifying the key BMPs that need to be implemented to meet certain goal pertaining to soil health and to measure and track improvements over time. As such, the practice of establishing a baseline, whether by identifying the issues and/or by defining the objectives, and by assessing and tracking the state of soil health, was considered essential in most interviews conducted with key informants.

Soil information can also be collected at the regional level by other stakeholders, including governments, farm groups and researchers. Regional soil assessments (e.g. point data, map unit data, spatial data, and interpretative data) are a powerful tool for private or public organizations to evaluate baselines, measure progress and raise public awareness about the health of local soil. It can also help identify areas in need of action for improved soil health. In other words, regional and farm level soil information is complementary and necessary to manage soil health effectively. Yet, according to key informants, there is a lack of such information on the current status of soil health. This data gap is problematic for researchers (as well as policymakers and producers) as it limits the ability to understand, identify, manage, and track improvements over time.

[16] In addition, new comprehensive soil health assessment methods evaluate physical, chemical and biological indicators such as aggregate stability, available water capacity, bulk density, infiltration, soil structure, reactive carbon, electrical conductivity, earthworm numbers, particulate organic matter, potentially mineralizable nitrogen, microbial biomass, soil enzymes, soil respiration and total organic carbon (Norris et al. 2020; Karlen et al. 2017; NRCS 2015). Several new comprehensive soil health test systems that measure these indicators are becoming available at laboratories, such as the Cornell system, Haney and Solvita, to name just a few (Norris et al. 2020; Chahal & Van Eerd 2018).

Table 1.2
Key BMPs for soil health

Name of the BMP	Description	Related practices and/or considerations:
Conservation tillage	Any tillage sequence designed to minimize or reduce the loss of soil and water; operationally, a tillage and planting system that leaves 30% or more crop residue cover on the soil surface.	No-till (or zero-till)**:** Procedure by which a crop is planted directly into the soil using a special planter, with no primary or secondary tillage after harvest of the previous crop (Clearwater et al., 2016). Strip-till**:** Narrow strips 6 to 12 inches wide are tilled in crop stubble, with the area between the rows left undisturbed (Nowatzki, Endres and DeJong-Hughes, 2017). This tillage operation removes the residue from the row area, allowing sunlight to hit the soil surface and warm the soil. Planting with strip-till takes place in the residue free strips (UNL, N. D.a). Direct seeding**:** The soil is not tilled before planting. However, in contrast to zero tillage, direct seeding allows some soil disturbance to deal with special situations (Alberta's ministry of Agriculture, Food and Rural Development. 2004). Strip-cropping**:** The practice of alternating strips of crops with strips of fallow. The strips run along the contours of the land if the main purpose is to reduce water erosion. They go across the prevailing direction of wind if the main purpose is to reduce wind erosion. Crop residues on the fallow strips are retained with reduced tillage fallow (Alberta's ministry of Agriculture, Food and Rural Development. 2004).
Cover crops	Secondary crop grown after a primary crop or between rows of the primary crop to provide a protective soil cover that can minimize soil erosion and leaching of nutrients (Clearwater et al., 2016).	There are many different options related to cover crops that can be used by farmers: planting after harvest, frost-seeding, inter-seeding, terminating after planting, roller crimping, not killing the cover crop, green manure (Greenbelt. 2018). Winter cover crop**:** Crop planted in the fall to provide cover and thus curb soil erosion during winter and spring (Clearwater et al., 2016). Inter-seeding**:** Planting of one or more cover crop species into an existing or established crop (OMAFRA. N. D.). Green Manure**:** Crops grown specifically to replenish the soil system, typically with N, but also P and other nutrients (U. of Manitoba, 2018).
Organic amendments	Organic amendments include manure, compost, composted sludge, food waste, digestate, sewage biosolids, crop residue.	Compost**:** Organic material, such as leaves, stalks and roots, municipal, industrial and domestic materials or digestate from biogas facilities that have decomposed and is being added to soil as a fertilizer and to rejuvenate soil. Manure: It is both a natural by-product of livestock production and an excellent source of plant nutrients (Manitoba Agriculture, Food and Rural Initiatives. 2008). Manure application rate should be based on manure nutrient content determined by manure analysis (preferred) or on "book value" manure nutrient content. Manure is injected or incorporated immediately after application (preferred), or broadcast and incorporated soon afterwards.

Name of the BMP	Description	Related practices and/or considerations:
Nutrient management	Applying nutrient sources based on an anticipated yield target, crop nutrient requirements and soil nutrient availability is the best practice. Nutrient application should follow the 4R Nutrient Stewardship principles of right source, right rate, right timing, right place to optimize nutrient performance, reduce inputs and to minimize environmental impacts.	Right source**:** Fertilizers are in chemical forms best used by the target crop and soil. Right amount**:** Fertilizer rate to match nutrient supply (considering all sources) with crop requirements (Robertson, 2004; Dalal et al., 2003; Paustian et al., 2004; Cole et al., 1997; Monteny et al., 2006). Right time**:** Fertilizer application is timed so that nutrients will be available when crop demand is high. Right place**:** Fertilizer is placed where the crop can access nutrients most effectively. Slow and controlled release (SCR) fertilizers: Forms of N-fertilizers that extend the time of N availability for plant uptake. The SCR fertilizers slow the release of N into the soil solution by special chemical and physical characteristics (Subbarao et al., 2012) Nitrogen stabilizers: Help prevent losses by inhibiting specific parts of the nitrogen cycle that lead to losses. The two broad categories of nitrogen stabilizer products are urease inhibitors and nitrification inhibitors (White, 2018; Yanni et al., 2018; Clearwater et al., 2016). Variable rate technology**:** Agronomists can program a fertilizer or manure prescription for a farmer based on soil tests and the planter or fertilizer spreader will adjust rates on the go. Farmers can also increase and decrease the seeding rate and plant populations in certain areas as needed (Greenbelt. 2018).
Diverse crop rotation	Crop rotation consists of growing different types of crops (alternating forage or cereal crops with row crops) in the same field in sequenced seasons (OMAFRA. N. D.). Depending upon the duration of the rotation, more types of crops can be added.	Duration**:** Long rotation allows to maintain or increase soil fertility based on the amount of organic matter added over the entire rotation (Chitrit and Gautronneau, 2011). Type: Adding perennial forages into the rotation is a great way to improve soil quality and sequester carbon (SSCA, n. d.). Perennial crops: fruit trees, asparagus, and rhubarb are all examples of perennial crops that can grow for years without tillage and can be part of long rotation. Hay and pasture are also perennial crops, along with miscanthus, which is grown for bedding or biomass (Greenbelt, 2018).
Conservation Buffers	Conservation buffers are small areas or strips of land in permanent vegetation, designed to intercept pollutants and manage other environmental concerns (NRCS N. D.b)	Buffer strips**:** Planted alongside watercourses, they are intended to keep agriculture and natural areas separated and reduce the risk of cropland and pasture runoff entering surface water. Windbreaks/Shelterbelts**:** Single or multi-row, healthy, diverse stands of trees and shrubs, or existing native woody windbreaks, that shelter fields. Riparian areas**:** Lands adjacent to streams, rivers, lakes, ponds, and wetlands. These areas are frequently flooded transitional lands, with no definite boundaries, between the body of water and drier upland areas (Harris, 2010). Agroforestry systems: Include both traditional and modern land-use systems where trees are managed together with crops and/or animal production systems in agricultural settings (FAO, 2015). Grassed waterways**:** These buffers, planted with grass, are wide and often shaped like a shallow saucer (Stone and McKague, 2009). They are typically established in pre-existing drainage ways that are part of the natural topography of a field.

Name of the BMP	Description	Related practices and/or considerations:
Prevention of soil compaction	Any measures that limit the bulk density and the reduction in the soil pore space available for air and water due to the impact of raindrops, equipment or animals.	Axle or wheel load: It is the total load supported by one axle, usually expressed in tons or pounds. Farm equipment with high axle loads will cause compaction in the topsoil and subsoil, and multiple passes increase the impact (Duiker, 2005). The automatic air inflation deflation (AAID) system**:** Inflate tires for road transport (for higher road speed) and deflate tires for field operation (to reduce soil compaction) from the tractor cab. Controlled traffic farming (CTF)**:** restricts compaction to precise traffic lanes, where it improves wheel performance. Tramlines are set so that all farm machinery traffic travels in the same wheel tracks in a field. The system separates the tramlines from the crop areas. As a result, the traffic lanes where all machinery travels are permanently set up within a field (Vermeulen et al., 2010; Papworth, 2015). Agronomic measures: Other BMPs like conservation tillage, direct seeding, cover crops and crop rotation can also reduce compaction in combination with reduced loads.
Integrated pest management	Strategy that includes cultural, mechanical, biological and chemical pest control measures and regular pest identification and monitoring to prevent, measure, anticipate and avoid or reduce agrochemical use (OMAFRA. N. D.).	Integrated Pest Management (IPM) strategy: Includes cultural, mechanical, biological and chemical pest control measures and regular crop scouting for pest identification and monitoring to identify, manage and reduce risk from pests and pest management tools and strategies in a way that minimizes overall economic, health and environmental risks. Economic threshold calculators: It have been developed for major negatively impacting crops in Canada. These calculators help farmers make management decisions by providing guidance as to whether pest control will have an economic benefit. Climate-smart pest management (CSPM): It is a cross-sectoral approach that aims to reduce pest-induced crop losses, enhance ecosystem services, reduce greenhouse gas emissions and strengthen the resilience of agricultural systems in the face of climate change (FAO, 2017b).
Pasture management	The management of grazing involving the control of livestock access to areas of native or tame pasture land.	Regenerative Grazing**:** The land can rest for an optimal amount of time before the grazing animals are allowed to return to that spot. This allows the grasses to build up their root structure (Thorbecke and Dettling, 2019). Intensive rotational grazing: Intensive grazing practices employing high animal stocking rates for short duration, from a few hours to a few days, on an area of pasture, with frequent movement of animals and relatively long “rest periods” for the vegetation between grazing events (Paustian et al., 2019).
Land retirement	Retirement plantings cover the soil with perennial vegetation such as trees, grass or shrubs, providing a permanent cover to protect soil from erosion and rehabilitate degraded soils over their lifetime.	Cropland retirement: It is the removal of fragile and marginal cropland from production, and planting them to grass, trees, or other long-term vegetation. Retired lands may remain out of production permanently or may be brought into production after a period (usually decades) of rehabilitation (OMAFRA N. D.). Some soils are not suitable for intensive cropping, and efforts and costs to work them will not show a return. Agricultural lands that are shallow to bedrock may not be suitable for cropping or pasture use. These lands should be retired or allowed to revert slowly to natural vegetative cover (OMAFRA N. D.).

Name of the BMP	Description	Related practices and/or considerations:
Soil information collection	Soil information plays an important role in crop production and nutrient management. The primary objective of soil sampling is to provide a representative sample of the fertility within the field. Based on the variability throughout the field, the number of acres per sample will vary.	Soil test: Soil tests can determine the status of plant-available nutrients and be used to monitor for changes in pH, organic matter and Cation Exchange Capacity (CEC), for macro-nutrients (e.g. N, P, K and S), and where available micronutrients (e.g. copper, iron, zinc and manganese). Although nutrient content can vary somewhat from year to year, testing every five years is the minimum testing rate. Soil organic matter is a critical measure of biological state. Soil health assessments: In recent years, new soil health tests or assessments seek to assess biological, chemical and physical parameters of soil health including microbial biomass, respiration, soil structure, aggregate stability, using different methodologies including the Cornell, Haney and Solvita methods to mention a few. Precision Agriculture Data**:** Site-specific farming methods combine GPS and supportive technology along with modern farm machinery to collect very detailed information on crops harvested, yield, elevation and topography, and precise geographic location (Agricultural Soil Health and Conservation Working Group. 2018). Soil profile**:** Describes the various layers within the soil and can be seen as a vertical section through the soil. Each of the layers in the profile can affect plant growth due to differences in soil physical, chemical and biological properties. Record keeping**:** Documentation improves producers' ability to manage nutrients in a way that maximizes the economic benefits while minimizing the environmental risks (Manitoba Agriculture, Food and Rural Initiatives. 2008).

Source: Groupe AGÉCO.

1.3 BMPs' BENEFITS, RISKS AND LIMITATIONS

The 11 BMPs described in section 1.2 are recognized in the literature for being beneficial to soil health because of their positive outcomes. In this section, a description of these benefits is proposed for each of the BMPs based on a list of criteria developed in line with the four perspectives on soil health described in Table 1.1.

Table 1.3 presents an overview of the link between each BMP and the five soil health principles. Then, Table 1.4 to Table 1.14 present the main benefits, risks and limitations associated to each BMP. This evaluation is based on four criteria:

- **GHG emissions**: the potential of the BMP to capture C and/or participate to GHG emissions reduction;
- **Soil degradation:** the types of degradation the BMP can likely stop and/or mitigate;
- **Soil functions:** the types of functions the BMP can likely support and/or enhance;
- **Others:** the other environmental, economic or social co-benefits associated to the BMP.

The above classification system is used to organize the information in a structured way. However, many of the benefits, risks and limitations discussed are interrelated. Moreover, several risks and limitations also tie-in with the barriers to adoption discussed in section 2.

Table 1.4 to Table 1.14 also describe examples of optimal conditions (e.g. climate, soil types, production systems) under which each BMPs can deliver their benefits, as well as suboptimal ones.

1.3.1 METHODOLOGY

The benefits, risks and limitations associated with each identified BMPs, as presented in this section, are based on a review of more than a hundred scientific publications (see Appendix 4).[17] Selected publications include those submitted by the client and experts during the course of the project in addition to those researched online by the project team to complete the review. A particular attention was given to Canadian publications.

The review was not systematic and is not meant to be comprehensive. As such, it was not possible based on the reviewed literature to document benefits, gaps and limitations, as well as optimal and sub-optimal conditions, for all BMPs.[18] The objective was to reflect the current state of knowledge and identify major known benefits, limitations and risks, and to identify differences due to region, climate, soil type or crop.[19]

Given the range of conditions that need to be accounted for to quantitatively measure the impacts of a particular practice (let alone a set of practices), the evaluation is mostly qualitative and based on a description of the key results from the reviewed publications. Whenever possible and appropriate, quantitative results are presented (see Appendix 4).

For the same reason it is not possible to rank or benchmark BMPs based on the review of their benefits. Results depend on several exogenous factors, in turn limiting the ability to generalise and compare expected outcomes from each BMP. This is why most key informants interviewed preferred prioritizing soil health-related issues rather than BMPs. The main soil health issues mentioned during the interviews include the loss of SOM (due to erosion), decline in soil structure (due to compaction) and soil pollution (due to over fertilization).

[17] A particular attention was given to the scientific literature. The reason is that policy approaches documents as well as governmental publications, while providing useful information to list and describe BMPs, usually do not provide the level of information needed to measure the specific benefits of these BMPs in regards to soil health. Such level of information is provided by the scientific literature.

[18] Additional and more specific research would be needed but this would go beyond the scope of this project.

[19] Results from this literature review were reviewed by members of an advisory committee comprised of soil health scientists.

Table 1.3
Connections between the main BMPs and the soil health principles

Selected BMPS	Soil health principles				
	Build soil organic matter	Minimize soil disturbance and compaction	Keep the soil covered as much as possible	Diversify crops to increase diversity in the soil	Keep living roots throughout the year as much as possible
Conservation Tillage	✓	✓	✓		
Cover crops	✓		✓	✓	✓
Organic amendments	✓				
Nutrient management	✓	✓			
Diverse crop rotation	✓			✓	✓
Conservation buffers	✓	✓	✓	✓	✓
Prevention of soil compaction		✓	✓		
Integrated pest management		✓		✓	
Pasture management	✓	✓	✓	✓	✓
Land retirement	✓	✓	✓	✓	✓
Soil information collection	✓*	✓*	✓*	✓*	✓*

* This practice indirectly impacts soil health principles

Source: Groupe AGÉCO

1.3.2 KEY FINDINGS

The review of the benefits, risks and limitations shows that, in general, there is an abundant literature documenting and confirming the various benefits to soil health of selected BMPs. These clear and robust evidence confirm that BMPs can positively impact soil health with respect to GHG emissions, soil degradation and soil functions.

The review also confirms that a given BMP can contribute to several positive outcomes and that a particular outcome can be obtained by using different BMPs. Characterizing BMPs based on the way through which they protect soils (cf. Table 1.3) or based on the potential outcomes of their adoption (cf. Table 1.4 to Table 1.14) helps understanding how and in which circumstances they are relevant and should be implemented.

The review highlighted that the way each BMP delivers results, and the extent of those results is context specific. This observation is critical. In other words, it requires an in-depth understanding of the context (e.g. climate, soil types, crops) in which BMPs are implemented prior to setting expectations around specific outcomes.

Furthermore, each BMP is associated to a certain number of risks and limitations linked to exogenous factors (e.g., climate, typography, soil type, previous and current crops and management practices) or involving trade-offs and collateral consequences within and across the four criteria considered (GHG emissions, soil functions, soil degradations and co-benefits). This situation reinforces the need to understand the specific benefits of a BMP (or set of BMPs) within a systems approach to assess its net impact on the entire production system in a given context.

Considering the existence of trade-offs and feedback loops, to determine the appropriate BMPs in a given situation, it is also critical to identify the soil health objectives being prioritized. For instance, a BMP beneficial to SOM may negatively impact water quality through increased soil erosion within a given context. This observation speaks to the importance of the BMP ‘Soil information collection', which informs such objectives and helps tracking progress over time.

In other words, while it is practical and useful to identify and evaluate the benefits of individual BMPs to justify their effectiveness, improvements to soil health require a systems approach to consider all aspects of the production system and agroecosystem. This situation makes the benefit evaluation even more challenging and context specific. However, it allows for a more effective, customized, holistic approach aimed at long-term soil health.

In this context, additional research is needed to better understand the benefits, risks and limitations of BMPs within and across the four criteria considered, but also in conjunction to one another. As discussed during the interviews with key informants, research is too oftentimes conducted in silos and based on specific scope and methodologies. More transversal and multidisciplinary approaches are needed to take into account the complexity of soil and its ecosystems. Also, more on-farm research pilots would be needed to better reflect the reality of farming. It is essential to consider soil system as being dynamic and not static. Soil resilience, in particular, is an area of research not well developed and an important research topic that needs to be investigated further. Similarly, information on the regional implications of BMP adoption, as well as on their net impact is lacking. There is a need for additional research to point out specific regional differences.

A review of the opportunities and limitations of soil carbon (c) sequestration provides a clear case of the challenge of evaluating the benefits of BMPs given the complexity of the processes involved and the need for additional research to reduce the current level of results uncertainty (cf. side box below).

SIDE BOX: OPPORTUNITIES AND LIMITATIONS OF SOIL CARBON (C) SEQUESTRATION

The opportunity to increase C sequestration in soil is seen as a promising strategy to take C out of the atmosphere, thus contributing to climate mitigation goals. This strategy attracts more and more attention among scientists, practitioners, and policy makers.

Some authors, such as Paustian (2019), argue that with the complete adoption of BMP for soil C sequestration, we **could remove up to 4-5 GT CO_2 per year globally.** This amount could reach up to 8 GT CO2 per year if new technologies are successfully deployed. The amount of C stored as soil organic matter is increased, by increasing the rate of input of plant-derived residues or reducing the rates of turnover of C stocks already in the soil.

Implementing effective soil-based C sequestration strategies on a large scale requires the capacity to measure and monitor C sequestration and GHG reductions with acceptable accuracy, quantifiable uncertainty and at relatively low cost (Paustian et al., 2016). **However, current estimations methods have a high level of uncertainty and present several limits** that have been highlighted by many authors:

- First, soils are **not endless C sinks**. C sequestration consists to rebuild the C removed from soils over years due to conventional agriculture practices and land transformation. Those lost has been estimated to 80 Gt of C globally (Lal, 2009). Changes in practices could help restore a part of these losses until the system reaches a level of saturation (Maillard, 2020). Indeed, the potential of soil C sequestration decreases over time as stocks approach a new equilibrium. Therefore, net CO_2 removals are of limited duration, often levelling off after two to three decades (Paustian et al., 2016).
- The rate and total amount of C that can be rebuilt on a soil are dependent on biophysical conditions. In other words, the effects of management on soil C will **differ from place to place and are hard to predict with high certainty** for anyone locale (Bradford, 2019). The capacity of soil C storage in a specific area depends on climate factors (temperature, rainfall), soil chemico-physical properties, topographic conditions, soil use background and soil level of degradation.
- The potential of C capture **depends on agricultural practices and the duration of the practices** (Maillard, 2020). A wide variety of C sequestration practices can be applied, and the best solutions vary according to climate, soil, and farming conditions.
- Synergies of actions may improve the results but the lack of empirical data for multi-intervention strategies, that may interact in unexpected ways, and the difficulties of modeling complex systems make predictions very uncertain (Paustian et al., 2016).
- For the same reason, the timeline to achieve significant C sequestration results combined with the potential influence of climate change and climatic upset on the results, make current estimation very uncertain (Nazir, 2017).

In fact, **70% of agricultural GHG emissions are associated with the manufacture and use of nitrogen (N) fertilizers**, in large part through nitrous oxide (N_2O) emissions (Powlson et al., 2011), a GHG with a warming potential estimated 298 times worse than CO_2 (IPCC, 2013). Furthermore, N and C cycles are intimately correlated in the mechanisms of plants nutrition. Authors, such as Zaehle (2013) studying N and C cycle interactions and showed that N addition in agriculture practices enhance nitrogen and carbon sequestration in the soil but cause at the same time increased emissions of NOx and N_2O from soils. Li et al. have already showed in 2005 that increased N_2O emissions resulting from C sequestration practices over 20 years can offset 75 to 310% of the reduction in climate warming potential (based on climate radiative forcing). It appears that any effort to increase the efficiency of N use through improved management of fertilizers, manures and legumes would seem at least as important as increasing soil C sequestration (Powlson et al., 2011).

More recently, a study conducted by Deng (2019), based on a dataset of 275 sites from multiple territorial ecosystems around the world, showed that an increase of 3.7% in soil C sequestration, increases GHG emissions by 0.3% for CO_2, 24.5% for CH_4 and 91.3% for N_2O. In 2019, Bradford also concluded that **without proper nitrogen fertilizer management, greater soil carbon can increase emissions of greenhouse gases** from agriculture and that rebuilding soil carbon should be treated as a distinct objective than climate change mitigation.

In sum, soil based GHG mitigation activities are at an early stage and accurately quantifying emissions and reductions remains a substantial challenge. Management practices that increase C sequestration may have no benefit for climate change mitigation but are likely to be beneficial in other ways. Therefore, **a system approach that considers GHG emissions and soil C sequestration together is critical for accurately evaluating agricultural management practices**.

Table 1.4
Benefits, risks and limitations of conservation tillage

	Benefits	Risks and limitations
GHG Emissions	Can reduce CO_2 released to the atmosphere Can store more C in the topsoil Can reduce N_2O emissions Can reduce NO_3-N content under continuous NT Strip tillage can release less CO_2 than moldboard plowing	NT not always increases soil C (affected by type and depth of tillage, soil climatic conditions, the quantity and quality of residue C inputs, and soil fauna). Higher N_2O emissions may occur when both the soil carbon and moisture increase Can increase the risk of nutrient loss with surface application of manure
Soil Degradation	Conserves SOM Reduces the risks of erosion and SOC losses Improves drought tolerance Crop residues may mitigate the impact of hot and dry weather Conserves soil structure which reduces soil compaction Reduces the risk of soil salinization Reduces the risk of nutrient and pesticides loss by leaching or runoff	Since no or limited mechanical methods can be used to control weeds, conservation tillage is more dependent on herbicide usage which, in some cases, can increase the risk of herbicide runoff. The type of crops and residue left on the soil will have an important impact on the reduction of erosion. In some cases, herbicide runoff is greater in NT The reduction of erosion also depends on the type of crops
Soil Functions	Provide food and cover for wildlife Improve water infiltration and the water-holding capacity Crop residues reduce water loss, delay soil warming, reduce air temperature at the soil surface and reduce evaporation potential NT can improve microbial biomass and enzyme activities Can increase the amount of deep burrowing earthworms Under NT, arbuscular mycorrhizal fungi survive better Soil bulk density may decrease over the long-term	By not disturbing the soil surface and the root system, it may increase groundwater recharge via intact root channels. Furthermore, the effect on bulk density will vary depending on the soil horizon (organic, surface, subsurface, etc.) In the soil surface, soil bulk density may increase, but in the deeper soil zones, it does not consistently influence either bulk density or penetration Stratification of P in surface layers that can reduce its uptake when surface dry Increase acidification rate of soil surface since carbonate minerals not mixed from below planting depth.

Others	Can improve the distribution of snowmelt water Reduce fuel and diesel requirements Reduce equipment wear-and-tear Reduce air pollution from dust during harvest Can reduce weed pressure Reduce expenses associated with primary and secondary tillage [mainly for strip-till] Reduce labour use Reduce production costs Improves rotation benefits to soil health, yield stability and corn yields under unfavorable growing conditions	Can increase weed pressure in the transition period (no option to control weeds mechanically under NT) Can delay N release to cash crops Can complicate crop establishment Less suited for certain crops [e.g. potato] Nutrient incorporation (organic or mineral nutrient) is less suited under NT (but banding, injection and at planting allow for this) Scouting is required NT can involve more intensive management of crops and soil Direct seeding is frequently associated with the use of GMO, which implies more herbicide applications Slow rate of soil warming and drying and can thereby delay planting and crop emergence

Optimal Conditions

The greatest positive effects on N_2O emission in eastern Canada were measured in fine-textured soils (Gregorich et al., 2005).

In Western Canada, NT was most effective in increasing C storage in the Chernozemic soil zones of the Canadian Prairies (VandenBygaart et al., 2003) and in both coarse- and fine-textured soils (Liang et al., 2020).

Microbial biomass and enzyme activities were found to be higher in silt loam soil under no-till than under plow conditions over a period of 2, 5 and 19 years (Bossche et al., 2009).

The soil temperature advantage with strip-till, compared with no till, is enhanced when soil temperatures are lower and approach the lower threshold for crop seed germination (Nowatzki et al., 2017).

Use of a no-till system and other practices is especially important for soils that have inherent limitations, such as those that are sandy, have a very high content of clay, have a claypan or fragipan, or have other physical limitations that affect the amount of water available for plants, plant growth and vigor, and plant yields (USDA, 2015).

Suboptimal Conditions

The effect on increased N_2O emission is likely less important under the much drier climate in the western Canadian Prairies (Gregorich et al., 2005)

On an average, NT practices more than doubled N_2O emissions as compared with moldboard plow in fine-textured soils (Pasricha, 2017)

Carbon losses were particularly high on fine and coarse textured soils, whereas in medium textured soils NT tended to increase SOC (Liang et al., 2020).

In Eastern Canada, overall, there was no difference in SOC between NT and CT in moister soils (VandenBygaart et al., 2003). On average NT sequestered C in the medium-textured soils whereas NT lost C in the fine-textured soils (Liang et al., 2020).

It shows that climate, soil texture and duration of management are main drivers of SOC change under NT in Canada and that key factors must be considered in the development of either national or regional SOC models (Liang et al.,2020).

The absence of an effect of NT on SOC has been observed in many wet and cool climates, and that under those conditions, differences in tillage systems only result in differences in SOC distribution in the soil profile (Liang et al.,2020).

There was no statistical difference in SOC storage between NT and CT in the coarse-textured soils, even though NT tended to lose C (Liang et al.,2020).

No-till does not always produce equivalent crop yields in climates with cold springs, suboptimal soil temperatures, and poorly drained and heavy-textured soils (Lal, 2007).

In poorly drained soils, NT slows down soil warming in the spring.

Strip-till is less recommended in sloped fields, in warm springs or in warm, well-drained soils.

Strip-till practice is less suited for drilled crops and in dryer regions since the strip may dry too much and form a crust.

Residues can delay soil warming, planting date and emergence in warmer regions in short growing seasons, which may decrease crop yield potential (Gaudin et al., 2015).

Table 1.5
Benefits, risks and limitations of cover crops

	Benefits	Risks and limitations
GHG Emissions	Can sequester carbon and improve SOC stock Reduce N_2O emissions	Cover crops terminated when relatively small (less than 2 tons per acre of biomass yield) appear not to affect CO2 emissions Late-terminated cover crops with higher biomass production can increase CO_2 emissions, most likely due to plant respiration Increased SOC concentration can increase CO_2 emissions
Soil Degradation	Fixes N (legumes) and returns plant material and nitrogen to the field Recovers and retains nutrients Suppresses weeds Reduces the risks of erosion, runoff and SOC losses Reduces the risk of soil salinization Conserve soil structure which reduces soil compaction Conserve/improve SOM Reduce risk of soil crusting Improves the environment for soil biological activity Can reduce average total phosphorus loads to waterways	Consumes soil moisture Can tie up N (non-legumes) Can leach N (legumes, crucifers)
Soil Functions	Over the long term, can improve soil water infiltration and soil water capacity Conserve soil moisture Improve soil food web [e.g., Arbuscular Mycorrhizal fungi] and hence soil biodiversity Can increase the number and types of earthworms Can improve microbial biomass Improve mean weight diameter of aggregates (MWDA) Roots add organic materials, improve soil structure, and penetrate compacted layers	Can decreased microbial biomass Less effective under conditions like continental climate, chemical cover crop termination, and conservation tillage Complicate management of nutrients, particularly nitrogen for subsequent cash crop Additional cost of cover-crop seed, seeding, and termination
Others	Can reduce fertilizer use Can reduce pests, weed pressure and diseases The residue of a cover crop can protect the soil while cash crops are getting established and keep it from getting too hot. Allelopathy [killing weed species] Can provide new cropping and market options for producers (grazed or harvested for hay or silage). Can improve seasonal yields compared to single cropping system	Can delay cash crop planting and seedling emergence Less suited for certain crops (e.g. potato, sugarbeet) Difficult to incorporate with tillage Allelopathy [may suppress subsequent crop growth] Can reduce some crop yields [e.g. vegetable] May increase pest populations in the transition period

	Benefits	Risks and limitations
Optimal Conditions		
A study by Poeplau and Don (2015; cited in Yanni et al., 2018) modeled C sequestration under CC systems from widespread data (73% from temperate regions) and reported a SOC sequestration potential of 0.32 ± 0.08 Mg C/ha/y which was not affected by the type of CC or the tillage system.		
The land area at risk of soil salinization decreased between 1981-2011 in all three Prairie provinces, with the greatest decrease in risk occurring in Saskatchewan, mainly because of CC (Clearwater et al.,2016; FAO, 2017a).		
Under humid conditions including Eastern Canada meta-analysis determined cover crops wheat and corn yields and that this benefit increased as soil organic matter levels dropped below 5% (Bourgeois et al., 2020).		
Best suited where other advantages are important such as weed suppression and management of pests and diseases.		
Suboptimal Conditions		
In drier conditions, cover crop's water usage can reduce soil moisture and may hurt cash crop yield (Hoorman, 2009; Dabney et al., 2001).		
Cover cropping effects were less pronounced under conditions like continental climate (Kim et al., 2020).		
In northern regions, cover crops may not have time to establish themselves after the cash crop has been harvested in the fall (Union of Concerned Scientists, 2013).		
Where there are not ancillary benefits to weed, pest, and/or disease management, the economics of cover crops is poor.		

Table 1.6
Benefits, risks and limitations of organic amendments

	Benefits	Risks and limitations
GHG Emissions	Can have a global N_2O emission factor (EF) for all organic sources, lower than the IPCC default EF for synthetic fertilizers The N_2O EF depends on the type of amendment (C/N ratio), soil texture, drainage, organic C and N and climatic (precipitation) factors Lower N_2O emission when applying solid manure compared to liquid manure or mineral fertilizer The use of biosolid organic N as an N source resulted in lower N_2O emissions than raw manures Increase C inputs Composting manure can increase soil-carbon sequestration rates Composting manure can reduce some of the GHG emissions [e.g. methane and nitrous oxide] Digestate produced lower N_2O emissions compared to raw manure only when it was injected Can reduce CO_2 emissions [in a life cycle perspective] Increases SOC contents in different aggregate size fractions	Can increase CO_2 emissions from the soil Sewage sludge combinations showed the highest N_2O flux rates Ammonium (NH_4 +) in manure converted to ammonia (NH_3) gas can be lost to the atmosphere
Soil Degradation	Composting manure can reduce runoff (and thus nutrient loss and pollution) Build and conserve SOM Improve microbial activity and microbial biomass Improves SOC level and soil structure Pastures generally respond well to fertilization by manure Improve soil aggregates and reduce soil erosion	Can lose nutrients if the manure is applied too early (runoff, leaching) Excess of easily degradable SOM may contribute to environmental damage Repeat applications of manure at rates exceeding agronomic requirements can increase soil salinity Can increase compaction
Soil Functions	Improve water infiltration, nutrient, water-holding capacity, drainage, aeration and soil biodiversity Greater inorganic nitrogen (i.e., NO_3) concentrations can be beneficial for soil health Reduce soil bulk density and increase mean weight diameter [MWD] (Smith, 2015) Improve biological activities in the soil [e.g. nonmycorrhizal fungi and WSA]	Greater inorganic nitrogen (i.e., NO_3) concentrations can increase the potential for nutrient losses with a negative impact on the environment Difficult to estimate timing of availability of nutrient in manure, particularly nitrogen that can lead to overapplication of N with mineral fertilizers

	Benefits	Risks and limitations
Others	Can reduce the amount of fertilizer required Can increase vegetable crop yields Provides slow-release nutrients	Can build excess P or other nutrients Types of amendments can pose food safety risks Limited period of application In some provinces, the availability of good quality manure or compost is more complicated Composting manure takes time and effort and doesn't provide the quick boost of nutrients that raw manure does Crops can be less prone to insect pests and diseases where organic soil amendments are used

Optimal Conditions

The major role of climate variability on soil N_2O emissions likely explains why several local EF estimates in dry regions are lower than the IPCC default value that was originally estimated mostly from humid agricultural regions (Rochette et al., 2018).

Suboptimal Conditions

EFs were on average 2.8 times greater in fine-textured than coarse-textured soils (Charles et al., 2017).

A decrease in sand content would likely reduce drainage rates that, for a given seasonal precipitation and mean annual air temperature, and therefore would result in greater soil WFPS and N_2O production (Rochette et al., 2018).

Greater N_2O emissions in Eastern Canada compared to Western Canada can be due to the more humid climate and heavier textured soils typical of Eastern Canada (Rochette et al., 2018).

Agricultural soils in eastern Canada are a weak sink of CH_4 and that this sink may be diminished through manuring (Gregorich et al.,2005).

Manure use results in between 50-80% more N_2O emissions than mineral fertilizer on coarse and medium-textured soils (Yanni et al., 2018).

Having a wet and/or cold spring could delay manure application and then planting.

Table 1.7
Benefits, risks and limitations of nutrient management

	Benefits	Risks and limitations
GHG Emissions	Optimal use of fertilizer can reduce GHG emissions especially N_20 Fertilizer application methods can reduce gaseous nitrogen losses Can improve soil carbon sequestration The us of Inhibitors can reduce N_2O emissions and volatilization A shift from AA to urea, from urea to urea+NI+UI, and finally from urea to PCU can reduce N_2O emissions	Can increase denitrification losses from soils and could result in pollution-swapping trade-offs (ex. N_2O emissions and/or P losses in surface runoff) Ammonium (NH_4+) in manure or fertilizer converted to ammonia (NH_3) gas can be lost to the atmosphere
Soil Degradation	Fertilizer application methods can improve N use efficiency, which can reduce leaching Inhibitors can reduce N leaching Broadcast incorporated improves crop uptake Enhanced soil organic matter levels by producing more root and crop residue biomass Using variable rate allows farmers to use less fertilizer, which improves both soil health and water quality	Surface broadcast can cause high nutrient losses and have low uniformity
Soil Functions	Diverse sources of nutrient inputs can help ensure the supply of important secondary and micronutrients Can improve soil biological activity & physical properties by increasing SOM Can help conserve water quality	---
Others	Fertilizer application methods can reduce the amount of fertilizer required or optimize the use Can improve crop yields	Injection of fertilizer is slow and more expensive High rates of seed placed fertilizer can damage seeds and seedlings Lack of a regionally validated robust test for soil N supply in many regions of Canada Increased management complexity that may require hiring crop consultants Increased costs for machinery able to precision apply Increased costs for soil, tissue, and manure nutrient testing Increased costs for enhanced efficiency fertilizers.

Optimal Conditions

The limited importance of N application rate on cumulative emissions is explained by the low emissions where substantial amounts of N are applied under well-aerated conditions in Canada such as in coarse-textured soils and in regions with a dry climate (Rochette et al., 2018).

Compared to another simulation study in Western Ontario (Anderson, 2016; cited in Yanni et al., 2018), where split-N was applied as 70% pre-plant and 30% side-dress (at the V4-V6 stage), there were 21% less N_2O emissions compared to when all N was applied at planting.

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For corn, N_2O emissions were reduced by an average of 36% (–55 to –17%) with UI use compared to conventional fertilizers and in coarse-textured soils N_2O emissions were reduced by 28% (–55 to –4%) with UI use (Yanni et al., 2018).

Whereas low N_2O emissions can occur at any soil water-filled pore space (WFPS) level, high emissions are rarely observed at low WFPS (Rochette et al., 2018).

Suboptimal Conditions

There are no estimates specific for eastern Canada, but several factors contribute to increased indirect emission in the region. For example, the combination of high application rate of mineral N fertilizers in corn and potato production with relatively abundant rainfall increases the risk of N loss through surface runoff and leaching (Gregorich et al.,2005).

A study in Ontario and Quebec by Ma et al. (2010) on corn showed that, across years and locations, the relationship between N fertilization rate and N_2O emission is described by an exponential function such that increasing the N rate from 90 to 150 kg N/ha resulted in doubling N_2O emission from 0.46 kg N_2O-N/ha to 1.04 kg N_2O-N/ha.

Modifying one of the 4R components by itself may not be reliable in reducing N_2O emissions, particularly in rainfed cropping systems (Venterea et al., 2016; cited in Yanni et al., 2018).

Under no-till the side-dress-N produced 53-83% more N_2O emissions in the 2 wet years whereas N_2O emissions were only slightly more from the N applied at planting in the dry year in Ontario (Yanni et al., 2018).

Table 1.8
Benefits, risks and limitations of diversified crop rotation

	Benefits	Risks and limitations
GHG Emissions	Replacing fallow with wheat can increase SOC storage Including hay in rotation with wheat can increasing SOC storage Varieties or species with greater and deeper root systems to deposit C in deeper layers and hence mitigate GHG emission Perennial deep-rooted crops can reduce indirect N_2O emission Perennial crops can reduce N_2O and CO_2 emission and sequester more C compared to annual cropland Yield-scaled emissions of N_2O can be lower for corn in rotation Rotation of pulses and other legumes requires less nitrogen fertilizer Legume crops reduce N2O emissions and emissions for N fertilizer manufacture	---
Soil Degradation	Introducing crops with high P uptake (e.g. forages) in the rotation can decrease P-enriched soils Pulses and other legumes increase soil fertilizer Adding crops that produce abundant residues can improve SOC levels Perennial crops protect soil from erosion and improve soil structure Can conserve water and minimize salinity problems Can reduce the risk of nitrate leaching to surface and groundwater Continuous cropping increase SOC and N, then the wheat-fallow system	Switching to crops that produce less residue can increase soil erosion
Soil Functions	Can improve soil structure (reduce compaction), root systems, aggregate structure, microbial activity, and nutrient profile It can support higher biodiversity of soil organisms Crop rotations that exclude nonmycorrhizal species can increase Arbuscular mycorrhizal fungi Perennial crops increase ecosystem nutrient retention, and water infiltration Lower-intensity management, manure application and conservation tillage can increase soil respiration, water-stable aggregates, fungi and mycorrhizae	---
Others	Can improve yield and the profitability Reduce pressure from weeds, pests, and diseases Improve the resilience to environmental impacts Improve yield stability of main crops when integrated into more diverse rotations Crop diversity lowers risk of crop failure	Some crops may not be favorable in certain growing conditions Allelopathy [may suppress subsequent crop growth]

	Benefits	Risks and limitations
Optimal Conditions		
	Inclusion of a perennial crop in rotation was reported in Ontario by Gregorich et al. (2001; cited in Yanni et al., 2018). The amount of SOC was about 20 Mg C/ha greater in the rotation than the continuous corn.	
	In dryland, crop rotation can conserve water and minimize salinity problems.	
	Yield increases due to forages in rotation, with 71% reporting enhanced grain yields after forages compared with annual crop rotations in a survey of Manitoba and Saskatchewan forage producers (Entz et al.,1995).	
	In hot and dry years, diversification of corn-soybean rotations and reduced tillage increased yield by 7% and 22%for corn and soybean respectively (Gaudin et al., 2015).	
	In droughty years, inclusion of wheat and red clover dramatically improved soybean yield stability by 16% compared to CCSS [Corn-Corn-Soybean-Soybean] rotations for tilled systems (Gaudin et al., 2015).	
	Maize yields were higher during adverse weather, including droughts, when maize was grown as part of a more diverse rotation. Rotation diversification also increased maize yields over time and under better growing conditions (Bowles et al., 2020).	
Suboptimal Conditions		
		Yield benefits of crop diversity are less pronounced in wet and cool weather (Gaudin et al., 2015).
		Although reduction in tillage decreased yield variability in favorable years, tillage and rotation diversity had no effects on corn yield variation in abnormal hot/dry or cool/wet conditions (Gaudin et al., 2015).

Table 1.9
Benefits, risks and limitations of conservation buffers

	Benefits	Risks and limitations
GHG Emissions	Can store carbon Partial conversion of cropland to buffers, riparian grass buffers, shelterbelts, field borders, etc., all result in net GHG-avoidance Shelterbelts emits less N_2O likely due to fertilization, compared to croplands Agroforestry can reduce GHG emissions [CO_2, N_2O]	Shelterbelts can emit more CO_2 compared to cropland
Soil Degradation	Minimize the movement of soil sediment, nutrients phosphorus and nitrate, pesticides, and pathogens through the soil profile and from the field as runoff Pesticides can be absorbed and degraded Improve water quality and preserve aquatic ecosystems Trap snow for increased spring soil moisture Reduce wind speed and wind damage to crops Reduce risk of erosion Act as water storage Can reduce evaporative of soil moisture and microclimate effects Agroforestry can improve SOM level	Can lead to an increase in leaching of pesticides Driving heavy equipment on buffers leads to soil compaction and reduced water infiltration The waterway lacks the depth necessary to serve as a tile drainage outlet Trees are much less effective in reducing erosion in their leafless state than they are in the summer
Soil Functions	Improve wildlife habitat and air quality Nitrate can be taken up by plants Denitrification can occur within buffers Improve SOM Agroforestry improves crop resilience to extreme climate conditions (e.g. drought)	---
Others	Riparian area can be used as a sustainable grazing resource Provide aesthetic and recreational value May economically offset the land taken from food crops [e.g. timber or biofuel production] Can reduce risks of young plants growing in open and exposed conditions (dry and extreme temperature) Agroforestry can improve rural attractivity Agroforestry diversify revenues [wood, fruits, nuts]	Establishing vegetation may be difficult The effectiveness of buffers will vary significantly depending on the flow conditions in the buffer, the location, the design and the maintenance Excessive distance between trees in the row can also greatly reduce shelterbelt effectiveness May have a profitability at the terrestrial level, but it is not always the case at the producer's level (Anel et al., 2017). May need maintenance High cost to establish and maintain

Optimal Conditions

Suboptimal Conditions

Would not be effective in the winter in colder climates. Cold-climate VBS implemented in Canada, the northern United States, and northern Europe have shown P removal efficiency ranging from −36% to +89%, a range that identifies the uncertainty surrounding the use of VBS in these landscapes (Kieta et al., 2018).

Table 1.10
Benefits, risks and limitations of prevention of compaction

	Benefits	Risks and limitations
GHG Emissions	Indirect effects of CTF include reduced GHG emissions Reduce the risk of N_2O, methane emissions and methane oxidation	---
Soil Degradation	CTF improves infiltration and drainage CTF reduce run-off and erosion CTF can reduce waterlogging, improve denitrification and soil biological activity [SOM] CTF and reducing the inflation pressure during the planting operation can improve traction, which can reduce soil compaction Low axle loads reduce soil compaction Use flotation tires, adopt radial-ply tires, install larger diameter tires, properly ballast tractors for each field operation and/or use tractors with four-wheel or front-wheel help to reduce soil compaction Equipment using tracks increase footprint and therefore reduce surface pressure	---
Soil Functions	Improves soil porosity Improves water infiltration and increases water availability to the crop Improves crop rooting and the efficiency of nutrient uptake, leading to less waste and potential for environmental pollution	---
Others	Immediate benefits of CTF include reduced fossil energy use CTF can provide more workable days at planting and increases yields CTF reduces costs and provides better financial and environmental performance Reducing the inflation pressure can improve fuel efficiency GPS technology that include yield mapping and soil sampling, as well as tracking systems can improve the overall efficiency	Equipment and system changes are necessary to achieve controlled traffic

Optimal Conditions

Infiltration was significantly reduced by 3 to 5 times under 10 Mg loads and by up to 30 times under 20 Mg loads in the silt loam soil and by 5 to 40 times under 20 Mg loads in the clay loam soil (Smith, 2015).

CTF can often provide more profit and less financial risk than uncontrolled traffic systems, especially in very wet or very dry seasons (GRDC, 2013).

Suboptimal Conditions

Table 1.11
Benefits, risks and limitations of integrated pest management

	Benefits	Risks and limitations
GHG Emissions	By decreasing avoidable yield losses, CSPM can reduce the overall GHG emissions intensity Biological control can reduce annual CO_2 emissions	---
Soil Degradation	Prevent further issues and mitigate existing pollution Preserve beneficial insects and pathogens Reduced nutrient leaching Improve SOM level Judicious use of pesticides in combination with non-chemical strategies, which results in improved protection of environment and health	---
Soil Functions	Preserve beneficial insects and pathogens [biodiversity] Populations of beneficial fungi that can kill plant-feeding insect pests can be improved Can conserve the populations of arthropod predators Microbial decomposition tends to be faster Improve agriculture's ability to adapt within well-functioning ecosystem	---
Others	Adopting an IPM strategy can be an effective way for managing pests in an economical and environmentally sound way Planting trap crops, such as a field margin can result in treating a smaller area with a pesticide Reduce pest resistance and severity of pest infestations Can reduce pesticide use without revenue losses, or losses in yields	Regular crop scouting for pest identification and monitoring Time consuming, resource-intensive and demands care High cost of shifting from chemical pest control paradigm to IPM

Optimal Conditions

Infiltration was significantly reduced by 3 to 5 times under 10 Mg loads and by up to 30 times under 20 Mg loads in the silt loam soil and by 5 to 40 times under 20 Mg loads in the clay loam soil (Smith, 2015).

CTF can often provide more profit and less financial risk than uncontrolled traffic systems, especially in very wet or very dry seasons (GRDC, 2013).

Suboptimal Conditions

Table 1.12
Benefits, risks and limitations of pasture management

	Benefits	Risks and limitations
GHG Emissions	Improved grazing land management (including adjusting animal stocking rates and managing plant species) can increase C inputs and SOC stock	---
Soil Degradation	Can increase SOM More nutrients available for plant growth Improve soil conditions for germination, seedling establishment, vegetative reproduction and root growth Reduce water erosion Pasture sites can improve available water capacity [AWC]	High stocking density may lead to soil compaction. Under certain conditions, runoff increases, wind erosion increases, and water erosion increases
Soil Functions	Lower-intensity management (with adoption of other BMP) improve soil respiration, water-stable aggregates, fungi, and mycorrhizae Improve aggregate structure, which will improve infiltration Ability of the soil to act as a filter, protecting water and air quality Control grazing ensure the presence of roots to provide organic carbon	---
Others	Rotational grazing system allows for more drought resistance in the pasture Increase plant production and reproduction The prevention of overgrazing allows the vegetation to recover quickly when the animals have moved on	Disadvantage of continuous grazing: uneven grazing patterns; variable plane of nutrition; uneven distribution of manure; change in pasture botanical composition over; and negative energy status [overly mature forage] Higher labour needs and additional cost for new fencing and water sources.
Optimal Conditions		
Permanent grasslands are effective for carbon accumulation in mineral soils, especially when grass and legume species are combined (Siebielec et al., 2019). Grasslands generally take up and store more carbon than croplands; for example, in the Great Plains, the average uptake rates were about 45 g C/m^2 per year for grasslands and 31 g C/m^2/year for croplands from 2000 to 2008 (Wylie et al., 2016).		
Suboptimal Conditions		
When pasture is dominated by undesirable and invader plants and more bare soil exists, runoff increases dramatically from exposed soils, less water goes into the soil, wind and water erosion increases		

Table 1.13
Benefits, risks and limitations of land retirement

	Benefits	Risks and limitations
GHG Emissions	Conversion of annual cropland to permanent vegetation [secondary forest or a managed plantation] can improve SOC stock Conversion to perennial grasses and legumes increase C inputs and reduce C losses Conversion to willow fields can improve SOC stock	---
Soil Degradation	Reduce soil erosion Reduce nutrient leaching Retired croplands offer protection to adjacent surface waters. Improve infiltration rates, resulting in less runoff	Some species have exact soil and site requirements. A soil and species mismatch can be costly and frustrating.
Soil Functions	Roots add organic materials, improve soil structure, and penetrate compacted layers Can attract wildlife, which can attract more desirable species [Biodiversity] Improve waterways water quality. Can improve surface and subsurface structure	---
Others	Indirect economic benefits from the reduction in the discharge of sediment, nitrogen, and phosphorus Improve wildlife habitat for hunting and no consumptive uses Reduce use of insecticides, herbicides, fungicides and fertilizer Can reduce risks of young plants growing in open and exposed conditions (dry and extreme temperature).	A soil and species mismatch can be costly During the establishment period of natural areas, it can attract nuisance wildlife that can cause crop damage in adjacent fields
Optimal Conditions		
Laganiere et al. (2010) reported that in temperate climates the potential for C sequestration from afforestation is in the range of –5 to +20% (av. +7%; results from 49 comparisons). It was found that clay soils (with clay >33%) had the biggest potential for C sequestration and that broadleaf (excluding eucalyptus) trees also offer the highest SOC stock increase of on average 25%.		
Suboptimal Conditions		

Table 1.14
Benefits, risks and limitations of soil information collection

	Benefits	Risks and limitations
GHG Emissions	Soil tests can help determine the status of plant-available nutrients to develop recommendations to achieve optimum nutrient management and minimize GHG emissions. The use of variable rate N fertilization (precision agriculture) can reduce N application, which in turn can reduce N_2O emissions and NH_3 volatilization	---
Soil Degradation	Soil tests can help determine the status of plant-available nutrients to develop recommendations to achieve optimum nutrient management Soil tests help tracking holistic soil health over time Can identify soil erosion issues and risks Technological innovation can help manage and remediate salt-affected soils Variable rate N fertilization can reduce NO_3 leaching Digital soil mapping can precisely determine field management zones for targeted soil organic matter and soil health improvement	---
Soil Functions	Identifies SOM levels to be enhanced through other BMPs New soil digital technologies (soil sensing, telemetry, digital mapping, big data analysis and precision agriculture) will bring a new understanding of how soil functions at the optimal and sustainable level to improve farm management practices	---
Others	Frequent soil and tissue tests are often required to adjust rates based on contributions from the SOM, crop residues and cover crops Generalized soil maps can serve as a basis for targeting and implementing agricultural and conservation programs Compared to traditional maps, digital soil maps have a better quality and as a greater amount of data available	Nutrient content can vary somewhat from year to year and from field to field. Access to up to date, easy-to-use soil maps and data layers is critical for land use planning and precision agriculture
Optimal Conditions		

Suboptimal Conditions		
Very coarse-textured soils rarely have elevated levels of nitrate-nitrogen present for long enough periods of time to be detected by soil testing. These soils represent a greater risk to water quality (Manitoba Agriculture, Food and Rural Initiatives. 2008).		

2. IDENTIFYING THE FACTORS INFLUENCING THE ADOPTION OF SOIL HEALTH BMPS IN CANADA

Chapter highlights

- Farmers' decision to adopt a BMP or not is an individual one, significantly influenced by a person's distinctive behavioural factors. In turn, these factors are influenced by many other considerations (farmer profile, farmer attitude and behavior, farm characteristics, awareness and access to information, and economic factors). All these factors are interrelated, making the understanding of the decision-making process complex.
- Given this, it is essential to understand the individual person behind the decision-making process leading to BMP adoption, especially in the context of a systems approach.
- Based on a literature review and discussions with key informants, three core factors contributing to successful BMP adoption and implementation are identified: a strong business case that relates to the perceived benefits, costs, and risks of adopting new BMPs, access to information and expertise, and the ability to track progress over time.
- Better understanding these factors is an important step in designing better policies to foster BMP adoption.

The knowledge on BMPs' positive impacts on soil health and the environments is rapidly growing. However, farmers' adoption of these practices remains a challenge due to a wide range of factors. Identifying and understanding the key factors influencing adoption of soil health BMPs among farmers is important for two reasons. First, it is necessary to develop the right tools to better communicate to farmers the effectiveness and necessity of adopting soil health BMPs. Second, once farmers decide to move forward with the adoption of BMPs to improve soil health, it is essential to design appropriate policies to support their successful implementation.

The content of this section is based on a review of the literature and interviews with key informants, including soil health scientists and governmental representatives. Section 2.1 summarizes the key factors influencing BMP adoption as found in the literature. Building upon these factors and the systems approach, Section 2.2 provides additional information to better understand farmers' decision-making process and support them throughout the BMP adoption and implementation process. Section 2.3 concludes with a brief discussion on policy implications.

2.1 KEY FACTORS INFLUENCING BMP ADOPTION

A significant number of studies over the years have examined the variables or factors influencing BMP adoption. Based on this literature, these factors can be classified under 5 broad interrelated categories:

- **Farmer profile**: age, education, training, farmer experience, farmer objectives.
- **Farmer attitude and behavior**: environmental concern, perceived environmental benefits, risk tolerance, attitude toward a program/practice, farmer identity, attitude toward expertise, resistance to change, neighbour influence, need for recognition.

- **Farm characteristics**: farm size, diversity, vulnerable lands, tenure and succession.
- **Awareness and access to information**: access to information, awareness of the practice/program, awareness of the agriculture impact on the environment, environment knowledge, farmer networking and farmer affiliation/implications.
- **Economic factors:** income, capital, land value, profitability of practice, access to labour and equipment, crop insurance and marketing.

The relationship found in the literature between each factor and BMP adoption is described below. In addition, Table 2.1 summarizes the main factors influencing BMP adoption among farmers and whether they are positively or negatively correlated with BMP adoption.

FARMER PROFILE

- **Farmer age** is usually negatively correlated with BMP adoption. Older farmers tend to have a shorter planning horizon than younger farmers (Baumgart-Getz et al., 2012). Also, they tend to be less concerned by environment and less inclined to change their practices (Dessart et al., 2019).
- **Level of education** and **training** have generally a positive relationship with BMP adoption. Lack of skills is a common reason for non-adopting soil conservation practices, especially reduced tillage (Wauters et al., 2010).
- **Farmers with conservation objectives** are more likely to adopt BMPs than those who have strictly economic objectives. Farmers adopt BMPs if they expect these to help them achieve their objectives (Dessart et al., 2019). Conservation objectives are often perceived to be in opposition with economic objectives.

FARMER ATTITUDE AND BEHAVIOR

- **Attitudes[20] toward a program or practice, risk tolerance, neighbour influence** and **resistance to change** are considered strong predictors of BMP adoption (Prokopy et al., 2019; Dessart et al., 2019).
  - Farmers who have a positive attitude toward a program or a BMP are generally more likely to adopt conservation practices. Farmers who have already enrolled in a program or have adopted a BMP are also more inclined to adopt conservation practices (Prokopy et al., 2019).
  - Farmers who have a high level of risk tolerance tend to adopt more BMPs (Prokopy et al., 2019; Dessart et al., 2019). Farmer's willingness to take risks that come with BMP adoption influence behaviors as farmers might worry about losing yields or that they do not have the necessary skills for BMP success (Liu et al., 2018). According to Dessart et al. (2019), risk-averse farmers tend to perceive higher financial risk on BMP adoption than farmers that are risk-seekers.

[20] An attitude is defined as a settled way of thinking, feeling or evaluation about someone or something. Having a positive attitude toward a behavior is often associated with the adoption of a behavior (Prokopy et al., 2019).

  - Farmers who live in proximity to farmers who have adopted BMPs are more likely to adopt them since farmers in the same neighborhood tend to exhibit similar patterns of adoption. For instance, farmers who are aware that conservation tillage is used by other farmers in their locality are more inclined to adopt BMPs as they might have access to information about the real costs, benefits and risks of conversion (Dessart et al.,2019).
  - Resistance to change is often mentioned as a barrier to adopt BMP. Farmers who are resistant to change are less likely to change their practices and adopt a new BMP or technology (Dessart et al., 2019). Resistance to change is highly correlated with age and farming experience. Financial anxieties (market, revenue and investment) often occur when a major change is being considered which can reinforce resistance to change (York University, N. D.a).

- **Concern about environment, perceived environmental benefits** and **farm identity** have also an influence on behavior. Farmers concerned about the environment are generally more inclined to adopt soil conservation practices, as they tend to have more conservation objectives (Dessart et al., 2019). Farmers who perceive an environmental benefit of adopting a practice are also more prone to adopt a BMP (Arbuckle et al., 2015; Dessart et al., 2019). Sustainable practices are expected to bring environmental benefits. For instance, farmers who use cover crops hope to improve soil organic matter, reduce soil erosion and soil compaction (Myers and Watts, 2015). Farmers who consider other people in their interest (lower level of self-interest) are also likely to adopt more BMP (Prokopy et al., 2019).
- **Trust in professional expertise** (extension services, sciences, etc.) also tend to lead to BMP adoption (Dessart et al., 2019). Indeed, farmers who trust professional expertise are more likely to consider advisors proposed BMPs. According to Liu et al. (2018), building the trust of farmers is critical for conservation practice adoption.
- **Farmers valuing recognition for stewardship or enhanced public image and status** are generally more inclined to adopt BMPs as they want to be well perceived in their community. However, this finding mainly applies to BMPs that can be recognized and seen by the general public. Indeed, less visible BMPs such as carbon sequestration on soils and reducing CO_2 emissions may receive less praise (Dessart et al., 2019) and may thus not lead to changes in practices (Alberta's Ministry of Agriculture and Forestry, 2016). This nuance might help explain why observable practices such as conservation tillage are usually preferred by farmers (Liu et al., 2018).

FARM CHARACTERISTICS

- Farm characteristics play an important role in BMP adoption, including **farm size** (acreage, income). Farmers managing larger farms are generally more likely to adopt BMPs since they are more aware of environmental issues and have a better knowledge of BMPs. They also tend to have more machinery, higher revenues and more capital to invest in new technologies (Liu et al., 2018).

- Other factors such as **farm diversity** (more than one agricultural activity: crop or livestock), having **vulnerable lands** (highly erodible land, higher levels slope, leaching, etc.) and **succession** (plans to pass on the farm) are also positively correlated with BMP adoption. Farmers with vulnerable lands are more inclined to adopt BMPs as they need solution to resolve their land issues (Prokopy et al., 2019). Moreover, farms with succession plans tend to adopt conservation practices to preserve their land for future generation (Liu. et al., 2018).
- **Tenure** (owning or renting the land) is not always a predictor of BMP adoption. Tenure has generally no effect on the adoption of BMPs with short term benefits (e.g. conservation till). However, tenant farmers are less likely to adopt BMPs which require investments with long term benefits (Weber 2017).

AWARENESS AND INFORMATION

- Awareness and knowledge of behaviors or situations play an important role in the process of BMP adoption, as they are the first step of action towards adoption. Several studies have confirmed that **farmers who are aware that a program or practice** exists are more likely to enroll or adopt it (Wauters et al., 2010; Dessart et al., 2019; Prokopy et al., 2019).
- **Access to relevant and quality information**, especially from extension services and local authorities, is also decisive in adoption of agronomic innovations (Dessart et al., 2019). Information sources play a strong role in influencing farmers decisions and behaviors as they "shape the initial knowledge of issues" (Prokopy et al., 2019) and provide effective information on practices and new technologies. Farmers who seek and use information are also more likely to adopt BMPs (Prokopy et al., 2019).
- **Farmers aware of the quality of environment** and their farm characteristics (e.g. soil types and quality) on their farm are usually more prone to adopt BMP as they know their issues and what they can improve (Prokopy et al., 2019; Wauters et al., 2010). However, for soil health, methods to assess and monitor soil quality and carbon tend to be complex and difficult for farmer to implement. **Awareness of agricultural impact on environment** does not always have a positive relationship with BMP adoption (Prokopy et al., 2019). For instance, knowing that using heavy agricultural tractor may lead to soil compaction does not always stop farmers from using that type of machinery.
- **Social networking and connections** can also be a predictor of BMP adoption (Prokopy et al., 2019; Wauters et al., 2010). Key stakeholders such as crop certified advisors, extensions services and other farmers play an important role in informing farmers on practices and technologies. Farmers who interact in networks which give importance to environment or soil preservation (e.g. contacts with farmers who have already adopted BMPs or contacts with advisors or dealers who are well aware of BMP) are more likely to adopt BMPs. However, interactions with other stakeholders such as input dealers (fertilizer, pesticides, machinery, etc.) might not always have a positive correlation with BMP adoption. The same applies to **farm organization affiliation and participation**. Organizations or associations are not always positively associated with BMP adoption. The position of the organization (promoting or not conservation practices) can be decisive for farmers.

ECONOMIC FACTORS

- Income and capital are important predictors of BMP adoption. Farmers with **better incomes** and **access to capital** (better market or personal financial conditions) are generally more prone to adopt BMP as it reduces economic constraints associated with adoption (Prokopy et al., 2019; Wauters et al., 2010).
- Farmers with **high valued land** are also generally more inclined to adopt BMP since they want to preserve that value (Prokopy et al., 2019) or increase land aesthetic value (Liu et al., 2018).
- **Farmers' expectations of financial benefits** (e.g. higher productivity (yields), labour savings, higher returns, tax benefits, increased soil fertility, etc.) are positively related with BMP adoption (Dessart et al.,2019). Expected yields have a strong influence on BMP adoption since "competition between farmers is often based on yield rather than on environmental performance" (Dessart et al., 2019).
- **Access to labour and equipment** generally has a positive relationship with BMP adoption (Liu et al., 2018). It is expected that a greater labour availability will improve the adoption as these farm operations will not be too time-constrained to implement new practices. On the other hand, the lack of access to equipment required to adopt BMP constitutes an important barrier to adoption (Prokopy et al., 2019). For instance, according to Ulrich-Schad et al. (2017), farmers concerned about lack of access for necessary equipment are less likely to conduct soil tests than those who are not concerned.
- Farmers who use **crop insurance** as a strategy to manage risk can be more inclined to adopting BMPs (e.g. integrated pest management) or new technologies. As such, protection against yield loss from BMP adoption can decrease perceived risks. However, this correlation is not always positive if farmers are not confident that they will receive indemnities (Dessart et al., 2019).
- Farmers who are engaged in **marketing practices** to maximize revenues or profits are more likely to adopt BMPs (Prokopy et al., 2019). For instance, marketing contracts are generally associated with income stability (predetermined prices), market stability and access to capital (the contractor generally provides most of the inputs (USDA, 1996).

Table 2.1
Summary of factors influencing BMP adoption by farmers

Factors	Description	Relationship with BMP adoption	Explanation
Farm characteristics			
Size of the farm	Number of acres farmed	●	Generally, large farms are more likely to adopt BMPs since they are more aware of environmental issues and BMPs (Liu et al., 2018), have more capital to invest in new technologies (Weber, 2017) and more have machinery (AAC, 2012).
Diversity	Activities on the farm (more than one crop in rotation, livestock, etc.)	●	Diverse operation (diversity of crops and livestock) are more prone to adopt BMPs (Prokopy et al., 2019)
Land vulnerability	Having vulnerable lands (highly erodible land, higher levels slope, leaching, etc.)	●	Farmers who have vulnerable lands have a positive relationship with BMP adoption since as they look for solution to resolve their land issues (Prokopy et al., 2019)
Tenure	Possessing of the land vs renting	◆	Tenure influences the adoption of BMPs, especially for BMPs which require investments with long term benefits. Tenure has generally no effect on BMPs which have short term benefits (e.g. conservation till) (Weber, 2017)
Succession	Plans to pass farm on	●	Farmers who plan to pass on the farm to a family or are positively correlated with BMP adoption (Liu et al., 2018)
Farmer profile			
Age	Farmer age	■	Age has usually a negative impact on BMP adoption as older farmers usually have a shorter planning horizon than younger farmers (Baumgart-Getz et al., 2012). They also tend to be less concerned by environment and less inclined to change their practices (Dessart et al., 2019)
Education	Level of education	●	Level of education has a positive impact on BMP adoption.
Training	Training and technical skill with technology or to adopt the practice	●	Perceived difficulties and lack of skills are generally correlated with the non-adoption of soil conservation practices, especially reduced tillage (Wauters et al., 2010).

Factors	Description	Relationship with BMP adoption	Explanation
Farmer experience	Years of farming	■	Farming experience has generally a negative impact on BMP adoption since it is correlated with age (Dessart et al., 2019)
Farmer objectives	Sustainability is part of farmer objective	●	Farmers with conservation objectives are more likely to adopt BMPs that those who have economic objectives (Dessart et al., 2019)
Farmer attitude and behaviors			
Program / practice	Attitude toward the program or the practice	●	Farmers who have a positive attitude toward a program or a BMP are generally more likely to adopt conservation practices (Prokopy et al., 2019)
	Behavior toward a program of practice (current or past use of related practice / program)	●	Farmers who have adopted a BMP or have engaged in program in the past are more likely to adopt a BMP (Prokopy et al., 2019)
Environmental concern	Attitude towards environment (level of concern)	●	Farmers concerned about the environment are generally more likely to adopt soil conservation practices than those who are not concerned (Prokopy et al., 2019; Dessart et al., 2019)
Environmental benefice of the practice	Perceived environmental benefits of adoption a BMP	●	Farmers who perceive an environmental benefit of adopting a practice are more likely to adopt it (Arbuckle et al., 2015; Dessart et al., 2019). Sustainable practices are expected to bring environmental benefits (Myers and Watts, 2015)
Risk tolerance	Farmer level of tolerance to risk (examples of risks: environmental, yields, incomes)	●	Farmers who have a high level of risk tolerance tend to adopt more BMPs (Prokopy et al., 2019; Dessart et al., 2019)
Farmer identity	Other oriented vs self oriented (self-interest)	●	Other-oriented farmers are more prone to adopt BMPs than those who have higher levels of self-interest (Prokopy et al., 2019)
Expertise	Confidence towards expertise (extension services, etc.) and value science are more likely to adopt BMPs and new technologies (Liu et al., 2018).	●	Farmers who are confident towards expertise (extension services, etc.) and value science are more likely to adopt BMPs and new technologies (Liu et al., 2018).
Resistance to change	Resistance to adopt a new practice	■	Farmers resistant to change are less likely to adopt BMPs (Dessart et al.,2019)

Factors	Description	Relationship with BMP adoption	Explanation
Neighbour influence	Influence of neighbours on behaviors	◆	Farmers who live in proximity to farmers who have adopted BMPs are more likely to adopt them since farmers in the same neighborhood tend to exhibit similar patterns of adoption. (Dessart et al., 2019)
Recognition	Value to social recognition and status	●	Farmers who need for praise or improve their local public image and status area generally more motivated to adopt BMPs (Dessart et al., 2019)
Awareness and information			
Access to information	Access to adequate information (quality and expertise)	●	Having access to quality information is critical in BMPs since it is the initial knowledge that leads to adoption (Dessart et al., 2019; Wauters et al., 2010)
	Using/seeking information	●	Seeking or using information (sought/use) is positively related to BMPs adoption (Prokopy et al., 2019)
Practice / program	Awareness that BMPs or program exist	●	Farmers who are aware that a program or practice exists are more likely to enroll or adopt it (Wauters et al., 2010; Dessart et al., 2019; Prokopy et al., 2019)
Agriculture impact on the environment	Awareness of the impact of the practices on environment	◆	Awareness of agricultural impact on environment does not always have a positive relationship with BMP adoption (Prokopy et al., 2019)
Environment knowledge	Awareness of environment quality on the farm (e.g. soil quality)	●	Farmers aware of the quality of environment on their farm are more prone to adopt BMP (Prokopy et al., 2019; Wauters et al., 2010)
Networking	Interactions with other farmers, extensions services, certified crop advisors, input dealers	◆	Networking is an important predictor of BMP adoption (Prokypy et al., 2019; Wauters et al., 2010). Extension services, crop advisors and input dealers (fertilizer, pesticides, machinery, etc.) might gave different interest in BMPs and influence differently farmers.
Affiliation / implications	Affiliation why an organization, association, etc. (e.g. membership)	◆	Affiliation and implications with an organization or association is not always positively associated with BMP adoption. The position of the organization (promoting or not conservation practices) can be decisive (Prokopy et al., 2019).

Factors	Description	Relationship with BMP adoption	Explanation
Economic factors			
Income	Revenues (including crop values)	●	Farmers with better incomes (better market or personal financial conditions) are generally more prone to adopt BMP since it reduces economic constraints associated with adoption (Prokopy et al., 2019; Wauters et al., 2010)
Capital	Available capital (assets or investment into farm, access to credit, debt-asset ratio)	●	Access to capital is an important predictor of BMP adoption since costs are often associated with BMP adoption (Prokopy et al., 2019; Wauters et al., 2010)
Land value	Measures of land value	●	Farmers with high valued land are generally more inclined to adopt BMP since they want to presert that value (Prokopy et al., 2019)
Profitability of practice	Practice that lead to higher productivity (higher yields), labour savings, higher returns, tax benefits, etc.	●	Farmers' expectations of financial benefits are positively related with BMP adoption (Dessart et al., 2019). Practices who are perceived to have a positive impact on yields are more likely to be adopted by farmers (Prokopy et al., 2019; Dessart et al., 2019)
Labour	Access to labour (family and hired)	●	Access to labour has generally a positive relationship with BMP adoption (Liu et al., 2018)
Equipment	Access to equipment	●	The lack of access to equipment required to adopt BMP is an important obstacle to adoption (Prokopy et al., 2019)
Crop insurance	Use of crop insurance	◆	Farmers who use crop insurance as a strategy to manage risk can be more inclined adopting BMP (e.g. integrated pest management) or new technologies. However, this correlation is not always positive.
Marketing	Marketing arrangements (e.g. contracts)	●	Farmers who are engage in marketing practices to maximize revenues or profits are more likely to adopt BMP (Prokopy et al., 2019)

Legend:

- ● Positive relationship with BMP adoption
- ◆ Positive or negative relationship with BMP adoption (depending on literature)
- ■ Negative relationship with BMP adoption

Source: Groupe AGÉCO.

Some studies have also identified barriers associated with specific soil heath practices. Table 2.2 describes the main barriers identified for each key BMP described in section 1.2. For many BMPs, the lack of information about the benefits of practices and how to measure them have a negative impact on adoption (Carlisle, 2016). The lack of understanding of how to optimize the practice, the lack of regionally specific information on the practice, the costs associated with implantation (including equipment) and the lack of time and labour are also obstacles to implementation.

Table 2.2
Summary of barriers associated with soil health BMPs

BMPs	Barriers
Conservation tillage	• Equipment: already owning conventional equipment and cost of acquiring new equipment (Wandel and Smithers, 2000) • Adaptability of the technology to certain types of soils (e.g. fine-textured soils) and crop environments • Risk aversion and risk of yield reduction (Wandel and Smithers, 2000) • Long transition period • Limitations on no-till in humid climates and with high biomass crops
Cover crops	• Understanding of how to optimize cover cropping with cash cropping as not all systems are equally suited to cover cropping (e.g. long-season cash crop rotations may not be compatible with cover crops) • Lack of regionally specific information on selecting cover crop variety (Carlisle 2016) • Expenditures required for new equipment • Added costs of seeds, planting and killing pests (USDA, 2015) • Short term start up costs versus long term financial and environmental benefits (Union of Concerned Scientists, 2013; Hoorman, 2009; Kaspar et al., 2008) • Increased complexity of the management system and associated time and labour required for planting and managing cover crops (Chillrud, 2016)
Organic amendments	• Composting may require new equipment and new management practices • Increased purchase and shipping costs • Variable availability and transport of compost, and variable compost quality and composition (Viaene et al., 2016)
Nutrient management	• Costs (installation and operating expenses) (Clearwater et al., 2016)
Diverse crop rotation	• Lack of markets and profitability for alternative and new crops • May require new or more equipment and skills • May give lower financial returns during the transition period • Increased system complexity of the management system • Actual trends: technology specialization, subsequent field and landscape-scale homogeneity, which makes crop diversification more difficult to adopt (Roesch-McNally et al., 2018)
Conservation buffers	• Perceived as impediment to agricultural activities • Costs of planting, establishing, and maintaining the buffers and cost of land being taken out of production, (Helmers et al., 2008) • The short-term cost of implementing an maintaining does not necessarily equal the short-term economic returns

BMPs	Barriers
	• Working around natural waterways with farm equipment can be difficult
Prevention of soil compaction	• The cost associated with the adoption of new equipment or novel technologies (e.g. cost of buying and installing variable air pressure systems) • Lower capacity equipment (less compaction) are less efficient (seeding and harvesting) compared to high-capacity machinery [heavier] Efficiency of seeding and harvesting equipment wider than 12m (GRDC, 2013) • Poor spreading of straw and lime beyond 9m (GRDC, 2013) • Poor understanding of controlled traffic farming • Difficulty moving burned windrows (GRDC, 2013) • Concerns about managing erosion and weeds in permanent wheel tracks
Integrated pest management	• Increased complexity of IPM system versus conventional pest management • Lack of IPM tools, information and training • Time required to adopt an IPM system • Cost and expenses associated with IPM system implementation (can be more expensive than traditional methods (spraying pesticides))
Pasture management	• Labour required (requires more labour than continuous grazing to set up paddocks (PennState Extension, 2016). • Costs (temporary fencing materials and infrastructure to provide water in all paddocks) (PennState Extension, 2016)
Land retirement	• Costs (establishment and maintenance)
Soil information & data	• Knowledge, accessible tools, or reliable assistance to decipher soil data and take decisions (Zelikova et al., 2020) • There are multiple industry players and platforms, creating compatibility challenges for software and data

Source: Groupe AGÉCO

2.2 UNDERSTANDING FARMERS' DECISION MAKING PROCESS BEHIND BMP ADOPTION

As discussed in the previous section, farmers' individual characteristics such as environmental concern, risk tolerance, environmental knowledge, a willingness to seek information related to BMPs, and awareness of sustainable practices are positively correlated with BMP adoption. This key finding from the literature review illustrates the importance of understanding the individual person behind the decision-making process leading to BMP adoption, especially in the context of a systems approach. Humans are complex, and a wide range of internal and external factors influence their decisions. In turn, better understanding individuals and their motivations is an important step in designing better policies to foster BMP adoption.

In any given situation, different people react differently based on their underlying behavioural and psychological factors. The decision by a farmer to adopt or not a BMP is an individual one, significantly influenced by a person's distinctive behavioural factors. Better understanding the links between farmers' behavioural characteristics and BMP adoption is essential for an appropriate understanding of their decision-making process.

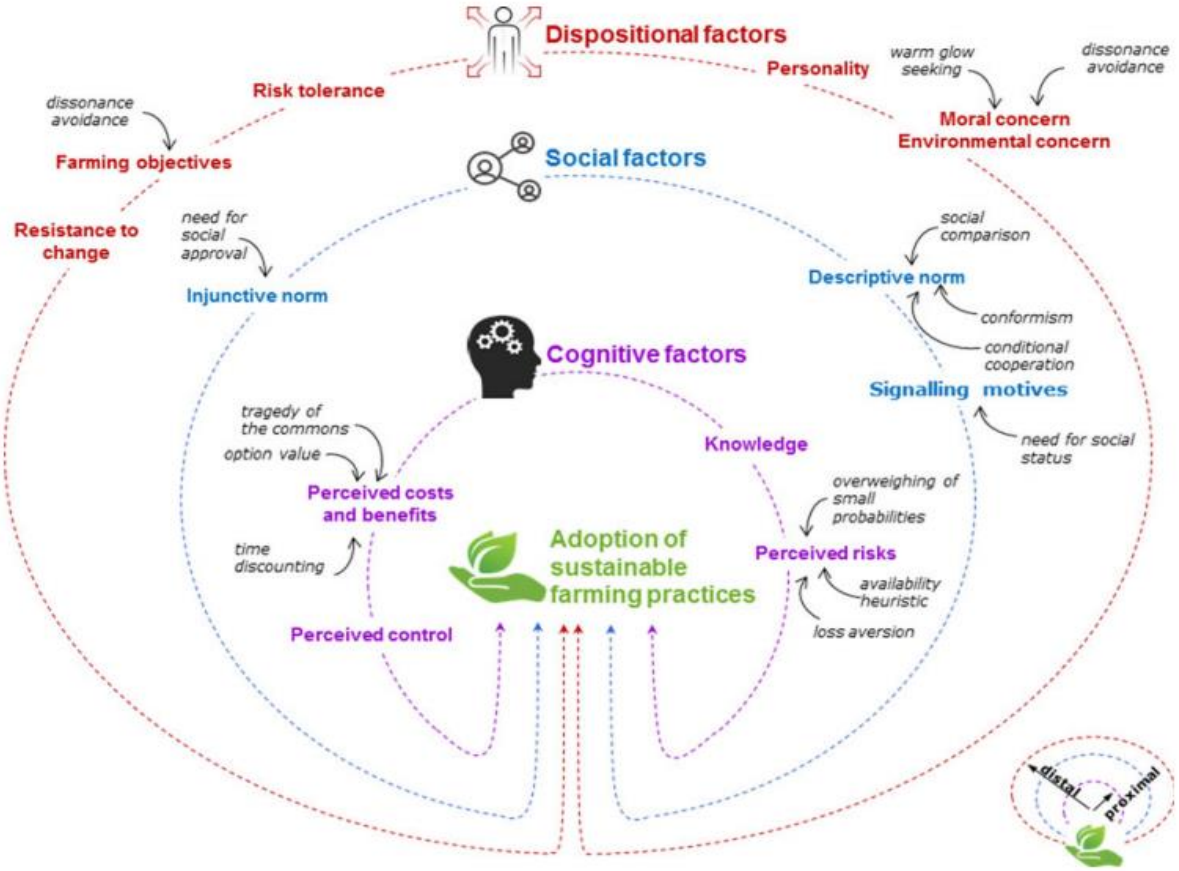
There is a vast literature looking at the links between behavioural characteristics and the adoption of sustainable farming practices. Dessart et al. (2019) reviewed the literature on this topic over the past two decades and proposes a structured framework, which classifies behavioural factors under three categories: dispositional factors, social factors, and cognitive factors (See Figure 2.1).

Behavioural factors, also known as psychological factors, refer to the "cognitive, emotional, personal and social processes or stimuli underlying human behaviour" (Dessart et al. 2019). **Dispositional factors** consist of internal variables including an individual's personality, motivations, values, beliefs, preferences, and objectives. These include personality traits, risk tolerance, moral concern, environmental concern, etc. These traits and beliefs tend to be relatively stable over time. **Social factors** refer to farmers' interactions with others as well as social norms, such as perceived pressure from peers. Lastly, **cognitive factors** refer to farmers' knowledge and awareness of sustainable farming practices as well as their perceptions of the benefits, costs, and risks associated with their implementation.

Dessart et al. (2019) found that **cognitive factors** were directly related to the decision-making process behind the adoption of sustainable farming practices. In other words, compared with dispositional and social factors, cognitive factors such as being aware of sustainable practices or expecting a positive return on investment by implementing them are much more likely to result in farmers making the decision to adopt sustainable farming practices.

However, these cognitive factors, can be strongly influenced by dispositional and social factors. For example, as confirmed in the literature review, a farmer with an aversion to risk (dispositional factor) is much less likely to recognize the potential benefits associated with a given BMP, and thus less likely to seek relevant information on it and adopt it.

Figure 2.1
Framework of behavioural factors affecting farmer's adoption of BMP



Source: Dessart et al., 2019.

2.2.1 BUILDING A STRONG BUSINESS CASE SUPPORTING BMP ADOPTION

Building on the above framework, our literature review, as well as interviews with key informants, the number one consideration behind farmers' decision to adopt sustainable farming practices (or BMPs) relates to their **perceived** benefits, costs, and risks. In other words, a farmers' willingness to adopt BMPs is closely tied to the **business case** behind it.

Building a strong business case is the number one step the Soil Health Institute has identified behind the adoption of soil health systems (c.f. Figure 2.2) (Soil Health Institute, 2020). Examples of considerations farmers will look at include:

- Will the recommended system be profitable?
- Will the system increase or reduce the economic risk?
- What will be the impact on yields?
- Can the environmental benefits be credited back to the farm?

As discussed in section 2.1, farmers' expectations of **financial benefits** are positively related with BMP adoption (Dessart et al., 2019). Practices who are perceived to have a positive impact on yields are more likely to be adopted by farmers (Prokopy et al., 2019; Dessart et al., 2019). The need for a strong business case was also confirmed by our interviews with key informants. Interviewees reported that BMPs need to be aligned with the farm's **business objectives** and take into account the risks and economic impacts of their adoption. Moreover, soil health BMPs should be linked to **yields**, **productivity**, and **profitability** and the benefits should also be measurable at the field level (e.g. crop yield and profit uniformity and stability over time and space). In other words, "if it pays it stays".

Given the importance of the business case to support the adoption of BMPs, it is not surprising that key considerations related to perceived benefits, costs and risks were found to act as major barriers to BMP adoption in the literature. According to the Farm Environmental Management Survey (Statistic Canada, 2013), 55% of farmers identify **economic pressures** as the main reason for not implementing BMPs. Likewise, the **risk of loss of crop yield** as well as concerns about reduced yields are key barriers to BMP adoption (Gagné et al., 2018). In terms of adoption of specific BMPs, the **additional costs** associated with the necessary purchases of **new equipment** were identified as a key barrier to the adoption of all BMPs apart from soil information collection (see Table 2.2).

Financial incentives can help alleviate the perceived costs barriers to BMP adoption. Several studies have reviewed the role of financial incentives in motivating BMP adoption. Their findings conclude that financial incentives (government subsidies, credits or loans) generally encourage BMP adoption (positive correlation), especially when barriers to adoption are financial (lack of capital and cash flow) (Liu et al, 2018) and when the primary farming objective is maximizing profit (Dessart et al, 2019). Moreover, according to a 2018 study of 285 Quebec agricultural producers, 75% of farmers would be motivated to adopt more BMPs if they had access to a financial compensation during adoption or to financial support on a yearly basis (Gagné et al., 2018). Indeed, financial incentives can reduce the perceived risks associated with the transition to more sustainable practices.

Despite a strong business case, dispositional, social and cognitive factors can still act as key barriers to BMP adoption. This is where the notion of '**perceived**' benefits, costs and risks comes into play. On paper, a business case supporting BMP adoption may be strong, with financial benefits outweighing the costs. However, in practice, a strong business case can still result in different decisions by farmers, based on their respective beliefs, personality traits, and social context (i.e. dispositional and social factors, as per Figure 2.1). For example, as confirmed in the literature discussed in section 2.1, farmers who are resistant to change and risk averse are less likely to adopt soil health BMPs. Farmers with these traits could thus still decide not to move forward with BMP adoption, even with a sound business case supporting it, as its **perceived** risks remain too high. This example highlights the importance to consider and understand farmers' underlying motivation.

As such, studies on the drivers associated with BMP implementation identified **motivation** as a prerequisite to practice change. According to Weber (2017), "economic, technological, and structural factors are only relevant **once a farmer is motivated to change practice**". To support farmers' motivation and increase their perceived benefits of BMP adoption, specific action can be taken:

- Improved communications focused on the benefits: understanding the benefits is ranked as one of the strongest motivator for farmers. Regarding soil health, they want to know for instance if the practice will reduce erosion, increase soil organic matter or reduce soil compaction (SARE, ASTA and CTIC, 2016). According to Weber (2017), messages about adoption of soil health BMPs should also focus on on-farm benefits and promote their growing use among farmer community as part of farmer identity.
- Increase awareness of environmental issues, BMPs and programs: being aware of a program or practice is a critical early step in the diffusion of innovations framework.
  - A survey carried out in 2018 on the adoption of BMPs by Quebec agricultural producers (Gagné et al., 2018) concluded that relying on **advisors** (independent and input suppliers) is the most useful tool to inform farmers about BMPs. **Extension services from neutral agents familiar with the local community** can also help farmers reduce their sense of risk and uncertainty.
  - **Peer to peer experimentation**: many studies conclude one of the best ways to get farmers to try new innovations or adopt new practices is to get information from their peers (Ontario Cover Crop Strategy, 2019). Discussions with a producer who uses BMP and farm visits (including one-on-one visit) were identified as one of the most useful tools to change farmer's behavior (Gagné et al., 2018).
  - **Field demonstrations** and self-testing opportunities are also relevant, as are **workshops and short seminars** on BMPs (Gagné et al., 2018).
  - **Provide social recognition of farmers' efforts**: considering farmer's need for recognition and the influence of neighbors on BMP adoption, recognizing farmers or regions that have a high level of adoption can be a good way to increase farmer's adoption. Conversely, informing farmers and regions which have poor environmental performance can also be a way to touch farmer pride and bring behavior changes.
- **Increase positive attitude toward BMPs and program:** helping farmers form a positive attitude about a specific practice or program is also important to promote the adoption.

Each of the action listed above can influence an individual's underlying dispositional, social, and cognitive factors, and eventually contribute to a positive decision towards BMP adoption and implementation.

2.2.2 SUPPORTING BMP ADOPTION AND IMPLEMENTATION: AN ONGOING PROCESS

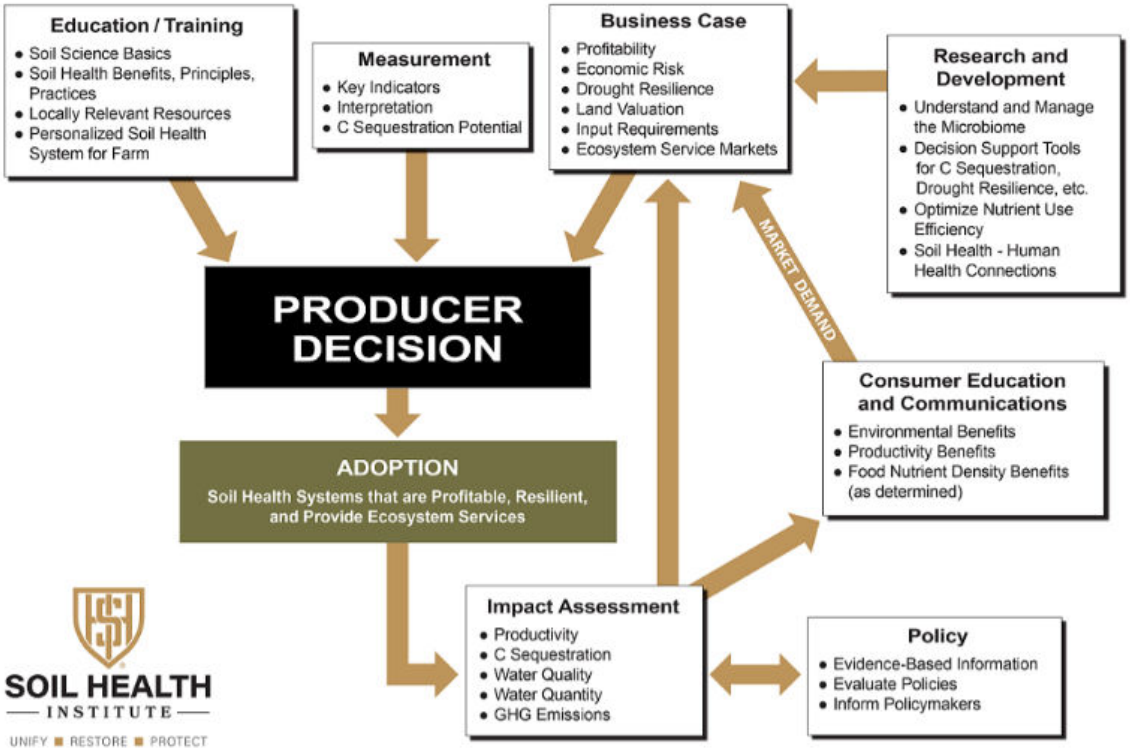
Researchers have developed a process comprised of four different stages by which farmers usually adopt BMP (Liu et al., 2018):

- Farmers become aware of available BMPs and their potential relevance to them.
- Farmers collect information about BMPs and verify their suitability and possibility of adoption.
- Trial and evaluation (BMP testing) to reduce risk and develop skills, often on small plots or areas.

- Based on trial results, adoption and adaptation take place.

Generally, a lag is observed between each step. As a result, BMP adoption and implementation is a **continuous process**. Based on the literature review and interviews with key informants, two key areas stand out to support a successful BMP adoption and implementation across the four steps listed above: education and training and tracking progress. These two areas were also identified by the Soil Health Institute as part of the strategy to increase adoption of "soil heath systems" (cf. Figure 2.2) (Soil Health Institute, 2020).

Figure 2.2
Strategy to increase adoption of "soil heath systems"



Source: Soil Health Institute, 2020.

EDUCATION AND TRAINING

As discussed in section 2.1, having access to quality information is critical for BMP adoption. As such, it is the initial knowledge that leads to adoption (Dessart et al., 2019; Wauters et al., 2010). Moreover, access to education and training also helps farmers develop and implement a soil heath management plan that suits their farm (Soil Health Institute, 2020). Lastly, interviews with key informants confirmed that farmers should be provided with the expertise they need to assess, plan and implement solutions (as they don't have time to explore that by themselves). The lack of qualified expertise in soil health is considered by most key informants as one of the biggest barriers to BMP adoption.

TRACKING PROGRESS (IMPACT ASSESSMENT)

The second important aspect for a successful BMP adoption and implementation relates to farmers' ability to **track their progress**. The Soil Health Institute's strategy refers to this as the "impact assessment" (cf. Figure 2.2) (Soil Health Institute, 2020). As such, farmers need to know how to measure the health of their soil, so they can determine their current status and monitor progress. Once a BMP is adopted, it is also critical to assess its impact on productivity, C sequestration, GHG emissions, etc. Similarly, interviews with key informants highlighted the importance for farmers to have a **better access to data** to help them establish a baseline and identify successful interventions.

To conclude, building on the literature review, interviews with key informants and the Soil Health Institute's proposed strategy in Figure 2.2, three core factors contribute to successful BMP adoption and implementation (cf. Figure 2.3):

- A strong business case (perceived benefits > perceived costs)
- Access to information and expertise (i.e. education and training)
- Ability to track progress

Figure 2.3
Successful BMP adoption and implementation framework

Source: Groupe AGÉCO.

2.3 POLICY IMPLICATIONS

This section has reviewed a broad range of factors influencing BMP adoption. It also highlighted the importance to understand farmers' decision-making process, in turn influenced by a multitude of behavioural factors unique to everyone.

As discussed, the perceived benefits, costs and risks associated with BMPs play a decisive role behind their adoption. Robust information on BMPs and their benefits to soil health and the environment can certainly help increase the perceived benefits of these practices among farmers. Also, measures aimed at alleviating the significant costs associated with BMP adoption and implementation can reduce the perceived costs and strengthen the business case around it.

In addition, many studies have proposed recommendations for programs and policies to increase BMP adoption among farm producers. Several of them mention the importance to address the **heterogeneity** between farmers and segment them in groups or 'farm types' according to their sociodemographic and geographic characteristics. According to Dessart et al. (2019), "Programs should not be one-size-fits-all". Designing region-specific environmental policies can also be a way to take into account cultural barriers, as well as specific environmental issues.

Mixing different policy tools (voluntary and mandatory adoption of sustainable practices) can be a solution to address the different farmer attitudes and situations. A mix of policy tools is usually more effective than a single approach (OECD 2010). The current mix of education, planning and grants has merit, but a wider range of tools would meet more farmers' needs. Offering a range of alternative options within programs can help address differences in farmers' styles of learning, interests, values and other attributes. For example, farmer-to-farmer learning, technical advisors, agronomic smartphone apps and how-to-videos can serve similar purposes but appeal to different people.

Policies should also focus on practices that have **real and tangible environmental benefits** to farmers, as it will increase farmer participation. As benefits may interact with one another, bundling different BMPs may make adoption more cost-effective, and thus increase the extent of adoption (Liu et al., 2018). New programs should frame farms as multifunctional enterprises, to stimulate agronomic and market innovations.

To conclude, we have seen in this section that barriers and drivers behind BMP adoption are closely related to individuals' unique characteristics, decision-making process, and motivations. Better understanding these dimensions is an important step in designing better policies to foster BMP adoption. Moreover, just like the soil, humans evolve over time. Therefore, policies aimed at supporting BMP adoption should be accompanying farmers in the long run, as they learn more about the soil, as well as themselves, throughout the process. With BMP adoption being a continuous process, **long term support**, rather than one-off interventions, is likely to be more appropriate to support farmers throughout the different stages outlined in this section.

With these considerations in mind, the next chapter dives deeper into the various policy approaches currently in place in Canada to support BMP adoption, looking at their strengths, gaps and limitations.

3. REVIEW OF POLICY APPROACHES TO BMP ADOPTION AND SYSTEM CHANGES

Chapter highlights

- To improve BMP adoption rate and foster system changes at the production level, farmers need to operate in a business environment offering the appropriate support and signals through successful policy proposals.
- A variety of public policy tools are used across Canada and elsewhere to promote and incentivize system changes and the adoption of various practices by farmers.
- Put together, these public and private tools, when designed properly, can be viewed as the components of a policy system that can help soil health systems become more attractive and accessible to farmers.
- This chapter documents 7 policy tool categories used in Canada and the provinces under the federal-provincial-territorial Canadian Agricultural Partnership (CAP). The chapter also presents some inspirational programs used here and abroad, along with their respective strengths, limitations, and gaps, as well as suggestions as to how they could be enhanced.
- Based on these observations, many different innovative, improved, or new approaches can address some of the limitations faced by any type of farmers across the country. There are thus many inspiring examples in Canada and around the world deserving to be tested on a larger scale, for the benefit of soil health.

Soil health systems and BMPs are well-known and their benefits widely documented (cf. section 1). However, as discussed in the previous chapter, their adoption and large-scale implementation is significantly influenced by the business case behind BMP adoption as well as farmers' unique behavioural factors. To improve BMP adoption rate and foster system changes at the production level, farmers need to operate in a business environment offering the appropriate support and signals through successful policy proposals.

A variety of public policy tools are used across Canada and elsewhere to promote and incentivize system changes and the adoption of various practices by farmers. Environmental risk assessment tools, cost sharing grants, tax and finance incentives, demonstrations, extension, technical advice, workshops, peer-to-peer learning, and area-based payments are all among the many approaches used in Canada (e.g. Agricultural Soil Health and Conservation Working Group, 2018; OECD 2010, 2012). These approaches are implemented differently (if at all) in each province and jurisdiction where they are used. Similar initiatives are also undertaken by the agriculture and food industry, sometimes in partnership with government (e.g. 4Rs program, sustainability initiatives). Increasingly, processors, retailers and food industry consortia are leading initiatives to promote soil health among their producers and producer organizations as part of sustainability work. Regulatory approaches are used for specific purposes within agricultural policy, such as siting large livestock facilities and manure management. Regulatory approaches are not emphasized in this report in part as no consensus exists on the application of such tools and the power of voluntary tools has not been fully harnessed.

A multitude (similar and non similar) of approaches are used in the US, Europe, Australia, Japan and other OECD countries (e.g. Henderson et al., 2020; Dessart et al., 2019; OECD 2010).

Put together, these public and private tools, when designed properly, can be viewed as the components of a policy system that can help make soil health systems more attractive and accessible to farmers. The main categories of policy tools are:

- Assessment and planning tools.
- Grants to farmers.
- Education and extension services.
- Business risk management tools.
- Payments for ecological services.
- Offset programs.

Through a review of the literature and discussion with key informants, this section documents each of the policy tools listed above in Canada and the provinces under the federal-provincial-territorial Canadian Agricultural Partnership (CAP).[21] An entire section is dedicated to each type of policy tool, summarized in sections 3.2 to 3.6. In addition to this, some inspirational programs used here and abroad are also presented, along with their respective strengths, limitations, and gaps and suggestions as to how they could be enhanced.

Prior to the presentation of each type of policy tool, section 3.1 begins with an overview of the Canadian policy framework and key agri-environmental policies and programs that form the basis of the policy system in which Canadian farmers operate and make their decisions.

3.1 CANADA'S POLICY FRAMEWORK AND AGRI-ENVIRONMENTAL PROGRAMS

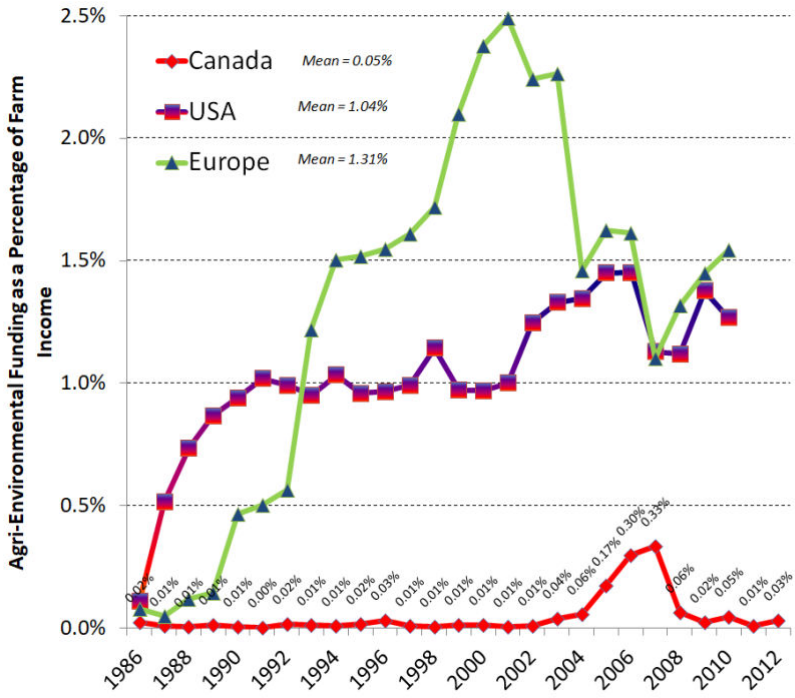
Canada's federal, provincial and territorial agricultural policies seek to achieve many objectives related to agriculture and food, including environmental sustainability. Jurisdiction for agriculture in Canada is a shared responsibility between the federal and provincial-territorial governments. Therefore, policies and programs vary significantly across the country.

Canada's approach to agricultural business risk and income stabilization policy has focused on provision of whole-farm support programs, which drive minimal production incentives. These programs aim to offer protection from "severe market volatility and disasters" (AAFC, 2014; cited in Eagle et al, 2016) and are referred to as Business Risk Management (BRM).

[21] Investments in research as well as regulatory approaches are excluded from the scope of this review.

Canada's experience with agri-environmental policies is more limited than with BRM. Canada's agri-environmental policies mostly involve cost-sharing activities, e.g. for provision of ecosystem services, including soil health (Eagle et al, 2016). In comparison to the BRM programs, funding of agri-environmental programs has been low. As well, while resourcing of farm programming aimed at environmental issues is increasing over time, the resources devoted to agri-environmental incentives in Canada remain relatively low. For example, from 2003-2010, total government agricultural payments for environmental incentives in the US and the EU amounted to 1.3% and 1.6% of all farm income. This is considerably more than the 0.13% of farm income invested similarly in Canada (OECD, 2015; cited in Eagle et al, 2016). Canada's expenditures remained similar 1986-2012 except for an increase 2005-2008 under the first Agricultural Policy Framework (Figure 3.1). That temporary surge in funding has been noted as a highly successful stage of agri-environment policy (Morrison and Fitzgibbon 2014). Funding levels could evolve in the coming years through the development and implementation of national and provincial climate policies (see side box below).

Figure 3.1
Agri-environmental expenditures in Canada, US and EU 1986-2012



Source: Data from Alison Eagle

The November 2020 federal Fall Economic Statement and the new climate plan (ECCC, 2020b) promised "to establish a new Natural Climate Solutions for Agriculture Fund" beginning in 2021-2022. $100 million was promised over the ten years, and this would leverage an additional $85 million from existing programming. A new "Canadian Agri-Environmental Strategy" would guide the fund and "be developed in collaboration with partners to support the sector's actions on climate change and other environmental priorities towards 2030 and 2050." This is a significant infusion of funding, but it is not yet clear what that funding would support (ECCC, 2020b; Government of Canada, 2020).

SIDE BOX: NATIONAL AND PROVINCIAL CLIMATE POLICIES

Canada and each provincial and territorial government have policies and programs related to climate change mitigation and adaptation. Canada sought to coordinate policies through the Pan Canadian Framework on Clean Growth and Climate Change, which falls under Environment and Climate Change Canada.

The Pan Canadian Framework contained relatively little information related to agriculture. However, it did acknowledge the potential role of agricultural soils for climate mitigation through "increasing adoption of land management practices like increasing perennial and permanent cover crops and zero-till farming". It also stressed innovation and new technology including "precision farming and 'smart' fertilizers".

Action on climate change in agriculture was deferred to the Federal-Provincial-Territorial (FPT) agricultural agreements, namely the current CAP. While there was modest emphasis on climate in the CAP, that emphasis is not sufficient for significant change.

A new federal climate plan, "A Healthy Environment and A Healthy Economy" was released in December 2020 (ECCC, 2020b) with new proposals including related to agriculture including:

- "Invest $165.7 million over seven years to support the agriculture industry in developing transformative clean technologies and help farmers adopt commercially available clean technology". Details are not yet available on how this funding would be used, whether for research or on-the-ground action or both."
- "Set a national emission reduction target of 30% below 2020 levels from fertilizers and work with fertilizer manufacturers, farmers, provinces and territories, to develop an approach to meet it. Improving how fertilizers are used through better products and practices will save farmers money and time and help protect Canada's land and water."
- "Invest up to $631 million over 10 years to work with provinces, territories, conservation organizations, Indigenous communities, private landowners, and others to restore and enhance wetlands, peatlands, grasslands and agricultural lands to boost carbon sequestration. This initiative will support improved land and resource management practices in sectors that have some of the greatest potential for increased carbon storage and will conserve carbon-rich ecosystems."
- "Provide $98.4 million over 10 years to establish a new Natural Climate Solutions for Agriculture Fund. This fund will leverage $85 million in existing programming and will be guided by a new Canadian Agri-Environmental Strategy, to be developed in collaboration with partners, to support the sector's actions on climate change and other environmental priorities towards 2030 and 2050." More detail is needed on what exactly the fund would be directed to."
- "Invest up to $3.16 billion over 10 years, to partner with provinces, territories, non-government organizations, Indigenous communities, municipalities, private landowners, and others to plant two billion trees."

Alberta, Ontario, Québec, British Columbia and other provinces have recognized agriculture in their climate policies from both mitigation and adaptation perspectives.

The OECD recently reviewed member states' climate mitigation policies for agriculture and found relatively limited action, Canada being no exception (Henderson et al., 2020). They suggest "policy efforts will need to intensify for the ... sector to contribute effectively to limiting global temperature increases."

Martorell (2017) comments that recent agriculture policy frameworks in Canada tend to emphasize economic growth over rural, social and environmental sustainability. Emphasis is on improving input use efficiency, reducing environmental impacts, and increasing outputs through genetic improvements (OECD, 2013; cited in Martorell, 2017). Technology and genomic research are emphasized, as well as farm insurance programs (Martorell, 2017). Even programs with an environmental element are oriented toward technology and market development. As well, agri-environmental policy in Canada is decentralized, in comparison to that in the US and EU (Monpetit, 2002; MacRae, 2002; cited in Martorell, 2017).

At the core of the policies surrounding agricultural production in Canada, over the past few decades, is a set of federal-provincial programs whereby federal and provincial governments regulate and fund initiatives relating to agriculture and environment. From 2008 to 2013, the Growing Forward (GF) policy framework was in place. This was followed from 2013 to 2018 with Growing Forward 2 (GF2), with a total of $3 billion of funding over the five years of the program, including a 50% increase over GF in cost-shared investments for provincially targeted initiatives.

GF2 was followed by the CAP, running from 2018 to 2023. CAP follows the overall structure of GF and GF2, again with a $3 billion investment over the five years of the program, from federal, provincial, and territorial governments. The CAP provides the foundation for government agricultural programs and services in Canada. Relative to its predecessors, the CAP focuses on streamlined programming, and programs that help farmers managing risks beyond their individual capabilities. Similar to its predecessors, the CAP comprises key agri-environmental programs, as well as programs to address markets, diversification and innovation.

The CAP comprises **federal activities and programs**, as well as **cost-shared programs** between the federal, provincial and territorial governments. In addition, producers continue to have access to a suite of **Business Risk Management (BRM)** programs designed to help them manage specific business risks on the farm and stabilize income. Each of these categories of programs is outlined briefly below.

3.1.2 FEDERAL ACTIVITIES AND PROGRAMS UNDER CAP

Agriculture and Agri-Food Canada delivers federal programs under the CAP aimed at generating economic growth in the agricultural sector. These are open to National Industry Associations, small and medium-sized enterprises, clusters, projects, and small and medium-sized enterprises with programs in the following areas.

- Growing trade and expanding markets - $297 million
  - AgriMarketing Program

  - AgriCompetitiveness Program
- Innovative and Sustainable growth in the sector - $690 million
  - AgriScience Program
  - AgriInnovate Program
- Supporting Diversity and a dynamic, evolving sector - $166.5 million
  - AgriDiversity Program
  - AgriAssurance Program

SIDE BOX: QUÉBEC'S NEW SUSTAINABLE AGRICULTURE PLAN

"Soil health and conservation practices are efficient and easily accessible, and they have a direct impact on the management and quality of water as well as on soil productivity. In addition to helping plants better adapt to climate change, soil can absorb carbon and improve the resilience of our agricultural ecosystems." Quebec Sustainable Agriculture Plan (MAPAQ, 2020).

In the fall of 2020, the Quebec government adopted an ambitious plan for sustainable agriculture, the "Agir pour une agriculture durable" that has a strong focus on healthy soils. The new ten-year plan follows many years of debate and advocacy by agricultural and civil society organizations and adopts five goals that include: "conserve and improve soil health" and "improve fertilizer management" (MAPAQ, 2020).

Each goal has targets and indicators of success. For soil health, the aim is to have 75% of cultivated areas covered by crops or crop residue during winter months (up from 50% now), as well as ensuring that 85% of all cultivated soils have at least 4% organic matter (organic matter has been declining and only 75% of fields currently meet the 4% target). The plan also incorporates the principles of soil health and best management practices under other goals as well. For example, the Plan intends to double the number of fields with conservation buffers (under protecting biodiversity). The goals to reduce the use of synthetic pesticides (by 500,000 kilos) and nitrogen fertilizers (by 15%) will also improve pest and nutrient management.

The plan has a $125 million budget for the first five years to: reward producers who have adopted sustainable practices; further knowledge development and research; implement regionally specific knowledge transfer; extension services and training (notably by the addition of 75 extension agents to advise producers). In addition, the government wants to improve the independence and impartiality of research by modernizing the law governing agronomists and other measures.

3.1.3 PROGRAMS COST-SHARED BY FEDERAL, PROVINCIAL AND TERRITORIAL GOVERNMENTS

Federal, provincial and territorial governments also continue to work under 5-year bilateral agreements. These investments are cost-shared on a 60:40 basis between the federal and provincial / territorial governments and delivered by the provinces and territories to ensure that the programs are tailored to meet regional needs.

Many of these cost-shared programs provide educational and financial support to producers implementing BMPs designed to improve environmental health or reduce environmental degradation on the farm. These programs comprise a major and increasing element of agri-environmental policy programming in Canada.

In Canada, environmental stewardship programming largely relies on supporting the adoption of on-farm BMPs through these programs. This is the primary means by which federal and provincial governments address environmental issues in the agricultural sector (Rollins and Boxall, 2018).

3.1.4 BUSINESS RISK MANAGEMENT (BRM) PROGRAMS

Producers continue to have access to a robust suite of BRM programs to help manage significant risks that threaten the viability of their farm and are beyond their capacity to manage.

- **AgriStability** is an **income stabilization** program – AgriStability is margin-based, and provides support when producers experience a large margin decline
- **AgriInvest** is an **income stabilization** program that provides cash flow to help producers manage income declines
- **AgriInsurance** provides cost-shared **insurance** against natural hazards to reduce the financial impact of production or asset losses
- **AgriRecovery** is a **disaster relief** framework to help producers with the cost of activities necessary for recovery following natural disaster events

3.2 ASSESSMENT AND PLANNING TOOLS

The main public agri-environmental assessment and planning tool used in Canada is the **Environmental Farm Plan** (EFP). Canada's EFP program is a voluntary environmental education and awareness program. It comprises a whole-farm self assessment tool that helps producers identify environmental risks on their farms and develop plans to mitigate those risks. This program is largely self-directed by the producer, with support from the provincial agency administering the program.[22] As of 2017, 40% of Canadian farms have a completed EFP, making this the most widely used environmental program in Canadian agriculture (CRSC, 2020).

[22] In several provinces, e.g., BC, Ontario and Nova Scotia, farmer organizations deliver the program at arm's length form the provincial government. Delivery of the EFP initiative varies somewhat from province to province. For example, in some provinces the farmer completes his risk assessment and action plan relatively independently, while in others this is done in consultation with a representative of the delivery agency on site at the farm. Over the past two decades, control of the EFP initiative has shifted from producer organizations and local farm communities, to the federal government, then to provincial governments (Martorell, 2017).

Throughout Canada, eligibility for producer funding under a range of federal-provincial cost-share programs are contingent on completion of an EFP. The funding basis for these programs is to offer grants to producers and local conservation associations to implement a wide variety of BMPs (see section 3.2 below).[23] Both the EFP and most of Canada's cost-share funding for producers fall under the CAP. Together, these two programs are the primary means by which Canada's federal and provincial governments address environmental issues in the agriculture sector (Rollins and Boxall, 2018). In other words, in the Canadian context, environmental farm planning has emerged as an innovative approach to addressing environmental concerns at the farm level (Holmes et al., 2011).

Over the past five years, the option of shifting toward a National EFP (NEFP) has been actively explored, and the content and delivery methods of the different provincial EFPs was compared (Table 3.1). Note that this summary is based on a study conducted in 2016. Since then, many EFPs were updated and their content may have changed. As Table 3.1 shows, EFPs cover most of the soil health issues discussed in section 1.1.

Note that the inclusion of GHG emissions in EFPs across Canada differs significantly. GHG emissions were not directly mentioned in many EFP documents in 2016. However, many factors that would contribute to GHG emission reductions are still addressed by those plans. For example, BMPs that reduce compaction, introduce cover crops, ensure proper nutrient balance, and foster proper manure storage could all contribute to GHG emission reductions.

Table 3.1
Areas of commonality found in all or almost all provincial EFP programs

BMPs	Concern covered by ALL eleven reviewed jurisdictions	Concern covered by almost ALL (8 or more) jurisdictions
Water	Water wells Stream, ditch and floodplain management Irrigation	Farm wastewater / washwater Treatment of household wastewater Water use efficiency
Air and climate	---	Energy efficiency Open burning Odour
Soil	Water erosion Tillage erosion Soil nutrients Soil structure	Field windbreaks Farmstead windbreaks

[23] The incentive system involved a variable cost share approach with funding maximums (i.e., applicants were required to provide a share of the BMP adoption/implementation costs).

BMPs	Concern covered by ALL eleven reviewed jurisdictions	Concern covered by almost ALL (8 or more) jurisdictions
Biodiversity	Non-cultivated lands Wetlands and ponds	Riparian areas
Crop Management	Crop rotation Management nutrients in growing crops Pest management Greenhouse crops Pesticide handling and storage	Seeding Equipment maintenance Field horticultural crops Fertilizers handling and storage Storage of petroleum products
Livestock Management	Intensive livestock operations Pasture and grazing management	Livestock wintering sites Storage and feeding of silage Disposal of livestock mortalities Veterinary materials waste
Manure Management	Structure of manure storage facilities Composting Nutrient management planning Application methods	Manure handling and transport
Other	Disposal of inorganic farm waste	Nuisances and normal farm practices Emergency planning

Source: National EFP Summit (CFA, 2017)

EFPs are not the only assessment and planning tools available to Canadian farmers. Another leading initiative is the **4R Nutrient Stewardship program**. In line with the need to manage nutrients to limit their loss to the environment, 4R Nutrient Stewardship is a science-based approach that applies BMPs to optimize plant nutrient availability so growers can sustainably increase yields and profitability on their farms. By implementing 4R Nutrient Stewardship, growers are better able to balance the environmental, economic and social goals of crop production.

Led in Canada by Fertilizers Canada, 4R Nutrient Stewardship has been promoted and applied across Canada under Agriculture and Agri-Food Canada's Agricultural Greenhouse Gases Program and the AgriInnovation Program (Growing Forward 2).

4R Nutrient Stewardship has been promoted and applied across Canada through a number of provincial and regional programs and initiatives. 4R Nutrient Stewardship is currently being practiced in Alberta, Manitoba, Ontario, New Brunswick, and Prince Edward Island (Fertilizers Canada 2018).[24] The initiatives under way include the following:

- **4R Designation**: 4R Designation provides recognition for farmers who complete and apply 4R Nutrient Stewardship grower plans. This initiative involves producers, agronomists and agri-retailers in a 6-steps process (Education; Planning; Reporting; Implementation; Recognition; Review).
- **eLearning**: Fertilizer Canada has developed nutrient stewardship eLearning courses to help farmers, agri-retailers, crop advisors and industry professionals adopt fertilizer best management practices.
- **4R Certification**: The 4R Certification Program is a voluntary program for Nutrient Service Providers, which include agricultural retailers, agricultural service provides, and certified professionals. The 4R Certification program translates 4R Nutrient Stewardship into a set of auditable criteria. To become 4R Certified, a Nutrient Service Provider must complete a third-party audit every two years to maintain certification. The 4R Certification program evaluates retailers on sustainable 4R Nutrient Stewardship practices in the areas of training & education, nutrient recommendations & nutrient application, and documentation. In addition to Ohio and New York, the program is now available and implemented in Ontario and Prince Edward Island.

The different 4R Nutrient Stewardship initiatives address a number of environmental concerns related to agriculture, including excessive phosphorous loadings, nitrate levels in drinking water, soil conservation, salinity, and soil and air quality concerns (Fertilizer Canada, 2020). Implementing the 4Rs system through agricultural retailers is meant to make participation much easier for individual farmers. 4R certified agronomists preparing crop plans for farmers do most of the work.

The potential for 4R nutrient stewardship to reduce nitrous oxide emissions, the most powerful GHG from crop agriculture, means that 4Rs can be an important role in future policy scenarios. The Nitrous Oxide Emission Reduction Protocol quantifies those reductions. This is also addressed in the offset section below.

Other assessment and planning tools available to and used by farmers in Canada include **certification schemes** (e.g. Canadian Organic Standard; International Sustainability & Carbon Certification (ISCC) Plus; Certified Sustainable Beef Framework), **sustainability standards** (e.g. SAI Platform's Farm Sustainability Assessment) and **self-assessment tools** (e.g. farmsustainability.ca; Dairy Farms +; Field To Market Canada). In addition to these tools, the Canadian Agricultural Sustainability Initiative (CASI) is trying to create linkages between the EFP and many of these certification systems to reduce duplication and allow farmers to navigate the range of systems more easily.

[24] Memorandum of Cooperation (MOC) to work together on the ongoing implementation and adoption of fertilizer application practices using 4R Nutrient Stewardship are in place in Saskatchewan and Québec.

These industry-led initiatives have in common that they all require farmers to go through a process of assessing their current practices and/or performance in regards to a set of criteria to meet certain requirements and/or develop action plans to improve their performance overtime. Also, while their objectives, delivery modes and scope of application differ, their content all address soil health one way or another. For instance, SAI FSA—one of the leading industry-driven sustainability tools used in Canada—covers all the BMPs in Chapter 2 except 'Pasture management' (which is out of scope for the tool) and 'Land retirement'.

Another example would be the **Certified Sustainable Beef Framework** which uses an outcome-based model, meaning that the practices used to meet the individual indicators in the standard are what is measured, not prescribing specific ways to achieve them. It has for advantage to let beef producers decide which way is best to demonstrate sustainable practices based on their individual operation, climate, region, soil type, production style, and more. The Natural Resource requirements in the Framework points out many key BMPs mentioned in section 1 to manage resources responsibly and maintain or enhance ecosystem health (CRSB, 2020).

There are also emerging initiatives such as **Responsible grain** that deserve particular attention. Responsible Grain is a national Code of Practice that demonstrates Canadian grain farmers' care and commitment to the environment. Similar to the Codes of Practice for the care and handling of farm animals, Responsible Grain contains both required and recommended practices. An entire Module of the Code is dedicated to soil health and many other sections (e.g. nutrient management, pest management, water management) cover soil health related BMPs. While participation by farmers is voluntary, Responsible Grain will foster continuous improvement in environmental sustainability in general and soil health in particular by guiding farmers towards the adoption of BMPs. This Code is expected to be released in 2021.

In sum, there are numerous agri-environmental planning and risk assessment tools available to farmers in Canada to support them in the adoption of BMPs. Given this, the question is: are they sufficient and effective at supporting farmers in adopting soil health BMPs? And if not, what improvements should be considered?

To answer this question an overview of the strengths, gaps and limitations of the current assessment and planning tools available to farmers is provided below. This review is based on a review of the literature and interviews with key informants.

3.2.1 STRENGTHS OF CURRENT ASSESSMENT AND PLANNING TOOLS

REGARDING THE EFPS:

- EFPs are available in all Canadian jurisdictions and the level of participation is significant (although far from universal). It is the most widely used environmental program in Canadian agriculture (Centre for Environmental Stewardship and Conservation, 2009: cited in Holmes et al, 2011).

- EFPs have a good track record with producers and are perceived by the farm community as being reasonably credible and meaningful to producers. Many farm organizations (e.g. Chicken Farmers of Canada; Dairy Farmers of Canada) have also identified the EFPs as a building block of their sustainability strategy.
- As an agri-environmental risk management tool, EFPs enable farmers to identify and prioritize risks based on the farm specific situations and develop customized action plans.
- Environmental farm planning is one of the most comprehensive farm planning effort in the world from an environmental perspective (Hilts, 1997; cited in Holmes et al, 2011). Specifically, EFPs address most soil health issues and include numerous BMPs beneficial to soil health.
- Except for Saskatchewan, producers can access cost-share programs based on completion of an EFP thus creating a financial incentive for developing one. Other industry-specific incentives also exist.[25]
- The EFP program has improved environmental awareness in the farm community (van Osch, 1997; cited in Holmes et al, 2011), and started to narrow the disconnect between the farm community and non-farming rural neighbors (Atari et al, 2009; cited in Holmes et al, 2011).

REGARDING THE INDUSTRY-DRIVEN TOOLS:

- Most of these tools provide clear information as to what practices are required and guidance on those that are recommended and how to implement them.
- These initiatives send strong market signals to producers about the importance of adopting BMPs to meet market demand for sustainability or maintain public trust.
- Some tools, such as the 4R Stewardship and certifications, provide recognition to producers and, in some circumstances, market premiums (e.g. organic certification).
- 4R Stewardship can help reduce nitrous oxide emissions. It is thus important as part of the suite crop agriculture climate BMPs.
- While some tools are sector-specific (e.g. Certified Sustainable Beef Framework) or address specific concerns (4R Stewardship) or production systems (e.g. FSA for crop production), they promote a whole-farm approach by addressing overall management practices (in opposition of being crop-specific).

Some industry-led initiatives, such as the Certified Sustainable Beef Framework and the Grain Code, are the results of discussions involving all key actors of the industry, ranging from producer associations, processors, input suppliers, governments and NGOs; they are therefore credible and accepted. Some initiatives such as the Certified Sustainable Beef Framework are pioneering the sustainability agenda in the industry.

[25] For instance, the environment module of proAction is likely to be based on the Environmental Farm Plan, thus requiring all Canadian dairy farmers to have an EFP on their farm.

3.2.2 GAPS AND LIMITATIONS OF CURRENT ASSESSMENT AND PLANNING TOOLS

REGARDING THE EFPS:

- EFPs are not consistently focusing on soil health or soil conservation in a detailed manner but refer to additional resources for detail. However, Alberta is working on the development of 'soil health reports' based on the content of the current EFP.
- While workbooks provide a wealth of information on BMPs and their rationale, many EFPs are delivered without much education and extension services provided to farmers.
- Barriers exist to further increase participation to the EFP program. Also, a high drop-out rate is seen beyond certain stages in the program, due to the following reasons:
  - Early in the program there were concerns regarding the confidentiality of the process, and fears of government intervention in agricultural land use (Smithers and Furman, 2003; cited in Holmes et al, 2011).
  - Financial costs of implementing environmental improvements (e.g. van Osch, 1997; cited in Holmes et al, 2011).
- Possible limited transparency resulting from privileging of farmer views, given that the process is based on self-assessment and peer review (Robinson, 2006; cited in Holmes et al, 2011).
- EFPs are activity-based rather than performance-based. In other words, the programs involve the adoption/implementation of BMPs at the producer level rather than selecting projects based upon forecasting levels of environmental improvements from BMP adoption (Boxall, 2018). Consequently, it remains challenging to unequivocally demonstrate environmental outcomes, including to producers (e.g. Smithers and Furman, 2003; cited in Holmes et al, 2011; Summers et al., 2008). While participation is important, as EFP programs have evolved, better measures of effectiveness are needed (Smith et al., 2020).
- More data needs to be gathered on EFP enrolment – effective program evaluation requires an understanding of the pool of potential participants, particularly those who have not yet adopted EFPs (Rollins and Boxall, 2018; Smith et al., 2020).
- Sample surveys is an approach used to document level of EFP implementation and evaluate effectiveness (Summers et al., 2008; Smith et al., 2020).
- EFPs are not necessarily supporting innovation as they have a built-in list of BMPs to be considered by farmers.
- EFPs are farm-specific. They do not provide landscape-based solutions to address issues that are being experienced at a regional level (e.g. watershed level).

REGARDING THE INDUSTRY-DRIVEN TOOLS:

- None of the leading industry-driven tools are focusing on soil health or soil conservation in a meaningful way.
- The industry-driven tools are not available in all provinces or applicable to all sectors.
- Except for a few examples (e.g. 4R Stewardship), no education or training is provided to farmers to help them implement the tools and related BMPs.

- Most industry-driven tools are designed as checklist to assess performance or verify compliance. They lack the flexibility needed to account for each farm's specific situation.
- Incentives for using these tools are not universal and depend on each farm's particular situation. For instance, feed production offers very limited incentives for crop producers to comply with sustainability standards compared to those producing grain for human consumption given the different demand for sustainability in the two markets.
- The growing number of overlapping initiatives is a source of confusion for farmers and agri-food businesses alike. The Canadian Agricultural Sustainability Initiative seeks to connect the many approaches.
- Market-driven initiatives may be volatile and depend on market demand in regard to certain concerns.

In sum, EFPs and other industry-driven tools are well-established resources or initiatives designed to meet specific market demand for sustainability. They are also addressing soil health and promoting the adoption of many key beneficial BMPs. However, the review shows that these tools are associated to important limitations:

- They are not always focusing on soil health or soil conservation in a detailed way. Furthermore, each tool is addressing soil health issues or looking at soil health BMPs differently. This limits the ability of farmers and advisors using these tools to assess and manage soil health in a systematic and consistent way.
- These tools are usually not delivered together with education and training to support farmers in the implementation of BMPs.
- These tools are associated to relatively limited incentives (financial or others).

3.2.3 INNOVATIVE APPROACHES TO CONSIDER

Below are examples of innovative approaches that address some of EFPs limitations and other industry driven tools.

INNOVATIVE APPROACH #1: FARMLAND HEALTH CHECK-UP ONTARIO

Geography: Ontario

Farmland Health Check-up is a detailed soil health planning tool prepared by farmers with assistance of a Certified Crop Advisor. It looks at three fields and all current practices leading to a prescription for each field for changes in practices. The intent is to get farmers started on a few fields in one year and that will continue to other fields and years.

Pros	It provides detailed soil health analysis and prescriptions for several fields It provides subsidized access to advice from Certified Crop Advisors
Cons	Requires having access to trained professionals to work with farmers

Benefits	Addresses knowledge and advice barriers Provides the opportunity identify site-specific solutions

INNOVATIVE APPROACH #2: SOIL HEALTH MANAGEMENT PLAN

Geography: United States

The Natural Resources Conservation Service (NRCS) developed a new system for Soil Health Management Plans under the US Farm Bill. These are plans developed by extension specialists working with farmers/landowners. The NRCS has recently issued new directions and supports to their staff, Conservation Districts and private sector providers of technical assistance on the plans.

Pros	Comprehensive planning approach prepared by trained professional working with farmer
Cons	Requires having access to trained professionals to work with farmers
Benefits	Addresses knowledge and advice barriers Provides the opportunity identify site-specific solutions

INNOVATIVE APPROACH #3: GENERAL MILLS REGENERATIVE AGRICULTURE SELF-ASSESSMENT V2

Geography: Global

Version 2.0 of the General Mills Regenerative Agriculture Self-Assessment is a user-friendly tool for farmers to better align their agricultural practices with the principles of regenerative agriculture. The tool is designed to be inclusive of all farming systems — small and large, organic and conventional, crop and livestock, domestic and international. This questionnaire is not a standard or a framework for a given product, but rather a self-assessment designed to be completed in under 20 minutes. Web-based tool upcoming.

Pros	A user-friendly way to self-assess soil health related BMPs at the farm level Market-driven initiatives send a signal that there is a demand for beneficial soil health practices
Cons	Not tied to any specific incentive Could be seen by producers as a developing mandatory standard Specific to regenerative agriculture - and not soil health in general
Benefits	Addresses knowledge and advice barriers

INNOVATIVE APPROACH #4: IP-SUISSE STANDARDS

Geography: Switzerland

IP-SUISSE is a farm organization that owns a third-party verified sustainable production standard. The standard is comprised of general and crop-specific requirements. One particularity of this standard is that some requirements are based on a points system. This system is based on a list of BMPs, to which are associated a certain number of points. To get certified, farmers need to select and implement BMPs from that list to obtain a minimum of 15 points. 18 500 farmers are members of IP-SUISSE.

Pros	A practice-based tool that is outcome-oriented. It recognizes that different paths can lead to similar outcomes
	Allows producers to identify those BMPs that are best suited to their farm
	Gamification (incentive for producers to get more points)
Cons	Does not support innovation (producers have to select amongst listed BMPs)
Benefits	A flexible yet structured approach to support BMP adoption and lead to positive environmental outcomes

3.3 GRANTS TO FARMERS

Grants to farmers, also known as cost-share programs, largely under the CAP, are the primary means by which Canada's federal and provincial governments incentivize addressing environmental issues in the agriculture sector (Rollins and Boxall, 2018). The structure of these programs is relatively similar across the country, although provinces vary in the emphasis they place on each environmental objective. In each province, a set of BMPs is defined, and producers with completed, valid EFPs can apply to implement a BMP. Successful applicants receive a fixed percentage of the implementation costs to be covered by the government, up to a pre-defined limit.

Despite these similarities, there is a range of cost-share delivery models being used by provincial agencies in charge of their delivery. In turn, each of these delivery models has advantages and disadvantages. These models range from being very streamlined and predictable (first-come, first-served) to being merit-based and focused on support for projects that maximize measured benefit toward desired outcomes. Table 3.2 provides a comparison of the strengths and limitations of four distinct stewardship program structures (OSCIA 2014):

- **Conventional First-come, First-served**: Under this delivery mechanism, applications are approved or rejected in the order in which they are received. Cost shares are set for each BMP, and targeting is established at the stage of setting eligibility requirements, with funding levels and selection of actions taking place at the design stage. Cost-share levels are equal for all applicants implementing similar projects.

- **Merit-Based First-come, First-served**: This builds on the first-come, first-served model, adding an element of targeting. Cost-share levels vary, focusing funding on projects of high environmental value, while also supporting those with more modest impact. Cost-share allocations for approved projects are based on the achievement level proposed, as measured by practice change or through project results. This requires development of a streamlined Environmental Benefits Index (EBI) to identify the level of environmental benefit associated with a given project application.
- **Merit-Based with Intake Periods:** This approach uses a competitive process in that applications are accepted within assigned intake periods throughout the year, rather than on a first-come, first-served basis. Applications from each intake period are compared and ranked relative to one another for environmental benefits. This requires development of an assessment tool to identify projects that offer the most significant benefits.
- **Conservation Tender:** Cost-share levels are determined by the farmer. Applicants identify the funding they require to complete the proposed project, based on their financial needs. In this way, individual needs are taken into account. The application process is competitive in that applications received during a set window are assessed against each other as to benefits for dollars invested. A robust EBI is needed, using available science to create key questions.

Table 3.2
Comparison of four distinct stewardship program structures

Funding models	Strengths	Weaknesses
Conventional first-come, first-served	Works well to encourage broad adoption of a BMP Quick response to applications Simple to implement, no subject matter expertise required Low administration costs	Program budget and project demand need to be well matched Monitoring environmental impact is difficult (inadequate data - limited to eligibility criteria - to tell what benefits were provided) No targeting, so often the worst offenders don't participate and the value of the improvement is modest
Merit-based first-come, first-served	Program dollars are focused on projects with high benefit to society Applicants know what to expect (e.g. cost-share level is known) Targeting is defendable and transparent	Slower application process – additional effort is required from the applicant to provide (and verify) additional information Requires development of a streamlined Environmental Benefits Index (EBI) to identify the level of environmental benefit associated with a given project application EBI must be defendable, likely requiring consultation with experts Program budget must match project demand Producers may go back to old conventional practices if the program is turned down
Merit-based with intake periods	The EBI, developed with subject matter experts, eliminates the need for an application review committee, providing an efficient and objective review process Only projects that score well on established parameters (providing most benefit) are funded Use of the EBI provides farm-level data on project impacts Repeating intakes eliminate jockeying for first-come, first-served funding, allowing applicants time to think projects through	Evaluation may be perceived as complex (not yet well understood) Application process is lengthy relative to first-come, first-served, and program-specific, requiring more upfront work by farmers with no guarantee of funding Parameters are needed around multiple applications from the same producer, to maintain the integrity of the system
Conservation Tender	Sophisticated and technical EBIs have been developed to enable comparisons of different projects Decisions can target the best outcome for reasonable cost, not necessarily the lowest cost The necessity of obtaining expert input helps build relationships between farmers and stewardship organizations	Most effective when higher proportions of applications are turned down, hence clear communication is critical Requirement for some applicants to involve specialists Considerable work is required to apply, with no guarantee of success

Source: OSCIA 2014 and Groupe AGÉCO.

Many of the current cost-share programs funded under the federal-provincial-territorial Canadian Agricultural Partnership are relevant to soil health. In fact, a review of the provincial programs under the federal-provincial-territorial Canadian Agricultural Partnership shows that existing cost-share programs are addressing many of the main soil issues or types of degradation (Table 3.3). This result also reflects the different provincial priorities when it comes to addressing soil health issues.

Table 3.3
Share of cost-share programs addressing soil health issues

Soil issues	Share of programs addressing the issue
Water erosion	67%
Wind erosion	56%
Salinity	18%
Loss of SOM	61%
Decline in soil fertility	50%
Soil acidity / alkalinity	14%
Decline in soil structure	51%
Soil pollution	24%

Note: 84 programs were identified nationally. Connections to soil issues is based on the program description.
Source: Groupe AGÉCO.

Grants to farmers are a pillar of the Canadian agri-environmental policy. However, the effectiveness of their structure and the application process may be questioned. In a recent development, the 2020 federal Fall Economic Statement and the new federal climate plan (ECCC, 2020b) promised “a new Natural Climate Solutions for Agriculture Fund” beginning in 2021-2022 with approximately $100 million over the ten years. Another $631 million was promised “to restore and enhance wetlands, peatlands, grasslands and agricultural lands to boost carbon sequestration”. A further $3.16 billion over 10 years is promised “to partner with provinces, territories, non-government organizations, Indigenous communities, municipalities, private landowners, and others to plant two billion trees.” These are significant infusions of funding, but it is not yet clear what that funding would support to help farmers with soil health.

Based on a review of the literature and interviews with key informants a review of the strengths, gaps and limitations of these programs is provided below.

3.3.1 STRENGTHS OF CURRENT GRANTS TO FARMERS

- Grants to producers help address a key barrier to BMP adoption, the capital cost of adopting BMPs.
- Grants allow producers to make real changes and have been successful in advancing soil health amongst other objectives. For instance, a study undertaken in 2010-11 in Ontario to evaluate the level of implementation of the EFP showed that farmers who had completed or were implementing 67.5% (median) of their action plans, invested an average of C$69,600 per farm in agri-environmental activities (of which 73% was drawn from their own funds) and spent 130 hours of their time per farm (Smith et al., 2020). These efforts may not have taken place without the financial support provided to farmers.
- In-keeping with FPT agreements, cost-share programs are designed at the provincial level which allows to regionalize intervention to address specific agri-environmental issues.

3.3.2 GAPS AND LIMITATIONS OF CURRENT GRANTS TO FARMERS

- The Auditor General of Canada has criticized the failure to measure the efficiency and efficacy of Canada's agri-environmental cost-share programs (Office of the Auditor General, 2008). Since then, little publicly available evidence can be found of these concerns regarding program evaluation being addressed (Rollins and Boxall, 2018).
  - Canada's federal and provincial governments, between them, hold a wealth of data that could be combined to evaluate the efficiency and efficacy of the cost-share programs. For example, provincial agriculture ministries have data on BMP adoption and AAFC (agri-environmental indicators) has data defining baselines and trends in environmental quality across Canada. However, little meaningful evaluation has taken place (Rollins and Boxall, 2018).
  - Using BMP adoption data from Alberta Agriculture and Forestry, and environmental data from NAHARP, a rudimentary evaluation of environmental stewardship programming in Alberta was made. Findings suggested that public spending on BMPs in Alberta has failed to target regions and issues of public importance. E.g., for some BMPs, more BMP funding appears to have been spent per acre on lower-risk land that is already improving. More data is needed (e.g. existing data that is not currently available) to confirm this (Rollins and Boxall, 2018).
  - To better assess grant programs, more data is needed on EFP enrolment (as noted above under the EFP program). Since an EFP is required to apply to cost-share programs, research is needed to identify which farmers have not completed an EFP, the reasons why, and how their participation to EFP could be encouraged (Rollins and Boxall, 2018; Smith et al., 2020).
  - Across Canada, only 40% of farms had an EFP in 2016 (Statistics Canada 2019), which is required to access most grant programs. Therefore, 60% of farmers are not participating in the agri-environmental grant programs. Many of the above gaps and limitations can be considered as contributors to this situation.

  - Funding allocated to agri-environmental incentives in Canada is low compared to some comparable jurisdictions like the United States and Europe (Eagle et al., 2016). Agri-environmental programs are routinely oversubscribed with demand significantly outstripping available funding (Morrison and FitzGibbon, 2014).
- Grants to farmers are not necessarily targeting producers or issues that need it most:
  - Larger farms are less likely to use these programs because they have the necessary resources to assess and manage agri-environmental risks or because funding ceilings are too low for their needs. Smaller farmers may not find time to go through the complex application process or see the value of these programs.
  - Adoption levels show that BMPs primarily resulting in private benefits to the producer (e.g., safe product storage, shelters, and watering systems) are the most popular BMPs adopted. In contrast, BMPs primarily resulting in public benefits (e.g., wetland restoration, native range restoration, etc.) were the least commonly adopted BMPs (Boxall, 2018). Higher cost share levels are sometimes offered for BMPs with higher public and low private benefits.
- Barriers and impediments exist for the uptake of the cost-share programs:
  - Producers need to pay upfront and be reimbursed later.
  - Depending on the delivery mode, applications can be quite complex and become a major deterrent. It is often cited by individual farmers and farm organizations.
  - Changes in farm practices usually occur in small steps and trial and error, often on small acreages with low costs and sometimes with borrowed equipment or hiring a custom operator. A small project may not be worth completing the paperwork to get a small grant.
  - Depending on the available cost-share (i.e. percentage and maximum funding) the proposed grants may offer an insufficient return on investment to farmers.
- Most grants provide one-off payments to access equipment or services. They do not provide incentive over time to support system change. Governments are generally unable to fund multi-year projects. Furthermore, programs are based on a 5-year funding agreement and lack continuity.
- While some flexibility may exist, cost-share programs are not necessarily supporting innovation as they target a list of specific BMPs to be considered by farmers.
- Current grants do not sufficiently reward positive and innovative behaviors among farmers.

3.3.3 INNOVATIVE APPROACHES TO CONSIDER

Grants are an essential tool to support farmers in adopting BMPs. However, there are limitations and existing gaps that need to be addressed. Below are examples of innovative, improved or new program approaches that could address some of these limitations.

INNOVATIVE APPROACH #1: 2020 HEALTHY SOILS PROGRAM (HSP) INCENTIVES PROGRAM

Geography: California (United States)

The objectives of the HSP are to increase implementation of conservation management practices that improve soil health, carbon sequestration, and reduce atmospheric greenhouse gases (GHGs). The program does so by:

1. Providing financial incentives to California growers and ranchers for agricultural management practices that sequester carbon, reduce atmospheric GHGs, and improve soil health.
2. Funding on-farm demonstration projects that conduct research and/or showcase conservation management practices that mitigate GHG emissions and improve soil health.
3. Creating a platform promoting widespread adoption of conservation management practices throughout the state.

Pros	Specifically targets soil health and GHG emission reductions
	Covers a large number of eligible BMPs
	Cost-sharing is not required (but encouraged)
	Recipients may be eligible for advance payments of up to 25 percent of the grant award
	Recipients are required to maintain implementation of practices incentivized through this program through the term of the grant agreement (3 to 10 years)
Cons	Applications require effort from the applicants to meet requirements
Benefits	Advance payment option addresses access to capital barrier
	The requirement to maintain the BMP in place ensures that benefits last over time
	Supports innovation

INNOVATIVE APPROACH #2: COVER CROP PROGRAM MARYLAND DEPARTMENT OF AGRICULTURE

Geography: Maryland (United States)

The Maryland Agricultural Water Quality Cost-Share (MACS) Program provides grants to help farmers offset seed, labour, and equipment costs to plant cover crops in their fields following the harvest of summer crops. The base payment is $40/acre. The base rate for aerial/aerial ground seeding is $45/acre. Incorporated seed qualifies for a $10/acre early planting incentive. There is a five-acre minimum. The total number of acres enrolled may not exceed acreage managed under the farm's current Nutrient Management Plan.

To receive payment, farmers must certify cover crops with their soil conservation district within one week of planting and no later than November 13, 2020. There are also eligibility requirements (compliance with Maryland's nutrient management regulations; a nutrient Management Plan Certification is required).

Pros	Grants make planting cover crops more affordable (capital cost risks)
	Ease of application (mail-in enrollment for this year)
	Eligibility conditional with compliance with Maryland's nutrient management regulations and having a current Nutrient Management Plan Certification
Cons	Program is evolving year to year based on budget availability
	No extension services attached
Benefits	Provide direct support to farmers to adopt BMP
	Preconditions apply

INNOVATIVE APPROACH #3: SUPPORT FOR THE TRANSITION TOWARD ORGANIC AGRICULTURE

Geography: Québec

The objective is to support businesses that help increase the supply of organic agricultural products by converting plant, maple and bee production units to organic production. Maximum $ 20,000 per farm business, i.e. $ 10,000 for pre-certification and $ 10,000 for certification.

Pros	Designed to support farmers in the transition process towards a new production system
	Provides direct financial support to cover additional costs (not tied to a particular BMP)
	Support is provided at key stages of the certification process
	Tied to other government interventions supporting conversion to organic agriculture
Cons	Support may not be sufficient to make a difference in the decision to transition towards organic agriculture
Benefits	The program recognizes the need to support farmers in a system shift

INNOVATIVE APPROACH #4: CIG ON-FARM CONSERVATION INNOVATION TRIALS

Geography: United States

Authorized in the 2018 Farm Bill, On-Farm Conservation Innovation Trials support more widespread adoption of innovative approaches, practices and systems on working lands. On-Farm Trials projects feature collaboration between NRCS and partners to implement on-the-ground conservation activities and then evaluate their impact. Incentive payments are provided to producers to offset the risk of implementing innovative approaches. The Soil Health Demonstration Trial (SHD) component of On-Farm Trials focuses exclusively on implementation of conservation practices and systems that improve soil health.

Up to $25 million annually is available for On-Farm Trials. Funding goes directly to partners, which in turn provide technical assistance and incentive payments to producers to implement innovative approaches on their lands. Producers receiving On-Farm Trials payments must be eligible to participate in the Environmental Quality Incentives Program (EQIP). The maximum On-Farm Trials award for 2020 is $5 million. The minimum award is $250,000.

Pros	Directly supports innovation Directly addresses soil health (issues and BMPs) Features collaboration between NRCS and partners Aims at generating data and knowledge to scale-up benefits
Cons	Project-based; farmers need to prepare and submit an application and be awarded funding
Benefits	Supports innovation and innovators in testing new approaches and techniques beneficial to soil health

INNOVATIVE APPROACH #5: SOIL HEALTH ANALYSIS FOR PEI PRODUCERS & WATERSHEDS PROJECT

Geography: Prince Edward Island

The Soil Health Analysis for PEI Island Producers and Watersheds Project is a project under the Strategic Industry Growth Initiative. The project is designed to support environmental sustainability and environmental management decisions, soil health, and improvements to agronomic productivity. The project covers the additional costs of soil health analysis, which is considered an add-on testing package to standard chemistry analysis. The funding does not cover the cost of the S3 chemistry analysis (which is required to complete a soil health analysis on a soil sample).

Pros	Vital component of nutrient management planning Necessary for understanding soil health Provides concrete scientific evidence for farmers on soil nutrient needs
Cons	Does not cover the entire cost of soil analysis.
Benefits	Soil health analysis is the starting point for farmers to take action and monitor soil health. Facilitating access to soil analysis is key.

	Provides supports for adoption and demonstration until farmers become comfortable to perform soil testing or see its economic value

INNOVATIVE APPROACH #6: REPLANT CAPITAL

Geography: United States

RePlant Capital is a new farmer-first financial platform. It provides flexible, low-cost loans to leading farmers, with simplified documentation and minimal security/collateral requirements to support farmers in adopting regenerative and organic practices and increase their profitability. At the same time, the Fund will invest in ag tech solutions that allow farmers to save money, save their topsoil and water, while doing more on-farm processing and more direct-to-consumer distribution.

The 10-year flagship Soil Fund is targeting an allocation of 80% loans to the most capable farmers transitioning to regenerative and organic practices and 20% equity investments in the most innovative entrepreneurs looking to disrupt and redesign the extractive U.S. food system. $250M in integrated capital fund is available for these projects.

Pros	A fund dedicated to addressing soil health issues and supporting farmers' adoption of BMPs
	Capital targeting the most capable farmers
	A private initiative; no public investment involved
Cons	Few public information on the terms and conditions to access funding
	Supports only farmers and projects likely to be profitable and to generate returns on investment
	Relies on private funds
Benefits	Demonstrates that investing in soil health can be financially sound and generate returns on investment for producers as well as for financial institutions

3.4 EDUCATION AND EXTENSION SERVICES

Acquiring knowledge on soil health practices is intensive and requires trial and error. Therefore, experience, advice, mentoring, demonstration, and ongoing technical advice are essential to success and increasing adoption. Agricultural training and extension services are also critical to facilitate farmers' access to improved technology and knowledge, in turn enabling them to adapt to changing circumstances (OECD, 2015).

Research shows that in Canada, between 1985-2016, the government expenditures decreased in real terms and as a share of agricultural GDP, for all innovation-related activities such as agricultural research and development, education, and extension, not just agri-environmental (Agricultural Institute of Canada, 2017). Nevertheless, the share of total GDP in support of innovation-related activities such as agricultural R&D, education, and extension in Canada was higher than the average in OECD countries 1985-2016 (Agricultural Institute of Canada, 2017; OECD, 2015). In part, this reflects the increasing role of non-government actors in those activities. It also reflects decreasing engagement of the government in activities such as extension services.

Given the large number of farmers in Canada, extension services are particularly important for facilitating access to technology and knowledge, as well as for effective participation in innovation networks (Agricultural Institute of Canada, 2017; OECD, 2015). In Canada, in the past, knowledge transfer has been provided through provincial extension agents, working closely with producers. This extension was complemented by formal and informal training offered by post-secondary agricultural institutions, at either degree, or diploma level or as continuing education. Individual university and government researchers would provide research results directly to producers and provide outreach on their results.

Government extension services are led by provincial governments but have been substantially reduced over the past few decades (OECD, 2015) with the general downsizing of government services, but trends differ among provinces (Agricultural Institute of Canada, 2017). In 2020, there are divergent approaches with Alberta implementing another downsizing while Québec announced the hiring of 75 new extension staff as part of its Sustainable Agriculture Plan. Several factors have contributed to the decline of Canada's public extension system (OECD, 2015), including:

- The challenge of documenting the economic benefits of extension and overall effectiveness of the dominant extension model.
- Funding and program cuts to government extension services.
- Increasing involvement of industry in knowledge transfer (related to government funding cuts).

Over the past 20 years, the use of provincial extension agents and researcher publications has ceased to be the main extension mechanism, with increasing participation of industry-led groups and private companies. The result is a risk that advice is often bundle with the product being sold.

Producer organizations also offer information through various media on a wide range of agronomic and environmental topics. Indeed, a review of the agri-environmental programs and tools funded under CAP found that there are relatively few programs provided by provincial governments supporting extension services and peer-to-peer learning available to producers (Table 3.4).

Table 3.4
Examples of provincial agricultural education and extension services funded under CAP

BMPs	Objectives
Farm Adaptation Innovator Program (B.C.)	To develop farm-level, applied research projects in line with adaptation to climate change
Environmental Stewardship and Climate Change – Group (AB)	To support extension delivery, carry out applied research, and strategically manage data that improve producer understanding of key environmental practices (including soil health) that can increase market access
Accelerating the Advancement of Agricultural Innovation (AB)	To support activities that demonstrate applicability of innovations new to Alberta, including those advancing environmental stewardship
Ag Demonstration of Practices and Technologies (ADOPT) (SK)	The ADOPT program provides funding to help producer groups demonstrate and evaluate new agricultural practices and technologies at the local level. The results of successful trials can then be adopted by farming operations in the region.
Ontario Soil Network (ON)	The purpose is to improve Ontario's soils by connecting and supporting farmers across the province through training, access to research, and networking opportunities.
Appui à l'utilisation des services-conseils par les entreprises (QC)	To access a variety of consulting services to improve business practices and make informed decisions.

Source: Groupe AGÉCO.

Private companies now train professionals to provide customer services related to input and equipment sales (e.g. agronomists advising on timing of herbicide application). In other examples, private companies also host field days, on-site demonstrations, research trials, trade shows, etc. As mentioned above, the result is a risk that advice is often bundled with the product being sold, while health management is about ecological knowledge which typically results in lower input purchases.

Interaction of federal and provincial government science and technical staff with the private sector has become an important mechanism to promote knowledge transfer and adoption (Agricultural Institute of Canada, 2017; OECD, 2015). Public research institutions are supplementing their own outreach by working with industry distribution channels. Technology transfer mechanisms include:

- Direct transfer from regional specialists.
- Transfer through industry organizations or delivery agents.
- Toll-free call centres providing professional and technical advice.
- Transfer through digital tools and platforms.

- Detailed technical manuals informing users about issues and providing guidance on adoption.

In addition to agricultural training and extension services, other tactics can be used by farmers to learn more about soil health practices. For instance, farmers can access **technical information** on BMPs which is plentiful online. For example, EFP soil management worksheet (and other related topics) and info sheets provided by governmental agencies can help inform farmers on soil health BMPs.[26] Similarly, more and more digital resources, videos, and podcasts are available to farmers.[27] Smartphone applications can also provide assistance to farmers with their daily operations and decision-making processes.[28]

Farmers can also access to and participate in **demonstration and workshops**, including demonstration sites, on-farm research and events. These activities are conducted throughout the country and led by different groups (e.g. Caravane des sols in Quebec; On-Farm Applied Research and Monitoring (ONFARM) in Ontario; Discovery Farm and AgriARM in Saskatchewan. These activities also provide the opportunity to support **peer-to-peer learning,** a very effective driver behind BMP implementation. Existing organizations and networks such as Ontario Soil Network, OSCIA, Réseau Agriconseils in Quebec, Saskatchewan Soil Conservation Association, can also support peer-to-peer learning for farmers and advisors alike.

However, the question is whether existing services have enough support to convey the knowledge needed to adopt key soil health practices. Key informants interviewed as part of this project all agreed that the answer to this question is no. In fact, education and extension services pertaining to soil health in particular are considered a real gap in Canada. While the industry picked-up a substantive part of that role after governments divested that field, major gaps remain:

- Soil health is knowledge intensive and there are too few professionals with the expertise needed to support producers. According to many key informants, most agricultural professionals are not sufficiently trained in that field to support farmers in assessing their specific needs, identifying adapted solutions and implementing them in an effective way over time; yet accessing such support is one of the major drivers to BMP adoption (cf. Section 3.4).
- With extension services mostly delivered by private companies, BMPs not associated to direct or short-term economic awards (but with medium to high social value) are not supported the way they should be; even public networks (e.g. Réseau Agriconseils in Quebec) have less and less time to provide education given the funding system they rely on). Therefore, there is a risk for the advice given to be bundled with the short-term interest of selling the products.

Many key informants noted that the access to such expertise is instrumental given the particular challenges farmers are facing when it comes to soil health:

[26] For instance, OMAFRA provides short publications based on EFP content specifically on soil health topics (source).

[27] For instance, the Ontario Soil and Crop Improvement Association (OSCIA) is currently working on a series of videos on soil health BMPs for farmers. The *Centre de référence en agriculture et agroalimentaire du Québec* (CRAAQ) also offers webinars a series of webinar on soil health.

[28] In 2018 a study conducted for the Ontario Federation of Agriculture identified 103 agri-environmental assessment tools primarily developed and/or used in Ontario alone. These tools were most commonly developed for the purposes of nutrient management, pest management, disease management, weather forecasting, and soil health (Wilton Consulting Group, 2018).

- The barriers to BMP adoption can be more social and economic than agronomic. Producers may know what the practices are. However, changing practices often requires a fundamental shift in mindset. This process requires time and adequate support from professionals and peers.
- Soil health benefits take time to come to fruition. Farmers often have to go through a transition period during which losses may be experienced (e.g. lower yields; higher costs; lower revenue). This is why in Europe, instruments specifically supporting the transition period exist. Many producers will prefer to deal with issues with short-term solutions rather than taking additional risks with uncertain outcomes (e.g. drain compacted soils rather than adopting BMPs to address this issue over time).
- New BMPs need to make economic sense ("if it pays it stays"). However not all BMPs beneficial to soil health are proven to be 'marketable'. Documentation of economics is often lacking. For instance, adding small grains to crop rotation makes agronomic sense but market prices may not be sufficient to sustain this practice. Also, farmers facing labour shortage will look for solutions that save time rather than the opposite.
- Adopting new practices (and changing production systems) is financially risky and many producers are not in a financial position to undertake any additional financial risks.

For all these reasons access to relevant and quality information and extension services is decisive to overcome these barriers and support producers in implementing agronomic innovations. Conversely the lack of knowledge about BMPs and insufficient understanding of their benefits are major barriers for farmers (cf. section 2).

Based on the above discussion, a summary of the strengths, gaps and limitations associated to current education and services provided to Canadian farmers in general and soil health in particular is provided below.

3.4.1 STRENGTHS OF CURRENT EDUCATION AND SERVICES

- Overall, contracted agronomists and crop advisors can provide well-informed standards and are good at answering the questions of their clients.
- Nutrient management training through 4Rs nutrient stewardship shows promise in offering economical training to farm advisors on a critical issue related to GHG emissions. But this is a new training system that is still in early stages.
- There is a wealth of information available online about soil health both in Canada and abroad.

3.4.2 GAPS AND LIMITATIONS OF CURRENT EDUCATION AND SERVICES

- There is a general lack of education and extension services pertaining to soil health in particular.
- While a wealth of information is available online about soil health, these resources are not always sufficiently 'actionable' for farmers and advisors. Also, not all this information is made available in user-friendly formats (e.g. videos, podcasts, apps).

- Resources about soil health is spread out across jurisdictions, platforms and websites. There are many overlaps and a lack of coordination in how these resources are developed and made available to farmers and advisors. As of now, it is not possible to determine 'who does what' with respect to soil health in Canada and to make that information available for farmers and advisors in an efficient way.
- Soil health information is not always available for all production systems, commodities, and soil types, leaving gaps in how to interpret general principles for specific situations.
- In-service soil health training for farm advisors (e.g. agronomists, agrologists, certified crop advisors) can be difficult to access.

3.4.3 INNOVATIVE APPROACHES TO CONSIDER

Education and extension services are critical to support farmers and their advisors in adopting soil health BMPs. However significant gaps exist in Canada. Below are examples of innovative approaches that address some of these limitations and could be considered for the development of improved/new and innovative program instruments.

INNOVATIVE APPROACH #1: ON-FARM APPLIED RESEARCH AND MONITORING (ONFARM)

Geography: Ontario

ONFARM is a $5.75 million, multi-year project to help Ontario farmers strengthen environmental stewardship, enhance water quality, improve soil health, and better protect our environment. The program supports a host of new activities to be carried out with farmers and other partners and build on environmental stewardship achievements in the agricultural sector by:

- Developing a comprehensive, science-based method to measure soil health in Ontario.
- Measuring the effectiveness and impact of agricultural BMPs aimed at reducing nutrient run-off on farms.
- Working with farmers to gain evidence and awareness of how to improve productivity, soil health and water quality.
- Establishing applied research and monitoring sites to facilitate peer-to-peer knowledge transfer and capacity-building among industry professionals.

ONFARM also supports and leverages other related actions with industry targeting improved soil health, such as the 4R Nutrient Stewardship program.

Pros	Supports knowledge transfer, peer-to-peer learning and capacity building in the area of soil health Supports innovation and practical solutions that could be used later by other farmers Rely on a science-based approach
Cons	Resource intensive. Hardly scalable
Benefits	A grass-root approach that builds on partnerships and knowledge transfer

INNOVATIVE APPROACH #2: HEALTHY SOILS CARAVAN

Geography: Québec

The Healthy Soils Caravan is not a vehicle, but a team of three MAPAQ advisers. They are touring the province to train producers on various aspects related to soil health: soil profiles, soil permeability and drainage, soil life and structural stability of the soil as well as tractor swinging and tire pressure adjustment. These workshops take place on the farm, in rotation during the day. Up to 40 producers can attend each activity.

Pros	Brings extension services to producers (on demand) Takes place in different regions
Cons	Small scale (3 advisors)
Benefits	Help meets the need for tailored extension services to help farmers understand what soil health is and what can be done to improve it

INNOVATIVE APPROACH #3: LIVING LABORATORIES INITIATIVE

Geography: Canada

This is an integrated approach to agricultural innovation that brings farmers, scientists, and other partners together to co-develop, test, and monitor new practices and technologies in a real-life context. The result will be more practical technologies and sustainable farming practices adopted more quickly by Canadian farmers. A nationwide network of sites will be developed to create innovative solutions.

The Living Laboratories Initiative is based on three core principles:

User centered innovation: The farmers and the local landowners are the users of the technology or practice. They participate in the design of the projects and corresponding solutions and take part in the experiments from the very beginning.

Private-Public-People partnership: Experts from various disciplines and backgrounds (government, non-government, local producers) work together to tackle a common issue.

Real-life experimental setups: Working farms are the incubators of innovative technologies.

Pros	Supports knowledge transfer, peer-to-peer learning and capacity building in the area of soil health Supports innovation and practical solutions that could be used later on by other farmers Rely on a science-based approach
Cons	Resource intensive. Hardly scalable
Benefits	A grass-root approach that builds on partnerships and knowledge transfer

INNOVATIVE APPROACH #4: ONTARIO SOIL NETWORK

Geography: Ontario

Ontario Soil Network is an independent organization working with many partners to bring together farmers to share experiences and learn from each other about soil health practices such as cover crops, biostrips, strip till and many others. The network also builds leadership and communication skills for further dissemination of knowledge.

Pros	Provides valuable knowledge and social learning between farmers and build soil health leaders
Cons	Limited resources and geographic scope
Benefits	A model for effective peer-to-peer learning about soil health in other provinces

INNOVATIVE APPROACH #5: SOIL HEALTH PARTNERSHIP

Geography: United States

By building a peer-to-peer network, the Soil Health Partnership partners with farmers to explore the financial, economic, and environmental benefits and risks of soil health practices. SHP collects on-farm data to evaluate the impacts of soil health practices on the soil, the environment, and the farmer's bottom line.

SHP brings together diverse partners to work toward common goals, partnering with organizations at the federal, state, and county levels. These organizations include state government, commodity associations, non-profit organizations, foundations, and private companies.

Pros	Provides valuable knowledge and social learning between farmers and build soil health leaders A multi-stakeholder approach The website is a hub of practical and actional information about soil health An industry-driven initiative
Cons	Relies on industry funding and the willingness of industry members to participate
Benefits	A model for effective peer-to-peer learning about soil health in other provinces A model for a hub for practical information about soil health

INNOVATIVE APPROACH #6: SHELTERBELT PLANNING TOOL / CURRENT SHELTERBELT EVALUATION

Geography: Saskatchewan

Tool to help farmers learn about what other landowners are planting in the region. Based on it, and other information, they can plan a new shelterbelt and find out how helpful it can be for their land. They can also learn about the carbon and economic value of their shelterbelt.

Pros	A user-friendly decision-making tool
Cons	BMP (shelterbelts) and province (Saskatchewan) specific Not associated to any particular incentive
Benefits	A user-friendly tool to help farmers realize the value of their practices

INNOVATIVE APPROACH #7: LANDONLINE GEOGRAPHIC INFORMATION

Geography: Prince Edward Island

Over the years, the Department of agriculture has collected geographic information to aid in managing land and water resources. This data is being made available free of charge to all individuals who own land through this mapping tool.

Pros	Free access to field level data
Cons	Provides data and information but no support on how to inform decisions
Benefits	Access to data is essential for farmers and advisors to help decision making and monitor improvements

INNOVATIVE APPROACH #8: ROOTS TO SUCCESS

Geography: Canada

Led by Farm Management Canada, Roots to Success was created to increase the awareness and adoption of a comprehensive approach to managing farm risk by farmers, service providers and government officials to position Canada's agricultural sector for sustainable growth and prosperity through farm business management.

Roots to Success involves a variety of activities in support of managing farm risk, including training sessions with farmers and advisors. The objectives of these sessions are amongst others to share experiences and expertise with peers and create an opportunity to create long-lasting relationships with the producers.

Pros	Free online training for farmers and advisors Gives a free access to an online tool to manage on-farm risks (AgriShield) Helps connects farmers and advisors from different regions and sectors
Cons	Not specific to soil health or agri-environental risks

Benefits	Builds capacity within the farming community on risk management by giving access to practical tools and facilitating peer-to-peer learning

INNOVATIVE APPROACH #9: TRANSITION ADVISORY SERVICES

Geography: European Union

In Europe, farm advisory services have operated in a more than a dozen nations and typically offer combinations of multiple programs [e.g. telephone helplines, information packages, farm advisory visits, courses, handbooks and manuals, and farmer mentoring programs] (York University, N.D.b).

Pros	Provides critical information and support during key moments in the decision-making process
Cons	Success depends on the quality of the advisors and the degree to which services are provided at low or no cost to farmers
Benefits	Facilitate the transition to a more sustainable agriculture

3.5 BUSINESS RISK MANAGEMENT TOOLS

As mentioned in section 3.1, Business Risk Management (BRM) programs are central to Canada's agricultural policy framework. While BRM programs are designed for income stabilization, and not for environmental sustainability, they are still an important element of the policy environment in which Canada's agri-environmental policies operate.

Both agricultural risk management and environmental sustainability are stated priorities of the recent Canadian agricultural policy frameworks, including the CAP. However, it has been argued that there are unintended links through which Canada's BRM programs may influence adoption of environmental stewardship practices. In fact, empirical results suggest that the net impact of BRM programs on environmental quality and adoption of certain BMPs could be negative.

For example, while BRM programs are widely seen as successful in improving farm financial performance, there is also evidence that participation in BRM programs contributes to increased use of fertilizers and pesticides (Eagle et al, 2016). In addition, Jeffrey et al (2017) found that participation to BRM programs reinforces incentives to adopt BMPs that already have positive net benefits (e.g. crop rotation BMPs), but increases disincentives (net costs) associated with adoption of BMPs involving land use change (e.g. buffer strips, wetlands restoration). In other words, participation in Canada's BRM programs may increase the costs to adopt BMPs involving land use change, thereby potentially reducing their adoption. In turn, this raises questions on the compatibility of Canada's risk management and agri-environmental policies.

Other authors have explored the opportunity of using **cross-compliance** with requirements to access Business Risk Management (BRM) program funding (c.f. side box). Risk management policy and agri-environmental policy are not explicitly linked in Canada (Eagle et al, 2015). Although Canada does have eligibility requirement of an Environmental Farm Plan (EFP) to access the associated cost-shared BMP grant programs under the CAP, some suggest this is a weak form of cross compliance (cf. section 3.3).[29]

Over the years there has been a significant amount of debate on the potential to implement cross-compliance policies at the Federal-Provincial-Territorial (FTP) government level.[30] However, this idea has never been taken further than initial discussions. Many reasons explain the situation:[31]

- There is no evidence that the adoption of BMPs or the participation in agri-environmental programs (e.g. Environmental Farm Plans – EFPs) reduces the risk for either AgriStability payouts or AgriInsurance payouts. So, there is no justification in theory for this requirement and therefore may not be consistent with legislation. Pilots would be needed to build the necessary evidence.
- BMPs or agri-environmental programs are currently voluntary and significant steps are required to moving to a government-mandated requirement, potentially requiring legislative change.
- Many provinces have implemented legislative requirements to address the most pressing farming environmental challenges, such as Intensive Livestock Operations regulations, nutrient management regulations.
- In those provinces with the lowest enrolment of agri-environmental programs and EFP's, there is not the capacity to provide EFP guidance to all producers enrolled in BRM programs and/or funding to assist in remediating environmental risks on farm.

[29] Martorell (2017) also identifies the application of a cross-compliance mechanism to agriculture in Quebec, called the principle of éco-conditionalité. This was implemented in 2004 for the pork industry. Today, Quebec's agriculture ministry operates several programs allocated to producers with balanced phosphorus assessments. However, this regulatory requirement is minimal and easy to meet, and farmers with negative environmental impacts (e.g. high pesticide use, water pollution, soil erosion) remain eligible for funding.

[30] Cross-compliance has also been raised in the context of livestock traceability. As provinces introduced premises identification on a voluntary basis, discussion did arise regarding the need to have a premise registered prior to being eligible for BRM programs. Likewise, the connection between BRM and individual animal registration for age verification purposes. However, none of these ideas evolved beyond the initial discussion, and premises identification is now under regulation in all provinces, and there is no longer a need for ruminant age verification.

[31] Based on interviews with key informants.

SIDE BOX: ABOUT CROSS-COMPLIANCE

Cross-compliance refers to producers satisfying minimum management requirements to maintain eligibility for government support (Schmidt et al, 2012). In other words, it is a mechanism that links direct payments to compliance by farmers with basic standards concerning the environment, food safety, animal and plant health, and animal welfare, as well as the requirement of maintaining land in good agricultural and environmental condition.

The use of cross-compliance as an approach to government intervention is exemplified in the European Union, where it is linked to the single farm payment (an amalgam of past programs). To receive payments such as price supports and whole farm payments, producers must meet minimum cross-compliance standards, i.e. they must comply with minimum statutory management requirements and maintain good agricultural and environmental conditions. Cross-compliance became mandatory for EU producers receiving program payments in 2005.

Cross-compliance was included in the 1985 US Farm Bill as a mechanism to incentivize reduced cultivation of highly erodible land and drainage of wetlands (Beckie et al, 2019; Eagle et al, 2015). Under the cross-compliance mechanism, producers who cultivate erodible land or drain wetlands forfeit eligibility for various income support programs. About 40 million ha of US cropland meet cross-compliance requirements and receive direct payments for agri-environmental practices.

Schmidt et al (2012) discuss the incentive effects of cross-compliance, which have implications for the types of policy environment the cross-compliance approach is best suited for. In general, the greater the size and certainty level of the payment associated with a farm program, the greater the incentive to cross-comply. Indeed, when a farm program's benefit is significant and fixed, the effective cost of failing to cross-comply becomes tangible. In turn, this increases farmers' motivation to implement cross-compliance measures. By contrast, if a program's payments are uncertain, farmers will be less motivated to cross-comply. The EU single farm payment scheme is an example of a program facilitating implementation of cross-compliance. Indeed, the fact that payments under the program are known in advance on a non-contingent basis has a strong incentive effect.

Another key reason explaining the reluctance to connect voluntary actions (such as EFPs) with BRM programs is due to the nature of the BRM program approach: that is, they are statutory (in law) except for AgriRisk. That is, these programs are imbedded in legislation and do not have a time or financial limit and are open to all that are eligible (anyone meeting the eligibility requirements is entitled to participate in the programs and receive their benefits). Within these laws, some parameters can be changed (i.e. reducing the AgriInvest contribution to 1% rather then 2%). However, they are essentially non-discretionary programs: they must be offered to all eligible recipients, similar to Employment Insurance.[32]

[32] This observation was also made by Schmidt et al (2012) who argue that Canadian farm programs are not, for the most part, entitlement programs. Rather, they are stabilization or risk-sharing programs. As such, these are contingency-based programs and the incentive effect of cross-compliance is less. The cost of non-compliance in a contingent program is exclusion from future payouts if they occur. This is much less tangible than the cost of non-compliance under an entitlement program (Schmidt et al, 2012).

Other past programs could also be relevant for soil health. For example, programs such as funding for environmental risk identification and remediation, funding for Ecological Good and Services (EGS), Permanent Cover programs, and set-aside/alternative crop program (for example in PEI) are all discretionary with voted rather than statutory funding. As such, this type of funding is time limited; constrained; subject to decisions by the program administrators and available to only a portion of farmers enrolled in BRM programming.

Schmidt et al (2012) also argue that, in general, a cross-compliance initiative tied to Canada's BRM programs would be distortionary. This is because of the exemptions for supply management and the focus of insurance programs on crops rather than livestock. This is significantly different from the European history of comprehensive commodity-based payments, which provide for entitlements at the basis for powerful incentives from cross-compliance.

Jeffrey et al (2017) note that evidence of the effectiveness of cross-compliance, both in environmental terms and in terms of cost-effectiveness, is mixed. Similarly, DeBoe (2020) comments that environmental cross-compliance is an example of instruments that do not have significant impacts on farm productivity, and often fail to substantially improve environmental performance.

In their analysis of the environmental consequences of Canada's agricultural support policy, Eagle et al (2015) note that cross-compliance could be considered in the Canadian context, but that policies that directly target specific environmental issues in agriculture might have greater impact. The design of cross-compliance mechanisms has to consider that program payments need to be large enough to cover compliance costs as well as enabling the government to monitor the agent's actions. Tying threats to environmental quality to risk management policy in this way makes for a blunt instrument. It is suggested that it may be more effective to direct resources to different programs where farmers are paid to provide environmental benefits.

That being said, the applicability of cross-compliance as a policy instrument in Canada is considered by some authors. For instance, Schmidt et al (2012) argue that, in Canada, cross-compliance measures would be a better fit with entitlement programs such as AgriInvest (cf. section 3.1.4). AgriInvest is a self-managed producer-government savings account. Each year, a producer can deposit a portion of his eligible sales to his AgriInvest account and receive a matching contribution from the government.

In this case, producers know exactly what benefit they will receive from the program, and thus the cost of non-compliance. Eagle et al (2015) note that Canada's GF2 framework provided for the possibility of cross-compliance provisions for AgriInvest, where producers would need to meet certain criteria to be eligible to receive payments under AgriInvest. To date, no such provisions have been applied to AgriInvest.

Beckie et al (2019) also suggest that Canada has the opportunity to incentivise BMP implementation using the crop insurance program, which is publicly subsidized. Government could offer greater incentives through crop insurance, e.g. via reduced insurance premiums to those who implement BMPs. Specific BMPs mentioned include crop rotation, cover crops and tillage, which, in the context of this policy suggestion are framed as BMPs to control increasing pesticide resistance. In their recent review of evidence, Traxler and Li (2020) conclude that "reduced insurance premiums are an effective incentive to encourage voluntary adoption of BMPs."

As this discussion suggests, **the opportunity of using cross-compliance as an approach to support soil health in Canada is limited**. That being said, options exist of using incentives rather than requirements to foster the adoption of BMPs or the participation in agri-environmental programs. These incentives could build on or be embedded in BRM programs to achieve positive outcomes when it comes to soil health.

For instance, Équiterre and the Smart Prosperity Institute have explored different policy instruments and approaches to specifically support efficient nitrogen fertilizer management in Ontario corn-soybean-winter wheat systems (cf. Table 3.5) (Équiterre and Smart Prosperity Institute. (N. D.). In particular, using BMP insurance to improve farm management is a relatively new approach to overcome risk perceptions and promote BMP adoption by allowing farmers to try management practices risk-free (Mitchell and Hennessy, 2003 cited in Harris and Swinton 2012). It was also mentioned by some key informants as an interesting approach that should be further explored in Canada.

The need to examine existing BRM programs to identify and eliminate disincentives (market signals) and impediments (terms) to adoption of soil health BMPs is also motivated by the increased risks associated with climate change. For instance, the 2015 Task Force Report on Agriculture Risk Management in Manitoba (Manitoba Agriculture Risk Management Task Force, 2015) notes that since 2008, BRM programs have paid Manitoba farmers over $3 billion. While AgriStability, AgriInsurance and AgriRecovery have helped producers to address income losses, these programs, by design, will provide decreasing assistance if applicants qualify for payments with any regularity. For the authors, continuing in this path without changes would require these programs to cover increasing, recurrent losses among agricultural producers. They conclude that without careful consideration, it is possible these programs would be forced to scale back the assistance they offer, with serious long-term effects on agricultural production in this country.

Review processes are in place both at the provincial and federal levels to account for these impacts and how programs should be adapted. The industry has also access to the AgriRisk Initiatives (ARI) program in its efforts to research, develop and implement new agricultural risk management tools.

Specifically, ARI projects are intended to foster greater collaboration and partnership between agricultural stakeholder groups and the private sector, and to increase participation of the private sector financial services industry in providing risk management tools to the agricultural sector. For instance, 44 risk assessments were funded under the ARI Program over the course of the Growing Forward 2 AgriRisk Initiatives Program (2013 – 2018). Some of these assessments explored the opportunity to develop new BRM programs to account for new risks facing agriculture.

Based on the above discussion and discussions with key informants, the main strengths, gaps and limitations pertaining to BRM programs are summarized below, together with some examples of innovative approaches that could be used to foster soil health in Canada.

Table 3.5
Policy options for efficient nitrogen fertilizer management in Ontario corn-soybean-winter wheat systems

Policy instrument/approach	Supporting points	Risks, Drawbacks, Suggestions for	Supporting points
BMP Insurance Compensating farmers for loss in profit or yield as the result of BMP adoption	Increases adoption by de-risking BMPs Program only compensates farmers for adverse outcomes Similar programs tested in US, ON and PEI	High transaction costs Difficulties in monitoring and enforcement May create perverse incentives to poorly manage the land under the insurance policy	To reduce transaction costs, base insurance payment on the average regional yield rather than individual farm outcomes Address perverse incentives through audit and reporting requirements
Increased matching in Agri-Invest (conditional on BMP adoption)	Low implementation cost Current program matching dollars not sufficient for cross-compliance	Requires coordination and agreement among FPT governments (could be time-consuming) Need to carefully matching payment increase	Program should adopt a tiered approach, maintain existing access to Agri-Invest for non-adopters
Lower insurance premium on Agriinsurance (conditional on BMP adoption)	Low implementation cost Experience with similar tools within Canada and elsewhere e.g. PEI Potential to reward current and new adopters	Requires coordination and agreement among FPT governments (could be time-consuming)	Program should adopt a tiered approach, maintain existing access to Agri-Insurance for non-adopters

Source: Équiterre and the Smart Prosperity Institute.

3.5.1 STRENGTHS OF CURRENT BUSINESS RISK MANAGEMENT TOOLS

- BRM programs are widely seen as successful in improving farm financial performance.
- Opportunities exist to design and pilot new BRM programs in support of soil health and environment (e.g. insurance schemes).
- Perceived risk of reduced yield or profit is a commonly cited reason for not implementing BMPs. BMP insurance is a means of removing that reason for non-adoption. Such a policy could apply to a variety of BMPs.

3.5.2 GAPS AND LIMITATIONS OF CURRENT RISK MANAGEMENT TOOLS

- There is some evidence that participation in BRM programs contributes to increased use of fertilizers and pesticides and that the net impact of BRM programs on environmental quality is negative.
- Depending on program requirements, BRM programs may negatively influence the uptake of environmental stewardship practices (e.g. cover crop termination requirements under US Farm Bill).

3.5.3 INNOVATIVE APPROACHES TO CONSIDER

While there is a need to identify and eliminate disincentives (market signals) and impediments (terms) to adoption of soil health BMPs, new and innovative business risk management tools are also available in some jurisdictions that could address some of the existing gaps and be considered for the development of improved/new and innovative program instruments.

INNOVATIVE APPROACH #1: CROP INSURANCE DISCOUNTS

Geography: Iowa[33]

The project is set out as a three-year project through which farmers can receive a $5-per-acre rebate on their crop insurance if they implement cover crops. To participate in the program, farmers must abide by the state's cover crop best practices.

Pros	Offers a lower level of financial assistance for farmers
	Cost-share funding for cover crops
	Streamlined application process
	Minimal overhead to manage
	Integration to the existing crop insurance relationships
Cons	As an annual program, the BMP is likely to remain in place as long as the funding goes. But farmers may not pursue it if/once the funding ends.
Benefits	Can encourage producers that already adopted a BMP to continue in the long term
	If most producers participate in crop insurance, this program structure has more opportunity to grow than traditional structures

INNOVATIVE APPROACH #2: MESURE DE COHÉRENCE

Geography: Québec

The agricultural insurance program managed by the Financière agricole du Québec includes a "Mesure de cohérence" aimed at excluding the buffer zone areas (3 meters) from the calculations of the insurance coverage. The measures on riparian areas and the limitation of cultivated areas do not restrict access to financing and subsidy programs. However, the profitability assessment must be based on the areas complying with these consistency measures. This condition is to ensure consistency between this BRM program and regulatory requirements in place in Québec.

Pros	Ensures consistency between environmental regulations and BRM programs
	No additional costs to the insurer (and policy holder insofar as they comply with regulations)
Cons	Regulatory requirement needs to be in place and enforced
Benefits	Such measures help eliminate disincentives and impediments associated to BRM programs adoption

[33] A similar project is underway in Illinois (the "Fall Covers for Spring Savings" Cover Crop Premium Discount Program). Eligible applicants will receive a $5/acre insurance premium discount on the following year's crop insurance invoice for every acre of cover crop enrolled and verified in the program.

INNOVATIVE APPROACH #3: CORN MUTUAL FUND

Geography: Italie

The mutual fund is an approach that reduces the financial risk of significant pest damage to crops, while avoiding the environmental costs of pesticide use and encourages integrated pest management practices (IPM). To be eligible for coverage, farmers must buy into the scheme, avoid the use of priority pesticides and demonstrate rigorous implementation of IPM practices.

Risks covered include insufficient plant density (stand) due to adverse weather conditions, to soil pests and diseases.

The obligation for farmers is to follow IPM suggestions of the Annual Crops Bulletin for an actual implementation of IPM principles.

Pros	Because of the generally low risk level, the crop insurance program proved to be more convenient than insecticide protection on large scale (Furlan et al., 2018)
	Growers may purchase MF cover instead of soil insecticides, to provide financial compensation when yield losses can be attributed to pests or adverse weather conditions
Cons	Specific to pest management
	The design of this approach was informed by 20 years of data collection in Italy
Benefits	When risks are low, this approach is convenient for farmers and safe for people, biodiversity (including pollinators), the environment, and ecosystems
	An insurance approach is much more cost-effective than insecticides since its large-scale and multiannual implementations demonstrated that MF costs are much cheaper for farmers than insecticide use

INNOVATIVE APPROACH #4: BMP CHALLENGE

Geography: United-States

The BMP challenge allows the farmer to compare a new practice, designed to be more nitrogen efficient, to their regular practice with a guaranteed payment should they lose yield. By adopting water quality BMPs, it offers yield and income risk protection for corn farmers.

When a farmer agrees to participate in the BMP Challenge, a crop advisor works with them to collect a detailed history on the enrolled field and how much and what types of fertilizers have been applied to the ground (American Farmland Trust,2012). The farmers are then paid if they lose profit based on a Net Returns Analysis (Brandt and Baird, 2008).

Pros	Reduce nutrient applications without negatively affecting the economics of farming (Brandt and Baird, 2008)
	Provides a yield guarantee and incentive payment
	Great tool to help through the transition
Cons	Limited scale
Benefits	Allow farmers to conduct farm research and demonstrations to change their system without worrying about having a loss in profit
	After participating in the program, most farmers continued the new practices without any insurance (Great Lakes Protection Fund, N. D.).

3.6 PAYMENTS FOR ECOLOGICAL SERVICES

Based on the natural capital concept, this approach attempts to attach a price to EGS. This price is used as a basis for remunerating farmers who produce or enhance EGS, through various market-based instruments (Schmidt et al, 2012). Because there is normally no monetary value attached to non-renewable resources or EGS, markets typically undervalue them, and as a result they are degraded on an ongoing basis.

EGS-focused programs aim to increase the production of EGS. EGS programs have been defined as entailing payments to producers of well-defined EGS, under a contract, and the payments must be ongoing and must exceed the initial costs incurred, thus providing incentive (Gagnon, 2005, cited in Schmidt et al, 2012). Buyers are usually governments, conservation agencies, NGOs or private organizations, with public programs usually targeting externalities, e.g. soil erosion (Holmes, 2011). A variety of approaches to EGS were reviewed extensively by an FPT working group in 2004-2009, which included numerous pilot projects across Canada (AAFC and Pacific Habitat Joint Venture 2009; AAFC and Federal Provincial Ecological Goods and Services Working Group 2011).

In the context of the policy instruments described in this paper, EGS is a somewhat generic term, at least partially covering several of the policy approaches described in this section.

Agricultural land use planning and farmland preservation in Canada is under both provincial and municipal jurisdiction (Martorell, 2017). This results in a lot of regional variation, also reflecting diverse interests to effectively preserve farmland. Canada has no federal targets or fixed limits on farmland loss. Data is also lacking on the amount of prime farmland remaining, its ownership, and the effectiveness of relevant policies (Connell, 2016; cited in Martorell, 2017). Still, Schmidt et al (2012; cited in Martorell, 2017) identified a federal initiative in Canada that can potentially remunerate farmers for providing EGS, namely the **Ecological Gifts Program**. This program provides tax credits or deductions when landowners donate ecologically sensitive land to registered charities, with the goal of protecting environmental heritage.

The **Alternative Land Use Services (ALUS)** is a non-governmental program available in Canada. Specifically, ALUS is a community-led, farmer-delivered program to provide annual incentives to farmers to establish and maintain activities that may lead to production of EGS. These activities target local environmental opportunities, and include restoration, enhancement and protection of various wetland, riparian and upland ecosystems, typically with the goal of protecting sensitive land. The concept has been applied to projects in several provinces in Canada (Schmidt et al, 2012; Holmes, 2011). The PEI ALUS program is unique in being coupled with provincial regulatory requirements.

Typically, ALUS projects involve producers sharing the establishment costs of the project, and receiving an ongoing annual fee based on existing rental rates. The producer's actual costs include time spent applying to the program, project establishment, and revenues foregone for traditional production where land was taken out of production. Funding partners for projects typically comprise a mix of private, federal, provincial, and municipal sources, and a variety of producer and environmental organizations (Schmidt et al, 2012). Annual payments are generally covered by private funding.

ALUS projects have been used to provide habitat for birds and pollinators, to restore wetlands and forests, to protect soils from nutrient runoff, and to increase carbon sequestration (Martorell, 2017).

3.6.1 STRENGTHS OF CURRENT EGS PROGRAMS

- EGS programs such as ALUS support producers in going above and beyond minimum environmental standards established through regulation (Schmidt et al, 2012).
- EGS programs also demonstrate shared responsibility for environmental stewardship (Shawn Hill, ALUS Coordinator, PEI; cited in Schmidt et al, 2012). For instance, ALUS programs have spread through leadership from farmer associations, municipalities, conservation districts and provinces, but remain largely ad hoc (Martorell, 2017).

3.6.2 GAPS AND LIMITATIONS OF CURRENT EGS PROGRAMS

- Programs such as ALUS focus more on the non-productive spaces rather than the working landscape.

- Difficulties remain in identifying appropriate values for EGS. There are limitations on the ability to adequately reflect the complexity of ecosystems and the multiple simultaneous values they provide in dollar amounts. As well, the value of a given ecological good in one location may be different from its value in a different location. For instance, payments to producers under ALUS are not based on specific observed environmental outcomes. Rather, they are based on established stewardship and management practices.
- Measurement of specific environmental outcomes has been achieved for certain projects, but is not consistently achieved (Schmidt et al, 2012).
- The difficulties of identifying appropriate values for EGS may be magnified through the process of establishing costs and benefits of expenditure for environmental benefits.
  - For instance, "a cost-benefit analysis of the potential for a national ALUS program estimates a set-aside of 37,000,000 acres at a cost of approximately $740 million [per year], with associated benefits of $820 million." This cost would amount to an additional 16.4% of overall annual agricultural payments (2006 farm program payments) (Blay Palmer 2012; cited in Martorell, 2017).
- Ongoing annual payments are viewed as "the least cost-efficient option to enhance the provision of EGS" and "likely to be inefficient and have distortionary effects on land markets" (AAFC and Federal Provincial Ecological Goods and Services Working Group 2011; Sauve 2009). Limited term per acre payments have been funded in the past (Greecover Canada, Permanent Cover Program) and in some Conservation Authority programs in Ontario.
- With further research, the values of future costs and benefits from EGS may change substantially due to higher risks (e.g. flood risk reduction). Services which to date have not been valued in these types of analyses may increase the overall EGS values associated with projects.
- Financing EGS programs such as ALUS remains a barrier (Martorell, 2017). For this reason, there are likely to remain few of these programs, with a limited scope often using private funding.
- Monetizing behaviours that are seen today as being good stewardship may raise ethical concerns amongst farmers with BMPs already in place.

3.6.3 INNOVATIVE APPROACHES TO CONSIDER

There are many challenges associated with the approach of remunerating farmers for the ecological goods and services they deliver to society or for implementing BMPs associated to these benefits. However, many examples of innovative tools and approaches are available that could inspire the development of new policy approaches in Canada. Some of these examples are presented below.

INNOVATIVE APPROACH #1: ENVIRONMENTAL QUALITY INCENTIVES PROGRAM (EQIP)

Geography: United States

Delivered by the NRCS, this program provides financial and technical assistance to agricultural producers to address natural resource concerns and deliver environmental benefits such as improved water and air quality, conserved ground and surface water, increased soil health, reduced soil erosion and sedimentation, improved or created wildlife habitat, and mitigation against increased weather volatility.

The 2018 Farm Bill introduced EQIP incentive contracts to expand resource benefits to producers through incentive practices such as cover crops, transition to resource conserving crop rotations, and precision agriculture technologies. Every region within a State will have identified high-priority areas and each of these areas will target up to three priority resource concerns by land use. In addition to the payment for practice implementation, incentive contracts offer annual payments to address operations and maintenance costs as well as foregone income.

Projects start with an NRCS conservationist visiting the farm and evaluating the natural resources on the land. NRCS then presents a variety of conservation practices or system alternatives to help address identified concerns or management goals to improve or protect the natural resource conditions on the land.

Pros	A voluntary conservation program helps producers make conservation work for them
	A targeted approach that helps address high-priority areas
	Action plan and BMP identification designed based on a diagnostic conducted by a professional
	A large array of BMPs could be supported through this program
Cons	Resource intensive
Benefits	A cost-share program targeting ecological goods and services for some BMPs through annual payments per acre for contract duration

INNOVATIVE APPROACH #2: ASSURANCE: ECOLOGICAL GOODS AND SERVICES

Geography: Manitoba

This program consists of a grant to help watershed districts working with farmers to implement sustainable environmental practices. Eligible projects include activities related to water retention and runoff management, wetland restoration and enhancement, soil health improvement, riparian area enhancement, natural upland area rejuvenation and enhancement, land rehabilitation and tree plantings and woodlot management.

Watershed districts can be reimbursed for up to 100 per cent of total approved costs, with no funding cap.

Pros	Supports up to 100 per cent of total approved costs
	Supports projects at the watershed level

	Supports activities addressing environmental objectives to reduce the impact of agricultural activities on the environment and increase the delivery of EGS from agricultural landscapes
	Requires farmers to have an EFP completed
Cons	Number and size of approved projects dependent on available funds
Benefits	A program specifically targeting the delivery of EGS through the adoption of BMPs

INNOVATIVE APPROACH #3: MARGINAL AREAS RETIREMENT PROGRAM

Geography: Saskatchewan

Ducks Unlimited Canada is piloting a marginal areas retirement program in the Prairie region. The objective is to work with farmers to identify, using precision agriculture technology, economically marginal land to put it out of annual crop production. The program offers producers $150/acre (upfront) to set aside these fields for 10 years. The acreage can be used for hay production, but not for annual crop.

Pros	Leverages precision agriculture technology to identify economically marginal land
Cons	Small scale projects
	Limited funding
	Data intensive / requires farmers to use precision agriculture technology
	Only targets economically marginal lands
Benefits	Provides financial incentives not to cultivate certain areas on the farm

INNOVATIVE APPROACH #4: CONSERVATION RESERVE PROGRAM

Geography: United States

CRP is a land conservation program administered by Farm Service Agency. In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10-15 years in length. The long-term goal of the program is to re-establish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat. CRP contracts are ranked according to the Environmental Benefits Index (EBI).

CRP protects more than 20 million of acres of American topsoil from erosion and is designed to safeguard the nation's natural resources.

CRP participants are provided with annual rental payments, as well as certain incentive payments and cost-share assistance. FSA bases rental rates on the relative productivity of the soils within each county and the average cash rent using data provided by the National Agricultural Statistics Service (NASS). The soil rental rates are subject to an 85 percent proration for general signup and a 90 percent proration for continuous signup.

Pros	A large-scale program
	Value of payments based on rental rates taking into account the market value for that land
	Long-term enrollment
Cons	Significant public funding needed
Benefits	A large-scale EGS-program with long-term enrollment

INNOVATIVE APPROACH #5: SOIL HEALTH AND INCOME PROTECTION PLAN

Geography: United States

SHIPP is a voluntary program that allows contracts with agricultural producers for a term of 3, 4, or 5 years. Eligible land must meet the following criteria to enroll in SHIPP: be less productive land on the farm; have been planted (and not in CRP – see above) in crop years 2017, 2018, and 2019, and have a total of no more than 15 percent of the eligible land per farm enrolled in SHIPP. Up to 15 per cent of an individual farmer's land may be contracted into the program.

Annual rental payments will be made at 50 percent of the weighted average soil rental rate for the SHIPP offer, using the county average rental rate for the applicable county.

Pros	Payment can be front-loaded over the entire contract period
	A revenue subsidy tied to the adoption of a BMP beneficial to soil health
Cons	Significant public funding needed
	Temporary programs
	Following the end of the contract there is no guarantee the BMP will remain in place
Benefits	A program that enhances the long-term viability of the sector through both improved soil health and competitiveness

INNOVATIVE APPROACH #6: CONSERVATION STEWARDSHIP PROGRAM

Geography: United States

The Conservation Stewardship Program (CSP) helps producers build on existing conservation efforts while strengthening operation. CSP can help identify natural resource problems in the operation and provide technical and financial assistance to solve those problems or attain higher stewardship levels in an environmentally beneficial and cost-effective manner (e.g. ways to address the amount of soil lost; mitigate the impact of excess water; reduce the contribution of agricultural operations to airborne soil particles and greenhouse gas emissions; improve the cover, food, and water available for domestic and wildlife species; or promote energy efficiencies for on-farm activities).

CSP contracts are for five years, with the option for renewal for an additional five years.

CSP provides free technical assistance to agricultural producers.

Pros	For working lands
	To participate in CSP and receive financial assistance, producers must control or own the land and comply with highly erodible land and wetland conservation requirements
Cons	Significant public funding needed
Benefits	A large-scale EGS-program with long-term enrollment

3.7 GREENHOUSE GAS OFFSET PROGRAMS

The growing concern about climate change has resulted in the development of multiple strategies to encourage the adoption of practices that help reduce GHG emissions. Offset programs are one example that is gathering more interest in recent years. Environment and Climate Change Canada has identified the potential for use of offset programs and protocols as part of the federal legislative action on climate under the Pan Canadian Framework.[34]

Typically, in order to obtain offset 'credits', emission reduction projects or practices must be adopted and put in place for a period of time, specified in a protocol (EPRI, 2011) and sold to a second party looking to offset their emissions either voluntarily or as required by mandatory GHG emission limits (regulation). Project protocols outline the eligibility requirements for projects to be accepted (i.e., methodology, timeframe, method of measurement, and types of applicable project/practices).

There are multiple potential methodologies in use and in development for regulatory and voluntary GHG offset projects in both the private and public sector, and at the provincial, national and international level. With respect to agricultural production, these offset programs focus on topics such as land use, carbon sequestration in working land, and nitrous oxide emissions. The differing protocols make the development of agricultural offset programs even more complex. For instance, Table 3.6 presents examples of protocols applying SOC quantification and shows how they differ in terms of methodologies and data requirements.

Some issues in protocols include:

- Measuring, monitoring and verifying increased levels of soil carbon in a cost-effective way.
- Ensuring the longevity or permanence of soil carbon.
- Taking into account the profound influence of environmental factors on agricultural GHG fluxes.
- Accounting for past sequestration, i.e. producers that already adopted BMPs which helped sequester carbon. Determination of a baseline (temporally and geographically) is crucial for proper crediting and to accurately determine net GHG emissions reductions achieved (Rice and Debbie, 2007).

The above issues are all important to ensure that a GHG emissions reduction market achieves actual emissions reductions. There are also significant practical challenges faced by farmers who want to implement these protocols (e.g. measurement, record-keeping, permanency, high transaction costs and small amounts per acre). In fact, their complexity and rigid standards have made them less useful for application in agriculture.

[34] ECCC has identified potential for GHG offsets and suggested a list of priority protocols that could be developed for large emitters. Federal offset protocols will set out a consistent approach for quantifying GHG emissions reductions for a given project type, including clear rules for establishing baselines for approved offset project activities. The protocols will also include requirements for project planning and implementation (ECCC, 2020).

That being said, some of these protocols are already being used in Canada. For instance, there are several Alberta-approved quantification protocols applicable to agriculture:

- Conservation Cropping
- Nitrous Oxide Emissions Reduction
- Fed Cattle (Reducing Greenhouse Gas Emissions from Fed Cattle)
- Microgeneration (Distributed Renewable Energy Generation)
- Biogas (Anaerobic Decomposition of Agricultural Materials)
- The Conservation Cropping Protocol continues to provide opportunities for farmers to earn carbon offsets by:
  - Increasing soil carbon levels through no-till management
  - Reducing greenhouse gas emissions from lower fuel use

Farmers may want to use these protocols to participate in compliance or voluntary carbon markets.[35] These two markets create market incentives insofar that the price for carbon is high enough to cover the cost of implementing the protocols. Note that according to key informants, protocols focusing on nitrogen fertilizer use may offer the most potential for both compliance and voluntary offsets because of the focus on N_2O. Due to associated uncertainty, soil carbon offsets may not be well suited to the compliance market. However, it may hold potential for the voluntary market such as through the proposed Soil Enrichment Protocol of the Climate Action Reserve.[36]

Two main protocols, originally developed by Fertilizers Canada, focusing on nitrogen fertilizer use are available in Canada (Fertilizer Canada, N. D.):

- **Nitrous Oxide Emission Reduction Protocol** (NERP) is a science-based protocol designed to meet international standards for improving nitrogen management in cropping systems and estimating the nitrous oxide reduction associated with better nitrogen management. The protocol was originally approved for use within Alberta's greenhouse gas management framework as a protocol for delivery of compliance quality offsets for Alberta's regulated large final emitters.
- The **4R Climate-Smart Protocol** is an easily adaptable, science-based solution for Canada's growers to optimize nitrogen management in their cropping systems and quantifiably demonstrate carbon reductions.

[35] Compliance markets refer to a regulatory trading system where persons responsible for covered facilities are required to compensate for GHG emissions that exceed the facility's annual emissions limit by making an excess emissions charge payment OR by remitting compliance units, namely surplus credits, offset credits, or recognized units. Voluntary markets refer to the process of compensating for GHG emissions by purchasing offset credits (Environment and Climate Change Canada, 2020).

[36] Yet nitrogen fertilizer use is not identified as one of the priority project types for federal offset protocol development. Soil organic carbon is (Environment and Climate Change Canada, 2020).

Other types of offsets may have potential applications on farms. This is the case for afforestation/reforestation offsets[37] through planting of trees and other woody species for shelterbelts, buffer strips and other applications. Grassland conservation offsets such as the Canada Grassland Protocol of Climate Action Reserve also offer opportunities for agriculture in the voluntary market and possibly the compliance market. Given the multiple ecological services provided and the negative consequences of conversion to annual crops, financial incentives to drive maintenance are warranted.[38]

Another approach used in Ontario was to fund soil health activities and practices from climate policy sources ($30 million). These practices generally support climate change mitigation and adaptation, even though the mitigation could not be quantified sufficiently at the individual farm level to qualify as offsets. In Quebec, the Fonds Vert, which collects revenues from the regulated carbon market, does provide funding to programs aiming at reducing GHG. Only one program currently applies to agriculture (bio methanization). However, cost-share programs were previously funded through this system.

[37] Afforestation involves planting trees to create new forest on land that was previously agricultural, urban or some other non-forested land use. Reforestation involves planting trees on degraded forested land affected by natural and human disturbances, such as large-scale timber harvesting, fire, flooding, wind or pest outbreak (Environment and Climate Change Canada, 2020).

[38] Very recently, the 2020 federal Fall Economic Statement and new climate plan (ECCC, 2020a) promised “a new Natural Climate Solutions for Agriculture Fund” beginning in 2021-2022. No details are available on what that funding would support and its relation to climate targets (Government of Canada, 2020). In addition, the climate plan proposed to provide up to $631 million over ten years, to Environment and Climate Change Canada “to restore and enhance wetlands, peatlands, grasslands and agricultural lands to boost carbon sequestration” for “climate smart, natural solutions to reduce greenhouse gas emissions related to ecosystem loss”.

Table 3.6
Summary Table of Protocols Applying SOC Quantification for Offset Markets

Protocols	Methodologies (Measurements/Models)	Data and monitoring requirements	Uncertainty
VM0021 Soil Carbon Quantification Methodology	Combination of measurements and models	Significant level of technical ability, significant data requirements for estimation and projection.	Not mentioned
VM0026 Sustainable Grassland Management	Combination of direct measurement methods and biogeochemical models	Very conservative approach, significant data requirements for estimation of SOC pool changes	Uncertainty depends on the situation
VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing	Rely on measured or modeled approaches	Depends on the methodology	Monte Carlo simulations/ weighting uncertainties according to the magnitude of emission or removal
Australia Carbon Credits Methodology Determination 2018	Direct measurement through sampling analysis	Depends on sampling design	Standard error calculated based on sampling round
Soil Enrichment Protocol: Reducing emissions and enhancing soil carbon sequestration on agricultural lands	Both direct measurement and models	The direct measurement is used to back-calculate the previous year's SOC stock using the same model and to subsequently modify the model to fit the empirical measurements	Uncertainty deductions depends on the uncertainty size
C-Sequ: Project of draft guidelines for the calculation of Carbon Sequestration for the Dairy cattle sector	Empirical soil organic carbon (SOC) models, Process-based SOC models, Measurements, Allometric equations for trees and hedges	Unknown - draft	Not mentioned
Soil Organic Carbon Framework Methodology	On-site measurements and using tier 1 & 2 level approach	Direct measurement preferred. Extent not yet known – draft	The project proponent shall use a precision of 20% of the mean at the 90% confidence level as the criteria for accuracy of total SOC change calculation.

Source: Viresco Solutions 2020.

3.7.2 STRENGTHS OF OFFSET PROGRAMS

- Provides financial incentives to drive the adoption of BMPs and the delivery of ecological goods and services.
- A market-driven system with no direct costs for government.
- Potentially cost-effective tool for greenhouse gas mitigation.
- Some protocols already developed.

3.7.3 GAPS AND LIMITATIONS OF OFFSET PROGRAMS

- Research is still needed to reduce the uncertainty around the quantification of GHG reductions.
- Protocols are not yet available for all markets, sectors and activities.
- The market demand for offsets is still precarious.
- Protocols are complex, rigid, and costly to implement at the farm level with extensive record-keeping and monitoring requirements.

4. CONCLUSION

Healthy soils represent an opportunity to build prosperous and resilient farms that can sustain us into the future. Through widespread adoption of soil health systems, Canadian farmers can provide positive solutions to climate change mitigation while helping themselves adapt to climate extremes and maintaining and improving their profitability.

To do so, policies that encourage better management practices for soil health are needed to transition Canada to a lower GHG and more sustainable agricultural sector.

In this context the goal of this report was to present a holistic review of the different factors affecting soil health management practices and assess how policies can enhance their adoption in Canada. Specifically, using a systems approach, this technical report looked at the agronomic, psychological, social, economic, and political dimensions of soil health by answering the following questions:

1. What are the main agricultural practices benefiting soil health?
2. What are the key factors influencing BMP adoption by farmers?
3. What are the existing and innovative policies supporting BMP adoption in Canada?

The insights provided in this report offer some foundation for rethinking some of our agricultural and climate change policies and programs. More specifically, the findings are aimed at supporting program-level recommendations related to improvements to current program interventions in Canada. The content can assist in the development of soil health strategies and program instruments for Canada to meet its global climate change commitments and support the agricultural sector's ongoing adaptation to climate change. The conclusion can also be informative in the development of the new federal climate plan and the new FPT agricultural policy framework expected in 2023.

A comprehensive set of draft recommendations for changes in federal and provincial climate and agri-environmental policy, awareness building, easily accessible information and advice, farmer-to-farmer learning, and better financial incentives for soil health are presented in a companion report, "The Power of Soil: An Agenda for Change to Benefit Farmers and Climate Resilience" (Équiterre and Greenbelt Foundation, 2020). That report also summarizes the extensive material in this volume in a simpler format and more accessible language. The recommendations are inter-related, forming a system to support change, addressing known barriers to adoption of better soil management and constitute a roadmap for soil health in Canada.

APPENDIX 1
PROJECT ADVISORS AND KEY INFORMANTS

ADVISORS

NATIONAL ADVISORY COMMITTEE

Denis Angers (AAFC scientist), Quebec; Brian McConkey (Viresco Solutions); Jean-Marc Bertrand, (Danone); Odette Ménard (MAPAQ); David Burton (Dalhousie University); Marie-Élise Samson (Université Laval); Alan Kruszel, (Soil Conservation Council of Canada); Paul Smith (Paul Smith and Associates); Derek Lynch (Dalhousie University); Sean Smukler (UBC); Cedric MacLeod (MacLeod Agronomics); Claudia Wagner Riddle (University of Guelph); Karen Ross (Farmers for Climate Solutions)

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LIST OF KEY INFORMANTS

Name	Occupation	Organization	Time of interview
Kelsey Ellis	Policy analyst	Environment & Resource Policy Ministry of Agriculture (Saskatchewan)	June 25, 2020
Jim Tokarchuk	Executive director	Soil Conservation Council of Canada	June 29, 2020 September 14, 2020
David Lobb	Professor	University of Manitoba	July 2, 2020
Marie-Élise Samson	Agronomist, Ph. D. Candidate	Laval University	July 6, 2020
Christine Ouellette	President	CarbOne Biodiversité	July 8, 2020
Angela Straathof	Program Director	Ontario Soil and Crop Improvement Association	July 8, 2020
Jérôme Dupras	Professor	Université du Québec en Outaouais	July 8, 2020
Janylène Savard	Agronomist	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec	July 9, 2020
David Burton	Professor	Dalhousie University	July 13, 2020
Martin Champigny	Researcher	Agriculture and Agri-Food Canada	July 22, 2020
Marc-Olivier Gasser	Researcher	Institut de recherche et de développement en agroenvironnement (IRDA)	July 28, 2020
Paul Thorougood	Program Manager	Ducks Unlimited Canada	September 4, 2020
Paul Watson	Director	ARECA	September 4, 2020
Bruce Kelly	Program Manager	Farm & Food Care Ontario	September 9, 2020
Daniel Bernier	Agronomist	UPA	September 10, 2020
Sean Smukler	Professor	University of British Columbia	August 11, 2020
Derek Lynch	Professor	Dalhousie University	August 11, 2020
Brian McConkey	Chief Scientist	Viresco Solutions Inc.	August 11, 2020
Angela Pearson	Analyst	Serecon	August 27, 2020
Bob Burden	Senior Director	Serecon	August 27, 2020
Susie Miller	Executive Director	CRSC	August 27, 2020

Name	Occupation	Organization	Time of interview
Rod MacRae	Professor	York University	September 30, 2020
Karen Ross	Director	Farmers for Climate Solutions	September 30, 2020
Darrin Qualman	Director of climate crisis policy and action	NFU	September 30, 2020
Adrienne Deschutter	Education Coordinator, Environmental Mgt Branch	OMAFRA	September 30, 2020

APPENDIX 2
PERSPECTIVES ON SOIL HEALTH

PERSPECTIVES ON SOIL HEALTH

Based on a review of literature, four perspectives to soil health were identified. This appendix presents and describes the different components associated with each perspective.

PERSPECTIVE 1: THE FIVE SOIL HEALTH PRINCIPLES

Build soil organic matter

(Bot and Benites, 2005; Agricultural Soil Health and Conservation Working Group. 2018)

Plants obtain nutrients from two natural sources: organic matter and minerals. Organic matter includes any plant or animal material that returns to the soil and goes through the decomposition process. In addition to providing nutrients and habitat to organisms living in the soil, organic matter also binds soil particles into aggregates and improves the water-holding capacity of soil. Even in small amounts, organic matter is very important.

Soil organic matter – the product of on-site biological decomposition – affects the chemical and physical properties of the soil and its overall health. Its composition and breakdown rate affect: the soil structure and porosity; the water infiltration rate and moisture-holding capacity of soils; the diversity and biological activity of soil organisms; and plant nutrient availability.

Minimize soil disturbance and compaction

(Chessman et al., 2019; Environmental Commissioner of Ontario. 2016; Agricultural Soil Health and Conservation Working Group. 2018)

In some cropping systems, physical, chemical or biological soil disturbance is an inevitable consequence of crop production. However, advances in agronomic research and farm equipment and technology have created the potential for most annual cropland acres to be managed with reduced or often no tillage. Disturbance to the soil ecosystem can also result from the inappropriate use of nutrients and pesticides, over irrigation, or over grazing. Reducing disturbance helps to slow carbon losses from the soil, protects soil aggregates from physical destruction and maintains habitat for soil organisms.

Tillage disturbs the soil food web, altering the balance between bacteria and fungi. Plowing breaks the fungal hyphae, slowing fungal growth and reproduction. Fungi are very important for soil structure and also for disease suppression, as beneficial fungi can outcompete and suppress pathogenic (disease-causing) fungi under good soil conditions. Tillage also exposes decomposer bacteria to higher levels of oxygen, speeding up the decomposition of organic matter. This releases CO_2 to the atmosphere too quickly (i.e., faster than it can be replaced), reducing overall soil organic matter levels.

Reduced soil organic matter then depletes the fungal populations further, resulting in a loss of stable soil aggregates. This leads to further carbon loss, as well as erosion and compacted soils. Reducing soil disturbance helps reduce soil loss through erosion, reduces the risk of structural degradation, such as compaction and aggregate instability, and allows soil ecosystems to flourish.

Keep the soil covered as much as possible
(Chessman et al., 2019; Environmental Commissioner of Ontario. 2016; Agricultural Soil Health and Conservation Working Group. 2018)

Crop residue and other organic materials such as mulch and compost, when left on the soil surface, provide a protective barrier between the soil and the destructive force of raindrops and wind. In addition, they moderate extremes in soil temperature and reduce evaporative losses from the soil. Soil cover can also be provided by leaves of growing plants. Keeping the soil covered throughout the year helps maintain soil aggregate integrity, protects habitat and provides food for soil organisms.

This practice protects the underground habitat of soil organisms, encouraging their growth and activity. Surface residues feed the soil food web by providing organic matter for microbes to feed on; main crops and cover crops feed the microbes with their root exudates. It helps sustain soil life, retain soil fertility, structure and organic matter, and it also prevents erosion and other degradation.

Diversify crops to increase diversity in the soil
(Chessman et al., 2019; Agricultural Soil Health and Conservation Working Group. 2018)

Primarily through their roots, plants affect the kinds and abundance of soil organisms, thus directly influencing soil biology and biological processes such as nutrient cycling. Different plant species, and even cultivars, are typically associated with distinct soil microbial communities. In addition, plant roots architecture often differs between species with resulting different effects on function. Above-ground diversity encourages diversity in soil biology, and can help improve soil organic matter, provide food and habitat for a diverse soil community, promote greater aggregate stability, and help alleviate compaction.

Keep living roots throughout the year as much as possible
(Chessman et al., 2019; Environmental Commissioner of Ontario. 2016; Agricultural Soil Health and Conservation Working Group. 2018)

The area immediately around plant roots is typically where the highest number and greatest diversity of soil microorganisms are found. Living plant roots exude numerous carbon compounds, and remove cells from root surfaces. These organic carbon additions to the ecosystem feed soil organisms and contribute to habitat development. Plant roots are also involved in complex biochemical communication with soil microbes whereby beneficial organisms are recruited and pathogenic organisms deterred. In addition, roots can enmesh soil particles thereby creating and preserving soil aggregates. Also, living plant roots can help alleviate or prevent soil compaction.

Live roots feed the soil food web, via exudates. In particular, mycorrhizal fungi cannot survive without live roots as hosts; bare fields deplete mycorrhizal populations, depriving the following year's crop of their abundant benefits.

PERSPECTIVE 2: SOIL FUNCTIONS

Water flow and retention

Soil water flow is conditioned by the existence of a gradient of the total potential of soil water in both, the soil fully saturated by water (saturated flow) as well as in soil not fully saturated by water (unsaturated flow). The flow of water in soil can be described microscopically and macroscopically. On the microscopic scale, the flow in each individual pore is considered and for each defined continuous pore (Kutílek 2011).

Solute transport and retention

Group of processes by which solutes are transported through a medium. Soil is a natural medium at the interface between rocks, air, water bodies, and biota. As a result of this particular position in the biosphere, soil is crossed through by multiple flows: flow of air, water, heat, energy, solutes, solid particles, cells, organisms. Most of the transport processes in soil occur through its pores, either filled with air in the case of gases, or filled with water in the case of solutes and suspended particles (Coquet et Pot 2011).

Physical stability and support

Soil has the ability to maintain its porous structure and regulate passage of air, gases, and water, withstand erosive forces, support heavy loads, and provide a medium for plant roots (Hoorman et al., 2012).

Retention and cycling of nutrient

Nutrient cycling refers to the transfers, chemical transformations, and recycling of nutrients in ecosystems (Freedman 2018). Soil stores, moderates the release of, and cycles nutrients and other elements. During these biogeochemical processes, analogous to the water cycle, nutrients can be transformed into plant available forms, held in the soil, or even lost to air or water. Nutrient cycling can be assessed by measuring the following indicators: Fertility Indicators, Organic Matter Indicators, Soil Reaction Indicators (Soil Quality for Environmental Health 2011). Healthy soils also have the capacity to store carbon in a non-labile form with the aim to reduce the CO_2 concentration in the atmosphere (LandMark, 2020).

Retention and cycling of nutrient

Soil acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients can be neutralized, transformed, or otherwise made unavailable to plants and animals (Hoorman et al., 2012).

Maintenance of soil biodiversity and habitat

According to the Convention on Biological Diversity (CBD), soil biodiversity is defined as “the variation in soil life, from genes to communities, and the ecological complexes of which they are part, that is from soil micro-habitats to landscapes.” Healthy soils offer an environment where an animal, plant, or microbe lives and grows (NRCS, N. D.a).

Cation Exchange Capacity

The cations are positively charged ions (e.g. calcium (Ca2+), magnesium (Mg2+), potassium (K+), etc.). The capacity of the soil to hold on to these cations called the cation exchange capacity (CEC). These cations are held by the negatively charged clay and organic matter particles in the soil through electrostatic forces (negative soil particles attract the positive cations). The cations on the CEC of the soil particles are easily exchangeable with other cations and as a result, they are available for plants. Thus, the CEC of a soil represents the total amount of exchangeable cations that the soil can adsorb (Cornell University Cooperative Extension, 2007).

PERSPECTIVE 3: SOIL CHARACTERISTICS

Soil composition

The soil is a combination of different types of minerals, organic and matter, different gases together with the water portion. Because of this, soil can be termed as a heterogeneous body (Munna, 2017).

Soil structure

The arrangement of soil particles into aggregates which form structural units. Size, shape, and distinctness are used to describe soil structure (NRCS, N. D.a).

Soil organic matter

The total organic matter in the soil. It can be divided into three general pools: living biomass of microorganisms, fresh and partially decomposed residues (the active fraction), and the well decomposed and highly stable organic material. Surface litter is generally not included as part of soil organic matter (NRCS, N. D.a).

Soil chemical composition and fertility

Soils are heterogeneous mixtures of air, water, inorganic and organic solids, and microorganisms. No two soils are exactly alike. Soil reactions and processes occur over a wide range of spatial and temporal scales. Soil chemistry is concerned with the chemical reactions and processes involving these phases (for example, cation anion exchange, acidity/alkalinity, main nutrients, salinity, etc.). Chemical reactions between the soil solids and the soil solution influence both plant growth and water quality (Sparks, 2019).

Soil water holding capacity

The amount of water that a given soil can hold for crop use. Field capacity is the point where the soil water holding capacity has reached its maximum for the entire field (Curell, 2011).

Colour

Soil colour and other characteristics are used to distinguish and identify soil horizons (layers) and to group soils according to the soil classification system called Soil Taxonomy. Colour development and distribution of colour within a soil profile are part of weathering. Colour is also affected by the environment: aerobic environments produce sweeping vistas of uniform or subtly changing colour, and anaerobic (lacking oxygen), wet environments disrupt colour flow with complex, often intriguing patterns and points of accents. Colour can be used as a clue to mineral content of a soil. Iron minerals, by far, provide the most and the greatest variety of pigments in earth and soil (NRCS, N. D.a).

Texture
Texture indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil. Texture influences the ease with which soil can be worked, the amount of water and air it holds, and the rate at which water can enter and move through soil (FAO, N. D.b).

Microbial activity and diversity
It is the activities of microorganisms resulting in chemical or physical changes. Microorganisms are generally divided into five major taxonomic categories: algae, bacteria, fungi, protists and viruses. Their activity and interaction with other microbes and larger organisms and with soil particles depend largely on conditions at the microhabitat level that may differ among micro habitats even over very small distances (Wieland et al., 2001).

PERSPECTIVE 4: SOIL DEGRADATIONS

Soil degradations can be defined as the deterioration of soil productivity by such processes as erosion, organic matter depletion, leaching of nutrients, compaction, breakdown of aggregates, waterlogging, and/or salinization.

Water erosion (including sheet, rill and gully erosion)
(Chapman et al., 2011)

Wind erosion
(Chapman et al., 2011)

Salinity
(Chapman et al., 2011; Manitoba Agriculture, Food and Rural Initiatives, 2008)

In the landscape, soil salinity develops as excess water from well drained recharge zones moves to and collects in imperfectly to poorly drained discharge zones. The buildup of excess water brings dissolved salts into the root zone of the discharge area. The concentration of these salts reduces the amount of available water, so that crops trying to grow in salt-affected areas cannot extract enough water to grow. As a result, many plants will exhibit symptoms of droughtiness, but the soil is often relatively moist. Human-induced salinity is the result of human activities that have changed the local water movement patterns of an area. Soils that were previously non-saline have become saline due changes in saline groundwater discharge.

Loss of SOM
(SOCO 2009; Chapman et al., 2011)
Soil organic matter is a source of food for soil fauna, and contributes to soil biodiversity by acting as a reservoir of soil nutrients such as nitrogen, phosphorus and sulphur; it is the main contributor to soil fertility.

Decline in soil fertility
(FAO N. D.)
Soil fertility is the ability of a soil to sustain plant growth by providing essential plant nutrients and favourable chemical, physical, and biological characteristics as a habitat for plant growth. Nutrient sources include chemical and mineral fertilizers, organic fertilizers, such as livestock manure and composts, and sources of recycled nutrients.

The main function provided by a fertile soil is the provision of food. A fertile soil also provides essential nutrients for plant growth, to produce healthy food with all the necessary nutrients needed for human health. Moreover, fertility has an impact on activities with an economic impact and is therefore related to economic growth and the fight against poverty. Finally, good management of soil fertility can help reduce soil, water and air pollution, regulate water resource availability, support a diverse and active biotic community, increase vegetation cover and allows for a carbon-neutral footprint.

Soil acidity or alkalinity
(Chapman et al., 2011)

Decline of soil structure (include compaction and surface sealing)
(Chapman et al., 2011)
Increase in density and a decline of macro-porosity in soil that impairs soil functions and impedes root penetration and water and gas exchange (FAO N. D.).

Densification of an unsaturated soil by the reduction of fractional air volume. Compaction can take place either under a static load or transient vibration or trampling by animals and machines (Gliński et al., 2011).

Soil and water pollution
(FAO N. D.)

Soil pollution implies the presence of chemicals and materials in soil that have a significant adverse effect on any organisms or soil functions. Soil pollutants include inorganic and organic compounds, some organic wastes and the so-called “chemicals of emerging concern.” Soil pollution has a direct impact on food security and there is a direct link between the quality and safety of the food and the level of soil contaminants. Additionally, soil pollution affects food availability by reducing crop yields due to toxic levels of contaminants that hamper crop growth and reduce soil biodiversity, thus increasing the problem of food security.

Soil acts as a filter and buffer for contaminants, but its potential to cope is finite. If the capacity of the soil to mitigate the effects of contaminants is exceeded, the soil turns into a time bomb that can pollute other compartments of the environment. Soil pollution also triggers a chain of soil degradation processes, starting from the loss of soil biodiversity, the reduction of soil organic carbon, to the destruction of soil structure and the increase of soil erodibility. Contaminants can leach into groundwater or become available for plant uptake and entry into the food chain. Contaminants accumulate in plant tissues and soil organisms, passing to grazing animals, birds, or to humans that consume them. Many contaminants become more concentrated as they rise up the food chain, increasing the potential for harm to human health.

APPENDIX 3
MAIN BMPS CONSIDERED IN THE LITERATURE

MAIN BMPS CONSIDERED IN THE LITERATURE

Sources	Description	
Policy approaches (13)		
Greenbelt. 2018	Growing a cover crop in between the main 'commercial' crops Adding organic amendments such as animal manures or composted food waste Reducing fertilizer and chemical inputs	Reducing tillage & minimizing soil compaction Diversifying the food grown Protecting soil from wind and water through windbreaks, berms, swales or grassed waterways.
Environmental Commissioner of Ontario. 2016 (Putting Soil Health First)	Conservation tillage Crop rotations Cover crops The 4Rs of fertilizer use	Composting and compost utilization Livestock integration Use an ecological approach to grazing management
Agricultural Soil Health and Conservation Working Group. 2018 (New Horizons: Ontario's Agricultural Soil Health and Conservation Strategy)	Diversify crop rotations Reduce tillage Keep soil covered	Apply organic amendments Control erosion Minimize compaction Bringing it all together (systems approach)
Siebielec et al., 2019 (EU – Sustainable Soil Management Policy Brief)	Vegetation cover Mulching soil (plant residues) Terracing Conservation tillage	Shelterbelts or windbreaks Application of permanent grasses Crop rotations with legumes Avoid land use changes (e.g. deforestation or conversion of grassland to cropland)
Zelikova et al., 2020 (Carbon 180)	Conservation tillage : Minimize soil disturbance. Perennialization: Develop and grow perennial crops, which reduce the need to till. Cover cropping: Grow crops during the off-season to maintain plant cover and reduce erosion.	Double Cropping: Grow an additional crop during the growing season. Crop rotation: Rotate the crop(s) between growing seasons. Managed grazing: Rotate grazing of livestock between pastures to stimulate plant regrowth and add manure to the soil. Compost application: Add compost to a field or pasture.
Ontario Cover Crops Steering Committee, 2019	Cover crops Crop rotations	
Field to Market, 2016	Soil tillage and residue management Crop rotations and cover crops	Nutrient management Measure soil health in the field
FAO. N. D. Global Soil Partnership	Strengthening of soil data and information: data collection, validation, reporting, monitoring and integration of data with other disciplines;	Cover crops Keep the soil surface always vegetated Optimizing soil nutrient management

	Limit tillage Build terraces	Minimizing the soil nutrients depletion and losses
FAO. 2017. Voluntary Guidelines for Sustainable Soil Management	Avoid land use changes Mulching, minimum tillage, no-till, strip cropping, managing crop residues Cover crops, intercropping Agro-ecological approaches Controlled vehicle traffic Continuous plant cover Crop rotation, Contour planting Cross slope barriers	Agroforestry, shelterbelts, grassed waterways or vegetated buffer strips, riparian buffers, vegetative or artificial wind breaks Appropriate stocking rates and grazing intensities Terraces Irrigation systems Organic farming Integrated soil fertility management Integrated pest management Apply manure, compost
FAO. 2015. Healthy soils are the basis for healthy food production	Agroecology Organic farming Conservation agriculture	Zero tillage Agroforestry
FAO, I. 2015. Status of the World's Soil Resources	Conservation tillage Artificial drainage Cover crops Crop rotation Windbreaks Organic amendments	Terraces Nutrient management Pesticide management Improved grazing Efficient irrigation
FAO.2019.	Minimum and zero tillage, Mulching, Cover cropping, Crop diversification, Agroecology,	Addition of organic matter and manure, Soil fertility management, Agroforestry, Rotational grazing, and Control of soil erosion by water and wind.
SCCC. 2020	Soil health awareness Cover Crops	4R nutrient Management
Government Websites and Publications (8)		
Clearwater, R. L. et al., (AAFC). 2016.	Increase use of soil testing Judicious nutrient application Adopt new technologies Reduced tillage and no-till Crop residues Manage manure, fertilizers and pesticides more efficiently Cover crops Nutrient management Riparian buffer	Permanent cover Environmental farm planning activities Watershed Grassed waterways, strip cropping, terracing, contour cultivation and cropping, winter cover crops and shelterbelts, inter-seeding row crops with other crops Perennial forages More spatially detailed and up-to-date data on soil Planting deep-rooted, high moisture-use perennials

	Testing of solid manure before application Winter cover crops Integrated pest management Shelterbelts	Use appropriate drainage systems Incorporating more tolerant crops to specific issues Adoption of precision farming techniques to reduce or optimize nitrogen fertilizer use
OMAFRA. N. D. Best Management Practices Series.	Adding organic amendments Buffer strips Cropland retirement Erosion control structures Field windbreaks Inter-seeding cover crops Mulch tillage, no-till	Residue management Crop rotation Wind strips Winter cover crops Buffer strips Integrated pest management
Alberta's Ministry of Agriculture, Food and Rural Development. 2004.	General considerations o Soil sampling and testing o Sampling and testing manure o Record keeping o Farm management planning Tillage and seeding practices o Conservation tillage systems o Seed quality and seeding practices Erosion control o Water erosion control structures o Buffer zones and riparian areas o Shelterbelts o Strip cropping o Cover crops o Emergency wind erosion control Cropping rotations o Continuous cropping o Fall-seeded crops o Perennial forages o Permanent cover o Green manuring	Crop residue management o Spreading crop residues o Removing straw and chaff o Handling difficult residue conditions Nutrient management o Nutrient management planning o Reducing nitrogen and phosphorus losses o Manure application Pest management and pesticides Integrated pest management o Pesticide application Irrigated crop production o Water efficient equipment o Irrigation applications Managing for special conditions o Infield variation o Saline soils, Acid soils, Peat soils, Solonetzic soils o Soil compaction Marginal crop lands
Manitoba Agriculture, Food and Rural Initiatives, 2008.	Conservation tillage Follow-up and monitoring Crop residue management Deep rooted crops Nutrient management Slow release N fertilizers Inclusion of leguminous cover crops	Manure Avoiding summer fallow Snow management – leave standing stubble, plant shelterbelts or annual barriers, or leave trap strips of stubble Good drainage management Buffer strips Calibration, timing and placement of nutrients

	Compost	Riparian areas
British Columbia Ministry of Agriculture. 2015.	Permanent soil cover Cover crops Strip cropping Crop residue	Minimum tillage Shelterbelts Fences
MAPAQ. 2020.	Adopter des pratiques culturales de conservation dans des zones à risque élevé d'érosion Cultiver des cultures de couverture (SCA) Implanter en fin de saison des cultures servant de protection hivernale des sols Cultiver les champs en contrepente Faire de la culture sur billons permanents Faire du semis direct Faire du travail en bandes alternées Faire la culture sur planches permanentes Faire le travail du sol au printemps plutôt qu'à l'automne Faire le travail réduit du sol Ajuster la pression des pneus pour diminuer les risques de compaction de surface Installer des roues doubles ou larges, des roues basse pression (pneus IF et VF) sur les tracteurs Adapter les pratiques culturales en zone inondable Faire des apports de matières organiques au champ Faire un plan de rotation amélioré des cultures en s'assurant d'avoir trois cultures ou plus	Évaluer l'état d'infiltration et de la compaction du sol Peser la machinerie agricole pour connaître son poids par essieu et, au besoin, procéder au lestage au bon endroit du tracteur Faire de la circulation contrôlée de la machinerie agricole (y compris la modification de la machinerie) Mettre en place des mesures de réduction à la source des matières résiduelles organiques d'origine végétale (résidus de culture de fruits et légumes) Faire de bonnes pratiques de gestion des fumiers au sol (ex. : amas au champ, amas au bout du bâtiment) Faire des essais de fertilisation à la ferme pour contribuer à limiter les pertes d'éléments fertilisants dans l'environnement Utiliser des outils pour mieux déterminer les besoins des plantes (ex. : tests de nitrate) Évaluer le potentiel des MRF afin de corriger ou d'entretenir le pH des sols, d'augmenter ou de maintenir le taux de matière organique des sols ou de réduire l'achat d'engrais minéraux. Utiliser des pesticides à moindre risque pour protéger l'environnement et la santé (IRE et IRS). Évaluation de l'état des sols
Ministry of Agriculture, Aquaculture and Fisheries. N. D.	Grassed waterways Conservation tillage Terraces Water and sediment control basins	Application of hay mulch after potato harvest Crop residues Windbreaks Surface drainage
USDA. 2015.	Conservation Crop Rotation Residue and Tillage Management, No-Till Cover Crop	Mulching Nutrient Management Manure application
Academic and Scientific Literature (21)		
Duiker, S. W. et al., 2017.	No-till Diversify crop rotations Plant cover crops Diversify cover crops Maximize living roots	Plant green Enhance soil armour Manage nutrients Manage manure Manage pests

	Grow living plants Manage carbon Use interseeding	Avoid compaction Integrate crops and livestock
White and Barbercheck, 2017.	Reduce inversion tillage and soil traffic Increase organic matter inputs Use cover crops	Reduce pesticide use and provide habitat for beneficial organisms Rotate crops Manage nutrients
Puran, M. A. L., Hesse, J. W., and Schmitz, M., 2015.	Conservation tillage Crop residues Cover crops	Intercrops Crop rotation
Samson. M.-E. et al., S. D.	Résidus de culture Engrais de ferme Matières résiduelles fertilisantes Engrais verts Travail réduit du sol	Systèmes agroforestiers Herbacées pérennes Engrais organiques Semis direct et résidus Couvrir le sol
Johnson, J. M. et al., 2007.	Tillage and residue management Crop rotations Amendment applications	Optimal use of fertilizers (e.g. N) Perennial grasses Cover crops
Kimble, J. M. et al., 2016.	Conservation tillage and residue management Cover crops Judicious use of fertilizers Integrating nutrient management by using biosolids and manure	Appropriately manage water Crop rotation Avoid land-use change
Bolinder, M. A. et al., 2020.	Crop residue Cover crops Recycled organic materials (e.g. manure)	N-fertilization Rotations containing more crops Reduced tillage
Gagné, G. et al. 2018.	La rotation planifiée des cultures, L'utilisation d'engrais verts ou de cultures de couverture, Les bandes riveraines, Les aménagements en conservation des sols et de l'eau, Les brise-vent	La lutte aux ennemies de culture et la gestion des mauvaises herbes. Travail réduit Gestion des fumiers Évaluation de l'état des sols Adapter la machinerie
Alberta's Ministry of Agriculture and Forestry. 2016.	Soil Management o Reduced tillage practices (#1) o Crop rotation, incorporating perennial or pulse crops (#5) o Cover crops (#4) Nutrient Management 4R o Fertilizer application – source (rank #9) o Fertilizer application – rate (rank #10) o Fertilizer application – timing (rank #11)	Water bodies o Buffer zones for field crops (near riparian areas) (rank #8) Water quality and market demand o Manage livestock access to water bodies and riparian areas (e.g. provide off-site watering) (rank #13) Livestock Yards o Siting – distance to nearest surface water body (rank #14)

	○ Fertilizer application – placement (rank #12) Livestock Yards ○ Setback distance for manure application in proximity to water bodies (rank #7) Manure Use/Management ○ Application rate based on testing and book values (rank #2) ○ Application method – conventionally tilled land (rank #3) ○ Timing of application for plant needs (rank #6)	○ Run-on control (rank #15) ○ Runoff control (rank #16) ○ Catch basin management (rank #17) 1. GHG emissions and market demand 2. Restoration of wetlands (rank #18)
Climate Action Reserve. 2020. Soil Enrichment Protocol V1.0	No or reduced tillage Crop rotation Cover crops Reduced inputs Integration of livestock	Biochar Woody biomass Optimize use of synthetic fertilizer Irrigation systems Use of non-synthetic fertilizer
Reid, K. et al., 2019	Manure application Optimal use of fertilizers (Phosphorus)	
Norris, C. E., & Congreves, K. A. 2018	Conservation tillage Amendments	Cover crops Crop rotation
Chessman, D. et al., 2019	Conservation cover Conservation crop rotation Cover crop Forage and biomass planting Pest management conservation system	Mulching Nutrient management Prescribed grazing Residue and tillage management
Venterea, R. T. et al., 2016	Weather and soil measurements 4R approach	
VandenBygaart, A. J. et al., 2003	Tillage management Crop residue	Crop rotation Fertilizer inputs (synthetic and organic)
Rasouli, S. et al., 2014	Tillage practices Crop selection Crop rotations	Manure application Fertilization Water management structure (e.g. drainage)
Paustian, K. et al., 2019	Improve crop rotations and increase crop residues Cover crops Conversion to perennial grasses and legumes Manure and compost addition	No-tillage and other conservation tillage Rewetting organic soil Improved grazing land management
Bradford, M. A. et al., 2019	Conservation tillage Cover crop	Fertilizer use

Maikhuri, R. K., & Rao, K. S. 2012	Environmental buffer or filter Avoid land conversion to agricultural land use	
Yanni, S. et al., 2018	Matching of N application rate to crop needs Use of nitrification inhibitors (NI) or nitrification plus urease inhibitors (NI+UI) Cover crops Afforestation	Biomass crop Conservation tillage Crop rotation Land-use change
Weber, M., 2017	Diverse crop rotations with perennials Use of cover crops to extend the months of ground cover with live plants Reduced tillage, residue management Organic amendments Afforestation, buffer strips, windbreaks, wind strips	Minimizing compaction Soil testing Nutrient management (4Rs) Retirement of fragile lands Erosion control

APPENDIX 4
REVIEW OF THE BENEFITS, RISKS AND LIMITATIONS OF BMPS

MAIN BMPS CONSIDERED IN THE LITERATURE

Conservation Tillage			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• Leaving crop residue on the soil surface in the autumn led to a lower level of N2O production (1.19 kg N2O N ha_1 year_1) compared to plowing manure or crop stubble into the soil (Gregorich et al.,2005). • In Western Canada, NT resulted in additional C storage of approximately 580 kg C ha−1 yr−1 or 1.75 % yr−1 in the coarse-textured soils, 300 kg C ha−1 yr−1 or 0.52 % yr−1 in the medium-textured soils, and 430 kg C ha−1 yr−1 or 1.1 % yr−1 in the fine-textured soils. Both coarse- and fine-textured soils had a greater rate of C sequestration with NT (Liang et al.,2020). • Can reduce C loss and more stored in the soil (Clearwater et al., 2016; Paustian et al., 2019; Field to Market, 2016; FAO, 2017a; Yanni, S. et al., 2018). • Can reduce N_2O emissions (Yanni, S. et al., 2018). • Reduce organic C oxidation, reducing the amount of CO_2 released in the atmosphere (Abdalla et al., 2013). • In the North-Eastern region (Germany), there is about 35 metric tons of CO_2 emission reduction in two crop rotations per farm (Puran, Hesse and Schmitz, 2015). • Carbon sequestration under conservation tillage results in reduction of carbon emission by 0.5 tone carbon ha-1year-1, which reduces 1.85 tons CO2 ha-1year-1 (Puran, Hesse and Schmitz, 2015). • Reduction of CO_2 & N_2O gas emissions (4% to 11%) (Puran, Hesse and Schmitz, 2015). • Soil Organic Carbon increased at topsoil (10% to 70%) and higher Carbon sequestration (Puran, Hesse and Schmitz, 2015). • Using global data, based on 67 long-term field experiments, change from CT to NT could sequester an average 43–71 g C m -2 year -1 (Pasricha, 2017). • Thirteen years after the establishment of the experiment, the SOC stock under long-term NT was 8.4 Mg C ha -1 greater than under CT (Pasricha, 2017).	• Excellent way to control erosion (tillage, water and wind erosion) (FAO. N. D.; FAO, 2017a; Field to Market, 2016; USDA, 2015). • Crop residues may have helped to mitigate the impact of hot and dry weather on corn yields by restricting water loss, delaying soil warming, reducing air temperature at the soil surface and reducing evaporation potential (Gaudin et al., 2015). • When combined with other BMPs, showed increase in SOM (Kahlon et al., 2013; So et al., 2009; Sharratt et al., 2006; Rhoton et al., 1993; Aziz et al., 2013). • Improve soil structure which reduces soil compaction (Greenbelt, 2018; Field to Market, 2016; FAO, I. 2015; FAO, 2017a). • Prevent soil salinization (FAO, 2017a). • Reduce the risk of nutrient loss by leaching (Field to Market, 2016; USDA, 2015). • Improve drought tolerance (Field to Market, 2016; USDA, 2015). • Reduction in the net erosion rate by about 87% and the proportion of the study area	• Provide food and cover for wildlife (Field to Market, 2016; FAO, 2017a). • Increase water infiltration and the water-holding capacity (Field to Market, 2016; USDA, 2015) • Can improve microbial biomass and enzyme activities under no-till system (Bossche et al., 2009). • Can increase the amount of deep burrowing earthworms (Joschko et al., 2009; Field to Market, 2016; FAO, 2017a). • Under no-till, Arbuscular mycorrhizal fungi survive better (Kabir, 2005). • More than 50% higher earthworms' abundance (110 earthworms pro m2 higher in average) (Puran, Hesse and Schmitz, 2015). • Proportion of deep burrowing earthworms *Lumbricus terrestris* was increased up to 55% (33 earthworms pro m2 higher) (Puran, Hesse and Schmitz, 2015). • Microbial biomass and enzyme activities were found to be higher in silt loam soil under no-till than under plow conditions over a period of 2, 5 and 19 years (Bossche et al., 2009). • Soil bulk density may decrease over the long-term (Field to Market, 2016). --- **Risks and limitations:** • May increase groundwater recharge via intact root channels. • Strip-till practice is less suited for drilled crops and in dryer regions since the strip may dry too much and form a crust.	• Can improve the distribution of snowmelt water (Alberta's ministry of Agriculture, Food and Rural Development. 2004, Clearwater et al., 2016) • Reduction in fuel requirements (Alberta's ministry of Agriculture, Food and Rural Development. 2004) • Reduction in equipment wear-and-tear (Alberta's ministry of Agriculture, Food and Rural Development. 2004) • Limit air pollution from dust during harvest (Kruger Seeds, n. d.) • Reduce weed pressure (Alberta's ministry of Agriculture, Food and Rural Development. 2004) • The soil temperature advantage with strip-till, compared with no till, is that it allows faster plant emergence and development. This advantage is enhanced when soil temperatures are lower and approach the lower threshold for crop seed germination (Nowatzki et al., 2017). • Converting to a strip-till method of production from conventional tillage will eliminate expenses associated with primary and secondary tillage (Nowatzki et al., 2017). • More than 25% reduction in labour use. Saving of 2h ha-1year-1 (Puran, Hesse and Schmitz, 2015). • More than 20% saving in production costs (Puran, Hesse and Schmitz, 2015). • About 30% reductions in diesel consumption (Puran, Hesse and Schmitz, 2015). • Less tillage further enhanced rotation benefits, yield stability and corn yields under

- Preseeding soil profile (0–90 cm) NO_3-N contents under continuous NT were 55–110 kg NO_3-N ha -1 less than under moldboard plow tillage in continuous corn (Pasricha, 2017).
- A study conducted in Ridgetown Ontario, in the top 0-10 cm the SOC content was 36 Mg/ha for NT and 29 Mg/ha for CT soils. NT had 36% more SOC content (and concentration) compared to CT in the top 0-5 cm, 26% more in the 0-10 cm, and 16% more in the 0-100 cm profile (Van Eerd et al., 2014; cited in Yanni et al., 2018).
- Strip tillage released 82.6%t less CO_2 than moldboard plowing (Nowatzki et al., 2017)

Risks and limitations:

- Adopting no-till did not always increase soil C. This apparent absence of no-till effects on C storage was attributed to the type and depth of tillage, soil climatic conditions, the quantity and quality of residue C inputs, and soil fauna (Gregorich et al.,2005).
- The greatest positive effects in eastern Canada were measured in fine-textured soils (Table 4) suggests that a significant part of the effect of no-till on increased N2O emission may be linked to its direct impact on soil density and water content, and its indirect impact on oxygen levels, gas diffusion, and aeration. This effect is likely less important under the much drier climate in the western Canadian Prairies (Gregorich et al.,2005).
- Carbon losses were particularly high on fine and coarse textured soils, whereas in medium textured soils NT tended to increase SOC. On the Canadian prairies NT consistently increased SOC. The rate of gain in SOC under NT decreased over time with higher rates in the 3−10 years following a change to NT at a rate of 740 kg C ha−1 yr−1 or 1.3 % yr−1. Rates declined to 260 kg C ha−1 yr−1 or 0.87 % yr−1 for periods from 11–20 years after tillage change, and to 95 kg C ha-1 yr−1 or 0.23 % for periods longer than 20 years. The results of this work clearly show climate, soil texture and duration of management as main drivers of SOC change under NT in Canada and key factors that must be considered in the development subject to erosion from 100% to 57% (Schuller et al., 2007).
- Reduction in soil loss (50 to 88%) (Puran, Hesse and Schmitz, 2015).
- Average runoff during three rainfall events was 25% in NT and 36% in CT (Pasricha, 2017).
- NT can still reduce soil losses by as much as 68% and SOC losses by around 50% which is a significant contribution of no-till practice alone (Pasricha, 2017).
- Up to a 30 percent increase was observed in yield, infiltration rate, and moisture levels under NT where residue mulch was applied compared to where residue cover was removed (Smith, 2015).
- A review of studies shows that a 4 to 50 percent reduction in runoff can result where NT, mulch, and/or cover crops are used compared to where CT is used without cover crops or mulch (Smith, 2015).

Risks and limitations:

- Studies indicate that no-till systems reduce herbicide runoff by up to 70% compared to conventional systems. However, in some cases herbicide runoff was greater in no-till (Hill and Mannering, 1995).
- This practice is also more dependent on the use of herbicide.
- Strip-till is less recommended in sloped fields
- In poorly drained soils, no-till practice slows down soil warming in the spring.
- In the soil surface, soil bulk density may increase compared to conventional tillage, but in the deeper soil zones, tillage system did not consistently influence either bulk density or penetration (Grant and Lafond 1993).

unfavorable growing conditions (Gaudin et al., 2015).

Risks and limitations:

- Potato is known to return negligible mounts of residues back to the soil and is characterized by a high degree of soil disturbance (Nyiraneza et al., 2017).
- The dominant soil texture in PEI is sandy, which explains the low SOM ranges (Nyiraneza et al., 2017).
- Residues in reduced tilled systems often delay soil warming, planting date and emergence which may have decreased corn yield potential in our short growing seasons when conditions were favorable (Gaudin et al., 2015).
- Under no-till, adding fertilizer or manure is problematic since it cannot be incorporated.
- The effect of the degree and type of tillage on soil health is contingent on a host of local and regional factors including climate, soil texture, crop rotation decisions and length of time a level of tillage has been practiced (Field to Market, 2016)
- Scouting is required because insects, disease, and weed problems may be different compared to pests that are found in conventional tillage systems.
- Strip-till has fewer benefits, compared to no-till, in warm springs or in warm, well-drained soils.
- With no-till, there is no option to control weeds mechanically.
- No-tillage farming can involve more intensive management of crops and soil than traditional tillage farming
- Direct seeding is frequently associated with the use of GMO, which implies more herbicide applications.
- No-till does not always produce equivalent crop yields in climates with cold springs, suboptimal soil temperatures, and poorly drained and heavy-textured soils (Lal, 2007).

of either national or regional SOC models (Liang et al.,2020). • In Eastern Canada, overall, there was no difference in SOC between NT and CT, while the amount of SOC under NT in Western Canada increased by 7 % (Liang et al.,2020). • The absence of an effect of NT on SOC has been observed in many wet and cool climates, and that under those conditions, differences in tillage systems only result in differences in SOC distribution in the soil profile (Liang et al.,2020). • In Eastern Canada, on average NT sequestered C at rates of 160 kg C ha−1 yr−1 or 0.24 % yr−1 in the medium-textured soils whereas NT lost C at rates of 660 kg C ha−1 yr−1 or 0.34 % yr−1 in the fine-textured soils (Table 2). There was no statistical difference in SOC storage between NT and CT in the coarse-textured soils, even though NT tended to lose C at a rate of 490 kg C ha−1 yr−1 or 0.82 % yr−1 (Liang et al.,2020). • No-till (NT) increased the storage of SOC in western Canada by 2.9 ± 1.3 Mg ha–1; however, in eastern Canada conversion to NT did not increase SOC (VandenBygaart et al., 2003). • Conversion to no-till from conventional tillage was most effective in increasing C storage in the Chernozemic soil zones of the Canadian Prairies, but did not increase SOC storage in moister soils of eastern Canada, suggesting that climate affects the ability of soils to store SOC under NT (VandenBygaart et al., 2003). • In a study conducted in Quebec, Canada, on a clay loam soil, Nyiraneza et al. (2009) reported that soil organic C declined by 0.25 g C kg−1 yr−1 after 28 yr of rotating silage corn and grain, with straw removed during the grain phase. The declining SOM in PEI can be attributed in part to low residue return and intensive farming operations (Nyiraneza et al., 2017). • Soils have a finite capacity to store carbon and, over time, will approach their maximum sequestration capacity (Clearwater et al., 2016). • In some cases, if limited tillage increases both the soil carbon and moisture, higher N_2O emissions may	• The reduction of erosion also depends on the type of crops		

occur. (Field to Market, 2016; Alberta's ministry of Agriculture, Food and Rural Development. 2004). • Surface application of manure in NT increase the risk of nutrient loss from volatilization and surface runoff (Manitoba Agriculture, Food and Rural Initiatives 2009).			

Cover crops			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• Systems containing legumes produced lower annual N2O emission than fertilized annual crops (Gregorich et al.,2005). • The time since introduction of cover crops in crop rotations was linearly correlated with SOC stock change (R2 = 0.19) with an annual change rate of 0.32 _ 0.08 Mg ha _1 yr _1 in a mean soil depth of 22 cm and during the observed period of up to 54 years (Poeplau and Don 2015; cited in Yanni et al., 2018). • Increase SOC (Yanni, S. et al., 2018). • Reduce N_2O emissions (Yanni, S. et al., 2018; IPCC, 2007). • Can sequester carbon in soil (Barthès et al., 2004; Freibauer et al., 2004; Paustian et al., 2019; Bradford et al., 2019; Siebielec et al., 2019; Field to Market, 2016; FAO, 2017a) • On an average, NT practices more than doubled N_2O emissions as compared with moldboard plow in fine-textured soils (Pasricha, 2017). • Cumulative N_2O emissions increased from 3.71 kg N ha -1 at zero N application to 5.51 kg N ha -1 with 180 kg N ha -1 application in NT (Pasricha, 2017). • A study by Poeplau and Don (2015; cited in Yanni et al., 2018) modeled C sequestration under CC systems from widespread data (73% from temperate regions) and reported a SOC sequestration potential of 0.32 ± 0.08 Mg C/ha/y which was not affected by the type of CC or the tillage system. --- **Risks and limitations:**	• Reduce risk of soil erosion and runoff (Clearwater et al., 2016; Field to Market, 2016; FAO. N. D.; FAO, 2017a; Myers, 2017) • Prevent soil salinization (Clearwater et al., 2016; Field to Market, 2016; FAO. N. D.; FAO, 2017a) • Improve soil structure which reduce soil compaction (FAO, I. 2015; FAO, 2017a; Greenbelt, 2018). • Sustain SOM at the current level or even increase its content (Barthès et al., 2004; Freibauer et al., 2004; Paustian et al., 2019; Bradford et al., 2019; Siebielec et al., 2019; Field to Market, 2016; FAO, 2017a; Myers, 2017). • Reduce average total phosphorus loads to waterways (Tellatin and Myers, 2017). • Reduce risk of soil crusting (USDA, 1996). • Increased organic matter improves the environment for soil biological activity that will increase the breakdown of pesticides (USDA, 1996).	• Can capture Residual Soil Nitrogen (RSN) which minimize N leaching losses (Alberta's ministry of Agriculture, Food and Rural Development. 2004; Clearwater et al., 2016; Siebielec et al., 2019). • Some crops can fix nitrogen in the soil (Alberta's ministry of Agriculture, Food and Rural Development. 2004; Greenbelt, 2018; Siebielec et al., 2019; Field to Market, 2016; Myers, 2017). • Over the long term, it can increase soil organic matter, soil water infiltration and soil water capacity (Basche et al., 2016; Field to Martket, 2016; Myers, 2017). • Soil moisture is conserved (Environmental Commissioner of Ontario. 2016). • Improve soil food web (e.g., Arbuscular Mycorrhizal fungi) and hence soil biodiversity (Environmental Commissioner of Ontario. 2016; FAO, 2017a; Field to Market, 2016). • Cover crops typically lead to much greater earthworm numbers and even the types of earthworms (Myers, 2017). • The more plant diversity in a field and the longer that living roots are growing, the more biodiversity there will be in soil organisms (Myers, 2017). • Can increase microbial biomass (Wyland et al., 1996; Bandick and Dick, 1999; Brennan and Acosta-Martinez, 2017).	• Recycle nutrients in the soil which can potentially reduce fertilizer use (Yanni, S. et al., 2018; Alberta's ministry of Agriculture, Food and Rural Development. 2004; Myers, 2017). • Can control weeds or diseases (Greenbelt, 2018). • Can reduce pests and diseases and offer a greater weed control (Davis et al., 2012; Field to Market, 2016). • No till farming can reduce labour costs. • The residue of a cover crop can protect the soil while cash crops are getting established and keep it from getting too hot. • Allelopathy [killing weed species] (Frick and Johnson, 2002). • Perennial crops provide new cropping and market options for producers. • If grasses and legumes are used, they can be grazed or harvested for hay or silage. • By increasing the efficiency of the land, seasonal yields can be increased by approximately 25%, when compared to just a single cropping system. --- **Risks and limitations:** • Some crops, such as potatoes or sugarbeet, which are harvested late, do not allow the cultivation of a cover crop (Poeplau and Don 2015; cited in Yanni et al., 2018). • Must be planted when time (labor) is limited (Dabney et al., 2001).

• Cover crops terminated when relatively small (less than 2 tons per acre of biomass yield) appear not to affect CO2 emissions (Ruis et al., 2018) • Late-terminated cover crops with higher biomass production can increase CO2 emissions, most likely due to plant respiration (Ruis et al., 2018) • When cover crops increased SOC concentration, it can increase CO_2 emissions (Liebig et al., 2010; Kim et al., 2012; Haque et al., 2015). • Soils have a finite capacity to store carbon and, over time, will approach their maximum sequestration capacity (Clearwater et al., 2016).	• The land area at risk of soil salinization decreased between 1981 and 2011 in all three Prairie Provinces, with the greatest decrease in risk occurring in Saskatchewan, mainly because of cover crops (Clearwater et al., 2016; FAO, 2017a). • Desiccating or haying the crop returns about 60% of the plant material and nitrogen to the field (Alberta's ministry of Agriculture, Food and Rural Development. 2004). • On average, cover crops reduced sediment losses from erosion by 20.8 tons per acre on conventional-till fields, 6.5 tons per acre on reduced-till fields and 1.2 tons per acre on no-till fields (Tellatin and Myers, 2017). • Cover crops have been shown to reduce these nitrogen losses by an average of 48% (concentration measurements, median of 10 studies), and as much as 89% in one study (Tellatin and Myers, 2017). • Several sources also illustrated the ability of cover crops to reduce average total phosphorus loads to waterways by 15% to 92%, though more research on this is needed (Tellatin and Myers, 2017). • Under humid conditions a meta-analysis (in Eastern Canada) determined that cover crops, wheat and corn yields increased as soil organic	• Cover crops increased mean weight diameter of aggregates (MWDA) by 80% in the 0- to 7.5-cm depth (Smith, 2015). • Legume cover crops were found to increase levels of soil organic matter by 8% to 114% (Tellatin and Myers, 2017). Roots add organic materials, improve soil structure, and penetrate compacted layers (OMAFRA. N. D.). --- **Risks and limitations:** • In drier conditions, cover crop's water usage can reduce soil moisture and may hurt cash crop yield (Hoorman, 2009; Dabney et al., 2001). • Can decreased microbial biomass (Bending et al., 2004), and mixed results were otherwise observed (Schutter et al., 2001; Marinari et al., 2015).	• Additional costs (planting and killing) (Dabney et al., 2001; Hoorman, 2009) • Difficult to incorporate with tillage (Dabney et al., 2001). • Allelopathy [may suppress subsequent crop growth] (Dabney et al., 2001; Field to Martket, 2016). • Vegetable crop yields were reduced due to cover cropping (Norris & Congreves, 2018). • Can interfere with seedling emergence (Field to Martket, 2016). • May increase pest populations in the transition period (Dabney et al., 2001; Fertilizer Canada, 2018). • In northern regions, cover crops may not have time to establish themselves after the cash crop has been harvested in the fall (Union of Concerned Scientists, 2013).

	matter levels dropped below 5% (Bourgeois et al., 2020).		

Organic amendments

GHG Emissions	Soil Degradation	Soil Functions	Others
• The analysis yielded a global N_2O emission factor (EF) for all organic sources, EForg, equal to 0.57 _ 0.30%, which is lower than the IPCC default EF of 1 for synthetic fertilizers (Charles et al., 2017). • The EF was modulated by amendments (C/N ratio), soil (texture, drainage, organic C and N) and climatic (precipitation) factors. For example, EFs were on average 2.8 times greater in fine-textured than coarse-textured soils (Charles et al., 2017). • Application of solid manure resulted in substantially lower N_2O emission (0.99 kg N_2O N ha_{-1} $year_{-1}$) than application of liquid manure (2.83 kg N_2O-N ha_{-1} $year_{-1}$) or mineral fertilizer (2.82 kg N_2O N ha_{-1} $year_{-1}$) (Gregorich et al.,2005). • The major role of climate variability on soil N2O emissions likely explains why several local EF estimates in dry regions are lower than the IPCC default value that was originally estimated mostly from humid agricultural regions (Rochette et al., 2018). • The negative correlation was expected given that a decrease in soil pH is known to decrease the efficiency of the N2O reducing enzymes, which would increase the N2O:(N2+N2O) ratio (Rochette et al., 2018). • The use of biosolid organic N as an N source resulted in lower N2O emissions than raw manures attributed lower N2O emissions from biosolid organic N of pig slurry or pulp paper sludge to a higher C:N ratio of biosolids (Rochette et al., 2018). • Increase C inputs (Paustian et al., 2019). • Composting manure can increase soil-carbon sequestration rates (Environmental Commissioner of Ontario. 2016). • Composting manure does not give off as many greenhouse gases, such as methane and nitrous oxide, when applied to fields (Greenbelt, 2018).	• Build and maintain the level of organic matter in the soil (OMAFRA. N. D.; Greenbelt, 2018). • Adding manure amendments improve microbial activity and microbial biomass (Manitoba, 2013). • Incorporating manure improves the soil organic carbon levels and soil structure (Clearwater et al., 2016; FAO, 2017a). • Pastures generally respond well to fertilization by manure because their soil fertility is typically depleted after many years of grazing (Manitoba Agriculture, Food and Rural Initiatives, 2008). • The application of manure to cropland can help maintain or improve soil organic matter levels and improve soil tilth, soil structure, water infiltration, nutrient and water-holding capacity and reduce soil erosion (Manitoba Agriculture, Food and Rural Initiatives, 2008). --- **Risks and limitations:** • Losing nutrients if the manure is applied too early • Excess of easily degradable SOM may contribute to	• Can improve water retention, permeability, water infiltration, drainage, aeration and soil biodiversity (OMAFRA. N. D.; FAO, 2017a). • Composting manure can reduce runoff (and thus nutrient loss and pollution (Environmental Commissioner of Ontario. 2016). • In some studies, greater inorganic nitrogen (i.e., NO_3) concentrations after amendment applications were interpreted as beneficial for soil health (Ninh et al., 2015). • Application of Farmyard manure significantly reduced soil bulk density and increased mean weight diameter (MWD) and SOC contents in different aggregate size fractions (Smith, 2015). • Manure application was linked to positive physical and biological indicators like respiration, AMF, nonmycorrhizal fungi and WSA (Mann et al.,2019). • A decrease in sand content would likely reduce drainage rates that, for a given seasonal precipitation and mean annual air temperature, and therefore would result in greater soil WFPS (Rochette et al., 2018). --- **Risks and limitations:** • In some studies, greater inorganic nitrogen (i.e., NO_3) concentrations after amendment applications were interpreted as increased potential for nutrient losses with a negative impact on the environment (Evanylo et al., 2008). • Difficult to estimate timing of availability of nutrient in manure, particularly nitrogen	• Improved manure application techniques can increase manure N efficiency and possibly reduce the amount of fertilizer required (Clearwater et al., 2016). • Can reduce the need for commercial fertilizers. • Can increase vegetable crop yields (Norris & Congreves, 2018). Crops can be less prone to insect pests and diseases where organic soil amendments are used (Altieri et al., 2005) --- **Risks and limitations:** • Reducing time for nutrients to release if the manure is applied too late • Having a wet and/or cold spring which could delay manure application and then planting. • In some provinces, the availability of good quality manure is more complicated • Composting manure takes time and effort and doesn't provide the quick boost of nutrients that raw manure does (Greenbelt, 2018). • Manure or compost not available and the cost of transporting manure can be important (Viaene et al., 2016).

• Digestate produced lower N_2O emissions compared to raw manure only when it was injected (2.5 kg N/ha) but not when it was broadcast (6.4 kg N/ha) or broadcast and incorporated (5.4 kg N/ha) (Yanni et al., 2018). • The modeled N_2O emission factors were 39% and 45% lower for the composted manure in dry hay production and haylage production, respectively (Yanni et al., 2018). • A study estimated an average net GHG mitigation of 23 tCO_2eq/ha, over the 3-year study duration, considering the full LCA including landfill waste emissions vs. compost production, transport, applications, and subsequent soil improvement impacts (DeLonge et al., 2013; cited in Paustian et al., 2019). --- **Risks and limitations:** • It appears that soils in the region are a weak sink of CH4 and that this sink may be diminished by application of manure (Gregorich et al.,2005). • Organic amendments can increase CO_2 emissions from the soil (Ray et al., 2020). • Sewage sludge combinations showed the highest N_2O flux rates (Brenzinger et al., 2018). • Ammonium (NH_4 +) in manure or fertilizer converted to ammonia (NH3) gas can be lost to the atmosphere when unincorporated surface applications (Alberta Agriculture and Food, 2008). • Soils have a finite capacity to store carbon and, over time, will approach their maximum sequestration capacity (Clearwater et al., 2016). • Decock et al. (2014; cited in Yanni et al., 2018) found that there is an average reduction in N_2O emissions of about 40% when using mineral fertilizers. • Manure use results in between 50-80% more N_2O emissions than mineral fertilizer on coarse and medium-textured soils (Yanni et al., 2018). • A decrease in sand content would likely reduce drainage rates that, for a given seasonal precipitation and mean annual air temperature, and therefore would result in greater N2O production (Rochette et al., 2018).	environmental damage (Siebielec et al., 2019). • Repeat applications of manure at rates exceeding agronomic requirements can contribute to saline soil conditions. • Frequent traveling by loaded application equipment on wet soils can lead to soil compaction.	that can lead to overapplication of N with mineral fertilizers.	

• Greater N2O emissions in Eastern Canada compared to Western Canada and suggested that this was due to the more humid climate and heavier textured soils typical of Eastern Canada (Rochette et al., 2018).			

Nutrient management			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• The limited importance of N application rate on cumulative emissions is explained by the low emissions where substantial amounts of N are applied under well-aerated conditions in Canada such as in coarse-textured soils and in regions with a dry climate (Rochette et al., 2018). • Optimal use of fertilizer can reduce GHG emissions especially N_20 (Clearwater et al., 2016). • Fertilizer application methods such as knifing, mixing with drip irrigation water (i.e., fertigation), or applied in banded rather than broadcasted, may also minimize leaching, gaseous nitrogen losses (e.g., nitrous oxide) (Field to Market, 2016; Yanni et al., 2018; Clearwater et al., 2016; Alberta's ministry of Agriculture, Food and Rural Development. 2004). • Can improve soil carbon sequestration through biomass production and restitution to the soil (FAO, 2017a). • Inhibitors can reduce N_2O emissions and lower N leaching and volatilization (Yanni et al., 2018). • Compared to another simulation study in Western Ontario (Anderson, 2016; cited in Yanni et al., 2018), where split-N was applied as 70% pre-plant and 30% side-dress (at the V4-V6 stage), there were 21% less N_2O emissions compared to when all N was applied at planting. • The only treatment that decreased N_2O (by 20–53%) was Sp combined with inhibitors and reduced N rate (Venterea et al., 2016; cited in Yanni et al., 2018). • A study in Ontario and Quebec by Ma et al. (2010) on corn showed that, across years and locations, the relationship between N fertilization rate and N_2O emission is described by an exponential function such that increasing the N rate from 90 to 150 kg N/ha	• Improved efficiency of N use can reduce leaching and volatile losses (Clearwater et al., 2016; FAO. N. D.; FAO, 2017a). • Injection of fertilizer reduce losses through precise application of nutrients (NRCCA, n. d.). • Broadcast incorporated improves on the efficiency of surface application and improves crop uptake (NRCCA, n. d.). • Band application slows NH_4+ conversion to NO_3- (nitrification), reducing the risk of leaching (NRCCA, n. d.). • Application techniques that conserve N maximize the fertility value of the manure and reduce the risk of N loss to air or water (Manitoba Agriculture, Food and Rural Initiatives, 2008). Enhanced soil organic matter levels by producing more root and crop residue biomass. --- **Risks and limitations:** • Surface broadcast can cause high nutrient losses and have low uniformity (NRCCA, n. d.).	• Diverse sources of nutrient inputs can help ensure the supply of important secondary and micronutrients (Field to Market, 2016; FAO, 2017a). • Can improve soil biological activity and physical properties through increases in soil organic matter (Field to Market, 2016; FAO, 2017a). • Nutrient management that considers the timing, rate, placement and source of the nutrient supply can help maintain water quality (Field to Market, 2016; FAO. N. D.; Alberta's ministry of Agriculture, Food and Rural Development. 2004).	• Adoption of precision fertilizer application can reduce or optimize nitrogen fertilizer (Clearwater et al., 2016). • Fertilizer application methods such as knifing, mixing with drip irrigation water (i.e., fertigation), or applied in banded rather than broadcasted, can possibly reduce the amount of fertilizer required (Field to Market, 2016; Yanni et al., 2018; Clearwater et al., 2016; Alberta's ministry of Agriculture, Food and Rural Development. 2004). • Nutrient management that considers the timing, rate, placement and source of the nutrient supply can improve crop yields (Field to Market, 2016; FAO. N. D.; Alberta's ministry of Agriculture, Food and Rural Development. 2004). --- **Risks and limitations:** • Injection of fertilizer is slow and more expensive (requires specialized equipment) (NRCCA, n. d.). • High rates of seed placed fertilizer can damage seeds and seedlings. • Lack of a regionally validated robust test for soil N supply in many regions of Canada Increased management complexity that may require hiring crop consultants Increased costs for machinery able to precision apply Increased costs for soil, tissue, and manure nutrient testing Increased costs for enhanced efficiency fertilizers.

resulted in doubling N_2O emission from 0.46 kg N_2O-N/ha to 1.04 kg N_2O-N/ha. ● The numerical average reduction in N_2O with side-dress was –18.5% and the range was +8 to -38% (Yanni et al., 2018). ● A simulation study in Western Ontario (Anderson, 2016; cited in Yanni et al., 2018), where split-N was applied as 70% pre-plant and 30% side-dress (at the V4-V6 stage), there were 21% less N_2O emissions compared to when all N was applied at planting. ● A meta-analysis on corn in North America (Eagle et al., 2017; cited in Yanni et al., 2018) reported that a shift from AA to urea results in a 45% reduction in N_2O emissions, while a shift from urea to urea+NI+UI results in a 26% reduction and finally a shift from urea to PCU results in a 15% reduction. ● For corn, N_2O emissions were reduced by an average of 36% (–55 to –17%) with UI use compared to conventional fertilizers and in coarse-textured soils N_2O emissions were reduced by 28% (–55 to –4%) with UI use (Yanni et al., 2018). --- **Risks and limitations:** ● There are no estimates specific for eastern Canada, but several factors contribute to increased indirect emission in the region. For example, the combination of high application rate of mineral N fertilizers in corn and potato production with relatively abundant rainfall increases the risk of N loss through surface runoff and leaching (Gregorich et al.,2005). ● Whereas low N2O emissions can occur at any soil water-filled pore space (WFPS) level, high emissions are rarely observed at low WFPS (Rochette et al., 2018). ● Some of these methods may enhance denitrification losses from soils and could result in (as yet unquantified) pollution-swapping trade-offs (ex. N_2O emissions and/or P losses in surface runoff) (Clearwater, R. L. et al., 2016). ● Modifying one of the 4R components by itself may not be reliable in reducing N_2O emissions, particularly in rainfed cropping systems (Venterea et al., 2016; cited in Yanni etal., 2018).			

• Ammonium (NH_4+) in manure or fertilizer converted to ammonia (NH_3) gas can be lost to the atmosphere when unincorporated surface applications (Alberta Agriculture and Food, 2008). • Under no-till the side-dress-N produced 53-83% more N_2O emissions in the 2 wet years whereas N_2O emissions were only slightly more from the N applied at planting in the dry year in Ontario (Yanni et al., 2018).			
Diverse Crop Rotation			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• Lower-intensity management (perennial forage, mixed annual-perennial cropping), manure application and low tillage were linked to higher soil respiration, water-stable aggregates, fungi, mycorrhizae, Gram negative (Mann et al 2019). • Replacing fallow with wheat generally resulted in an increase in SOC storage, but replacement with flax can result in a net loss in SOC. Including hay in rotation with wheat was an effective practice for increasing SOC storage (VandenBygaart et al., 2003). • The average amount of N2O emissions from perennial crops with the organic N application, assuming 500 g kg−1 of sand content, was approximately 28% of the emissions from annual crops (Rochette et al., 2018). • bacteria, and lower soil available P. • Varieties or species with greater and deeper root systems to deposit C in deeper layers and hence mitigate GHG emission (Paustian et al., 2016, IPCC, 2007; Field to Market, 2016; Yanni, S. et al., 2018). • Perennial deep-rooted crops can also be beneficial in reducing indirect N_2O emission because they can capture NO_3- and require less fertilizer inputs (Paustian et al., 2016, IPCC, 2007; Field to Market, 2016; Yanni, S. et al., 2018). • The impact of perennial biomass crops on GHG mitigation is through the replacement of fossil fuel use, et also through N_2O and CO2 emission reduction and C sequestration when compared to annual cropland (Yanni, S. et al., 2018).	• Introduction of crops with high P uptake (like forages) into crop rotations on P-enriched soils (Clearwater et al., 2016). • Increased production of pulses and other legumes increase soil fertilizer (Clearwater et al., 2016; Field to Market, 2016). • In soils with relatively low SOC levels, including crops that produce abundant residues in the rotation can improve SOC levels and hence soil fertility (Clearwater et al., 2016; Paustian et al., 2019; Field to Market, 2016; FAO, 2017a). • Perennial crops protect soil from erosion and improve soil structure (The Land Institute, N. D.). • In dryland, crop rotation can conserve water and minimize salinity problems. • Crop rotation can play a major role in minimizing the potential risk of nitrate leaching to surface and groundwater by enhancing soil N availability, reducing the amount of N fertilizer applied, and	• Diverse crop rotation can improve soil structure (reduce compaction), root systems, aggregate structure, microbial activity, and nutrient profile, which may result in fertility, yield and long-term profitability improvements. It can also potentially support higher biodiversity of soil organisms (Environmental Commissioner of Ontario. 2016; Agricultural Soil Health and Conservation Working Group. 2018; Field to Market, 2016; FAO, I. 2015; FAO, 2017a). • Crop rotations that exclude nonmycorrhizal species can increase Arbuscular mycorrhizal fungi (Plenchette et al., 2005). • Perennial crops increase ecosystem nutrient retention, and water infiltration (The Land Institute, N. D.). • Lower-intensity management (perennial forage, mixed annual-perennial cropping), manure application and low tillage were linked to higher soil respiration, water-stable aggregates, fungi, mycorrhizae, Gram negative (Mann et al 2019).	• Increased production of pulses and other legumes requires less nitrogen fertilizer (Clearwater et al., 2016; Field to Market, 2016). Perennial crops provide new cropping and market options for producers. • Higher levels of productivity, increased disease resistance in crops, reduced pest problems, greater weed control and overall greater resilience to environmental impacts such as drought, extreme weather events, and temperature fluctuations (Basche et al., 2016; Environmental Commissioner of Ontario. 2016; Field to Market, 2016; Davis et al., 2012). • Yield increases due to forages in rotation, with 71% reporting enhanced grain yields after forages compared with annual crop rotations in a survey of Manitoba and Saskatchewan forage producers (Entz et al., 1995). • In hot and dry years, diversification of corn-soybean rotations and reduced tillage increased yield by 7% and 22%for corn and soybean respectively (Gaudin et al., 2015). • Yield stability significantly increased when corn and soybean were integrated into more diverse rotations (Gaudin et al., 2015). • Addition of forage legumes into the tilled system significantly increased cumulative

• On a 3-yr average, emissions were greater under continuous corn (7.4 kg N_2O-N/ha) compared to corn in rotation (6.5 kg N_2O-N /ha) and yield-scaled emissions were even lower in favor of corn in rotation (Yanni et al., 2018). • Inclusion of a perennial crop in rotation was reported in Ontario by Gregorich et al. (2001; cited in Yanni et al., 2018). Continuous corn was compared to corn-oat-alfalfa-alfalfa rotation from a 35-year experiment. The amount of SOC was about 20 Mg C/ha greater in the rotation than the continuous corn. • The 3-year average NECB was +0.07 ± 0.5 Mg C/ha/y for hay and +1.5 ± 0.79 Mg C/ha/y for corn, indicating hay was C neutral but corn was a C source (Yanni et al., 2018). • Inclusion of long-term perennials and biomass crop: SOC change (switchgrass, grass mixes, pasture, giant reed): –1.8 to +2.2 Mg C/ha/y; average of 0.6 Mg C/ha/y and median and median is 0.4 Mg C/ha/y (Yanni et al., 2018). • A synthesis by Conant et al. (2016) estimated C stock increases of 39% after conversion of annual cropland to permanent vegetation, with an average rate of almost 0.9 tC/ha/y. • Legume crops reduce N2O emissions and emissions for N fertilizer manufacture --- **Risks and limitations:** • Soils have a finite capacity to store carbon and, over time, will approach their maximum sequestration capacity (Clearwater et al., 2016).	minimizing the potential risk of N leaching (Al-Kaisi, 2001). • Continuous cropping had 35% and 17% more SOC and N, respectively, than the wheat-fallow system (Pasricha, 2017). • Compared with CT, SOC under NT was 36%, 60%, and 62% greater for continuous wheat, sorghum-wheat-sorghum and wheat-sorghum, respectively (Pasricha, 2017). --- **Risks and limitations:** • Switching to crops that produce less residue can increase soil erosion		and mean corn yields by 4% and 6%, respectively, compared to other rotations (Gaudin et al., 2015). • Diversification of a corn-soybean rotation with wheat increased mean soybean yields by 13% (Gaudin et al., 2015). • Crop diversity lowers risk of crop failure (Gaudin et al., 2015). • In droughty years, inclusion of wheat and red clover dramatically improved soybean yield stability by 16% compared to CCSS rotations for tilled systems (Gaudin et al., 2015). • Maize yields were higher during adverse weather, including droughts, when maize was grown as part of a more diverse rotation. Rotation diversification also increased maize yields over time and under better growing conditions (Bowles et al., 2020). • Diverse rotations accelerated maize yield gains over time (Bowles et al., 2020). --- **Risks and limitations:** • Requires more machinery • May give lower financial returns during the transition period • Some crops may not be favorable in certain growing conditions (Field to Market, 2016). • Allelopathy [may suppress subsequent crop growth] (Dabney et al., 2001; Field to Martket, 2016). • Yield benefits of crop diversity are less pronounced in wet and cool weather (Gaudin et al., 2015). • Although reduction in tillage decreased yield variability in favorable years, tillage and rotation diversity had no effects on corn yield variation in abnormal hot/dry or cool/wet conditions (Gaudin et al., 2015).

Conservation buffers			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• Can store carbon (Alberta's ministry of Agriculture, Food and Rural Development. 2004). • Riparian grass buffers reduce greenhouse gas emissions by 0.77 tons/acre (Ciborowski, 2019). • Of practices that involve cropland idling or conversion of cropland to buffers, shelterbelts, field borders and other land-uses that indirectly support crop production, all result in net GHG-avoidance, with avoidance falling into an estimated range of 0.8 to 2.7 CO_2-equivalent short tons per acre of practice (Ciborowski, 2019). • For each 100,000 acres of cropland retired to shelterbelts or hedgerows, an estimated 269,000 CO_2-equivalent short tons of emission that otherwise would have occurred are avoided (Ciborowski, 2019). • For each 100,000 acres of cropland converted to contour buffer strips, field borders, and vegetative and herbaceous wind barriers, an estimated 161,000 CO_2-equivalent short tons of greenhouse gases that otherwise would have occurred are avoided (Ciborowski, 2019). • The average emission from the shelterbelts was 4.1 Mg CO2-C /ha/y compared to 2.1 for adjacent cropland whereas N2O emissions were greater in the cropland (2.5 kg N2O-N/ha/y) than the shelterbelt (0.65 kg N2O-N/ha/y) likely as a result of fertilization (Amadi et al., 2016). --- **Risks and limitations:** • Soils have a finite capacity to store carbon and, over time, will approach their maximum sequestration capacity (Clearwater et al., 2016). • Shelterbelts can emit more CO_2 compared to cropland (Amadi et al., 2016).	• Minimize the movement of soil sediment, nutrients, pesticides, and pathogens through the soil profile and from the field as runoff, thereby improving water quality and ensure that aquatic ecosystems flourish (AAFC, 2020; FAO, 2017a). • Healthy buffer zones and riparian areas can remove up to 50% of phosphorus, 90% of sediment and 80% of nitrate runoff from fields before the runoff reaches the water body (Alberta's ministry of Agriculture, Food and Rural Development. 2004). • Trap snow for increased spring soil moisture, reduce wind damage to crops and decrease evaporation of soil moisture (Alberta's ministry of Agriculture, Food and Rural Development. 2004). • Can reduce environmental risk, creates a permanent soil cover against erosion, minimizes damage from flooding and acts as water storage, benefitting crops and pastures (FAO, 2015; FAO, 2017a). • Riparian buffer strips are also beneficial in reducing soluble N and PON transport in surface runoff (Rasouli, S. et al., 2014). • Reduction of wind speed during summer months may also reduce evaporative losses	• Improve wildlife habitat and air quality by reducing chemical emissions and providing aesthetic and recreational value, which can help support the rural economy (Clearwater et al., 2016; AAFC, 2020). • Effective in facilitating pesticide degradation and in lessening pesticide concentrations in subsurface water flow (Al-Kaisi, 2000). • Pesticides can be absorbed and degraded, and nitrate taken up by plants, or denitrification can occur within buffers (Al-Kaisi, 2000). • Enhance soil organic matter content (FAO, 2017a). • Mander et al. (1997) reported NO_3-N removal capacities of riparian buffers as high as 964 kg ha^{-1} yr^{-1} due to high denitrification rates (Rasouli, 2014).	• Riparian area can be used as a sustainable grazing resource (AAFC, 2020). Provide aesthetic and recreational value • May economically offset land taken from food crops (using timber or biofuel production) (Stutter et al., 2012). • Can reduce risks of young plants growing in open and exposed conditions (dry and extreme temperature). --- **Risks and limitations:** • Buffer strips have to be maintained, so it requires time and money by farmers. • Working around the waterway with farm equipment can be difficult (Stone and McKague, 2009). • Establishing vegetation may be difficult (Stone and McKague, 2009). • The short-term cost of implementing practices does not equal the short-term economic returns • High cost to establish and maintain

	and microclimate effects (Martens et al., 2015). --- **Risks and limitations:** ● Increase water infiltration may lead to an increase in leaching of pesticides, possibly to shallow groundwater (Al-Kaisi, 2000). ● Driving heavy equipment on buffers leads to soil compaction and reduced water infiltration (Al-Kaisi, 2000). ● The effectiveness of buffers will vary significantly depending on the flow conditions in the buffer (e.g., the concentration of flow) as well as the area of the buffer that overland flow will encounter (Helmers et al., 2008). ● Impact will be much lower if not properly located designed, or maintained (Helmers et al., 2008). ● The waterway lacks the depth necessary to serve as a tile drainage outlet (Stone and McKague, 2009). ● Would not be effective in the winter in colder climates. Cold-climate VBS implemented in Canada, the northern United States, and northern Europe has shown P removal efficiency ranging from −36% to +89%, a range that identifies the uncertainty surrounding the use of VBS in these landscapes. (Kieta et al., 2018).		

Prevention of soil compaction			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• Indirect effects of CTF include reduced greenhouse gas emissions (Vermeulen et al., 2010; GRDC, 2013).	• Immediate benefits of CTF include better infiltration and drainage reducing run-off and erosion (Vermeulen et al., 2010; GRDC, 2013). • Indirect effects of CTF include reduced waterlogging, denitrification and enhanced soil biological activity with improved organic matter levels (Vermeulen et al., 2010; GRDC, 2013). • CTF and tire pressure control systems can help reduce soil compaction (Vermeulen et al., 2010; FAO, 2017a; GRDC, 2013). • Reducing the inflation pressure during the planting operation would allow the tire to operate to its optimum, improving traction, reducing soil compaction (Casady, n. d.). • Using variable rate allows farmers to use less fertilizer, which improves both soil health and water quality (Greenbelt. 2018). • Low axle loads (reduce load or increase number of axles) will reduce soil compaction (Duiker, 2005). • Use flotation tires, adopt radial-ply tires, install larger diameter tires, properly ballast tractors for each field operation and/or use tractors with four-wheel or front-wheel	• Improves soil porosity (Gasso et al., 2013). • Improves water infiltration which reduces the potential for soil erosion and increases water availability to the crop (Gasso et al., 2013). • Improves drainage which avoids waterlogging and the potential for nitrous oxide and methane emissions and methane oxidation (Ball et al., 1999). • Improves crop rooting and the efficiency of nutrient uptake, leading to less waste and potential for environmental pollution (Wolkowski, 1990).	• Immediate benefits of CTF include reduced fossil energy use (Vermeulen et al., 2010; GRDC, 2013). • Indirect effects of CTF include timeliness benefits with more workable days (Vermeulen et al., 2010; GRDC, 2013). • Adoption reduces costs, increases yields and provides better financial and environmental performance (Vermeulen et al., 2010; GRDC, 2013). • CTF can often provide more profit and less financial risk than uncontrolled traffic systems, especially in very wet or very dry seasons (GRDC, 2013). • Reducing the inflation pressure during the planting operation would allow the tire to operate to its optimum, improving traction, increasing fuel efficiency (Casady, n. d.). • GPS technology for various applications that include yield mapping and soil sampling, as well as tracking systems using auto-steer equipped tractors to increase efficiency (Clearwater et al., 2016). --- **Risks and limitations:** • Equipment and system changes are necessary to achieve controlled traffic (Vermeulen et al., 2010). • The cost associated with the adoption of new equipment's or novel technologies.

	assist to reduce soil compaction (Duiker, 2005). • Equipment using tracks increase footprints and therefore reduce surface pressure (Duiker et al., 2017). • Infiltration was significantly reduced by 3 to 5 times under 10 Mg loads and by up to 30 times under 20 Mg loads in the silt loam soil and by 5 to 40 times under 20 Mg loads in the clay loam soil (Smith, 2015).		

Integrated pest management			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• By decreasing avoidable yield losses, CSPM can directly contribute to a reduction in the emissions per unit of food produced, thereby decreasing the overall GHG emissions intensity of these systems (FAO, 2017b). • CSPM can also lead to total avoidance of GHG emissions, due to the different approaches it uses compared with conventional pest management (FAO, 2017b). • In the United States, given the acreages involved this suggests that biological control results in annual emission reductions of over 200 million kg of CO_2 equivalents (Heimpel et al., 2013).	• Prevent further issues and mitigate existing pollution (FAO. N. D.). • Beneficial insects or pathogens that are naturally found in fields should be conserved (Knodel, etal., 2018). • Reduced nutrient leaching because of stable organic soil matter - Agriculture's ability to produce yields stable (Équiterre, 2017).	• Can benefit beneficial insect populations (biodiversity). • Populations of beneficial fungi that can kill plant-feeding insect pests tend to be lower where fungicides are used regularly (Tooker, 2019). • Can conserve the populations of arthropod predators (Tooker, 2019). • Microbial decomposition tends to be faster (Tooker, 2019). • Enhanced biodiversity because BMPs encourages diversity - Agriculture's ability to adapt within well-functioning ecosystem is enhanced (Équiterre, 2017).	• Adopting an IPM strategy can be an effective way for managing pests in an economical and environmentally sound way (FAO, 2017a). • Planting trap crops, such as a field margin of a susceptible variety or host crop that concentrates a pest in the trap area. This can result in treating a smaller area with a pesticide (Knodel, etal., 2018). • Reduced pest resistance (Knodel, etal., 2018). • Judicious use of pesticides in combination with non-chemical strategies, which results in improved protection of environment and health (Knodel, etal., 2018). • Decreased severity of pest infestations • A recent major study showed that synthetic pesticide use could be cut significantly on over three quarters of farms without revenue losses, or losses in yields (Équiterre, 2017). --- **Risks and limitations:** • Regular crop scouting for pest identification and monitoring which require more time and money

			• Time consuming, resource-intensive and demands care • High cost of shifting from chemical pest control paradigm to IPM (Bourgeault, 2009).
Pasture management			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• Improved grazing land management can increase C inputs (Paustian et al., 2019; NRCS, 2017) • Permanent grasslands are effective for carbon accumulation in mineral soils, especially when grass and legume species are combined (Siebielec et al., 2019). • Other analyses of grazing land BMPs (including adjusting animal stocking rates and managing plant species) found SOC stock increases of 0.07–0.3 tC/ha/y on rangelands and 0.3–1.4 tC/ha/y on managed pastures (Morgan et al., 2010). • Conant et al. (2016) estimated average positive stock changes for improved grazing (0.28 tC/ha/y), sowing legumes (0.66 tC/ha/y) and fertilization (0.57 tC/ha/y). • Grasslands generally take up and store more carbon than croplands; for example, in the Great Plains, the average uptake rates were about 45 g C per m2 per year for grasslands and 31 g C per m2 per year for croplands from 2000 to 2008 (Wylie et al., 2016).	• Increased soil organic matter increases water available for plant growth (NRCS, 2017). • More nutrients available for plant growth (NRCS, 2017). • Better soil conditions for germination, seedling establishment, vegetative reproduction and root growth (NRCS, 2017). • Reduced soil erosion from water (NRCS, 2017) • Pasture sites typically have greater available water capacity (AWC) than cultivated sites (Mugdal et al., 2010). --- **Risks and limitations:** • High stocking density may lead to soil compaction. • When pasture is dominated by undesirable and invader plants and more bare soil exists, runoff increases dramatically, less water goes into the soil, wind erosion increases, and water erosion increases due to the runoff from exposed soils.	• Lower-intensity management (with adoption of other BMP) improve soil respiration, water-stable aggregates, fungi, and mycorrhizae(Mann et al 2019). • Improve aggregate structure, which will improve infiltration (NRCS, 2017). • Ability of the soil to act as a filter, protecting water and air quality (NRCS, 2017). • Control grazing to optimize root growth and development of forage plants helps to ensure that an abundance of roots is present in the soil to provide organic carbon that drives the soil ecosystem.	• Rotational grazing system allows for more drought resistance in the pasture (PennState Extension, 2016). • Increased plant production and reproduction (NRCS, 2017). • The prevention of overgrazing ensures the retention of a significant capacity for photosynthesis, allowing the vegetation to recover quickly when the animals have moved on (Environmental Commissioner of Ontario, 2016). --- **Risks and limitations:** • Disadvantage of Continuous grazing: uneven grazing patterns; variable plane of nutrition (animals eat the best forage first then move to lower quality); uneven distribution of manure and resulting 'nutrient creep' toward water and shade; change in pasture botanical composition over time favoring plants that are not readily grazed; and overly mature forage in much of the pasture and resulting negative energy status (PennState Extension, 2016). • Higher labour needs and additional cost for new fencing and water sources.

Land Retirement			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• Estimated C stock increases of 39% after conversion of annual cropland to permanent vegetation, with an average rate of almost 0.9 tC/ha/y (Conan et al., 2016) • Conversion to perennial grasses and legumes increase C inputs and reduce C losses (Paustian et al., 2019). • Roots sequester carbon (OMAFRA. N. D.). • Soil OC accumulation compared to adjacent cropland was estimated at 0.7 to 1.5 Mg C/ha/y (Amadi et al., 2016). • Percent change between the concentration of organic C in the willow fields and the reference fields ranged from 0 to 40% greater in the willow with an average of 25% (Lafleur et al., 2015). • Conversion of crop land to a secondary forest or a managed plantation has potential SOC gain over the long-term by 38-65% for a forest and 10-30% for a plantation (Yanni et al., 2018). • Laganiere et al. (2010) reported that in temperate climates the potential for C sequestration from afforestation is in the range of –5 to +20% (av. +7%; results from 49 comparisons). It was found that clay soils (with clay >33%) had the biggest potential for C sequestration and that broadleaf (excluding eucalyptus) trees also offer the highest SOC stock increase of on average 25%. ◦ Soil tests can help determine the status of plant-available nutrients to develop recommendations to achieve optimum nutrient management and minimize GHG emissions. --- **Limitations:** • In a meta-analysis, Laganiere et al. (2010) reported that in temperate climates the potential for C sequestration from afforestation is in the range of –5 to +20% (av. +7%; results from 49 comparisons).	• Reduce soil erosion and nutrient leaching (FAO, 2017a; Ribaudo et al., 1994). • Retired croplands offer protection to adjacent surface waters. Infiltration rates are higher on retired lands, resulting in less runoff. Runoff is cleaner because the soil is covered (OMAFRA. N. D.; Ribaudo et al., 1994). --- **Limitations:** • Some species have exacting soil and site requirements. Others cannot survive severely degraded soil conditions.	• Planting any kind of perennial cover will attract wildlife. Adding wildlife structures can help to attract desirable species (OMAFRA. N. D.; Ribaudo et al., 1994). • Keeping soil and nutrients on the land and out of local waterways improves water quality. • Land retirement can improve surface and subsurface structure • Roots add organic materials, improve soil structure, and penetrate compacted layers (OMAFRA. N. D.).	• The economic benefits from the reduction in the discharge of sediment, nitrogen, and phosphorus were estimated for nine impact categories: recreational fishing, navigation, water storage, irrigation ditches, roadside ditches, water treatment, municipal and industrial water use, steam cooling, and flooding (Ribaudo et al., 1994). • Improved wildlife habitat for hunting and nonconsumptive uses (Ribaudo et al., 1994). • Reduce use of insecticides, herbicides, fungicides and fertilizer (Ribaudo et al., 1994). Can reduce risks of young plants growing in open and exposed conditions (dry and extreme temperature). --- **Limitations:** • There are times when the establishment of natural areas attracts nuisance wildlife that can cause crop damage in adjacent fields. • A soil and species mismatch can be costly

Soil information collection			
GHG Emissions	**Soil Degradation**	**Soil Functions**	**Others**
• The use of variable rate N fertilization (precision agriculture) reduced N application by 11% without decreasing grain corn yield. Reduction of N_2O emissions was predicted to be 10%, in addition to reducing NH3 volatilization by 23% (Li et al., 2016; cited in Yanni et al., 2018).	• Soil tests can help determine the status of plant-available nutrients to develop recommendations to achieve optimum nutrient management. This is useful for tracking holistic soil health over time (Agricultural Soil Health and Conservation Working Group. 2018). • Can identify soil erosion issues and risks • Technological innovation can help manage and remediate salt-affected soils (FAO, N. D.a). The use of variable rate N fertilization (precision agriculture) can reduce NO3 leaching (Li et al., 2016; cited in Yanni et al., 2018) Digital soil mapping can precisely determine field management zones for targeted soil organic matter and soil health improvement (Zebarth et al., 2019).	• Identifies soil organic matter levels to be enhanced through other BMPs • Newer comprehensive soil health analyses go beyond fertility to assess a range of physical, chemical, and biological indicators (Norris et al. 2020; Chahal & Van Eerd 2018). • New soil digital technologies (soil sensing, telemetry, digital mapping, big data analysis and precision agriculture) will bring a new understanding of how soil functions at the optimal and sustainable level to improve farm management practices (Benalcazar, 2019).	• Frequent soil and tissue tests are often required to adjust rates based on contributions from the soil organic matter, crop residues and cover crops (Field to Market, 2016). • Generalized soil maps can serve as a basis for targeting and implementing agricultural and conservation programs (Soil Science Division Staff, 2017). • Compared to traditional maps, digital soil maps as a better quality and as a greater amount of data available to make the map (Miller, 2015). --- **Risks and limitations:** • Nutrient content can vary somewhat from year to year and from field to field. • There are currently multiple industry players and platforms, creating challenges with compatibility for software and data (Agricultural Soil Health and Conservation Working Group. 2018). • Access to up to date, easy-to-use soil maps and data layers is critical for land use planning and precision agriculture (Agricultural Soil Health and Conservation Working Group. 2018). • Very coarse-textured soils rarely have elevated levels of nitrate-nitrogen present for long enough periods of time to be detected by soil testing. These soils represent a greater risk to water quality (Manitoba Agriculture, Food and Rural Initiatives. 2008).

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