NEW HORIZONS

Ontario's Agricultural Soil Health and Conservation Strategy

Ontario

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Executive Summary

Healthy soil is essential for life and is the heart of Ontario farms and our food system. Healthy soil has many economic and environmental benefits including improved crop growth, yield and quality, water and nutrient retention, resilience, biodiversity, and climate change adaptation and mitigation.

Ontario's agricultural soils face challenges to their health and conservation. There is growing evidence that soil organic matter is decreasing in many areas, and there is too much bare soil in winter, and soil at risk of erosion. Also concerning is that tillage is increasing, crop rotations are becoming less diverse, and there is an ongoing shift away from perennial forages to annual crops. The good news is a growing number of farmers are incorporating cover crops. Farmers should be recognized and rewarded for this and other soil care efforts.

This final strategy culminates a two and a half year process to collaboratively build a soil strategy to address these challenges. The work began with bringing together key stakeholders in a working group (Appendix 1). Broader engagement was undertaken on the discussion document "Sustaining Ontario's Agricultural Soils: Towards a Shared Vision" in 2016 and on a draft Strategy in 2017. This final strategy incorporates feedback from agricultural, conservation and academic communities, technical experts, Indigenous communities, partner organizations and the public.

This strategy is a long-term framework to guide collaborative soil health research, investments and activities until 2030. The strategy's vision is: *Healthy agricultural soils contribute to a vibrant agricultural sector, productive economy, sustainable environment and thriving society*.

The strategy's goals, objectives and actions are divided into four theme areas to address different aspects of the issues: Soil Management, Soil Data and Mapping, Soil Evaluation and Monitoring and Soil Knowledge and Innovation.

Soil Management: Improving soil health is complex and there is no single, simple solution. Soils in Ontario, are often highly variable, even within a field. The state of soil health also varies widely, depending on past management practices. This is why farmers are best positioned to make soil management decisions based on

their understanding of their fields and crops, their soil test data, the information and tools available, and what works best for their operation supported by partners, government and society.

Goal: Soil management practices sustain and enhance soil health and productivity for economic, environmental and societal needs.

Objectives:

- Soil health is sustained and improved to keep farmland fertile, productive and resilient.
- Soil is conserved to support production of, and access to, food and other products.
- Soil is protected from degradation including erosion, compaction, loss of organic matter and breakdown in structure.
- Soil health is enhanced to improve water quality, reduce greenhouse gas emissions and address other environmental issues.

To achieve these objectives, a series of actions are outlined under 12 topic areas:

1. Support soil Best Management Practices (BMPs) continuous improvement and adoption.
2. Customize soil health information by agricultural production system.
3. Diversify crop rotations (in annual cropping systems).
4. Support conservation tillage options.
5. Foster expansion of cover crop adoption.
6. Build use of organic soil amendments such as manure and compost (where appropriate).
7. Promote erosion assessment, prevention and mitigation.
8. Build awareness and capacity to assess and reduce soil compaction.
9. Expand and improve on-farm soil health planning tools like the Environmental Farm Plan (EFP) and Farmland Health Check-Up.
10. Provide incentives for soil care practices.
11. Build climate initiatives that improve soil health.
12. Public sector should lead by example with good soil management on publicly owned farmland.

Soil Data and Mapping: Good decisions rely on good data. Information on soils and land is important for farmers to make management decisions. Farmers need better access to high quality, current soil data, soil maps, and related information to support their on-farm decision-making so they can remain competitive in the global market. Policy makers also need access to soil interpretations, data and information for decision-making, including land use planning. New technologies increasingly used in agricultural operations can be important tools for soil health.

Goal: Reliable soil data and tools are available to allow for informed decision-making and analysis by producers, industry, government and the public.

Objectives:

- Soil inventory data are well documented, replicable and defensible.
- Soil data are comprehensive, accessible, and, where possible, publicly available.
- Accessible soil data provide for a wide range of analysis and decision-making.

To achieve these objectives a series of actions are outlined under five topic areas:

1. Modernize Ontario's soil maps and inventory.
2. Build and make soil databases available on public digital platforms.

3. Explore new technology for soil mapping and assessment.
4. Make better use of soil sample data and precision agriculture data.
5. Determine baselines for soil management practices in Ontario.

Soil Evaluation and Monitoring: It is important to assess the state of agricultural soil health over the varying landscapes of Ontario and track changes over time at different scales. Monitoring long-term trends will help inform actions and chart progress on soil health.

Goal: The health and status of Ontario's agricultural soils are tracked over time.

Objectives

- Capacity is developed to track changes in agricultural soil health, erosion and soil organic matter.
- Soil health and erosion monitoring is used to inform and evaluate policies and programs.

To achieve these objectives a series of actions are outlined under six topic areas:

1. Increase capacity to track farm scale soil health with new tools for farmers.
2. Promote farm-scale measures of success like suggested organic matter levels for different soil types.
3. Tracking soil health at a regional scale by conservation authorities.
4. Tracking the state of soil health and conservation at a provincial scale using indicators.
5. Develop provincial-scale measures of success during implementation.
6. Examine the potential of other indicators to assess soil carbon and other parameters.

Soil Knowledge and Innovation: Getting the best available knowledge in the hands of decision makers can lead to the best decisions. Knowing how to manage soils and understanding how soils function is key to their productivity and long-term sustainability. We need to work together to ensure that lessons from research and the farm field are shared and incorporated into the development of effective BMPs, programs and policies. Knowledge about building and maintaining healthy soils needs to get into the hands of the people who can best use it: farmers, agricultural landowners, industry partners and advisors. Knowledge is a two-way street – ongoing communication is essential between researchers, policy developers, farmers, agricultural landowners and other interested partners.

Goal: Soil knowledge and skills are optimized to meet societal and economic needs and drive innovation.

Objectives

- Sustain human resource capacity in soils knowledge to meet priorities.
- The education sector supports programs for appropriate soils knowledge and skills.
- Ongoing research supports innovation in soil knowledge and management.
- Agricultural sector engages and has access to people with soil-related knowledge and skills to meet client needs effectively and economically.
- Producers have access to the knowledge and support needed to maintain and enhance soil health.

To achieve these objectives a series of actions are outlined under 11 topic areas.

1. Support a long-term, collaborative soil research agenda (see Appendix 2).

2. Use research facilities to boost technology transfer with farmers.
3. Ensure standard soil data collection at research sites.
4. Ensure consistent messages on soil management.
5. Diversify learning approaches available to farmers.
6. Build better understanding of learning and motivation.
7. Build capacity for peer-to-peer learning and innovation.
8. Build soil knowledge among service providers.
9. Build provision of soil-related skills in post-secondary education.
10. Elementary and secondary education has resources to provide sound basic soils knowledge.
11. Build general public understanding of soil health.

Implementation

The soil strategy was developed collaboratively and implementation will also be a collaborative effort. The next steps after finalizing the strategy are to develop a collaborative implementation model and an implementation plan.

This final strategy will guide collaborative soil health action, research, investments and activities over the period 2018 to 2030, supported by annual work plans and periodic reviews of progress. To 2030 and beyond, together we can ensure that Ontario's productive agricultural soils remain so for future generations.

Introduction – Healthy Agricultural Soil for a Healthy Future

Healthy soil is essential for life, and is the heart of Ontario farms and our food system. As those closest to the land and its soil, the farming community understands this. The Agricultural Soil Health and Conservation Strategy is designed to ensure that together, we conserve our agricultural soils for future generations.

Healthy agricultural soil has an important role to play in our economy, environment and society. Productive soils are the foundation of Ontario's agri-food industry – an economic powerhouse that in 2016 accounted for 5.9 per cent of the province's Gross Domestic Product, employed over 800,000 people and yielded more than $13 billion in farm cash receipts for Ontario farmers. Healthy soil also:

- Helps improve crop growth and increases yields and product quality.
- Improves the rate at which soil absorbs and stores water, and reduces runoff, all of which enhances crop growth and resilience when water is in short supply.
- Helps protect water quality by retaining nutrients (e.g., phosphorus, nitrogen) for crops that might otherwise run off the land into adjacent streams and lakes (supporting the Canada-Ontario Lake Erie Action Plan aimed at reducing phosphorus).
- Can reduce greenhouse gas emissions and increase soil carbon through actions that improve soil health and mitigate climate change.
- Improves resilience to the impacts of climate change such as more extreme temperatures and weather events.
- Can increase the number of beneficial insects and other soil organisms while reducing pests, thereby contributing to biodiversity and healthier, more resilient ecosystems.

Why Do We Need a Soil Strategy?

The challenge with soil is that it is often undervalued, or seen as just dirt, and conserving our soils is often overshadowed by issues that are thought to be more pressing.

In its 2015 report, *The Status of the World's Soil Resources*, the Food and Agriculture Organization of the United Nations found that the world's soils are deteriorating due to soil erosion, nutrient depletion, loss of soil organic carbon, declining soil biodiversity and other issues. In addition, over-application of mineral fertilizers and pesticides can have negative effects on soil organisms.

In Ontario, as elsewhere around the world, soil is at risk from many threats[1], including:

- Increased demands on soils to grow food and bioproducts for an increasing provincial and global population.
- Changes in cropping, tillage and other practices that can degrade soil health.
- Pressure on farmers to balance short-term economic gain with long-term benefits of investing in soil health and conservation.
- Increased frequency of extreme weather due to climate change, which can alter systems and impact soil health.

"Our soils are at risk. Our future is eroding. It is time for action." Herb Sparrow from Soil at Risk – Canada's Eroding Future, 1984

Some of the tillage and cropping practices employed on some Ontario farms are considered unsustainable and risk not maintaining the health and productivity of the soil over generations. Ultimately, caring for the soil depends on individual farmers taking voluntary action on land they own or rent, and on agricultural land owners ensuring their land remains productive and valuable, with the best support from society and partner organizations. It will take determination, cooperation, time and a commitment by many to shift soil management practices and bring about significant improvements.

Agriculture and Agri-food Canada's (AAFC) Agri-Environmental Indicators measure the agriculture and agri-food sector's environmental performance for soil, water and air quality and farmland management at a national scale. These indicators help us track the status of Ontario's soil health and conservation and are the interim indicators used for this strategy, before a more specific set of indicators is developed (see Soil Evaluation and Monitoring).

Overall, these indicators suggest that soil health and conservation are not improving in Ontario. Key indicators of interest are: soil organic carbon, soil erosion risk and soil cover[2]. The latest estimates are that:

- 82 per cent of Ontario's agricultural soils are estimated to be losing more CO_2 to the atmosphere rather than increasing soil organic carbon.

1 Soil and farmland are also under threat from encroaching development; however, farmland protection is beyond the scope of this strategy, and is addressed through Ontario's land use policies. Forest, wetland, excess, urban and contaminated soils are also beyond the scope of this initiative because the focus is on agricultural soil. Other public policy addresses these issues such as the Excess Soil Management Policy Framework and associated guidance.

2 For more information see the 2016 report 'Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #4' and Figure 1. Soil indicator trends 1981-2011.

- 68 per cent of Ontario's farmland is estimated to be in an unsustainable erosion risk category.
- 53 per cent of Ontario's cropland is estimated to have low or very low soil cover, covered less than 275 days or 75 per cent of the year.

This analysis reflects trends in farming practices over recent decades that have had adverse effects on soil health and led to declines in soil organic matter. These changes include[3]:

- A shift to more annual crops (three main annual crops increased from 28 per cent to 61 per cent of crop and pasture lands 1976-2016) and less diverse rotations.
- More tillage (in 2016 the reported acreage of conventional tillage increased for the first time since 1991).
- Fewer fencerows and windbreaks.
- Fewer ruminant livestock farms resulting in a reduction in the total area of hay and pasture (52% decrease 1976-2016) and availability of manure.
- Consolidation of smaller fields.
- Use of larger, heavier equipment.

On the upside, more farmers are planting cover crops. The Census of Agriculture found that the percentage of farmers using cover crops doubled (12 per cent to 25 per cent) between 2011 and 2016.

While much work has been done to mitigate these concerns, there is a need for more strategic and coordinated solutions to ensure everyone involved in soil management is working toward a common vision.

What is Soil Health?

So what exactly is soil health? Agriculture and Agri-Food Canada defines soil health as its ability to support crop growth without becoming degraded or otherwise harming the environment. The U.S. Natural Resource Conservation Service suggests that soil health is the "continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans."

Soil health has physical, chemical and biological components. It encompasses a soil's ability to:

- Accept, hold, filter and release nutrients and water.
- Promote and sustain plant root growth.
- Maintain soil organic matter and a biologically diverse soil life (e.g. worms, microbes, fungi).
- Have well-balanced nutrients and a suitable pH for the crops being grown.
- Maintain its physical structure and be well aggregated to resist degradation (for example, by water and wind erosion and compaction).
- Have adequate pore spaces between particles to allow for the movement of water and air.

The flipside of soil health is soil degradation. Degradation includes decreased soil aggregation, reduced organic matter, diminished infiltration and water holding capacity and increased compaction. All contribute to reduced soil health and productivity as well as greater erosion.

No matter how it's defined, soil health is vital to long-term, sustainable crop production. Soil organic matter and microorganisms play a key role.

3 Data from Census of Agriculture, Statistics Canada. Also see Figure 2. Tillage on cropland and cover crop use.

Around the globe, countries and farmers are striving to ensure sustainable, productive agricultural soils for future generations. Ontario is experiencing a soil health renaissance. Many farmers are taking action to improve soil health on their land. There is renewed interest in ensuring policies and programs help farmers address the threats to agricultural soil. This is demonstrated by the ongoing dedication of the partners working together to develop this strategy and government investments in farm stewardship programming.

What is this strategy about?

The strategy is a long-term framework that sets a vision, goals and objectives for soil health and conservation in Ontario spanning 2018 to 2030. Actions to achieve the vision, goals and objectives are also described, as well as methods to measure progress. This will guide soil health action, research, investments and activities for decades to come. The strategy will be nimble, providing opportunities for adaptive management. Progress on the actions and toward achieving the strategy's objectives will be assessed regularly during implementation, and adjustments will be made as needed to ensure the strategy is on track. This document is not an instant fix for all issues affecting agricultural soils, but rather a plan to address these issues over time.

Ensuring the health and conservation of Ontario's agricultural soils is a shared responsibility and will require collective leadership and sustained commitment and action by those directly responsible for managing soil on farms. Key partners include farmers, agricultural land owners, the agri-business service sector, farm and conservation organizations, educational institutions, Indigenous peoples, government and the public. The multi-stakeholder Agricultural Soil Health and Conservation Working Group was instrumental in developing this strategy, and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) thanks them for their time and expertise (see Appendix 1 for a list of members). Continued collaboration with soil health partners will be essential to support its implementation.

This strategy builds on extensive engagement on the vision, goals, objectives and concepts presented in the *Sustaining Ontario's Agricultural Soils: Towards a Shared Vision* discussion document (2016) and *New Horizons: A Draft Agricultural Soil Health and Conservation Strategy for Ontario* (2017). It incorporates feedback from agricultural and academic communities, as well as technical experts, Indigenous communities, partner organizations and the public. It also helps respond to recommendations from the Environmental Commissioner of Ontario[4]. The strategy aims to make the best use of science, social science and knowledge as it evolves, including traditional Indigenous knowledge, and monitor our progress to continually improve.

There is a wide variety of farm types and sizes in Ontario. This strategy is intended to be broad in scope and inclusive of all people who manage agricultural soil regardless of farm size or type. It also addresses issues related to landowners who rent to farmers, recognizing that it is important to maintain the productive value of all farmland. Future research, policies and programs that will serve to implement the strategy will be designed in a way that accounts for the unique circumstances and needs of different types of farmers, land owners, and their communities.

4 The soil strategy is, in part, a major review initiated by OMAFRA in response to a request for review under the Environmental Bill of Rights. The Environmental Commissioner of Ontario has made many recommendations regarding agricultural soils since the 2008-09 annual report and issued two reports specifically on soils "Investing in soils for a sustainable future" in 2012 and "Putting Soil Health First. A Climate–Smart Idea for Ontario" in 2016.

To improve the health and care of our soils, this strategy is guided by a number of widely recognized soil health principles:

1. **Build soil organic matter[5] –** application of manure, compost or other organic materials, where appropriate[6], helps maintain and build soil organic matter, soil structure and aggregate stability, and feeds soil ecosystems. Broader and better integration of livestock into crop production can provide sources of manure as a soil organic amendment.
2. **Diversify crops –** support diversity by planting different kinds of crops over time (crop rotation, in annual cropping systems) and/or plant cover crops to increase soil biodiversity[7].
3. **Minimize soil disturbance –** manage soils by disturbing them less and by adopting no-till or reduced tillage practices (in annual cropping systems), which helps reduce soil loss through erosion, reduces the risk of structural degradation, such as compaction and aggregate instability, and allows soil ecosystems to flourish.
4. **Keep living roots throughout the year –** ideally have living roots and continuous cover from cover crops and perennial crops to help sustain soil life and soil health.
5. **Keep the soil covered –** soil protected by either living plants or plant residue helps sustain soil life, retain soil fertility, structure and organic matter, and it also prevents erosion and other degradation.

Another important consideration is soil structure in particular soil aggregation or how soil particles are held together in clumps. Aggregate stability is the ability of soil aggregates to resist breakdown by water or wind erosion, or compaction. Soil organisms are especially important in producing biological compounds that create and maintain aggregate stability – like a glue holding the particles together. In addition, judicious use of inputs based on nutrient management and integrated pest management approaches can help minimize impacts on soil ecology by reducing the need for pesticides and fertilizers. Water management, especially drainage, is important to reduce other impacts such as compaction.

Indigenous knowledge suggests we should consider the impact of our actions on seven generations. Indigenous peoples engage in and have engaged in agriculture in Ontario and across Turtle Island for millennia and Indigenous traditional knowledge and ceremonies reflect respect for the land and reciprocity with nature. This strategy is guided by that wisdom.

The way we care for our soil today will have lasting impacts on our society and farmers.

"We are all responsible. Our challenge is to replace soil degradation with soil restoration. We can counter the fate that history would predict for us. We have the technology and the tools to do that."
Don Lobb, at Soil Summit, August 2017

5 The Food and Agriculture Organization of the United Nations defines Soil Organic Matter as any material produced originally by living plants or animals that is returned to the soil through decomposition. It stores and supplies nutrients, improves soil structure and water infiltration, drives soil biological activity and soil microbial diversity as well as buffers against changes in soil pH. Higher soil organic matter levels improve water-holding capacity, which is critical in seasons with low water.

6 In many vegetable, fruit and specialty crop production systems, food safety standards preclude a number of organic amendments. Other BMPs also build soil organic matter.

7 The soil strategy contributes in a number of ways to "Biodiversity: It's in Our Nature, Ontario Government Plan to Conserve Biodiversity".

Building on Success

A community of champions across Ontario are deeply involved in activities that build healthy agricultural soil. From leading-edge research to practical, on-the-ground farm assessments, substantial work is already being done to monitor, measure, restore and protect this valuable resource, including:

- The Environmental Farm Plan (EFP) – Ontario farmers have completed more than 34,400 EFPs to identify potential risks and develop site-specific actions to reduce concerns.
- The Great Lakes Agricultural Stewardship Initiative (GLASI) – targeted the Lake Erie basin and southeastern shores of Lake Huron to help farmers improve soil health and improve environmental stewardship 2015-2018.
- The 4R Nutrient Stewardship – an industry-led initiative to help meet agricultural and environmental goals and reduce nutrient runoff, led by 4R Ontario.
- The Cover Crop Strategy – developed by the Ontario Cover Crops Steering Committee led by the Grain Farmers of Ontario to spur cover crop adoption.
- The Farmland Health Check-Up – a new approach facilitates an assessment of challenging areas on-farm, focused on soil health, with specific information on erosion, compaction, organic matter, soil life and soil chemistry.
- An initiative to begin the upgrade of soil inventory and mapping building on older legacy inventories, over two years (2016-2018) in selected areas in southern and northern Ontario.
- The new Canadian Agricultural Partnership (2018-2023) and Growing Forward 2 (2013-2018) – include initiatives to improve soil health and water quality.
- Ontario's Climate Change Action Plan – up to $30 million over 2017-2021 for soil health initiatives.
- BMP publications, which are collaborative efforts that summarize the state of knowledge and recommended practices.
- Workshops, field demonstrations and tours hosted by many partner organizations.

Ontario's Agricultural Soil Health and Conservation Strategy captures and builds on all of this good work, as well as the work of partners, in one cohesive framework. It also draws on the skills and knowledge of farmers, researchers and soil stewardship leaders across the province. The strategy provides farmers, citizens and governments with a roadmap for caring for our soil. Achieving on-the-ground results depends on the actions of everyone in our sector. From farmers to research institutions, we all have a role to play as stewards of Ontario soils.

Strategy Development Process

The Agricultural Soil Health and Conservation Strategy was developed in stages. In 2015 OMAFRA formed the collaborative Agricultural Soil Health and Conservation Working Group –made up of knowledgeable people from farm organizations, agri-food businesses, academia, conservation organizations and the federal government. It was instrumental in developing the 2016 discussion document, and the 2017 draft strategy, and has been collaborating regularly to develop this final strategy. Consensus on some issues was not possible. The organizations and their representatives who are members of the Working Group are listed in Appendix 1.

The working group's deep understanding of current and emerging issues, as well as where we are and where we need to go, has been invaluable in this

process. Continued collaboration with our partners will be essential to support its implementation. Ensuring the health and conservation of Ontario's agricultural soils is a shared responsibility and will require collective leadership and sustained commitment and action by those directly responsible for managing soil on farms.

What we Heard

Throughout the development of this strategy, there was extensive input from farm and soil care partner organizations, other stakeholders and the public. Their contributions of time and insight are greatly appreciated, and this document is a testament to their efforts and commitment to healthy agricultural soil in Ontario.

Feedback on the draft strategy was supportive of the concepts and actions presented, including establishing a collaborative group to oversee implementation. The actions in the draft strategy have been refined in consideration of the feedback received.

In addition to important improvements and additions to the actions, key revisions include:

- Reflecting the diversity of farms and commodities within agriculture.
- Emphasizing the systems approach to soil management.
- Additional information about tracking progress.
- Additional information about implementation and partners.
- Increased emphasis on the importance of soil life and soil health principles, and the link between soil health and economic viability.

Some concerns that were raised are addressed by other complementary policies and programs. For example, water management including drainage, and its link with soil health and soil care practices, was frequently mentioned. Subsurface agricultural drainage has been critical to improving crop productivity in Ontario. Appropriately implemented, drainage promotes plant uptake of nutrients, minimizes compaction, reduces surface runoff and erosion, and improves soil health. The Canada-Ontario Lake Erie Action Plan identifies several actions directly related to drainage, including a commitment to review the province's approach to rural stormwater and agricultural drainage management using an integrated watershed approach.

Other key issues raised require further analysis during strategy implementation and this is reflected in revisions. These include:

- The challenge of improving soil care on rented farmland, where farmers may not be motivated to invest in soil health on land they do not own and landowners may not appreciate the importance of soil health practices for long term productivity.
- Support for establishment of a governance approach to guide collaborative implementation and enable continuous improvement.
- Incentives to adopt soil care practices within broader agriculture policies and programs.
- The need to establish meaningful targets or measures of success to drive and track progress.

Diverse perspectives were expressed on target-setting as well as voluntary vs. more directive measures for change. Incorporating a regular, periodic review in this strategy will provide an opportunity to assess whether the actions are moving us toward our objectives, and if not, what if any alternative approaches should be considered.

A significant portion of feedback pertains to program details. Highlights include:

- Stewardship programs should be easier to access in terms of geographical availability and application processes.
- Early adopters should be recognized, rewarded and supported.
- Farmers unfamiliar with soil health should be encouraged to participate.
- Support should be provided for the 'transition risk' of trying new practices, to address potential temporary yield losses and additional expenses.

Program-related feedback will help inform the implementation of the strategy, including program design.

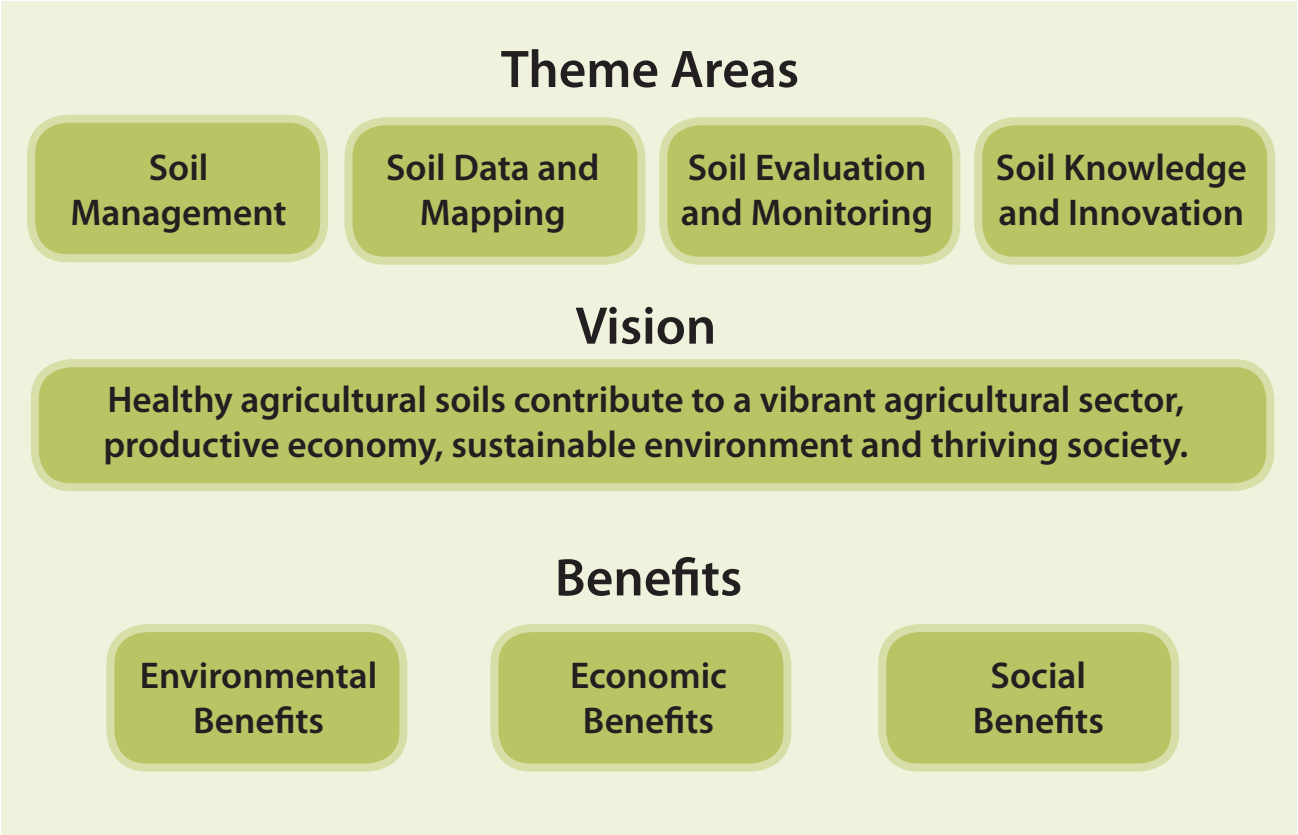
Strategy Vision, Goals, Objectives and Actions

The strategy vision, four overarching themes and benefits are illustrated in the graphic below. The themes are interconnected and there is some overlap among them, and have been grouped this way to help focus on the specific issues to develop effective solutions.

Each theme, detailed in the following pages,, has a goal and objectives along with actions to achieve them.

All of the elements must work together to bring about the necessary changes – particularly the education, incentives and behavioural change elements to help shift practices over time.

Soil Health and Conservation Strategy



Theme 1: Soil Management

Goal

Soil management practices sustain and enhance soil health and productivity for economic, environmental and societal needs.

Objectives

- Soil health is sustained and improved to keep farmland fertile, productive and resilient.
- Soil is conserved to support production of, and access to, food and other products.
- Soil is protected from degradation including erosion, compaction, loss of organic matter and breakdown in structure.
- Soil health is enhanced to improve water quality, reduce greenhouse gas emissions and address other environmental issues.

Improving soil health is not a one-size-fits-all endeavour across Ontario's varied landscape. Soil types vary widely from the flat, clay plains of southwestern and eastern Ontario to the rolling, loamy soils of central and western Ontario; from the shallow soils of parts of eastern and Northern Ontario to the sand plains of Norfolk region and the rich organic soils of the Holland Marsh. Soils in Ontario, even within a field, are often highly variable. The state of soil health also varies widely, depending on past management practices.

This is why farmers are best placed to make soil management decisions based on their understanding of their fields and crops, their soil test data, the information and tools available, and what works best for their operation. Different kinds of farming involve different practices, so not all of the approaches presented will apply to everyone.

BMPs can be practical and affordable approaches to conserving a farm's soil and water resources without sacrificing productivity. Investing in soil care has long term economic benefits for farmers and landowners. Farmers can choose a particular suite of BMPs depending on what they produce and how they produce it as well as their farm's unique soil characteristics, economics and production challenges. BMPs should be employed with a holistic, systems approach to realize the synergistic benefits of multiple BMPs and optimize production and environmental

benefits (e.g. EFP). Systemic change takes time and investment, and presents uncertain risks. Supporting farmers in their transition to new approaches is critical.

Actions

An important starting point is to recognize the need to approach soil management as a system. The US Soil Health Institute emphasizes the use of "soil health management systems" that "engage several practices simultaneously to enhance soil health while sustaining or enhancing productivity and environmental quality in economically feasible ways that are consistent with other on-farm decisions." Individual BMPs and suites of BMPs function within a production system and influence the soil ecosystem. Each BMP must be seen within the context of the system and the unique characteristics of each farm. Planning and diagnostic tools like EFP and Farmland Health Checkup help create and implement a systems approach. Each producer's commodities, crops, and production systems as well as their business and personal goals and objectives influence the systems approach.

Sometimes there are barriers to implementing BMPs. For example:

- High commodity prices make short-term gains more attractive than investments that have longer term payoffs in terms of soil health and yield stability. Short-term farmland rentals and highly leveraged operations are especially vulnerable to these pressures.
- Lower initial yields can sometimes result from the adoption of some new soil practices.
- What works well on one farm may not work well on another, and there is a management learning curve during adoption, resulting in uncertainty and hesitation to take risks.

OMAFRA and its partners continually improve BMP guidance based on the best available science and knowledge. The latest development is the release of the BMPs for Soil Health Fact sheet series focusing on best practices for soil health and the BMPs for Soil Health Diagnostics info sheet series aimed at identifying specific problems on farmers' fields.

Cycle of life with crops and poultry

As one of the first farmers in Ontario to complete an Environmental Farm Plan in the early 1990s, Eric Kaiser has a long history of paying attention to his soil, and he's passed his enthusiasm on to his son, Max.

Located near Napanee in eastern Ontario, they have an egg farm and 1,150 acres of crops, including corn, soybeans, wheat, sunflowers, barley and strawberries. They credit no-till, crop rotation, cover crops and manure as keys to their success. Minimizing compaction on their heavy clay soil is also a key goal for the Kaisers.

Eric Kaiser was named the Ontario Soil and Crop Improvement Association (OSCIA) Soil Champion for 2017. He encourages farmers to keep it simple and stay committed. He says, "It's a mindset. You don't need to try cover crops; you just have to do it."

Consistent with a systems approach, development of customized approaches for particular production systems can make adoption easier for individual producers. During consultation, livestock and horticultural producers especially identified the need to develop production system-specific information and tools. Farms producing the same commodities face very similar soil management issues and can benefit from information tailored to their production systems. On the other hand, generic information on general BMPs may be of little use to growers of less common crops.

Systems approach to soils – Actions:

- Use a systems approach to soil management to customize BMPs based on specific commodities, production systems, soil conditions and other factors. This can be implemented using planning and diagnostic tools (e.g. EFP, Farmland Health Checkup or other tools).

Support continuous improvement and adoption of soil BMPs – Actions:

- Expand the development, enhancement and promotion of suites of soil BMPs and their adoption.
- Identify and address barriers to the adoption of BMPs, both general barriers and specific barriers for individual BMPs and specific production systems.

Customize soil health information by agricultural production system – Actions:

Commodity groups, sectors and governments work together to identify specific and unique soil management issues and solutions for different production systems, including:

- Grain and oilseed commodities.
- Vegetable, fruit and specialty commodities.
- Livestock commodities.
- Other commodities.

More specific actions are needed to move forward on different approaches and tools. Here are a few.

Diversify Crop Rotations

For farms planting new crops each year, having a diversified crop rotation (planting different crops in the same field in successive growing seasons) helps to control pests, more effectively manage nutrients, and improve soil properties and yield, increasing long term profitability.

Some crops that might be used to diversify a crop rotation may not have a high value in the marketplace, or markets for these crops are not accessible to Ontario producers. That's why it is important to continue addressing economic barriers to BMP adoption. Rather than crop rotation, growers of perennial crop species (e.g. many fruit species) use other practices to diversify plant species cover.

Diversify crop rotations – Actions:

- Government and farm and commodity organizations work to grow markets for crops, such as hay, cereals and perennial biomass crops, which support diversified crop rotations. Each organization can incorporate relevant objectives to research, business and market development activities.

Rotation good for vegetables and soil

Dave Van Segbrook is a big believer in customizing his approach to the crops and conditions on his farm. He uses several different techniques, including crop rotation on his 1,600-acre farm near Tupperville, in Chatham-Kent.

He plants winter wheat and red clover in rotation with corn and his main crops which are processing vegetables – including peas, sweet corn, sugar beets, Brussels sprouts and peppers. He figures if he breaks even on wheat, the rest will be made up in yield benefits in his other crops as a result of healthier soil.

Van Segbrook has won numerous awards for his farming achievements, including a Premier's Award for Agri-Food Innovation in 2010 – in part because he keeps up to date on the latest production practices through continuous education.

Reduce Tillage

Research has shown that excessive tillage has a negative effect on soil health through the loss of soil structure, soil biota and soil organic matter. Yet there are challenges in implementing no-till, strip tillage or other reduced tillage in many production systems.

Ongoing research and development is needed to continue fine-tuning reduced tillage approaches under different production systems. For example, achieving optimal crop yields in a reduced till system with cover crops in the rotation may require modifications to pest and nutrient management practices, residue management and planting equipment. Also, as crop yields increase, new tools and techniques may be needed to effectively manage larger amounts of residue.

No-till a success for hardworking brothers

At Terwidlen Farms near Bowmanville, the three Barrie brothers decided to go no-till in 1993 when they expanded their cash crop operation. It was the only way they could see to work all that land profitably. Since then, it's become an integral part of their success, resulting in lower machinery costs, less fuel use, reduced erosion and a better seed bed that's easier to plant.

They now work 1,000 acres, offer custom farming services including no-till planting, and run a robotic milking operation.

The Barries continue to stay ahead of the curve when it comes to environmental sustainability. In 2013 they were presented with the Innovative Farmer of the Year Award by the Innovative Farmers Association of Ontario.

Support conservation tillage options – Actions:

- Promote, research, adapt and support the adoption of conservation tillage practices such as no-till, strip till and residue management.

Keep Soil Covered

To protect the soil from erosion, keep it covered with living plants or crop residue as much as possible.

Maintaining crop residue on the soil surface acts much in the same way as mulch does in gardens. It improves soil stability, reduces soil erosion and improves soil health over time.

Cover crops protect the soil by providing cover that helps to slow the flow of water across a field. Farmers are increasingly recognizing the value of using cover crops. Cover crops can be seeded after the main crop is harvested, before later-seeded crops in the spring or in between rows of row crops during the growing season (inter-seeding). In some situations, cover crops can provide feed for livestock. Using cover crops requires continued research to optimize their use for conditions across Ontario. Crops like winter wheat and perennial crops also provide cover during the critical winter period.

Foster expansion of cover crop adoption – Actions:

- Led by the Grain Farmers of Ontario, the Ontario Cover Crops Steering Committee will implement the Ontario Cover Crops Strategy to encourage widespread adoption of cover crops on farms in Ontario.
- Promote, develop and support use of cover crops through a range of tools including awareness, education, research and incentives.

Ontario Cover Crops Strategy

Ontario Cover Crops Steering Committee, a group of farmer, commodity and conservation organizations, have developed a Cover Crops Strategy for Ontario that will encourage widespread adoption of cover crops on farms in Ontario. The strategy has four areas of action (research, policy and programs, communications and supporting champions) that will address existing barriers for producers to adopt the practice.

Apply Organic Amendments

Soil organic matter can be maintained or increased by adding organic amendments such as manure or compost, along with other practices. These amendments are not always available or economical to apply in some locations. Moving compost and other organic amendments to farms that need them has many logistical challenges. Only about 20 per cent of Ontario cropland reportedly received manure in 2016 according to the Census of Agriculture. Food safety standards can limit the application of manure and other related amendments for many vegetable and fruit crops grown for direct human consumption. In those cases, other BMPs can be used to build soil organic matter.

Ontario is developing a Food and Organic Waste Framework that will help to reduce the amount of food that becomes waste and recover resources from food and organic waste intended to create safe and beneficial end-products such as compost and digestate. Compost and digestate can be used as a soil amendment for agricultural and some horticultural applications. These efforts will provide for greater availability of these products.

Build use of organic soil amendments – Actions:

- Promote, develop and support the use of organic amendments including the following.
    - Cost sharing support for organic amendments for soils in need of such amendments.
    - The food industry, municipalities, government (including Ministry of Environment and Climate Change and OMAFRA) and other partners work together to make suitable organic materials more broadly available.
    - Explore opportunities for web-based tools for locating and accessing organic amendment materials.

Control Erosion

Soil erosion from water, wind and tillage is a major form of soil degradation. Left unchecked, it can lead to other forms of soil health problems, such as loss of fertility, degraded soil structure, loss of organic matter and lower water infiltration rates.

A systems approach should be used to address erosion by water. Planning and risk assessment tools including EFP, Revised Universal Soil Loss Equation (RUSLE2)[8] and Farmland Health Checkup assist with that. The first step is to implement key non-structural, preventative BMPs including crop rotation, no-till or reduced till, residue management and cover crops. All contribute to improved soil aggregation essential to water erosion control. Each of these BMPs has its own challenges for different productions systems and crops. No-till is most desirable but can be challenging for some high-biomass crops and on certain soil types. Residue management may require specialized equipment and management knowledge. Learning from others can be a crucial way to aid adoption of these practices.

If these non-structural measures are not enough, further protection in the form of erosion control structures may be needed. Water and sediment control basins and grassed waterways, for example, are designed to manage runoff from intense rainstorms. In extreme cases, highly erodible lands on long, steep slopes should be considered for perennial cropping systems or retirement from cropping (e.g. plant trees instead). In some jurisdictions, removing steep, erodible lands from annual crop production is a major focus.

8 Revised Universal Soil Loss Equation is a mathematical model that estimates average long-term soil loss from sheet and rill erosion caused by rain and related overland runoff along a field hillslope.

For wind erosion, a workable combination of the following BMPs has been found to be most effective: residue management, cover crops, strip cropping, vegetative wind barriers, field windbreaks and shelterbelts.

Tillage erosion may be more challenging to address. In some cases, more than 70 cm of soil has been moved from the combined effects of ploughing, discing and cultivating. Assessing the extent of erosion will determine which BMPs are most suitable. These could include addition of organic amendments, cover crops and no-till or longer-term rehabilitation with perennial crops or cropland retirement. If the soil has been deposited in depressions, restoration is recommended. This involves moving soil from depressions to eroded areas and typically requires professional expertise.

Farmers are encouraged to understand their erosion risks and undertake preventative measures. Technical assistance and financial incentives are often available.

Promote erosion assessment, prevention and mitigation – Actions:

- Promote both agronomic and structural erosion control measures and help landowners find the most suitable and effective combination of each for their fields.
- Encourage conversion of fragile and marginal land from annual cropping to perennial crops or conservation cover (e.g. trees, shrubs and other perennial vegetation) where erosion risk is unsustainable.
- Integrate erosion assessment tools that can be used with existing planning tools to provide landowners with ways to determine long-term erosion control benefits or consequences of their management choices (also see "Expansion of Soil Erosion Assessment Tools").

Minimize Compaction

Compacted soil impairs crop production and soil health by reducing the air available for respiration, decreasing the amount of water that can reach plant roots, increasing the risk of surface runoff, reducing root penetration and degrading soil structure. Today there is a greater threat of compaction because farm equipment has become larger and heavier. Deep compaction can only be reduced by reducing the axle weight of machinery. Shallow compaction may be reduced by using lower tire inflation, or using tracks rather than tires, which reduce the downward force on the soil.

Subsurface compaction may also be in the form of tillage-pans caused by tillage passes (plough, disc, or cultivator) when soils are too wet. Tillage pans can reduce water percolation and root development.

Some farmers use a controlled traffic approach by only driving equipment on permanent wheel tracks in the fields to minimize compaction where the crops grow. Keeping machines out of wet fields also reduces the risk of severe compaction. However, timing of machine use is a challenge for farmers because they are not always able to avoid wet conditions, particularly growers of highly perishable crops like fruit and vegetables.

Build awareness and capacity to assess and reduce soil compaction – Actions:

- Raise awareness of the risks and impact of compaction with farmers, agri-business and equipment dealers and manufacturers.
- Using existing tools and developing new tools, help farmers assess their compaction risk, based on their soil type, equipment type and weight, and traffic frequency and patterns to help them identify ways to reduce the risk.

Bringing it all Together

Building and maintaining healthy agricultural soil means taking the time to get to know the soil well and which management practices best suit individual fields. It is important to identify where the risks for soil degradation are and make plans to prevent or mitigate their impact. Precision agriculture[9] presents an opportunity for site-specific management. By creating management zones based on the field's inherent soil characteristics (type, texture, drainage and topography), farmers are able to more effectively manage inputs on their fields, work with the limitations of their soil type and address the specific needs of parts of fields, rather than the average needs of whole fields. Good soil management is not inherent in precision agriculture technology, but it can help inform soil management decisions.

Carefully assessing the specific risks and designing a customized mix of BMPs for each farm is one key to success. Tools like the Environmental Farm Plan and Farmland Health Check-Up were designed for this kind of activity.

EFPs are voluntary, whole-farm assessments prepared by farmers to increase their environmental awareness and assess risks in up to 23 topic areas. Through local workshops or by accessing the online option, farmers highlight their farm's environmental strengths, identify areas of environmental concern, and set realistic action plans with timetables to improve conditions, including soil health. The EFP helps match particular issues with the right BMPs.

More recently, the Great Lakes Agricultural Stewardship Initiative's (GLASI) program uses the services of Certified Crop Advisors to help farmers assess on-farm soil health and water quality on a few selected fields and develop farm-specific solutions. Some farmers want to go further than the EFP and Farmland Health Check-Up. Innovators want to try techniques not mentioned or emphasized in those more general guides. A more detailed tool to plan for soil improvements is also under development for interested farmers. Increasingly, precision agriculture methods are driving crop planning; new guidance is needed to ensure soil health is integrated into precision technologies.

Systems approach means better soil health and stronger profits

At Schuyler Farms, their goal is to be a sustainable farm business, and they work hard to get there. In the long term, their soil drives profitability, and their quest to improve soils is also to improve their bottom line. That's why they take a systems approach in their Norfolk County farms, where their family grows apples, sour cherries, grains and oilseeds and raise sheep and lambs.

Mapping by soil type helps them use precision agriculture and guides soil sampling and nutrient applications. It also helps them calculate profits.

Their farming philosophy is to reduce tillage and inputs without sacrificing yields, use green bin and leaf litter compost, and strive to adopt better farming practices, such as managed grazing, whenever feasible.

Farmers rely on soil for their livelihood so profitability and sustainability go together.

9 Precision agriculture is an approach to farm management that uses technology to observe, measure and respond to inter- and intra-field variability in crops for the purpose of increasing input and resource use efficiency.

Making it work with cover crops and no-till

Cover crops and no-till are the perfect pairing for Sara Wood, her husband Chris and mother Deb Little. The team grows corn, identity-preserved soybeans and winter wheat near the town of Mitchell in Perth County.

They take a no-till approach for all crops and always use a cover crop mixture following winter wheat. Cover crops make their no-till system work. Their commitment to this system has paid off by requiring fewer field passes and improved soil fertility.

Sara says one of the biggest challenges is controlling weeds. They also think it's important to find an agronomist who understands your goals and what you are trying to accomplish and reading as much as possible.

Expand and improve on-farm soil health planning tools – Actions:

- Review and improve soil-related aspects of the Environmental Farm Plan and Farmland Health Check Up.
- Examine opportunities to expand the availability of the Farmland Health Check Up and Soil Health Check Up tools to other parts of Ontario.
- Develop a detailed soil risk assessment tool to help interested farmers dig deeper to further understand their soils, the risks associated with them, and make plans for improvements.
- Develop guidance for farmers regarding use of precision agriculture tools for site-specific management to benefit soil health.

De-dirting of carrots in the Holland Marsh

A collaborative research effort between OMAFRA and the Holland Marsh Growers Association, with direct involvement by its member producers and processors, has shown the benefits of upgrading harvesting equipment to minimize soil leaving fields during harvest. Testing showed that de-dirting technology on carrot harvesters can achieve up to 80 per cent of surface dirt removal in the field. Not only does this preserve soil, but it also reduces the amount of water needed to wash the vegetables. This knowledge can be applied to other root vegetables, other geographies and field crops across the province.

Invest In and Reward Soil Care

Investments are needed in building healthier soil. Implementing BMPs can sometimes be costly, often requiring more time to plan and manage. These costs cannot be passed along to the market without affecting competitiveness, as most farmers grow crops for markets where prices are set globally.

It takes time to integrate new practices into a farm management system. Site characteristics like slope, temperature, soil type and rainfall vary from farm to farm, so there is trial and error involved in getting the right combination of BMPs for optimal productivity and environmental benefit for the soil.

The economic value of the benefits and ecological services of soil health BMPs needs to be quantified. Financial assistance is often needed to encourage the uptake of new practices.

Easily accessible funding and advice to try a different practice on a small portion of land could help some farmers see how it works without significant economic risk (e.g. trial strip tillage by custom operator, cover crops). This could be modelled on similar successful programs in Ontario and elsewhere. Reduced requirements and paperwork for new participants could make trying something new more attractive to some farmers reluctant to try a new practice.

Access to cost-share funding for a wider range of soil management BMPs has been available in the Lake Erie and southwest Lake Huron watersheds and has led to success in changing practices. During 2017, the range of eligible soil BMPs was also expanded under *Growing Forward 2*. Conservation Authority programs also provide incentives for some soil BMPs. Providing access to cost-shared funding is a way to encourage the broader adoption of soil BMPs.

Innovative farmers often lead the way by trying new BMPs or borrowing ideas from other jurisdictions and adapting them to Ontario's conditions. Innovators often spend their own money to experiment with BMPs, and these experiments often lead to broader acceptance of new BMPs. This innovative spirit needs to be nurtured through policies and programs. Special incentives could be created to encourage innovators to experiment with new BMPs and new approaches to improve soil health, similar to other jurisdictions.

A variety of programs help farmers manage risk and reduce costs including production-related information and publications, production insurance and incentives. BMP insurance is available in some other jurisdictions. There could be potential to incorporate incentives or educational approaches to encourage practices that benefit soil health through these programs – specific opportunities need to be explored further. Further discussion and exploration of options with stakeholders will be pursued during strategy implementation.

A major challenge for soil health is that more than one third of farmland is rented rather than owned by the farmers working that land. The landowners may be relatives, neighbours, city dwellers, investors, land developers or even public agencies. They may have limited knowledge and appreciation for soil health practices and the relation to long term productivity. For short-term rentals, there is less incentive for farmer investment in stewardship than on land owned by the farmer. Stewardship leases are one tool to help address this. The feasibility and effectiveness of other tools that have been suggested, such as increased education and incentives, need further examination. Analysis of different approaches and development of initiatives will be undertaken during strategy implementation, in collaboration with key stakeholders.

Soil stewardship is a part of Ontario's Climate Change Action Plan. The initiative to build soil carbon and reduce net greenhouse gas emissions from soil is a commitment in that plan. Key elements include research on soil BMPs that mitigate greenhouse gases and on farmer motivations to adopt these BMPs, mapping, modelling and soil management initiatives. This will help demonstrate the value of healthy soil and estimate its contribution to climate change objectives, and contribute to our soil health knowledge.

Under the Climate Change Action Plan, a recent report on soil greenhouse gas science reviewed and synthesized science on the effectiveness of various soil BMPs at mitigating greenhouse gas emissions and increasing soil carbon. Reduced tillage, cover crops, BMPs involving vegetation planting (e.g. tree planting, shelterbelts, inter-cropping) and improved nitrogen management all help reduce greenhouse gas emissions. Results from this report will inform OMAFRA programming and focus future research.[10]

The creation of carbon or greenhouse gas credits for farmers is often cited as desirable outcome. Greenhouse gas emission offset protocols are being developed under the direction of the Ministry of Environment and Climate Change for compliance-related offsets for the cap and trade system. Potential for protocol development is being evaluated for nitrous oxide reduction from fertilizer management, emission reductions from livestock, organic waste digestion and management, grassland and conservation cropping. This will lay the groundwork for potential farmer participation in Ontario's carbon offset market. Voluntary carbon offsets are also being developed to support participation in the carbon market by the Indigenous, northern and agricultural communities and to provide additional environmental co-benefits beyond greenhouse gas emission reductions. Work is ongoing on these protocols and initiatives at the time of this document's publication.

Governments, public agencies and the broader public sector (e.g. municipalities, conservation authorities) own significant amounts of farmland across Ontario. Some of that land is used for ordinary agricultural production through rental agreements. It is in the public interest for good soil management practices be followed on public land managed for agricultural production. Public bodies should be leaders in the work for soil health and could use stewardship leases as a tool to that end. Of course there are exceptions, for example lands subject to scientific experimental design for research purposes.

Enhance incentives for soil care practices – Actions:

- Provide financial incentives for a wide range of soil BMPs across Ontario.
- Support for farmers to 'start small' in trying new practices and demonstrate proof-of-concept on their farms (e.g. small fields, low cost).
- Design future programs to support low barrier entry to cost share programs to encourage first time participants for selected BMPs.
- Examine incentives to encourage the innovators to try new practices to benefit soil health beyond currently accepted BMPs.
- Examine the potential of other agriculture programs to provide additional incentives for, and awareness of good soil management practices.
- Develop options to encourage owners of farmland to invest in soil care, including non-farm landowners and farmers renting land to other farmers.

10 Yanni S.F., Rajsic P., Wagner-Riddle C., Weersink A. 2018. A Review of the Efficacy and Cost-Effectiveness of On-Farm BMPs for Mitigating Soil-Related Greenhouse Gas Emissions. Report prepared for the OMAFRA/University of Guelph Partnership.

Build climate initiatives that improve soil health – Actions:

- Support the development of greenhouse gas offset protocols that align with soil health priorities for both voluntary and compliance markets (soil health research findings will help inform the protocol design).
- Develop and implement initiatives that encourage management practices that reduce net greenhouse gas emissions while also benefitting soil health under Ontario's Climate Change Action Plan.

Public sector lead by example in soil management – Actions:

- Recommend use of good soil management practices on publicly-owned working agricultural lands in Ontario including:
  - Lands on OMAFRA-funded research sites, managed by University of Guelph or other bodies (except research plots with specific experimental designs).
  - Other working agricultural lands held by the Ontario government.
  - Working agricultural lands held by Conservation Authorities and municipalities.
  - Working agricultural lands owned by the federal government.

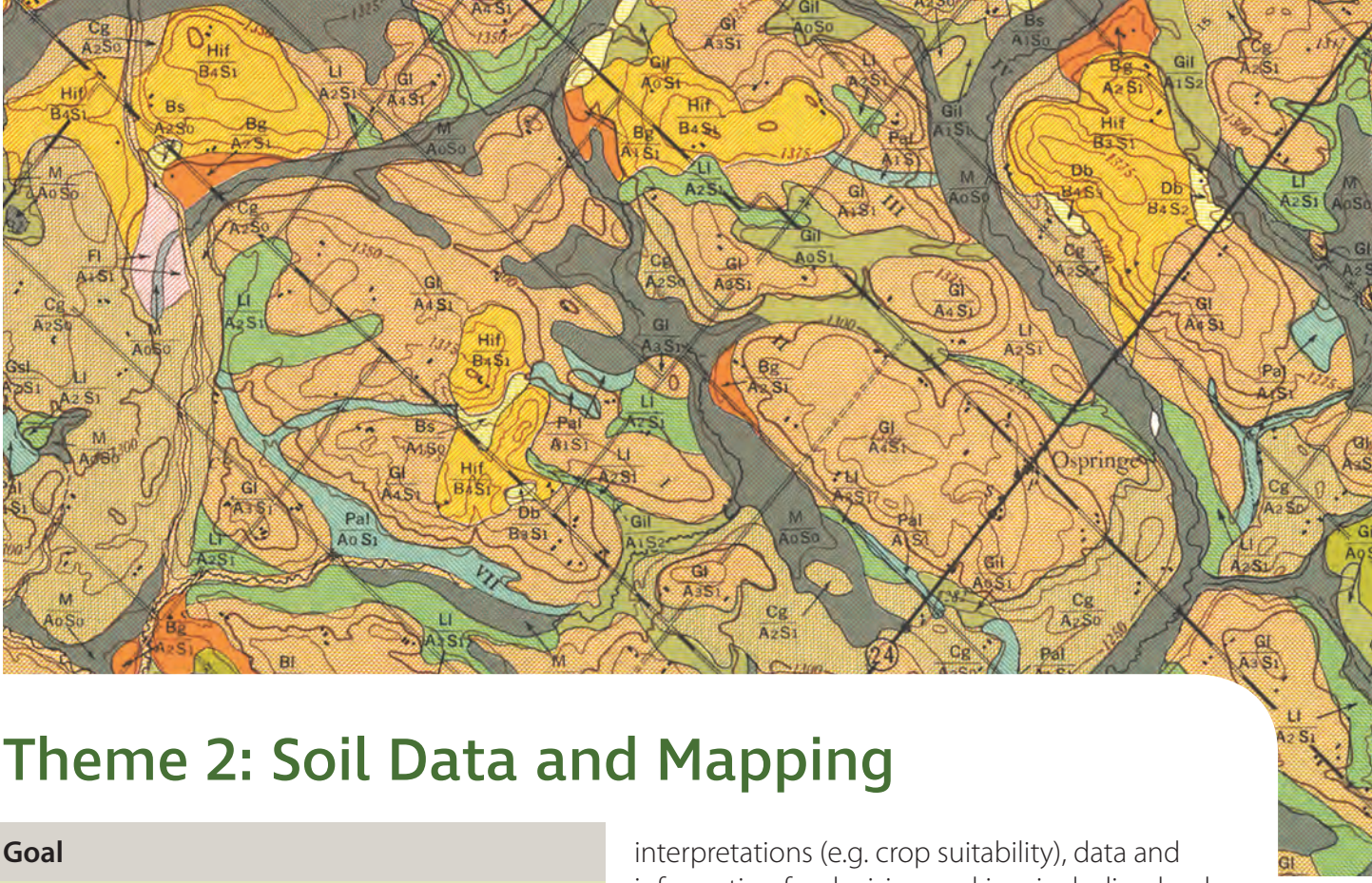
Spread the risk and reap the soil health benefits

In 2015 the three Drudge brothers, who farm in Huron County near Wroxeter, expanded their crop rotation from corn, soybeans and wheat to include canola, edible beans, oats and yellow peas. The move was in keeping with their successful farming approach – to find solutions that contribute to improved soil health and resilient crops.

With so many crops in rotation, the Drudges have a better buffer against falling prices, take advantage of more planting opportunities in spring and fall, spread out labour demands over time and improve soil health.

The Drudges are long-time no-tillers, and they now seed cover crops following the majority of their main crops, aiming to reach their goal of keeping the soil covered with live plants during as much of the year as possible.

Their advice to others about changing their soil management practices is to start small and gain experience and confidence with a new way of doing things and then scale up.



Theme 2: Soil Data and Mapping

Goal

Reliable soil data and tools are available to allow for informed decision-making and analysis by producers, industry, government and the public.

Objectives

- Soil inventory data are well documented, replicable and defensible.
- Soil data are comprehensive, accessible, and, where possible, publicly available.
- Accessible soil data provide for a wide range of analysis and decision-making.

Good decisions rely on good data. Technology is becoming increasingly integral to agricultural operations. Information on soils and land is important for farmers to make management decisions. Farmers need better access to data, soil interpretative maps (e.g. susceptibility to compaction), soil maps, and information to support their on-farm decision-making so they can remain competitive in the global market. Policy makers also need access to soil interpretations (e.g. crop suitability), data and information for decision-making, including land use planning.

For instance, many farmers are using or investigating the merits of using precision agriculture technologies, such as Real Time Kinematic Global Positioning Systems (RTK-GPS), precision planters and yield monitors. This technology can be harnessed for improved site-specific management decisions with potential soil health and other environmental benefits. However, the key to the successful integration of this technology in crop systems is access to detailed soil maps and landscape information.

There are many partners involved in collecting, generating and using soil data and maps. Collaboration should be the foundation for future actions. We need to make the most of soil data as well as common standards to guide the development and deployment of databases and mapping systems. We also need to build a better understanding of the respective needs and roles of the sector and government.

Actions

Soil Inventory and Mapping

Scientists have described, sampled, classified and mapped soils across southern and parts of Northern Ontario for more than 100 years. However, current soil maps in Ontario are dated, may not be easily used in a digital world and may not be available at an appropriate scale for precision agriculture. Access to up-to-date, easy-to-use soil maps and data layers is critical for land use planning and precision agriculture, as well as to support the work agri-businesses do for their clients.

Renewing soil maps will mean implementing new technologies such as Light Detection and Ranging (LiDAR[11]). This is needed to acquire detailed landscape elevation and topography data and to support predictive digital soil mapping techniques that incorporate computer-based programs, landscape data and field measurement to generate revised soil classifications and maps.

As part of a long-term goal, a two-year pilot initiative (2016-18) to renew soil maps for targeted areas of the province was undertaken with a goal of beginning the process of making Ontario's soil data and maps more relevant to today's users.

Ontario and Canada funded initial soil map renewal efforts (2016-2018) in Ottawa, Peterborough, Grand River, Cochrane-Hearst and the Temiskaming Shores regions, with other areas to be considered in the future. Updates to the legacy soil and land capability ratings (Canada Land Inventory) data and maps is ongoing at the same time as the soil mapping. Completing that work for all of Ontario is a long-term task.

Modernize soil maps and inventory – Actions:

- Continue inventory and mapping to complete the next generation soil resource inventory and maps within 20 years.
- Continue updates to the land suitability for agriculture classifications, under the Canada Land Inventory system, to assist in management decisions.
- Complete targeted LiDAR coverage for farmland in Ontario as a foundation for soil mapping, BMP tool development and land resource initiatives. Make LiDAR data publicly available as it is completed.
- Offer stakeholders opportunities to provide advice on priority areas for soil mapping and LiDAR data acquisition through a technical/advisory committee or similar body.
- Investigate the development of a next generation land suitability rating and capability systems that builds on the existing Canada Land Inventory system.

Soil Information System

Ontario's agricultural soil maps are available through OMAFRA's AgMaps portal on the Agricultural Information Atlas as well as the Canadian Soil Information Service website. As soil data is gathered, it requires a secure home for storage, maintenance and public access. A soil information system should be established in a central location and made widely available through a public digital platform. It would include existing and new Ontario soil information.

11 LiDAR is a system that measures distance by recording the return time of a laser pulse. In soil mapping, LiDAR is used from an aircraft to accurately record topography.

Build and make available soil databases – Actions:

- Develop a Soil Information System to house OMAFRA's legacy and new soil data.
- Determine best practices for standardizing data collection, storage and maintenance and metadata records.
- Make existing and next generation soil data available on a publicly accessible, digital platform.

Remote and Proximal Sensing

Remotely sensed data and imagery from satellites and other earth observation platforms are transforming many aspects of contemporary life, and agriculture is no exception. Agriculture and Agri-Food Canada (AAFC) now produces maps and data on the crops that are grown across Canada every year using satellite imagery and advanced computer analytical tools that process the data within the imagery. The availability of these data, in turn, enhances our ability to analyze trends and make decisions.

AAFC is also investigating the use of satellite remote sensing data and technology to map cover crops and agricultural crop residue.

Proximal (direct) soil sensing uses field-based sensors to measure soil characteristics at a high resolution. Information gathered from these sensors, in conjunction with soil sampling and analysis, is becoming increasingly important for defining soil properties in precision agriculture.

Explore new technology for soil assessment – Actions:

- Investigate and develop ways to use remote sensing data for collection of soil characteristics, information and analysis.
- Examine and recommend tools such as airborne or hand-held sensors that can assess soil physical, chemical and biological properties.

Soil Test Data

There is currently a wealth of information in soil samples taken for fertility testing by farmers, consultants, government, academia and others. Farmers and consultants collect soil samples to test for nutrients (such as phosphorus, nitrogen and potassium), organic matter and other soil parameters that are important for crop production. Tens of thousands of soil samples have been collected, with the data housed at many institutions and in filing cabinets across the province. Some preliminary analysis of soil sample data indicates the potential power of this data. The data shows declines in soil organic matter over time across Ontario and in many counties, suggesting further analysis is needed.

In its present form, these data cannot be easily accessed and used to look at trends or track the state of our soils. Ideally, there should be greater access to at least some of the wealth of soil test data that has been collected in one or a series of databases. This could be used to establish baseline levels of various soil characteristics, assess provincial, local and field-scale trends, and map soil test characteristics at different scales.

This data could help respond to recommendations from the Environmental Commissioner of Ontario's report Putting Soil Health First: A Climate-Smart Idea for Ontario regarding estimating soil carbon levels and monitoring them over time (also see Soil Evaluation and Monitoring).

However, there are many issues to consider in making soil test data more accessible.

- **Privacy:** Individual soil tests by private landowners are generally the property of those landowners and may be subject to legal protections. Other tests done for public agencies may not be constrained in the same way.
- **Data management:** A suitable location for data storage and management would need to be determined. For instance, a consortium of private laboratories may be able to pool soil test sample data for many clients. A university or consortium of academic institutions might be another approach worth pursuing.
- **Use of data:** Consideration would need to be given to use of data provided by farmers or others – for what purposes – and in what form would be the most useful.
- **Data standards:** There needs to be a standard method for data collection, analyses and outputs, to enable consolidation of data for use in analysis.

Stakeholders and experts in data ownership, use and privacy, must work through these issues together during the strategy's implementation.

Make better use of soil sample data – Actions:

- Engage stakeholders about how to provide greater accessibility of soil test data.
    - Research how to address privacy issues and roles of labs and clients.
    - Develop data-sharing partnerships among multiple partners.

Precision Agriculture Data

Similar to soil test data, there is a growing amount of soil and crop information generated by producers involved in crop-related precision agriculture. 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. But good soil management is not inherent in precision agriculture technology, it simply provides new and powerful data tools to make soil management decisions.

Precision agriculture is a rapidly changing, market-driven area in both technology and data analysis. There are currently multiple industry players and platforms, creating challenges with compatibility for software and data. A number of partner organizations and tech industry companies have projects and proposals to invest in data-related innovative agricultural products and services, research needs, and collaborative projects. In addition, these projects may facilitate investments to enhance the compatibility and availability of data for use in precision agriculture.

Better use of precision agriculture data – Actions:

- Industry and government work together to develop ways to better access and use soils data and precision agriculture data to maintain and enhance soil health.

Farm Practice Data

There is currently no good source of information about what practices are used by farmers that may affect soil health and conservation in Ontario. Establishing baselines is essential so that improvements in soil health can be monitored over time and so we can understand emerging trends. Baselines on tillage, cover crops, organic amendments, crop rotation and other practices are crucial to measuring progress.

A wealth of data exists that could be analyzed. This includes the Census of Agriculture, the Farm Environmental Management Survey, remote sensing data (e.g. AAFC annual crop inventory), collections of soil test data, academic research, and BMP adoption data from federal-provincial and conservation authority programs. Engaging Statistics Canada can harness more powerful analysis of farm level data. This work can build on work already done by AAFC for the Lake Erie basin.

Determine baselines for soil management practices – Actions:

- Complete an initial project to assess the state of soil-related agricultural practices and establish baselines from which to measure change, including:
    - Compiling existing information such as census, Farm Environmental Management. Survey, existing remote sensing data (e.g. AAFC annual crop inventory), aggregate soil test data and BMP adoption data.
    - Establishing a partnership with Statistics Canada for in-depth analysis of data on select practices.
    - Identifying data gaps and baselines to measure change in practices over time.

Theme 3: Soil Evaluation and Monitoring

Goal

The health and status of Ontario's agricultural soils are tracked over time.

Objectives

- Capacity is developed to track changes in agricultural soil health, erosion and soil organic matter.
- Soil health and erosion monitoring is used to inform and evaluate policies and programs.

We can only manage what we understand. We need to assess the state of agricultural soil health across the varying landscapes of Ontario and track changes over time to monitor the effectiveness of our collective actions, and to inform future policy and program decisions. To do that, we need the right metrics and tools to apply at different scales: at the farm, over different regions and across the province. We also need to understand the linkages between these scales.

The best way for farmers to monitor the health of their soils is to regularly explore it – whether it's using a shovel to see what the way it looks and feels like beneath the surface, or sending a soil sample to the lab for analysis. Easy-to-use measurement tools for quick assessments greatly benefit farmers when they are making production and management decisions. Some simple tools used by farmers include fertilizer and organic matter tests, earthworm counts (which are an indicator of biological activity) and tests used to demonstrate the rate of decomposition by soil organisms. More comprehensive soil health tests are also needed to assess more difficult to assess parameters, such as biological activity and aggregate stability.

Tools that measure across the landscape provide a regional or watershed picture of what's happening. Some conservation authorities work with farmers to assess soils and help them use BMPs to improve soil conditions.

Province-wide soil assessment tools are not well developed, except for indicators developed by the federal government. Creating Ontario-specific soil health indicators and making them consistent and comparable at different scales would increase their usefulness.

Actions

Farm Scale

Improving soil health is a long term commitment, and it can take decades (or more) to see a measurable change. A significant and sustained commitment at the farm level is critical. This starts with testing soil regularly, understanding the results, planning for change, and taking action. All farmers should be testing their soils, including soil organic matter.

Understanding the physical, chemical and biological conditions of the soil can be achieved a number of ways.

On-farm soil health assessment – digging through the soil, seeing soil profiles throughout the fields and testing soils to measure and track the nutrients as well as organic matter all help the farmer and agricultural landowner understand soil conditions.

With rapid advances in technology, there are a number of tools available and many opportunities for more that put soil health monitoring and evaluation at farmers' fingertips. Mobile applications for smartphones are emerging to assist farmers with their management decisions, and there is great potential for further innovation. For example, open source satellite imagery could be used to track soil cover.

Organic Matter as a Key Indicator

Soil organic matter stores and supplies nutrients, improves soil structure and water infiltration, drives soil biological activity and soil microbial diversity and buffers against changes in soil pH. Higher soil organic matter levels improve water holding capacity, which is critical in seasons with low water.

Tracking soil organic matter levels across farmers' fields is an important indicator of soil health, and it's easy to include, so it should generally be included as a parameter for analysis in soil sample analysis. However, benchmarking and tracking soil organic matter beyond the farm scale is a challenge, because different laboratories use different analytical methods. There may be an opportunity to improve consistency in the approach to analyzing soil organic matter.

Soil Health Testing

Different laboratory tests can be performed to measure soil parameters. Traditional soil testing determines the pH, estimates available nutrients to predict a crop response to added fertilizer and, if requested, soil organic matter. On the other hand, newer comprehensive soil health tests provide a measure of soil health and include indicators for biological, physical and chemical components. This is useful for tracking holistic soil health over time.

Some laboratories offer various soil health test packages. OMAFRA staff and researchers in Ontario are working on validating soil health tests such as the Cornell and Haney tests for Ontario conditions[12]. The next stage is to work with laboratories and other stakeholders to make a validated soil health test available at labs serving Ontario farmers.

Refining these tools and making them easy to use at the farm level is one way to ensure accurate information to better inform farmers' soil management decisions.

12 E.g., K. Congreves, A. Hayes, E. Verhallen, L. Van Eerd. 2015. Long-term impact of tillage and crop rotation on soil health at four temperate agroecosystems. Soil and Tillage Research 152, 17-28.

Expansion of Soil Erosion Assessment Tools

Tools are available to help farmers assess how much water soil erosion is happening on their fields and how to reduce it. These tools need further development to verify gully and tillage erosion estimates and integrate with sheet erosion estimators (such as RUSLE2[13]) to provide better estimates of total water erosion rates and to assess the effects of different practices on controlling these rates. In addition, these soil erosion assessment tools need to be packaged into software that is already commonly used by the industry. That way, land managers can accurately assess the soil degradation consequences of their decisions while reviewing their production activities (e.g. tools like the Soil Calculator[14] or an equivalent).

Developing and maintaining significant "behind-the-scenes" datasets is also needed, as discussed in the previous theme area. Examples of datasets to support these assessment tools include detailed, up-to-date soil maps that characterize the soil on a field, regional and possibly real-time rainfall and snowmelt intensity information, and a layer that describes the topography of a field.

Ideally, an approach that combines soil health assessments as well as erosion models and tools would be made available to farmers, extension personnel and industry agrologists to help them assess, reduce and prevent erosion.

Increase capacity to track farm scale soil health – Actions:

- Create and distribute a farm-level, all-in-one education tool kit for soil health assessment that farmers and advisors can use (could include slake tests, infiltration tests, and soil compaction measurement).
- Promote the importance of tracking changes in soil organic matter as a way to monitor soil health including ensuring soil organic matter is always included in normal soil testing.
- Work with the Ontario Soil Management Research Services Committee and laboratories to explore opportunities for a more consistent approach to soil organic matter analysis across the province.
- Develop and implement a comprehensive Ontario soil health test in collaboration with laboratories.
- Expand OMAFRA's and partners' capacity in soil erosion assessment:
    - Enable development of tools to estimate soil erosion under different management practices.
    - Continuously improve/maintain these water erosion assessment tools as new approaches become available (sheet, rill, gully and tillage erosion).
    - Investigate the possibility of equivalent tools for wind erosion and other forms of soil degradation.

Measures of Success for On-Farm Soil Health

Making our goals and objectives come to life means having indicators to assess progress over time, and using those to set measures of success. These must be meaningful, and flexible, as well as reflect the individual needs of farmers and their soils.

At a farm or field scale, OMAFRA suggests that farmers adopt measures of success suitable to the soil type and circumstances for their farms.

13 Revised Universal Soil Loss Equation is a mathematical model that estimates average long-term soil loss from sheet and rill erosion caused by rain and related overland runoff along a field hillslope.

14 https://www.agrentools.com/government-entity/our-tools/soilcalculator/

The table below presents measures of success for soil organic matter, crop rotation and cover crops. These suggestions are based, in part, on recommendations from other OMAFRA publications, as well as expert input. They will be refined over time as our soil knowledge evolves.

Topic	Farm-scale Measure of Success
Soil Organic Matter	At least a 'good' rating based on soil texture: Sandy Soils: 2.5 per cent, Sandy Loams: 3.5 per cent, Loam Soils: 4 per cent, Clay Loams: 4.5 per cent, Clay Soils: 4.5 per cent (see Ontario's "Agronomy Guide for Field Crops - Publication 811" for more information)
Crop rotation	At least three crop families in a rotation (for annual cropping systems)
Cover crops	50 per cent of a farm's annual cropland have a cover crop

In addition, other measures of success could be developed related to tillage, organic amendments and other measures, as our data and experience evolve.

These measures of success have most relevance to annual cropping systems of grains and oilseeds. Ruminant livestock and horticultural producers suggested the development of soil organic matter measures of success tailored to their production systems.

The soil strategy proposes many voluntary actions to support Ontario farmers meeting or exceeding these measures of success. These include supporting education, site-specific planning, and accessing resources and tools. Collectively, these actions will drive action at the farm level.

Measures of Success for On-Farm Soil Health – Actions:

- Promote farm-scale soil organic matter measures of success for cropland soils of different texture:
  - Sandy Soils: 2.5 per cent, Sandy Loams: 3.5 per cent, Loam Soils: 4 per cent, Clay Loams: 4.5 per cent, Clay Soils: 4.5 per cent (for annual cropping systems).
- Develop soil organic matter measures of success for pasture, horticultural and other production systems in collaboration with partners.
- Promote the following practice-based measures of success as suggestions for farmers:
  - Crop rotation: At least three crop families in a rotation (for annual cropping systems).
  - Cover crops: 50 per cent of a farm's annual cropland have a cover crop.
- Develop additional measures of success after analysis of soil management practice baselines is completed (see Soil Data and Mapping). These could include reducing bare soil through soil cover and residue.

Soil health benefits take time

Kyle Garlow farms near Ohsweken, just south of Brantford within Six Nations of the Grand River Territory. He cash crops approximately 1,200 acres on heavy clay soil. Kyle is a firm believer in the importance of crop rotation and grows equal acres corn, soybeans and winter wheat. The only tillage done occurs after wheat harvest to incorporate fertilizer, lime and cover crop seed.

Land rental is a challenge for Kyle, who leases the majority of his acreage. Short-term rental can make it difficult to justify long-term investments on land that may be lost to a higher bidder. Kyle makes the case to his landlords for the benefits of soil conservation and producing consistent yields year-to-year. He sees the biggest return from his soil health management during years of either excessive or scarce rainfall.

Kyle's advice when it comes to reducing tillage on heavy clay soils is that you have to give it at least four years to see benefits; changes in soil don't happen overnight. When it comes to no-till, "you don't get paid on looks," says Garlow, "you get paid on yield."

Regional Scale

Understanding soil health on a landscape or watershed scale develops understanding of the state of soil health on a regional level. For example, watershed-scale soil assessments are conducted by some conservation authorities, which sample and analyse soil at different scales to determine the effect of soil health on water quality and quantity. In-field monitoring is combined with Geographic Information Systems (GIS) techniques to better relate the field to watershed scales. Both scales are important in assessing overall watershed health.

These assessments can take various forms including direct field measurement and risk analyses studies. Direct field measurements can be challenging due to weather and labour requirements, whereas risk analyses studies can rely on land management data that is not readily available. There is a need to strengthen the understanding of the link between direct field measurements and the GIS based watershed scale assessments.

A regional soil assessment can be a powerful tool to evaluate baselines, measure progress and raise public awareness in the community about the health of local soil. Expanding these assessments to other watersheds would help identify areas in need of action for improved soil and watershed health. Many conservation authorities and municipalities routinely undertake watershed or sub-watershed studies that examine water quality, quantity and habitat issues. Inclusion of soil health analyses in more of these studies would also help increase attention on the need for soil health action.

Soil health and water quality

Healthy soils with good infiltration and aggregate stability reduce surface runoff and topsoil loss, resulting in better water quality. The Ausable Bayfield Conservation Authority (ABCA) is currently completing a general assessment of the state of soil health across the entire 2,400-square-kilometre ABCA watershed. Various approaches have been used at different scales including side-by-side trials at the field scale, sub-watershed risk based assessments and watershed-wide soil health sampling. Future work includes developing improved techniques to relate direct field measurements to the watershed scale assessments.

Regional Scale Assessment – Actions:

- Partner with on-the-ground organizations to ensure continuation and expansion of soil health monitoring on a watershed scale across the province.
- Conservation Authorities ensure sub-watershed plans include objectives and targets for soil health and conservation that relate directly to improving water quality.

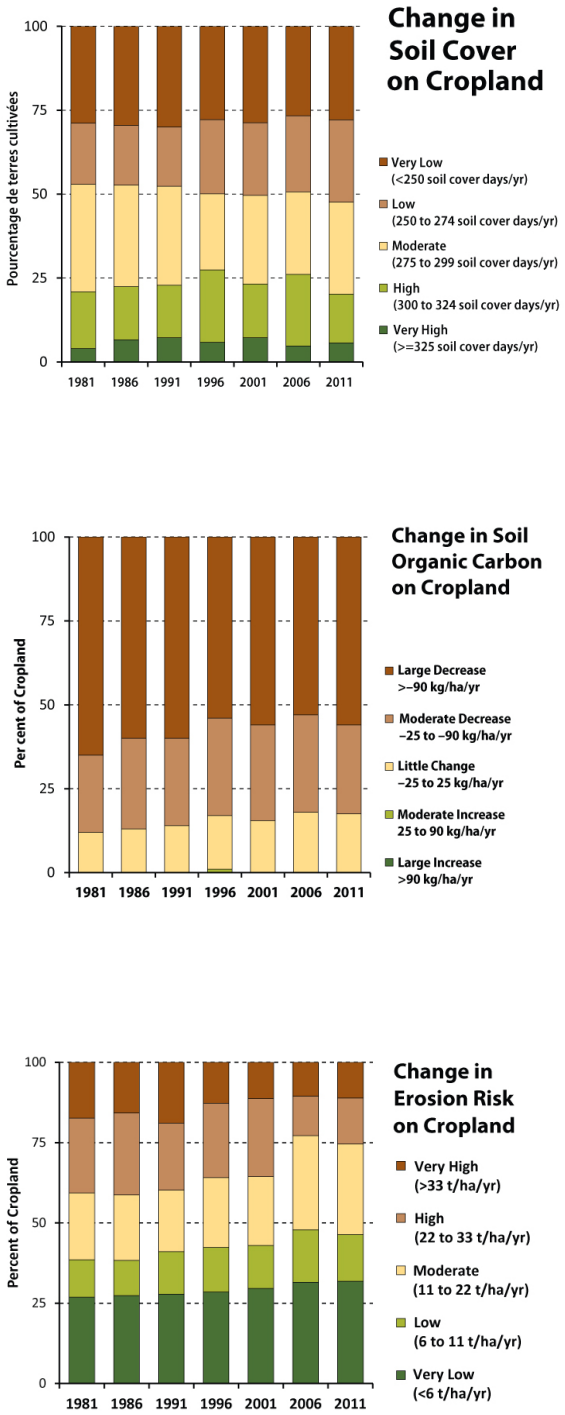
Monitoring Soil at a Provincial Scale

Measuring, estimating and tracking soil health indicators is a complex undertaking. Agriculture and Agri-Food Canada leads this analysis, resulting in Canada's "Agri-environmental Indicators," or sustainability metrics, which are reported every five years.

The three key soil health indicators used by the federal government are soil organic carbon, erosion risk and soil cover (including crops, residue and snow). They are considered the best available measures of the status of Ontario's soils[15]. They will serve as the interim indicators of progress for the soil strategy. Figure 1 shows the trends in these three indicators 1981-2011. There is a unique opportunity to adapt them to a more detailed scale in the future that would provide more Ontario-specific information.

Other sources of data that can help track soil health at a provincial scale include the global soil organic carbon map being developed by the Food and Agriculture Organization of the United Nations, and Ontario's Land Use Carbon inventory[16], which is also under development.

Figure 1. Soil Indicator trends 1981-2011



15 For more information see the 2016 report 'Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #4'

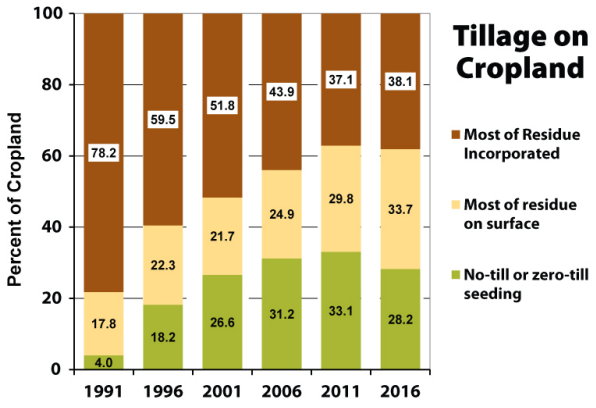
16 Ontario's Land Use Carbon Inventory project is an Ontario Climate Change Action Plan initiative. The purpose is to develop a land use carbon inventory for Ontario by 2020 to quantify greenhouse gas emissions and removals from agriculture, forestry and other land uses.

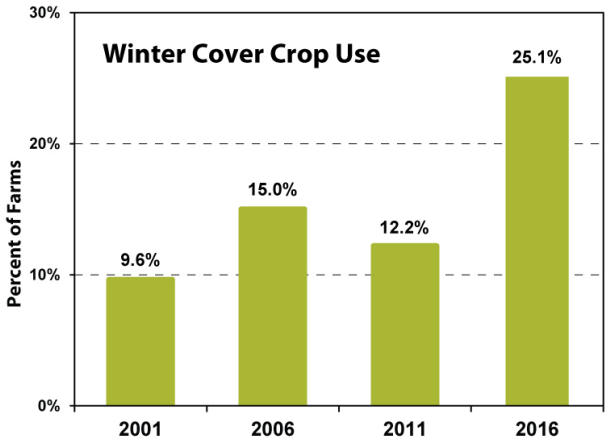
In order to have a robust monitoring and evaluation system, Ontario needs to have an organized system of collecting, retrieving and analyzing data and maps. A consolidated data base of existing and new soil samples from laboratories could be used to help track soil organic matter. An alternative view was suggested that soil organic matter should be measured for every field in Ontario, every five years, as a means of measuring change.

Statistics Canada's agricultural census conducted every five years offers opportunities for monitoring changes in farming practices. The proposed baseline study (see Soil Data and Mapping) would review census data along with other information.

In the interim, census data on cover crops and tillage can be used to assess progress in changing practices (see Figure 2). These two variables could also have potential to identify measures of success. For example, the census reports the number of farmers using cover crops. The percentage of farmers using cover crops doubled (from 12 per cent to 25 per cent) between 2011 and 2016. This suggests growing momentum in cover crops adoption. Continuing and enhancing the promotion of cover crops could help increase the percentage of farmers reporting the use of cover crops. To increase the percentage of farmers using cover crops from 25 per cent to 40 per cent would require an additional 7,400 farmers using cover crops. To reach 45 per cent would require an additional 10,000 farmers using cover crops.

Figure 2. Tillage on cropland and cover crop use





Similarly, the percentage of cropland prepared for seeding that received conventional tillage (where "most of residue was incorporated into the soil") had been decreasing markedly since 1991, until it went up slightly from 37 per cent in 2011 to 38 per cent in 2016 (Figure 2). No-till area also decreased from 33 per cent to 28 per cent of cropland. Reducing tillage further would be consistent with the objectives of this strategy. Greater adoption of no-till and strip or zone tillage, an alternative that is growing in popularity, could help reduce the land receiving conventional tillage ("most of residue was incorporated into the soil"). To decrease conventional tillage to 30 per cent of cropland would require an additional 600,000 acres, of the 7.5 million acres prepared for seeding, to be under conservation tillage rather than conventional tillage.

Adopt Provincial Indicators for Soil Health and Conservation – Actions:

- Use the existing AAFC soil indicators as interim measures to track improvements in soil organic matter, erosion risk and soil cover.
- Explore adaptation of the three AAFC soil indicators (soil organic carbon, erosion risk, soil cover) to a more detailed scale including:
    - Develop options to calculate indicators at more detailed scale.
    - Assess the availability of data on management practices at detailed scale (using census data).
    - Develop greater federal-provincial collaboration on indicators.
- In the interim, use agricultural census data on cover crop adoption and tillage practices as indicators to monitor change in soil management practices.
- Examine options to track and report on changes in soil carbon including continued participation in the development of a Global Soil Organic Carbon Map, Ontario's Land Use Carbon Inventory development, AAFC's soil organic carbon indicator and analysis of soil test data from labs.

Provincial Measures of Success

Making our goals and objectives come to life means having indicators to assess progress over time, and use those to set measures for improvement. Yet any measures of success selected must be meaningful, and flexible, as well as reflect the individual needs of farmers and their soils.

The strategy uses the existing AAFC soil indicators of soil organic carbon, soil erosion risk and soil cover as interim province-wide progress (see Figure 1). AAFC continues to refine and develop these indicators to provide more detailed information. Ontario intends to collaborate with AAFC to improve the data that is used to calculate the indicators, to increase their usefulness for more detailed analysis.

Potential practice-based measures of success can be explored further during the implementation of the soil strategy.

In some jurisdictions, monitoring long-term study plots with established management regimes is another common and complementary method of soil monitoring that provides more detailed, precise measures of change, compared to modelling. Ontario does have some long-term research plots at a number of research stations (AAFC and University of Guelph). These have not been used for formal monitoring in Ontario, but could be in the future.

The renewed soil mapping and inventory work presents another method of evaluating change in soils over time. Soil surveyors are now able to compare soil profiles from original soil surveys,

done early in the 20th century, with current profiles. This can reveal changes in different soil horizons or layers, something not revealed by other methods.

As technologies advance (e.g. remote sensing) and new information becomes available, it will continue to enhance our understanding and ability to monitor change.

Develop provincial-scale measures of success – Actions:

- Adopt the following long-term provincial measures of success:
  - Increase soil organic carbon – reverse the decline in soil organic carbon and stabilize or increase soil organic carbon.
  - Reduce soil erosion risk – lower risk of erosion and area of cropland in higher risk categories over the long term.
  - Increase soil cover – reduce the area of cropland with bare soil over winter.
- After completion of the analysis of soil management practices baseline study (see Soil Data and Mapping), examine the potential to identify additional practice-based measures of success.

Examine the potential of other provincial indicators – Actions:

- Establish and evaluate changes in benchmarked soil profiles across the province on an ongoing basis to monitor changes to the landscape and effects of cultivation on soil profiles (through the soil inventory and mapping).
- Examine the potential for ongoing monitoring of long-term soil plots across Ontario. This could include examining the potential for expanding the number of long-term plots to adequately cover the range of soil, climate and cropping systems for Ontario.

Theme 4: Soil Knowledge and Innovation

Goal

Soil knowledge and skills are optimized to meet societal and economic needs and drive innovation.

Objectives

- Sustain human resource capacity in soils knowledge to meet priorities.
- The education sector supports programs for appropriate soils knowledge and skills.
- Ongoing research supports innovation in soil knowledge and management.
- Agricultural sector engages and has access to people with soil-related knowledge and skills to meet client needs effectively and economically.
- Producers have access to the knowledge and support needed to maintain and enhance soil health.

Getting the best available knowledge in the hands of decision makers can lead to the best decisions. Knowing how to manage soils and understanding how soils function is key to their productivity and long-term sustainability. However, there is still much to learn about the connections between healthy soils, productivity and resilience.

There is limited site-specific (e.g. by production type) research and information, as it relates to Ontario conditions, readily available for those who need it. Ensuring timely, up-to-date information on the latest BMPs, maps and evaluations is available and accessible to farmers is important. We also need knowledgeable government, academic and industry support, to assist the sector with these efforts.

Modernizing the ways we communicate is essential for keeping pace with the changing times. We need to diversify the formats of our educational and communication products to better reflect the range of media and distribution channels used by today's farmers and other interested audiences.

Investments in education and capacity building are foundational to building awareness and driving behaviour change. This will require sustained, collective leadership. It will rely on

commitment and a coordinated effort from farmers, commodity groups, general farm organizations, conservation organizations, agri-food businesses, government and other partners. We need to work together to ensure that lessons from research and the field are shared and incorporated into the development of effective programs and policies. We also need to ensure that knowledge about building healthy soils gets into the hands of people who can best use it: farmers and the people they work with, and that the flow of knowledge is reciprocal.

Local knowledge was a common theme throughout input received. We also heard that farmers learn the best from each other. In addition to informal conversations, common approaches include practical workshops, demonstration sites and 'twilight tours' – in which a farmer will host a group of farming neighbours to learn about his or her practices. Farmers want to be able to see how someone else in their area have implemented soil health practices and what the results were. Indigenous participants spoke of the importance of learning from local knowledge keepers, who have traditional knowledge and have a relationship with the land and soil.

We also heard that it's important for people to know where their food comes from, to get young people excited about soils at an early age, and ensure they develop an appreciation about the importance of soil, seeing it as more than just 'dirt.' It's important to attract and train the next generation of soil management professionals so they have the skills and knowledge required to support ongoing stewardship efforts and continuous improvement.

Many partners, including innovative farmers, agri-business, researchers and conservation agency staff, provide workshops and informal, hands-on training to consulting agronomists and farmers. They help them learn how to diagnose the key forms of soil degradation, and assess the site-specific efficacy of soil health BMPs on Ontario's croplands.

Ultimately, we are laying the groundwork for what is needed to better manage our soil, as described in the first theme.

Actions

Research

There is still much to learn about agricultural soil and the best ways to manage it in modern agricultural production. Significant improvements in soil's physical, chemical and biological characteristics happen slowly, sometimes over decades. A longer term, multi-disciplinary approach to researching management systems is needed. Further to that, research needs to be linked with practical, on-farm knowledge and used to develop decision tools to help farmers use this knowledge.

As we do this, it is important to include economic implications. Many social, logistical, behavioural and convenience factors influence choices as well. These factors have often been overlooked, but they are increasingly being considered in addressing barriers to adoption.

In April 2017, a soil research workshop was held with researchers, experts, conservation authority staff and industry representatives to discuss and prioritize areas of soil research. The priorities identified by the group were further refined by OMAFRA staff and an array of academic researchers, experts and industry representatives. The more detailed proposed soil research priorities are included in Appendix 2. Highlights are listed on the following page.

Proposed Research Priorities for Soil Health

Systems Approach	• Encourage a multidisciplinary approach to soil health research, which considers the production system.

Physical	• Quantify the impact of land management on soil physical and hydraulic properties and their influence on soil health (including resilience):
	  • Diverse crop rotation with and without perennial crops, cover crops.
	  • Effects of tillage (no till, rotational tillage, strip tillage).
	  • Effect of crop residue removal, in interaction with other practices (what are tolerable removal levels).
	  • Specific cover crop species (including precision management).
	  • Soil compaction.
	• Determine key indicators for soil physical properties.

Chemical	• Assess impact of soil health practices on the fate (crop uptake, soil retention, loss from system) of nutrients in cropping systems regardless of source (soil, fertilizer, organic amendments, crop residue, etc.)
	• Assess chemical changes as soils become healthier:
	  • Priority nutrients (N, P, K, S, and organic C).
	• Consider unintended consequences and trade-offs when conducting systems analysis:
	  • Build on long-term research.

Biological	• Identify and link key functions for healthy soil with on-farm management. • Identify indicators that can be used for short term and long term sensitivity to management changes. • Determine the links between management practices (e.g. crop rotation, cover crops, organic amendments), production and soil biology.
Economics	• Develop methods to quantify economic aspects of soil health. • Evaluate the economic impact of physical soil degradation. • Conduct a cost/benefit analysis of BMPs as related to crop productivity / profitability/sustainability. • Integrate economic considerations as a deliverable for project funding where applicable.
Social Factors	• Identify key behaviour barriers and drivers, and the most effective approaches to address them.
Indicators	• Identify key indicators or functions for the chemical, physical and biological aspects of soil health at the local, regional and provincial scale. • Develop a clear list of robust measureable soil health parameters.

Since many BMPs have cumulative effects, we need to measure what happens in the soil over many years. In addition, climate change is leading to less predictable weather patterns. Understanding the long-term impacts of different management practices requires longer-term research projects. Having stable, long-term funding and research infrastructure, similar to the approach taken with livestock research facilities, would produce more results and attract research talent to the soil health discipline.

Long-term trials allow evaluation of the effects of BMPs on soil under different weather, climate, pest and weed pressures. A recent study from Ridgetown campus of the University of Guelph showed that over 11 and 15-year periods, no-till practices and inclusion of winter wheat in the three-crop rotation improved the quality and storage of carbon and nitrogen on clay loam soils.

Such a framework would facilitate:

- Verification of soil degradation diagnostics.
- Site-specific basis soil health BMP verification.
- Baseline and on-going monitoring and practical research of soil health and environmental outcomes in real time and real farm conditions.
- Refinement of detailed soil health assessment methods.
- Training of soil health assessment staff and partner service providers.
- Demonstration farms – for tours and informal education regarding soil degradation and effective, and site-specific soil health BMPs.

Fostering a strong communications loop between scientists, extension experts and farmers would make for a more robust research and learning environment and boost the drive to improve soil health.

It will also be important to work with Indigenous people and learn from their traditional knowledge of the land.

With the research that is happening on plots and farms, there is a huge opportunity to collect data and house it in the central database being developed (see Soil Data and Mapping), which would be made easily accessible to researchers. We heard that people are willing to collect these data during their research but they need to know what data is most useful and how to collect it.

Support a long-term, collaborative soil research agenda – Actions:

- Integrate identified soil research priorities (detail in Appendix 2) into research programs, distribute to other research organizations.
- Target funding for longer term research projects (>3 years), recognizing it takes a long time to see changes in soil health.
- Secure long-term cropland research platforms for soils research infrastructure that includes land allocations, funding and long-term access, analogous to livestock facilities (similar to the Elora Dairy facility).
- Strengthen industry, government and inter-jurisdictional research collaboration and leverage resources to advance shared soils research priorities.
- Encourage a multidisciplinary approach to soil health research including soil science, crop and animal science, ecology, social science and economics.

Use research facilities to boost tech transfer – Actions:

- Continue development of the Soil Health Interpretative Centre at Elora Research Station as a knowledge hub.
- Increase knowledge transfer and communication with farmers through research facilities.
- Explore the role of research facilities with the demonstration farm network.

Ensure soil data collection at research sites – Actions:

- Develop a protocol to outline what soil data is needed and the best procedures to collect that data, in collaboration with Ontario Soil Management Research Services Committee and researchers.
- Ensure basic soil data is collected from all long term research trials and other research plots and housed in the central, accessible database being developed.

Scientific rigour and practical applications combine for a triple win

On-farm, farmer-led research is a great way for farmers to find out if an alternative way of producing crops is profitable and compatible on their farm, and provide useful results from which other farmers can learn. It's a win-win-win situation for farmers, soil health and increasing our knowledge in ongoing efforts to protect and build soil health. The Ecological Farmers Association of Ontario (EFAO) and Ontario Soil and Crop Improvement Association (OSCIA) are two examples of organizations helping to make this happen.

The EFAO supports farmers through helping to design the experiment and write a research report and how to conduct robust scientific research. The OSCIA has ongoing, multi-year applied research projects supported through their Tier Two grants.

Communication Tools

The way that people learn and communicate has changed rapidly over the past decade. Social media including Twitter and YouTube have become mainstays for many in agriculture. It is now common for farmers to consult the Internet for short videos, share information and listen to podcasts for information and advice, to name a few.

There are many existing online and print publications such as our BMP series booklets, info sheets, training materials and other complementary media – such as videos, twitter messaging, etc. Using a variety of such media to relay soil health information is a more effective approach to reach and motivate Ontario farmers to improve their soil health.

It will also be important for partners to use consistent messaging in publications and communications to convey positive soil care messages and images, and not inadvertently promote soil degrading practices.

Diversify the learning approaches available to farmers – Actions:

- Increase the variety of communication tools used to connect with farmers, including optimizing the use of interactive maps, mobile technology and social media in addition to print materials, including:
    - Create an online information resource hub for farmers where they can get the latest knowledge, research, go-to-apps, etc.
    - Develop a series of videos profiling farmers and practices.

    - Deliver webinars and podcasts to share local and broader expertise.
- Increase the variety of hands-on soils learning for farmers at workshops, short courses, demonstrations, training sessions and other types of learning events.
- Establish a demonstration farm network across Ontario for best practices.
    - Convene a workshop to start planning and implementation.
    - Create a webpage to highlight locations and activities of demonstration farms.
- Ensure publications, websites, and other communications are consistent with soil BMPs and the direction of the soil strategy.

Better Understanding Farmers' Learning Styles and Motivation

In order to have a meaningful impact, we have to understand what informs farmers in their soil management decisions, the ways people learn most effectively, and the real barriers to soil care. Behavioural science, social marketing and adult education are developing new and innovative ways to understand and influence learning. An initial review of the literature reveals some likely directions for future research on more effective program design[17]. Further focus group work has helped build understanding of how farmers may differ in how they learn about soil BMPs and what might motivate them[18].

Build understanding of farmers' learning styles and motivation – Actions:

- Complete and build on studies on farmers' motivations, learning styles, and target audiences (commodity groups, etc.) to inform program approaches.

Technology Transfer

Digital learning is an effective tool, but there also needs to be other, more personal ways for farmers to stay on top of soil health advancements. This could include a mix of learning sessions for individual farmers, more peer-to-peer learning opportunities, demonstration farms and courses for farm advisors.

Since we know that farmers learn best from other farmers, offering more opportunities for peer-to-peer knowledge transfer and visiting demonstration sites would help increase both the awareness and uptake of practices that build healthy soil.

There are a number of soil health champions in Ontario sharing their experiences with other interested farmers. For example, a new organization called the Ontario Soil Network, is piloting an approach for coordinating these efforts. This group of leading-edge farmers is working to improve their soils, hone their communication and leadership skills, and share their messages about effective soil health practices with their farm neighbours and colleagues. Many organizations are also championing soil care including the Innovative Farmers Association of Ontario, the Soil Conservation Council of Canada, Grain Farmers of Ontario, and Ontario Soil and Crop Improvement Association.

17 Marian Weber, "Understanding Farmer Motivation and Attitudes Regarding the Adoption of Specific Soil Best Management Practices. Background Literature Review," report prepared for Farm and Food Care Ontario, December 18, 2017

18 Carmel Augustyn, "Enhancing Grower Adoption of Soil Best Management Practices Through Target Audience Segments." Prepared for Farm and Food Care Ontario, February 2018.

Demonstration farms are a proven means for successful technology transfer. Ontario Soil and Crop Improvement Association operate several demonstration farms including in Essex, Huron and Perth. Conservation Authorities also operate a couple of demonstration farms. Many individual private farms have demonstration projects located on-site or offer tours, and are sometimes thought of as "demonstration farms." Similarly, federal and provincial research sites are sometimes used as demonstration sites. Wisconsin's Discovery Farms have inspired a great deal of interest among Ontario farmers. A true network of demonstration farms across Ontario could play a significant role to demonstrate good soil practices under different conditions and could be composed of different combinations of public and private farms.

Farmers also require access to technical assistance, whether it's from a Certified Crop Advisor, professional agrologist, an OMAFRA specialist, or someone from their local Conservation Authority. We need to ensure that these technical experts also have access to soil knowledge and training. Technical assistance can be delivered in different formats, workshops, training sessions and one-to-one assistance. Government specialists increasingly have focused primarily on workshops and similar approaches. One-to-one assistance has primarily been provided by the private sector.

Build capacity for peer-to-peer learning and innovation – Actions:

- Recognize, enhance, and support the important role of innovative producers in experimenting, adapting and facilitating positive change related to soil management and cropping practices.
- Establish, fund and support peer-to-peer learning groups tailored to diverse needs.
- Build capacity among farmers as champions and advocates for soil health to speak with their peers about the issues and challenges of soil health.

Build soil health knowledge among service providers and specialists – Actions:

- Build soil health technical expertise among service providers and technical specialists, both private and public sector (e.g. agronomists, CCAs, planners, foresters, contractors, government staff).
- Build capacity to provide one-on-one soil health assistance for producers.
- Develop capacity in a wide variety of partner organizations to provide soil-health focused workshops.

Education

Colleges offer technical soil courses for a variety of programs with different applications, including agriculture and resource management. University undergraduate programs train many soil professionals in practice and can provide general soil knowledge to a broad range of professionals. The Canadian Soil Science Society Education Committee reviewed soil science education and found the need for introductory soil courses at several major Ontario universities and other improvements[19].

Graduate education programs at universities help deliver knowledge on soil research priorities and develop advanced knowledge and skills in soils. Currently, OMAFRA participates in a Highly Qualified Personnel program for graduate students, which includes a semester of hands-on work along with their courses. In addition, post-secondary students have been able to take advantage of the ministry's soil intern program.

19 Profiling undergraduate soil science education in Canada: Status and projected trends. A. Diochon, N. Basiliko, M. Krzic, T. Yates, E. Olson, J. Masse, B. Amiro, D. Kumaragamageg. Canadian Journal of Soil Science, 2017, 97(2): 122-132.

Research priorities focusing on soil health (Appendix 2) will help to foster soil care knowledge and skills development among graduate students.

A recent Canadian Soil Science Society review confirmed the need for a greater emphasis on soils in secondary schools. Sustaining action on soil health in the future will depend on people maintaining interest, engagement and knowledge about its many benefits – people who care about our soil. We need to teach young people about soils and how crucial they are for growing the food we eat and keeping our environment healthy. Teachers also need exposure to soil care issues and access to related teaching resources.

Raising awareness of the importance of soil health among the public and consumers is also important. Emphasis in elementary and secondary school will reach future generations. Broader general public education can use many of the materials produced for farmers and advisors. Other outreach might be tailored to consumers and gardeners.

Build provision of key soil-related skills in post-secondary education – Actions:

- Engage universities/colleges and other partners in review of technical skills and knowledge needs, current courses/programs and develop strategies to address gaps.
    - Explore options to build soil science, including pedology, and skills into courses
    - Explore course options including online courses, new field courses, and co-operation across Canada for some course content.
    - Create more opportunities for on-farm experiences for graduate students and foster greater two way communication among farmers and students.
    - Consider new courses related to skills inventory requirements revealed in the review.
- Consider new soil internships in industry, farm organizations and government.

Elementary and secondary education provides sound basic soil knowledge – Actions:

- Assess the need for revised and/or additional materials to support elementary/ secondary education related to soils.

Build public understanding of soil health – Actions:

- Make efforts to build understanding of soil health and soil management among consumers and the general public.

Learning about soil

- AgScape is an Ontario organization dedicated to providing resources and teacher ambassadors to teach children in grades 1 to 12 about agriculture and food production.
- The Canadian Society of Soil Science provides soil education resources for secondary school teachers through its 'Soil 4 Youth' program.
- 4-H, a youth development organization, offers a "Loyal to Soil" project to members, who are aged nine to 21.

Implementing the Soil Strategy

Since 2015, many partners have collaborated to build this soil strategy through the Working Group (Appendix 1) and broader engagement. Taking action to develop a collaborative implementation begins the next stage of the strategy's progress. Developing a collaborative implementation model will be an early implementation action in the process.

The goals, objectives and actions identified in this document cannot be all accomplished at once. The actions build on one another and must be staged over the implementation period 2018-2030. Specific roles and responsibilities of implementation partners must also be determined. A collaborative implementation plan will need to be developed to address this.

Funding for implementation is not addressed in this document. Existing funding of partner organizations will no doubt contribute to implementation. Government, conservation authorities, farm organizations, universities and colleges, conservation groups and other partners all have a role to play. The Canadian Agricultural Partnership will be a source of funding for many soil-related activities, as was *Growing Forward 2* and previous federal-provincial-territorial agreements. The Climate Change Action Plan identified up to a notional $30 million funding for 2017-2021, and has funded some aspects already, as noted.

Building on Our Momentum: A Future Ontario Soil Health Collaboration

Federal and provincial governments, farm organizations, conservation groups and universities have a long history of collaborating on soil conservation and agri-environmental initiatives.

Inspired by similar models in the US and UK, OMAFRA and the Working Group supports the establishment of a longer-term governance structure and oversight, involving interested working group organization members, and other organizations. The model would build on the working group's accomplishments and ensure collective momentum is maintained over

time. This group would help guide and monitor the strategy's implementation from 2018-2030, including the development of a more detailed implementation plan, and establishing a regular review process to facilitate continuous improvement as information and data evolves.

The establishment of such a collaboration would ensure that the profile of agricultural soil health in Ontario is elevated. It would enable adjustments, based on the best available science, technology and knowledge. It would also facilitate alignment of effort, leveraging the activities of different groups with shared objectives, generating higher value returns on the human and financial investments of all involved.

Beyond the strategy's governance structure, successfully implementing the strategy requires broader collaboration and shared leadership between the agricultural sector, government, and other partners. During engagement on the draft strategy, a number of participants, including farmers, agricultural organizations, agri-businesses, and conservation authorities, expressed interest in working with OMAFRA to support implementation of the strategy. OMAFRA will continue to engage with interested parties as the implementation plan evolves. Indigenous organizations may be partners for related outreach to Indigenous communities.

There are also already many soil champions who are actively engaged as water quality partners. As soil health and water issues are closely linked, these partnerships and actions can be leveraged to support implementation of the strategy. For example, the agriculture sector has partnered with municipalities and other levels of government in addressing nutrient and algal issues through the Canada-Ontario Lake Erie Action Plan, including:

- **4R Nutrient Stewardship**, led by 4R Ontario.
- **Cover Crop Strategy**, implemented by the Ontario Cover Crops Steering Committee led by the Grain Farmers of Ontario.
- **Timing Matters**, a peer-to-peer advisory committee led by the Ontario livestock and poultry sector.
- **Thames River Phosphorus Reduction Collaborative**, a partnership including the Ontario Federation of Agriculture and Grow Ontario Together – an industry coalition – to promote land management and drainage solutions.
- Education on proper drainage practice promoted by the **Land Improvement Contractors of Ontario**.

Conclusion and Next Steps

Building and maintaining healthy soil over the long term will strengthen Ontario farmers' and society's ability to prosper, help feed not only ourselves but people around the world and safeguard the environment.

The Ontario Agricultural Soil Health and Conservation Strategy (2018-2030) is a framework to conserve and improve the soil resources which provide our necessities of life and farmers' livelihoods, over the long term.

As the role of the Working Group concludes, our focus now turns to the details of implementation planning. With input from Working Group members, OMAFRA will establish the collaborative group which will deliver long-term steering and oversight of the strategy's implementation and continuous improvement. This group's purpose and objectives, membership and roles, and operating guidelines, as well as a schedule for regular review and progress reporting will be established.

Once established, the group will develop annual work plans, to include delivery by partners, based on the actions and phasing outlined in the Strategy. The work planning will also be informed by the program-related feedback received during consultations.

In the meantime, a vital part of implementation centres on the development and delivery of OMAFRA's stewardship and research programs, and the associated financial support, expertise, resources and tools they provide. These activities continue as the strategy and its implementation evolve.

Ontario has a strong foundation – our province is made up of willing and capable people and organizations in the public and private sectors who are deeply committed to ensuring long term healthy soils for agriculture in Ontario. Harnessing their collective energy and know-how to keep driving this initiative will help build and sustain Ontario's agricultural soil for generations to come!

Appendix 1 – The Agricultural Soil Health and Conservation Working Group

To guide development of the soil strategy, in 2015 OMAFRA brought together the collaborative Agricultural Soil Health and Conservation Working Group – made up of knowledgeable people from farm organizations, agri-food businesses, academia, conservation organizations and the federal government. They were instrumental in developing the 2016 discussion document and the draft strategy. The working group's understanding of the issues has been invaluable. The group continued to support the development of this final strategy. Continued collaboration with our partners will be essential to support implementation of the strategy.

Soil Working Group partners

Ontario Federation of Agriculture: Don McCabe

Christian Farmers Federation of Ontario: John Bos

Agriculture and Agri-Food Canada: Maxine Kingston

Ontario Soil and Crop Improvement Association: Andrew Graham

Conservation Ontario: Tracey Ryan, Grand River Conservation Authority

Universities and Research Community: Ralph Martin (University of Guelph), Claudia Wagner-Riddle (University of Guelph)

Ontario Certified Crop Advisor Association: Dale Cowan, CCA

Ecological Farmers Association of Ontario: Ken Laing

Soil Conservation Council of Canada: Don Lobb

Innovative Farmers Association of Ontario: Laurent (Woody) Van Arkel

Farm and Food Care: Sam Bradshaw

Grain Farmers of Ontario: Josh Cowan

Ontario Fruit and Vegetable Growers Association: Harold Schooley

National Farmers Union Ontario: Tony Straathof

Appendix 2 – Proposed Ontario Soil Health and Conservation Research Priorities

The following represents the top soil health and conservation research gaps and priorities in Ontario. These priorities were identified by a variety of agricultural organizations and reflect the most pressing demands from a production, environmental and scientific standpoint. These priorities were put together by OMAFRA staff, academic and AAFC soil researchers, experts and industry representatives.

Two events were held to identify soil research priorities and discuss knowledge transfer related to soils, a Soil Health Research Forum held November 28, 2016 and a Soil Health Research Workshop held April 26, 2017. These events respectively gathered together key practitioners in soil conservation and the top soil researchers (university, AAFC and private sector) to discuss the key issues and research topics for soils in Ontario.

Continuity of Research Funding

In recognition that it takes time to be able to measure soil health change, it is important to have long-term funding for soil health research.

- Commit long-term funding for soil health research and plots (basic plot maintenance and operation i.e. land, labour, equipment).
- Create a category of research funding for longer fixed term projects (i.e. multiple rotation cycles).

What Research is Required?

Soil Health Indicators

In order to measure and track our status for soil health, it is important to determine key measurable soil health parameters. The indicators can be used to help manage soils for improved soil health.

- Identify key indicators or functions for the chemical, physical and biological aspects of soil health at the local, regional and provincial scale.
- Develop a clear list of robust measureable soil health parameters.
- Develop soil health management tools that utilize soil health indicators and assist growers with implementation of soil health BMPs.
- Validation of applicability of site-specific data to larger scales (watershed, province).

Physical

Soil physical properties that are most often researched include: soil structure/aggregate stability, soil strength, soil porosity and hydraulic properties. Soil physical properties are influenced by and have influence on chemical and biological properties. They can have an influence on crop growth from a micro to a macro scale.

- Quantify the impact of land management on soil physical and hydraulic properties and their influence on soil health (including resilience):
    - Diverse crop rotation (three or more crop families (legumes, non-legume broadleaf, warm and cool season grasses) in rotation) with and without perennial crops (i.e. forages), cover crops (i.e. oats, radish, mixtures).
    - Effects of tillage (a continuous type of tillage such as no-till, or strip tillage or rotational tillage where several types of tillage are used in the crop rotation).
    - Effect of crop residue removal for biomass or other uses where with and without other compensating management practices, what are sustainable residue removal rates.
    - Specific cover crop species (includes precision management where specific species may be used for a specific purpose in the crop rotation or in part of a field).
    - The immediate and long-term effects of soil compaction on soil productivity and health, environmental effects, as influenced by cropping and equipment practices (e.g. tillage/no-till, crop rotation, vehicle dynamics).
    - The influence of compaction mitigation/correction strategies (e.g. controlled traffic farming, cover crops, tillage, delayed planting, tire characteristics, tracks vs tires, inflation/deflation systems, new technologies including autonomous machinery).

Biological

Soil biology links the chemical and physical aspects of soil health; however it remains the least studied. The study of biology within soil is a significant undertaking due to the complexity of the subject and the potential costs.

Farmers are very aware that their soil is alive; that it is an ecosystem in itself. There is growing interest in soil biology and the links to soil productivity and resilience, particularly in the face of a changing climate. It is critical to make direct connections between on-farm practices, BMPs and soil biology research.

Soils are complex ecosystems with a wide variety of organisms and often a degree of redundancy in that there are usually a series of organisms that perform the same or similar functions (for example, nitrogen mineralization).

- Development of tests/indicators for key functions in healthy soils for on-farm testing and validation.
- Development of a soil health test (suite of tests) calibrated to crop production response for Ontario soils (similar to the calibration of fertility tests).
- Document and validate the soil biology related links between soil health BMPs (such as crop rotation, cover crops, organic amendments) and production response across:
    - A variety of production systems common in Ontario (field vegetables, grain, perennial horticultural systems).
    - Representative soil textures and inherent soil quality (such as sands, clays and shallow soils).
    - A variety of weather conditions and climate extremes.

Chemical

The impact of soil health practices on fate (crop uptake, retention and loss) of nutrients in cropping systems, regardless of source (soil, fertilizer, organic amendments, crop residue, etc.) must be measured. Priority nutrients include N, P, K, S and trade-offs and unintended consequences should be considered when conducting such a systems analysis.

- A better understanding of the return on investment of adopting soil health practices in relation to nutrient input requirements. For example, determine the impact of enhanced soil health on fertilizer recommendations and critical soil test levels (e.g. for phosphorus and potassium).
- The efficacy of BMPs to reduce loss of nutrients (N and P) from agricultural land while maintaining productivity.
- Best practices to optimize plant nutrient use efficiency and economics of nutrient application (e.g. 4R nutrient stewardship).
- A better understanding of nitrogen availability from soil organic matter, organic amendments (manure, biosolids, compost, etc.) and cover crops (legumes and non-legumes) – in terms of amount released and synchronization with crop uptake.
- Determine impacts of crop rotation effects on nutrient management strategies (timing, placement, etc.)
- Determine the impact of soil health and 4R nutrient stewardship practices on greenhouse gas emissions (e.g. nitrous oxide).
- Develop decision support tools for farmers/agronomists:
    - How to adapt their nutrient management practices to extreme weather events.
    - To predict amount and timing of nitrogen immobilization as a result of application of high carbon: nitrogen organic material (e.g. high carbon manure source or high carbon cover crop) – how does a producer adjust inorganic N inputs and timing of application?

Chemistry alone is not enough to provide good information on soil health; it is necessary to integrate soil chemical measurements with those from other disciplines.

Research Project Structure and Management

A systems approach is encouraged for soil health research. The greatest advances for projects have come when a variety of expertise (e.g. physics, chemistry, microbiology) has been provided and works together. This may mean having more intensive studies, as opposed to having ten different sites with many unanswered questions. Farmers should be an integral part of the project development process and ongoing review and revision.

- Encourage a multidisciplinary approach to soil health research, which considers the production system.
- Develop interdisciplinary collaboration to establish soil health baseline datasets from a soil ecosystem perspective and linked to crop productivity and economics to document how management changes soil health.
- Involve farmers in research project development and management decisions.

Baseline Data

In addition to research priorities, the research community found it is imperative to collect a common set of baseline soil parameters at research sites; and to also create a mechanism to facilitate data sharing.

- Create a list of soil parameters (e.g. soil type, soil organic carbon, etc.) and methodology for use by those conducting research to collect baseline soil data.
- Establish and maintain sentinel sites for benchmarking across the province. Ideally, established at existing sites with the opportunity for long term sampling.
- Develop soil landscape information to guide or optimize soil sampling and make these data available and easy to access.
- Sampling needs to be long term, not project-based, need financial commitment from an organization to maintain sites.
- Create and update baseline maps of soil properties. Explore the potential for creating a coordinated network of voluntary sampling on a regular base.

Data Sharing

In light of the increase in precision agriculture data collection, limited research funds and increased collaboration at multiple locations, data sharing is a high priority.

- Establish a working group to facilitate this (sharing agreements, value of data, end use of data, where to store, who would house it).

Economics

Farmers experience the costs of implementing BMPs and the return in crop value today, while the benefits from improving soil health accrue over the long-term. This can make it challenging to sell the benefits of implementing practices to improve soil health without knowing the loss of value from erosion or the economic benefit of implementing BMPs.

- Evaluate the economic impact of physical soil degradation.
- Conduct a cost/benefit analysis of BMPs as it relates to crop productivity, profitability and sustainability.
- Develop methods to quantify economic aspects of soil health.
- Integrate economics as a deliverable for project funding where applicable.

Behavioral Science

What factors influence farmers' management choices in cropping and soil management (e. g. short or long term economics, social norms, family and social relationships, convenience, management experience, perceptions, beliefs, impulses, etc.) While these topics have been studied in depth in other jurisdictions, relatively little research has occurred in Ontario to inform policy and programs. Sociology, psychology, neuroscience, social marketing, and behavioral economics are revealing that decisions by farmers and all of us are influenced by many surprising, often non-rational factors. Differences among farmers in motivation and other factors can influence adoption of practices significantly.

Research is needed in Ontario on factors that affect farmers' decision making and contribute to, or detract from, soil management behaviour change. Differences in needs and barriers among farmers (e.g. commodity, part-time/ full-time, off-farm income) should be identified. Research can also test strategies to address these needs and barriers.

Appendix 3 – Actions Summary

Theme 1 – Soil Management

Support the continuous improvement and adoption of soil BMPs

- Use a systems approach to soil management to customize BMPs based on specific commodities, production systems, soil conditions and other factors. This can be implemented using planning and diagnostic tools (e.g. EFP, Farmland Health Checkup or other tools).
- Expand the development, enhancement and promotion of the suite of soil BMPs and their adoption
- Identify and address barriers to the adoption of BMPs, both general and specific barriers for individual BMPs and specific production systems (e.g. social, economic, regulatory, technical).

Customize soil health information by agricultural production system

- Commodity groups, sectors and government to identify specific and unique soil management issues and solutions for different production systems, including:
  - Grain and oilseed commodities.
  - Vegetable, fruit and specialty commodities.
  - Livestock commodities.
  - Other commodities.

Diversify crop rotations

- Government and farm and commodity organizations work to grow markets for crops such as hay, cereals, perennial biomass crops, etc. that support diversified crop rotations. Each can incorporate relevant objectives in research, business and market development activities.

Foster expansion of cover crop adoption

- Led by Grain Farmers of Ontario, the Ontario Cover Crops Steering Committee will implement the Ontario Cover Crops Strategy to encourage widespread adoption of cover crops on farms in Ontario

- Promote, develop and support use of cover crops through a range of tools including awareness, education, research and incentives.

Support conservation tillage options

- Promote, research, adapt and support the adoption of conservation tillage practices such as no-till, strip till and residue management.

Build use of organic soil amendments

- Promote, develop and support the use of organic amendments.
  - Cost sharing support for organic amendments for soils in need of such amendments
  - The food industry, municipalities, government (including Ministry of Environment and Climate Change and OMAFRA) and other partners work together to make suitable organic materials more broadly available.
  - Explore opportunities for web based tools for locating and accessing organic amendment material.

Promote erosion assessment, prevention and mitigation

- Promote both agronomic and structural erosion control measures and help landowners find the most suitable and effective combination of each for their fields.
- Encourage conversion of fragile and marginal land from annual cropping to perennial crops or conservation cover (e.g. trees, shrubs and other perennial vegetation) where erosion risk is unsustainable.
- Integrate erosion assessment tools that can be used with existing planning tools to provide landowners with ways to determine long-term erosion control benefits or consequences of their management choices (also see "Expansion of Soil Erosion Assessment Tools" under Theme 3).

Build awareness and capacity to assess and reduce soil compaction

- Raise awareness of the risks and impact of compaction with farmers, agri-business and equipment dealers and manufacturers.
- Using existing tools and developing new tools, help farmers assess and reduce their compaction risk, based on their soil type, equipment type and weight, and traffic frequency and patterns.

Expand and improve on-farm soil health planning tools

- Review and improve soil-related aspects of the Environmental Farm Plan, Farmland Health Check-Up.
- Examine opportunities to expand the availability of the Farmland Health Check-Up and Soil Health Check-Up tools to other parts of Ontario.
- Develop a detailed soil risk assessment tool to help interested farmers dig deeper to further understand their soils, and the risks associated with them, and make plans for improvements.
- Develop guidance for farmers regarding use of precision agriculture tools for site-specific management to benefit soil health.

Enhance incentives for soil care practices

- Provide financial incentives for a wide range of soil BMPs across Ontario.
- Support for farmers to 'start small' in trying new practices and demonstrate 'proof-of-concept' on their farms (e.g. small fields, low cost).
- Design future programs to support low barrier entry to cost share programs to encourage first time participants for selected BMPs.

- Examine incentives to encourage the innovators to try new practices to benefit soil health beyond currently accepted BMPs.
- Examine the potential of other agriculture programs to provide additional incentives for, and awareness of good soil management practices.
- Develop options to encourage owners of farmland to invest in soil care, including non-farm landowners and farmers renting land to other farmers.

Build climate initiatives that improve soil health

- Support the development of greenhouse gas offset protocols that align with soil health priorities, for both voluntary and compliance markets (soil health research findings will help inform the protocol design).
- Develop and implement initiatives that encourage management practices which reduce net greenhouse gas emissions while benefitting soil health under Ontario's Climate Change Action Plan.

Public sector lead by example in soil management

- Recommend use of good soil management practices on publicly-owned working agricultural lands in Ontario including:
    - Lands on OMAFRA-funded research sites, managed by University of Guelph or other bodies (except research plots with specific experimental designs).
    - Other working agricultural lands held by the Ontario government.
    - Working agricultural lands held by Conservation Authorities and municipalities.
    - Working agricultural lands owned by the federal government.

Theme 2 – Soil Data And Mapping

Modernize soil maps and inventory

- Continue inventory and mapping to complete the next generation of agricultural soil resource inventory and maps within 20 years.
- Continue updates to the land capability for agriculture classifications, under the Canada Land Inventory system, to assist in management decisions.
- Complete targeted LiDAR coverage for farmland in Ontario as a foundation for soil mapping, BMP tool development and land resource initiatives. Make LiDAR data publicly available as it is completed.
- Offer stakeholders opportunities to provide advice on priority areas for soil mapping and LiDAR data acquisition through a technical/advisory committee or similar body.
- Investigate the development of a next generation land suitability rating and capability systems that builds on the existing Canada Land Inventory system.

Build and make available soil databases

- Develop a Soil Information System to house OMAFRA's legacy and new soils data.
- Determine best practices for standardizing data collection, storage and maintenance and metadata records.
- Make existing and next generation soil data available on a publicly accessible, digital platform.

Explore new technology for soil assessment

- Investigate and develop ways to use remote sensing data for collection of soil characteristics, information and analysis.

- Examine and recommend tools such as airborne or hand-held sensors that can assess soil physical, chemical and biological properties.

Make better use of soil sample data and precision agriculture data

- Engage stakeholders in discussion of how to move toward greater accessibility of soil test data:
  - Research how to address privacy issues, roles of labs and clients.
  - Develop data sharing partnerships among multiple partners.
- Industry and government work together to leverage soils data and mapping for precision agriculture to maintain and enhance soil health.

Determine baselines for soil management practices in Ontario

- Complete an initial project to assess the state of soil-related agricultural practices and establish baselines from which to measure change, including:
  - Compile existing information such as Census, Farm Environmental Management Survey, existing remote sensing data (e.g. AAFC annual crop inventory), aggregate soil test data and BMP adoption data.
  - Establish a partnership with Statistics Canada for in-depth analysis of data on select practices.
  - Identify data gaps and baselines to measure change in practices over time.

Theme 3 – Soil Evaluation And Monitoring

Increase capacity to track farm scale soil health

- Create and distribute a farm-level, all-in-one education tool kit for soil health assessment that advisors and farmers can use (could include slake tests, infiltration tests, and soil compaction measurement).
- Promote the importance of tracking changes in soil organic matter as a way to monitor soil health including ensuring soil organic matter is always included in normal soil testing.
- Work with the Ontario Soil Management Research Services Committee and laboratories to explore opportunities for a more consistent approach to soil organic matter analysis across the province.
- Develop and implement a comprehensive Ontario soil health test in collaboration with laboratories.
- Expand OMAFRA's and partners' capacity in soil erosion assessment:
  - Enable development of tools to estimate soil erosion under different management practices.
  - Continuously improve/maintain water erosion assessment tools as new approaches become available (sheet, rill, gully and tillage erosion).
  - Investigate the possibility of equivalent tools for wind erosion and other forms of soil degradation.

Develop and promote farm-scale measures of success

- Promote farm-scale soil organic matter measures of success for cropland soils of different texture: Sandy Soils: 2.5 per cent, Sandy Loams: 3.5 per cent, Loam Soils: 4 per cent, Clay Loams: 4.5 per cent, Clay Soils: 4.5 per cent (for annual cropping systems).
- Develop soil organic matter measures of success for pasture, horticultural and other production systems in collaboration with partners.
- Promote the following practice-based measures of success as suggestions for farmers (for annual cropping systems):
    - Crop rotation: At least three crop families in a rotation (for annual cropping systems) and
    - Cover crops: 50 per cent of a farm's annual cropland have a cover crop.
- Develop additional measures of success after analysis of soil management practice baselines is completed (see Soil Data and Mapping). These could include reducing bare soil through soil cover and crop residue.

Track soil health at a regional scale

- Partner with on the ground organizations to ensure continuation and expansion of soil health monitoring on a watershed-scale across the province.
- Conservation Authorities ensure sub-watershed plans include objectives and targets for soil health and conservation that relate directly to improving water quality.

Adopt provincial indicators for soil health and conservation at a provincial scale

- Use the existing AAFC soil indicators as interim measures to track improvements in soil organic matter, erosion risk and soil cover.
- Explore adaptation of the three AAFC soil indicators (soil organic carbon, erosion risk, soil cover) to a more detailed scale including:
    - Develop options to calculate indicators at more detailed scale.
    - Assess the availability of data on management practices at detailed scale (Census).
    - Develop greater federal-provincial collaboration on indicators.
- In the interim, use agricultural census data on cover crop adoption and tillage practices as indicators to monitor change in soil management practices.
- Examine options to track and report on changes in soil carbon including continued participation in the development of a Global Soil Organic Carbon Map, Ontario's Land Use Carbon Inventory development, AAFC soil organic carbon indicator and analysis of soil test data from labs.

Develop provincial-scale measures of success

- Adopt the following long-term provincial measures of success:
    - Increase soil organic carbon – reverse the decline in soil organic carbon and stabilize or increase soil organic carbon over time
    - Reduce soil erosion risk – lower risk of erosion and area of cropland in higher risk categories over the long term.
    - Increase soil cover – reduce the area of cropland with bare soil over winter.
- After completion of the analysis of soil management practices baseline study (see Soil Data and Mapping), examine the potential to identify additional practice-based measures of success.

Examine the potential of other provincial indicators

- Establish and evaluate changes in benchmarked soil profiles across the province on an ongoing basis to monitor changes on the landscape / effects of cultivation on soil profiles (through the soil inventory and mapping).
- Examine the potential for ongoing monitoring of long-term soil plots across Ontario. This could include examining the potential for expanding the number of long-term plots to adequately cover the range of soil, climate and cropping systems for Ontario.

Theme 4 – Soil Knowledge And Innovation

Support a long-term, collaborative soil research agenda

- Integrate identified soil research priorities (detail in Appendix 2) into research programs, distribute to other research organizations.
- Target funding for longer term research projects (>3 years), recognizing it takes a long time to see changes in soil health.
- Secure long-term cropland research platforms for soils research infrastructure that includes land allocations, funding and long-term access, analogous to livestock facilities (similar to the Elora Dairy facility).
- Strengthen industry, government, and inter-jurisdictional research collaboration and leverage resources to advance shared soils research priorities.
- Encourage a multidisciplinary approach to soil health research including soil science, crop and animal science, ecology, social science and economics.

Use research facilities to boost tech transfer

- Continue development of the Soil Health Interpretative Centre at Elora Research Station as a knowledge hub.
- Increase knowledge transfer and communication with farmers through research facilities.
- Explore the role of research facilities with the demonstration farm network.

Ensure soil data collection at research sites

- Develop a protocol to outline what soil data is needed and the best procedures to collect that data, in collaboration with Ontario Soil Management Research Services Committee and researchers.
- Ensure basic soil data is collected from all long term research trials and other research plots and housed in a central, accessible database.

Diversify the learning approaches available to farmers

- Increase the variety of communication tools used to connect with farmers, including optimizing the use of interactive maps, mobile technology and social media in addition to print materials including:
    - Create an online resource hub for farmers where they can get the latest knowledge, research, go-to-apps, etc.
    - Develop videos profiling farmers and practices.
    - Deliver webinars and podcasts to share local and broader expertise.
- Increase the variety of hands-on soils learning for farmers at workshops, short courses, demonstrations, training sessions and other types of learning events.

- Establish a demonstration farm network across Ontario for best practices:
  - Convene a workshop to start planning and implementation
  - Create a webpage to highlight locations and activities of demonstration farms.
- Ensure publications, websites, and other communications are consistent with soil BMPs and the direction of the soil strategy.

Build understanding of farmers' learning styles and motivation

- Complete and build on studies on farmers' motivations, learning styles, and target audiences (commodity groups, etc.) to inform program approaches.

Build capacity for peer-to-peer learning and innovation

- Recognize, enhance, and support the important role of innovative producers in experimenting, adapting and facilitating positive change related to soil management and cropping practices.
- Establish, fund and support peer-to-peer learning groups tailored to diverse needs.
- Build capacity among farmers as champions and advocates for soil health to speak with their peers about the issues and challenges of soil health.

Build soil knowledge among service providers and specialists

- Build soil health technical expertise among service providers and technical specialists, both private and public sector (e.g. agronomists, CCAs, planners, foresters, contractors, government staff).
- Build capacity to provide one-on-one soil health assistance for producers.
- Develop capacity in a wide variety of partner organizations to provide soil-health focused workshops.

Build provision of key soil-related skills in post-secondary education

- Engage universities/colleges in review of technical skills and knowledge needs, current courses/ programs and develop strategies to address gaps.
  - Explore options to build soil science, including pedology, and skills into courses.
  - Explore course options including online courses, new field courses, co-operation across Canada for some course content.
  - Create more opportunities for on-farm experiences for graduate students and foster greater two way communication between farmers and students.
  - Consider new courses related to skills inventory requirements revealed in the review.
- Consider new soil internships in government, industry and farm organizations.

Elementary and secondary education provides sound basic soil knowledge

- Assess and address the need for revised and/or additional materials to support elementary/secondary education related to soils.

Build general understanding of soil health

- Make efforts to build understanding of soil health among consumers and the general public.

Many organizations worked collaboratively, as part of the Agricultural Soil Health and Conservation Working Group, to help develop this soil strategy aimed at improving agricultural soil health and conservation and we thank them for their contributions.

Agriculture and Agri-Food Canada

Ontario Federation of Agriculture

Ontario Fruit & Vegetable Growers' Association

Christian Farmers Federation of Ontario

OSCIA Grassroots Innovation Since 1939

Innovative Farmers Association of Ontario

University of Guelph

Certified Crop Adviser

Grain Farmers of Ontario

National Farmers Union Ontario / Union nationale des fermiers de l'Ontario

Ecological Farmers Association of Ontario

Conservation Ontario Natural Champions