# Soil Health and Soil Security: Regional, National, and International Dimensions A Case Study from Northern Ontario

CAPI Doctoral Fellow 2017-2019 Paper
By

**Paul Benalcazar, PhD Candidate, Lakehead University**

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The Canadian Agri-Food Policy Institute

960 Carling Avenue, CEF

Building 49, Room 318

Ottawa, ON K1A 0C6

Telephone: 613-232-8008

Fax: 613-232-8008

www.capi-icpa.ca

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**Author**
CAPI Doctoral Fellow 2017-2019: Paul Benalcazar, PhD Candidate, Lakehead University

**CAPI Project Management Team**
Don Buckingham, Tulay Yildirim, Margaret Zafiriou, Elise Bigley and Louise de Vynck

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## 1. A Case Study: Northern Ontario

Northern Ontario is not well-known for agriculture; nevertheless, it includes approximately 884,000 acres of farming land. Much of this farmland (624,000 acres) can be found in the Northern districts: Kenora, Rainy River, Thunder Bay, Algoma, Manitoulin Island, Cochrane, Temiskaming, Sudbury, Nipissing and Parry Sound (OMAFRA, 2018). This area has the estimated potential to increase by 20 to 50% over time (Caldwell, 2014). According to the agricultural census of 2016, there were 2,237 farms in this area which generated $209 million in gross farm cash receipts – up 9% compared to the previous census in 2011.

The Canada Land Inventory classifies some soils in Northern Ontario as class 1 to 3, with some sizable acreages for prime agriculture land, while other areas are classified as class 4 and 5, where soil has limitations (OMAFRA, 2018). A variety of agri-food products such as dairy, beef, grain, fruit and vegetables are produced in Northern Ontario.

Climate variability and climate change are expected to impact agricultural practices (Environment Canada, 2004) by affecting the hydrological cycle (precipitation, evaporation, transpiration, evapotranspiration), and temperature. According to Agriculture and Agri-Food Canada (AAFC), Canada will have longer growing seasons as a result of climate change (AAFC, 2014). In the Thunder Bay agricultural area, predictions indicate that effective growing degree days (EGDD) will increase to a range of 1200 to 1600 EGDD between the years 2010 to 2039, compared to 1050 to 1200 EGDD before that. The length of the growing season could rise to reach 100 to 160 days over the period 2010 to 2039, 40 days longer than the current growing season. Also, the moisture deficit (mm) for the period 2010 to 2039 could be significantly higher (i.e. -250 to - 150 mm), which is -50 mm more deficient than current deficits (C-CIARN, 2001).

As a result, climate change will bring challenges but also new opportunities for Northern Ontario's farming with more days to grow, affordable land, and fertile soils (Chapagain, 2017; Rita-Harty and Côté, 2016). However, in order to access new farming areas, land clearing projects have been implemented recently across Northern Ontario regions, with positive impacts on the local and national economies. Along with the positive impacts, have also been negative impacts on land and ecosystem services such as carbon (C) sequestration, clean water, air purification and soil aggregation (Acton and Gregorich, 1995).

Figure 1: Northern Ontario Region

## 2. The Challenge

Soil management practices are vital for addressing the risks associated with the increased demand for food and bioproducts, requiring changes in farming practices in cropping and tillage. Agriculture will be challenged to supply food to a growing global population, but it must be done in a sustainable way (Foley et al., 2005). The result of farming practices that do not recognize the importance of conservation practices (soil, water, environment) is leading to soil deterioration and degradation (Braimoh and Vlek, 2008).

According to the Food and Agricultural Organization (FAO, 2015) in the Status of the World's Soil Resources Report, the world's soils are deteriorating due to soil erosion, nutrient depletion, loss in organic C, and soil biodiversity. Land degradation and watershed pollution are the results of poor agricultural land use practices (Garbach et al., 2014). Also, land degradation has led to a reduction in soil productivity by 23% over the past decade (United Nations, 2019).

In this regard, boreal soils are more vulnerable to changes in vegetative cover and soil use. Soil health monitoring, as a metric of change, will inform farmers and policymakers. This will encourage better farm practices and reduce soil degradation (OMAFRA, 2016). It will also guide the development of policies to improve or maintain soil fertility in Northern Ontario.

## 3. The Value of Soil

The formation of soil depends on the interaction between biotic activities, climate, topography and weathering processes. Soils are slowly formed over millions of years (Fisher and Crawford, 2015), and have been modified by human use, especially in the last few decades. In the past, people recognized the value of soil because of its ability to provide food (crop production-provision services). However, now, the Millennium Ecosystem Assessment classified the soil as part of the critical elements that provide ecosystem services to humans, and from this, we know soils play the protagonist role in all three classes (regulation, support, and cultural) (Fisher & Crawford, 2015).

By definition, land clearing is the process by which trees, stumps, stones, and other elements in and on the field are removed to add more cultivated land to an existing farm or new farm operations (NOFIA, 2017). The main objective of land clearing is to increase land productivity and enhance farmers' livelihoods so that they can earn higher revenues for themselves and increase their well-being (DeFries et al., 2004; Ripley, 1946).

Soil degradation, following the conversion of native land to agricultural land, occurs when the soil system changes, as well as its physical, chemical, and biological properties. As soon as the soil is cultivated, the new soil system changes its water ecosystem balance, the soil suffers compaction and often becomes vulnerable to wind and water actions that lead to erosion and loss of organic matter (DeFries et al., 2004; Wei et al., 2014).

Once the land is cleared, carbon is released into the atmosphere, and when land is cleared by burning, C is released more rapidly. Carbon is released slowly by microorganisms' decomposition (Houghton, 1995; Wei et al., 2014). Water quality is also linked to land use and land use practice due to the inputs added to boost yields, such as fertilizer. Inputs alter the soil composition and leached out of the soils into lakes and rivers cause eutrophication in rivers, lakes, estuaries or coastal regions due to over-enrichment of phosphorous (P) and nitrogen (N) and their run-off into water bodies (Carpenter et al., 1998).

At the global level, agricultural production causes soil losses 2.6 times faster than through natural processes. As a result, 26 billion tons of topsoil are lost per year, which represents 35% of carbon dioxide ($CO_2$) emissions since 1850 (Science, 2004). Land-use change has therefore impacted the global C cycle, atmospheric deposition and lowered the fertility of the soil but also led to more nutrients in surface water (Foley et al., 2005; Wackernagel et al., 2002). Also, soil degradation is accelerated due to climate change: soil is becoming warmer, and organic matter decomposes more rapidly in these conditions (Foley et al., 2005).

In Canada, from 1990-1998, natural habitat net losses were 54,000 to 81,000 ha $year^{-1}$ (Robinson et al., 1999). Land clearing followed by cultivation caused a 22% decrease in soil C compared to uncleared adjacent areas in Eastern Canada (Angers et al., 1995). N mineralization increased, leading to a reduction in total soil organic C stock and increases in $CO_2$ concentration. Studies indicate that C stock declines vary depending on conversion from native forest to cropland ( -42%), from pasture to plantation by (-10%), from native forest to plantation ( -13%), and from pasture to cropland, (- 59%). However, these trends can be reversed, for example, with soil C stock increasing when native forest is converted to pasture (+8%), cropland is converted to pasture (+19%), cropland to plantation (+18%), and cropland to secondary forest (+53%) (Guo and Gifford, 2002).

The last report of the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 2017) indicates that 82% of agricultural soils in Ontario were losing more $CO_2$ to the atmosphere than storing organic carbon. Sixty-eight percent of farmlands were at risk of unsustainable erosion, and 53% of soil had low or shallow soil cover. Also, area under conventional tillage practices had increased in Ontario while areas in hay and pasture had decreased by 52% since 1976 due to fewer ruminant livestock. In 2016, there was more area in annual crops (61%), whereas, in 1976, only 28% of area was under crops, with less diverse crops in crop rotations. Finally, there are also more consolidated farm areas with heavy equipment (OMAFRA, 2017).

## 4. 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” (Acton and Gregorich, 1995). The concept of soil health is related to feed and food quality and how it nurtures all organisms (Moebius-Clune, 2016). The term soil health is related to sustainability and management, how soil can sustain the life of living organisms, and how soil health can be preserved for future generations (USDA NRCS, 2018). On the other hand, soil quality is “the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health” (Doran and Parkin, 1994).

The terms soil health and soil quality are often used interchangeably (Acton and Gregorich, 1995; Braimoh and Vlek, 2008; Moebius-Clune, 2016).

It is necessary to understand three essential components of soil in order to understand soil processes and functioning. These three components are 1) physical components that include soil structure and water movements through soil pores, 2) chemical components that include nutrient availability and other conditions like (pH), and 3) biological components that include soil organic matter and soil organisms (OMAFRA, 2016).

Table 1: Soil Health Changes over the Period 1970 to 2010 Based on SHA

| Period | Objective | Tools | Method |
|---|---|---|---|
| 1970s | Crop Growth | Visual Assessments | Colour and structure micro-fauna with scientific analysis and expert advice using few indicators |
| 2010s | Multi-functionality of ecosystem services; resistance; resilience | Analytical and digital | Added biochemistry, microbiology and multivariable statistics |

Source: Adapted from Bünemann et al., 2018

Soil Health Assessments (SHA) allow us to identify what are the constraints and disturbances affecting the soil, and help farmers or soil managers to improve resilience and resistance of soil functions (Schjonning et al., 2004). Besides, SHA helps to increase the understanding of how human activities impact soils (Soil Health Institute, 2018).

The SHA looks at two main characteristics of the soil: inherent soil and dynamic soil quality. The first one relates to the origin of the soil and its natural ability to function. It is almost permanent and can only change over a more extended geological period. The second one is related to soil management practices and land use over a shorter human time scale, where soil properties such as soil organic C, water holding capacity, soil structure and nutrients can vary (Moebius-Clune, 2016).

## 5. Soil Security and Land Degradation

In the middle of the twentieth century, different soil concepts showed how society valued and cared for soils. Soil conservation was first introduced to address soil erosion, promoting measurement to determine causes, and how to reduce soil erosion. At that time, land capability and land evaluation were the two criteria used to identify care for soils. Now, concepts like soil function, soil resilience, soil condition, soil health, soil quality, soil protection, and soil ecosystem services and soil security have become indicators of soil health in the community

(McBratney et al., 2017). In particular, soil security is a term used to relate to food security. Soil security refers to the maintenance and improvement of soils worldwide so that they can continue to provide food, fibre and freshwater, contribute to energy and climate sustainability and help to maintain biodiversity and protect ecosystem goods and services (Koch et al., 2013, 2012*;* McBratney and Koch 2014). Indeed, soil security requires maintaining soil function (McBratney et al., 2014).

Soil security's five dimensions include capability, condition, capital, connectivity and codification (McBratney et al., 2014).

- *Capability* is the ability of the soil to provide quality food, filter waste products and provide clean and safe water supplies.
- *Condition* is related to the nutritional quality of food obtained from agricultural products.
- *Capital* recognizes the value of the soil in providing services to enhance health. In addition, capital recognizes both costs associated with deteriorating human health and costs associated with soil that provides medication, for example.
- *Connectivity* is the connection between social interaction and the management strategies applied to it. Also, connectivity influences the loss of land and its implication for human health.
- *Codification* is the link to conservation policies that have focused on soil and water conservation rather than human health, but by improving these resources, indirect benefits are acquired, such as high-quality agricultural products (Brevik et al., 2017).

Soil health and soil quality defined by Doran (2002) and Karlen, et al. (1997) define soil security as a soil condition, which corresponds to soil assessment by using indicators to define soil disturbance (McBratney et al., 2017). Land degradation is closely related to soil security for two reasons. First, usually, land degradation involves soil degradation. Secondly, soil security is indirectly affected by land degradation due to the potential impacts on biodiversity, water security, ecosystem services and food security (Krasilnikov et al., 2017).

In higher-income countries, land degradation is often associated with intensive agricultural systems. In these systems, soil degradation is high because of direct inputs such as fertilizers and pesticides, as well as indirect effects such as compaction and salinization. Therefore, soil health losses are commonly referred to as soil degradation.

## 6. Initiatives to Improve Soil Health

At the international level, since the 1980s, many initiatives have provided a strong policy focus. For example, the World Soil Policy led to the development of the World Soils Charter for improving soil productivity and conservation (FAO, 1982) as part of the United Nations Environmental Program (UNEP). This program assessed soil degradation at the international and national levels. As a result of this initiative, the Soil Degradation's World Atlas of Desertification was published in 1997.

The International Union of Soil Science developed The World Soil Agenda to fight against soil degradation. Three main components were considered part of the agenda: Science, Policy and Implementation (McBratney et al., 2014).

- *Science for monitoring soil degradation, using soil assessment.*
- *Policy for implementing national and international agendas with multidisciplinary networks and approaches*
- *Implementation for adding programs to enhance soil fertility and reduce soil erosion at the national level*

In 2011, the FAO launched a program called the Global Soil Partnership for Sustainable Practices to Soil Resources. In 2013, the Global Soil Mapping Consortium and Intergovernmental Technical Panel of Soil was created to provide scientific and technical guidance to policymakers, thanks to FAO's soil experts in several regions (Montanarella, 2015).

At the national level in Canada, the 1984 Senate report "Soil At Risk: Canada's Eroding Future" indicated that unless actions were taken, Canadian agricultural soils would be degraded in 100 years. In 1988, during the National workshop on Soil Quality Monitoring, the Canadian government agreed to establish a national soil-quality monitoring system for Canada to measure specific soil and environmental characteristics at regular intervals.

Consequently, Agriculture and Agri-Food Canada introduced agri-environmental indicators to measure changes in agriculture, farm management practices and environmental conditions in soil, air and water quality and how these elements would evolve in the future (OMAFRA, 2016). Regarding soil monitoring, the following indicators were developed: soil organic C, soil organic matter, risk of soil erosion and soil cover.

The Ontario Government, through OMAFRA and in collaboration with the federal government, universities and private sector initiatives, has implemented five programs to monitor, measure, restore, and protect the soil and the environment. They are:

i) The Environmental Farm Plan which identifies potential risk and areas of concern in agricultural lands and recommends Best Management Practices to address them;

ii) The Great Lakes Agricultural Stewardship Initiative, focused on improving soil health and environmental management;

iii) The 4R Nutrient Stewardship program which was implemented by Fertilizer Canada to optimize nutrient use and reduce nutrient runoff to help meet environmental and agricultural goals;

iv) The Cover Crop Strategy promoting cover crop adoption; and

v) The Farm Health Check-up, which monitors soil erosion, compaction, organic matter, soil biology, and chemistry. (OMAFRA, 2016).

One of the challenges with these programs is that most farmland is privately owned. Therefore, the soil is managed privately, with farm decisions and management practices decided by individual owners. As a result, most of the soil management decisions depend on owners who may or may not take the environment into account (Braimoh and Vlek, 2008; Montanarella, 2015; Koch, 2017).

## 7. Reduction of Water Quality due to Soil Degradation

Water quality is affected by agricultural activities in agricultural landscapes. Natural hydrologic flows are often diverted and redistributed across the landscape as a result of agricultural production (Environment Canada, 2004). Human activities can also speed up the process of erosion, transport, and sedimentation, which impacts water quality. Water quality degradation is linked to land use, and intensive agriculture leads to erosion and heightened sedimentation loads to surface waters. Soil erosion is accelerated by plowing and tillage (Julien, 2010). Erosion can cause severe problems because it reduces the productivity of agricultural land, reduces ecosystem fertility, can initiate desertification processes, and can reduce ecosystem services overall, including carbon sequestration, water storage, soil microbial diversity, food production, and water quality (Soil Science Society of America, n.d.; Vaezi et al., 2017).

Eutrophication is a significant problem associated with nutrient run-off into rivers, lakes, estuaries and coastal regions caused by an over-enrichment of P and N primarily due to agricultural activities (Carpenter et al., 1998). Groundwater is also at high risk of contamination from agriculture because of chemicals leaching through the soil (Ritter, 2002). One of the primary groundwater pollutants is nitrates, which can, among other human health concerns, cause low levels of oxygen in the blood of infants and can cause death (Spalding and Exner, 1993).

Water erosion is a process that has three phases: First, surface soil particles are detached from the soil mass. Second, soil particles are transported either by rills or gullies. Third, the transport of soil particles ends up in surface waters as sediment. Erosion is a significant issue that is recognized worldwide as an environmental problem that endangers crop production and damages soil health. Soil erosion affects not only the hydrologic cycle but also biological and geochemical cycles (Vaezi et al., 2017).

High-intensity rainstorms can also lead to deterioration of soil physical properties with increased crusting, aggregate breakdown, compaction and lower infiltration rates. A significant correlation exists between soil erosion and the deterioration of soils' physical, chemical and biological properties (Vaezi et al., 2017), leading to a reduction of water quality. Water erosion can destroy the soil structure leading to soil crusts (Dickson et al., 1991) and runoff (Vaezi et al., 2017). Also, crop type, water amount and soil management can alter infiltration and the flow of water through the soil profile, modifying patterns of runoff and percolation. Cropping generally increases soil bulk density, leading to increases in peak runoff events and sediment loading into rivers leading to lower baseflows which can affect nearby wetlands and long-term groundwater supplies. Healthy soils with good structure and stable soil aggregation will be less susceptible to water erosion leading to higher water quality in surrounding waterbodies (Ran et al., 2012).

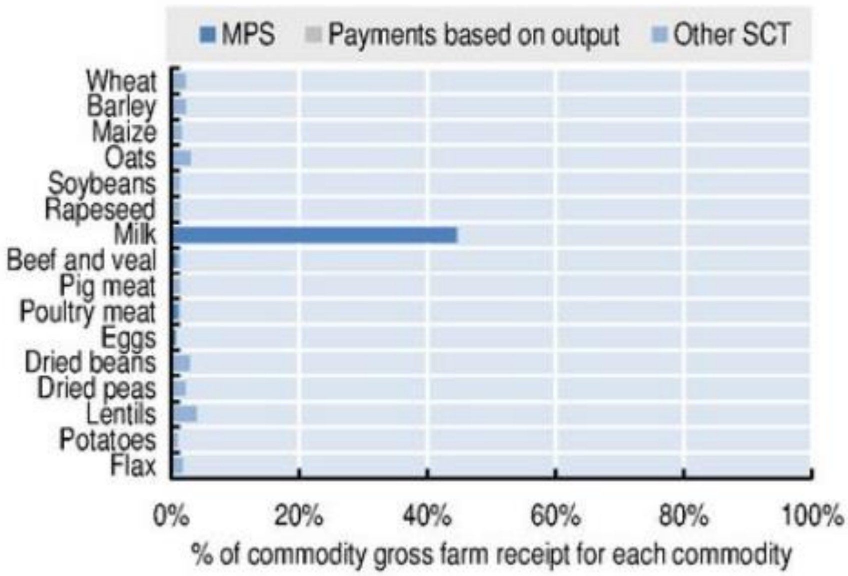
The Boreal Shield ecozone has shown signs of increased degradation, such as less soil organic matter, soil compaction, aggregate structure destruction, soil acidification, and decreases in water quality as indicated by increased phosphorus pollution in the Great Lakes and groundwater contamination by nitrates (Acton and Gregorich, 1995). Therefore, recovering soil health and its functions helps to maintain or improve environmental quality that includes physical, chemical, or biological properties that promote not only plant growth, water storage, infiltration, carbon sequestration, but also holds and cycles nutrients, controls diseases, pests and weeds, supports the production of food, fibre, and fuel, and detoxifies dangerous chemicals (Braimoh and Vlek, 2008; Moebius-Clune, 2016). These actions collectively enhance water quality and soil health.

## 8. Recent Policy Initiatives for Soil Health

In 2008, the Canadian federal and provincial governments implemented a policy framework called Growing Forward. Then in 2013, this framework was renewed as Growing Forward 2 (GF2) framework, which lasted until March 2018. Then in April 2018, the Canadian Agricultural Partnership (CAP) program was launched between provincial, territorial, and federal governments, prioritizing investment in several priority areas including environmental sustainability and climate change, risk management, and public trust, among others (OECD, 2018).

CAP programs under the Business Risk Management pillar protect farmers against different types of income and production losses. According to AAFC, (AAFC, 2017), there are three main programs: 1) AgriStability, which provides support to farmers when they have significant losses in farm income; 2) AgriInvest, which covers small decreases in farm income through matching savings; 3) AgriInsurance, which provides cost-share (federal-provincial government and producers) insurance against production losses from natural hazards, where farmers paid approximately 40% of the real cost. (Jeffrey et al., 2017).

Figure 2: Canada: Transfer to specific commodity (SCT), 2015-2017




Market price support

Payments based on output

Other Single Commodity transfer

Source: (OECD, 2018), "Producer and Consumer Support Estimated Estimates," OECD Agriculture statistics (database)

Governments' concern for agri-environmental policies and environmental stewardship has increased due to a growing public interest, although agri- environmental policies are limited (Eagle et al., 2016). Governments have promoted BMPs by sharing the cost of adopting practices like buffer strips or shelterbelts since the adoption of these BMPs is costly for farmers (Jeffrey et al., 2017). Canadian programs to protect the environment are shown in the following table from 2003 to 2010.

Table 2: Environmental programs from 2003 to 2010

| Programme | Year | Compensation | Objective |
|---|---|---|---|
| Wildlife Crop Damage Compensation | Until 2003 | $5.45 million | To pay farmers for damage to crops from big game and birds |
| Green-cover Canada | 2003-2007 | $110 million | To convert sensitive land to permanent grassland cover, shelterbelt and water quality |
| Cover-crop protection program | 2005-2010 | $90 million | To assist farmers in planting cover crops in flooded cropland to prevent soil erosion |
| National Farm Stewardship program | 2004-2008 | $ 200 million | To help farmers to adopt beneficial management practices to protect the environment |

Source: Eagle et al., 2016

A list of more recent provincial, territorial, and federal environmental programs is outlined in the Canadian Agri-Food Policy Institute's (CAPI) recent report on Clean Growth in Agriculture (CAPI, 2019). Even though these programs have enhanced the environment, BRM programs have contributed to the increased use of fertilizer and pesticides (Eagle et al., 2016). Therefore, "it may be possible to conclude that the net impact of BRM programs on environmental quality is negative" (Jeffrey et al., 2017).

## 9. Future Agricultural Policy Regarding Soil Health and Soil Security

Good quality soil is imperative for having future food, fibre and fuel to feed an increasing population. Without quality soil, humans will continue to feel the strain of decreasing productivity due to climate change and increased stress to soils (Montanarella, 2015). At the international level, reducing emissions and promoting C sequestration by implementing vigorous mitigation activities in a cost-effective manner could be feasible. Reducing the cost to governments for providing environment-based subsidies will help promote soil security or acceptance of soil management, Voluntary C offset markets could help as well. Also, meeting the demand of clients who are asking for low C products could improve soil health; therefore, soil security (Montanarella, 2015).

At the national level, the next discussion regarding soil policy could be the implementation of cross-compliance that has been used in the European Union and the United States. Cross-compliance links agri-environmental policies and environmental stewardship practices (Eagle et al., 2016; Jeffrey et al., 2017) and the Canadian government should consider implementing them in agricultural support policy (Eagle et al., 2016).

It is important to note that soil health, soil security and soil quality should be examined through three separate lenses: farmers, academics, and policymakers.

At the farm level, stakeholders should understand that soil is a complex system that is connected to ecosystem services and not only crop production. Soils require optimal conditions to function accordingly with their capacity.

At the academic level, new soil digital technologies (soil sensing, telemetry, digital mapping, big data analysis and precision agriculture) will bring a new understanding of how soil functions at the optimal and sustainable level to improve farm management practices. Besides, academic research should provide tools and resources to decision-makers in terms of values and cost of soil conservation practices so that programs can include a real value of those practices that would reduce the cost of programs that otherwise are absorbed either by the government through subsidies or incentivized for the user via payments.

At the policy level, cross-compliance policies should be applied for improving environmental practices on the farm. In this regard, 40% of the real cost of the crop insurance that farmers paid for can be discounted due to soil conservation practices that farmers apply to their field.

To sum up, Northern Ontario agricultural areas will open new frontiers for agro-production not only due to its soil characteristics but also local future climate conditions. However, within these new opportunities, there will be new challenges to face. Consequently, policies to improve, reduce or maintain healthy ecosystems must be implemented with a strong local focus. Concerning soil health and soil security, boreal soils are more vulnerable to climate conditions and farm management practices; therefore, better measurements to reduce soil degradation and improve soil conservation and fertility should be developed. Farm practices that promote carbon sequestration should continue as part of the policy agenda, and new policies should include cross-compliance in order to be implemented. By doing this, farmers will receive direct economic benefits and, enhanced conservation farm practices will take place at the farm level. Such practices can reach private land which is, nowadays, one of the primary constraints for applying sustainable farm management practices.

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