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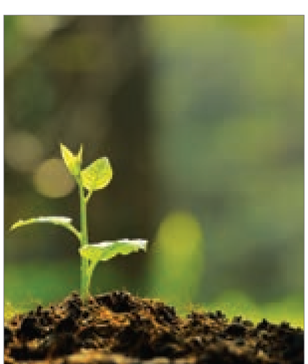
Canada

Report #4

Agri-Environmental Indicators Report Series

Environmental Sustainability of Canadian Agriculture





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Environmental Sustainability of Canadian Agriculture

Agri-Environmental Indicators Report Series

Report #4

CLEARWATER, R.L., T. MARTIN AND T. HOPPE (EDITORS)

Agriculture and Agri-Food Canada
2016

ERRATUM

A previous version of Table 18.2 (Chapter 18, p. 216) contained transcription errors in the values for oilseeds in BC, AB and SK, which have been corrected here.

A previous version of Table 6.3 (Chapter 6, p. 61) contained transcription errors in the values for all provinces, which have been corrected here.

We apologize for any confusion this may have caused.

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Executive Summary

The agricultural sector is continuously adapting to market demands, new innovations, regulatory changes, and trade opportunities and restrictions. Over the last thirty years, the average Canadian farm has grown larger and the number of farms has declined. Farm types have shifted, with a greater proportion of farmland now under arable production. National livestock numbers have declined, although the average head of livestock has increased on a per-farm basis, indicating an intensification and concentration of production. With nearly 65 million hectares of land used for crop and livestock production[1], Canada has one of the largest agricultural sectors in the world, and is the fifth largest agricultural exporter in the world[2]. As stewards of much of Canada's rural land base, farmers are increasingly aware of the impact that agricultural production can have on the quality of our air, water, soils and **biodiversity**[3]. As the global population rises, it is essential to ensure that our land base continues to provide food, fuel and fibre for future generations. Part of meeting this challenge lies in maintaining the health and sustainability of our natural resources, and the sector needs objective and useful information to help inform decision making on the farm, as well as for policy and program purposes.

Agriculture and Agri-Food Canada has developed a set of science-based **agri-environmental indicators** (**AEIs**) that integrate information on soils, climate and topography with statistics on land use and crop and livestock management practices. The indicators provide valuable information on the overall environmental risks and conditions in agriculture and how these change over time. The indicators are designed to be sensitive to the considerable differences in conditions and in the commodity mix across Canada, which are reflected in the significant variations in environmental performance between regions. At the same time, the systematic approach and common data sets used allow this information to be scaled up to the national level, enabling the identification of trends that may be consistent in all parts of the country.

The indicators measure the agriculture and agri-food sector's environmental performance for soil, water and air quality and farmland management. Results from multiple agri-environmental indicators related to soil, water and air quality, as well as biodiversity have been incorporated into agri-environmental performance indices to simplify the presentation of overall environmental performance. The indices are presented here to draw broad, national-level observations on the status and trends of agri-environmental sustainability of the agriculture and agri-food sector (refer to Chapter 2, Table 2-2 for a description of these indices). The regional variations are more explicitly discussed in the body of the report.

This publication can be used as a report card of agri-environmental performance for producers, consumers and the international community and can be used to identify areas where further efforts are required. It can also provide valuable information that decision makers can draw from when developing and evaluating agricultural policy. A summary of main findings follows.

1 Statistics Canada, 2011. Table 004-0002 - Census of Agriculture, total area of farms and use of farmland, Canada and provinces, every 5 years, CANSIM (database).

2 Agriculture and Agri-Food Canada, 2013. *We Grow a Lot More Than You May Think*. Ottawa, Ontario. Accessed from http://www.agr.gc.ca/eng/about-us/publications/we-grow-a-lot-more-than-you-may-think/?id=1251899760841

3 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each Chapter or section.

Farmland Management

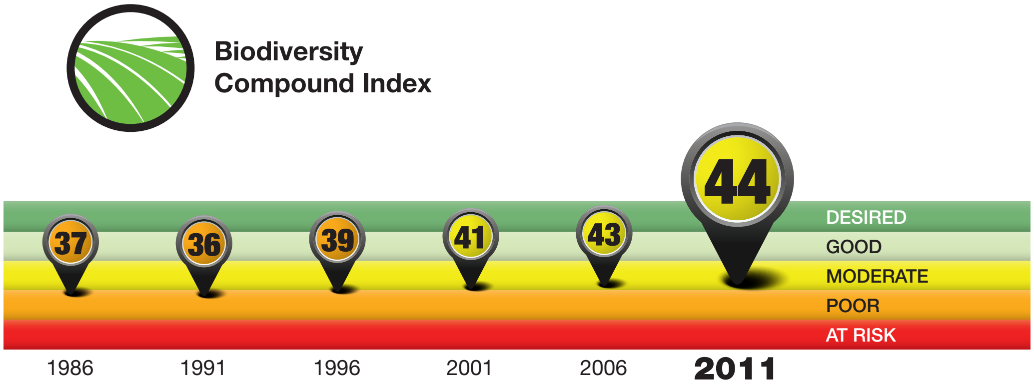

Figure E-1: Biodiversity Compound Index

Two prevalent trends in Canadian agricultural production were discernable between 1981 and 2011; consolidation of farmland into fewer farms, and increasing intensity of production on those farms. Increases in intensity are revealed by the growth in **oilseed** and pulse crop areas, declines in the area of **summerfallow** and **cereal** grains, and increases in livestock numbers per farm.

Total numbers of most major livestock categories increased over the 30-year period for the country as a whole. Since 1981, the beef cattle industry in Canada grew steadily, reaching a peak between 2001 and 2006. Since 2006, beef herd size has been declining, mainly as a result of a decline in consumer demand for beef, but also as a holdover from the **Bovine Spongiform Encephalitis (BSE)** outbreak in 2003-2004. Conversely, between 1981 and 2011, the number of dairy cows declined steadily with a 46% drop over the 30 years. The primary reason for this has been a dramatic increase in milk production per cow, which has been facilitated by the consolidation of dairy farms, and improved feed efficiency.

The overall trend from 1981 to 2011 for biodiversity shows steady and consistent improvements across Canada, moving from a 'Poor' status in 1981, to a 'Moderate' status in 2011, as depicted by the Biodiversity Compound Index (Figure E-1). This compound performance index is a weighted average of the Soil Cover and Wildlife Habitat Capacity performance indices[4]. As such, it is a highly statistical snapshot of these two variables both in terms of current state and over time[5].

The improvements are largely due to changes in tillage practices reflected in the Soil Cover Indicator in particular. The use of **reduced tillage** and **no-till** has been increasing continuously since the early 1990s, as a means to reduce fuel costs and improve soil health. Between 2006 and 2011, the total area of agricultural land under **intensive tillage** declined by 30.9%. In 2011, no-till land management was applied on more than 50% of all agricultural areas prepared for seeding in Canada (Statistics Canada, 2011[6]). This reduction in tillage, coupled with the decreased use of summerfallow, resulted in a national-scale improvement in average levels of soil cover in Canada. From 1981 to 2011, average levels of soil cover in Canada increased by 7.6%.

From 1986 to 1996, wildlife habitat capacity (WHC) was relatively stable; however from 1996 to 2011 there was an overall decline in WHC at the national scale, despite the drop in summerfallow (which offers limited capacity for wildlife) and rise in soil cover. The decline in WHC was primarily due to the intensification of farming as well as the loss of natural and semi-natural land, mainly resulting from the shift away from pasture and **forage** production to annual cropping, especially in Eastern Canada.

4 All national "core" indicators, to include Soil Cover and Wildlife Habitat Capacity on Farmland have a weighted value of 1.

5 More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

6 Statistics Canada, 2011. *Table 004-0010 – Census of Agriculture, selected land management practices and tillage practices used to prepare land for seeding*, Canada and provinces, every 5 years, CANSIM (database).

Soil Quality

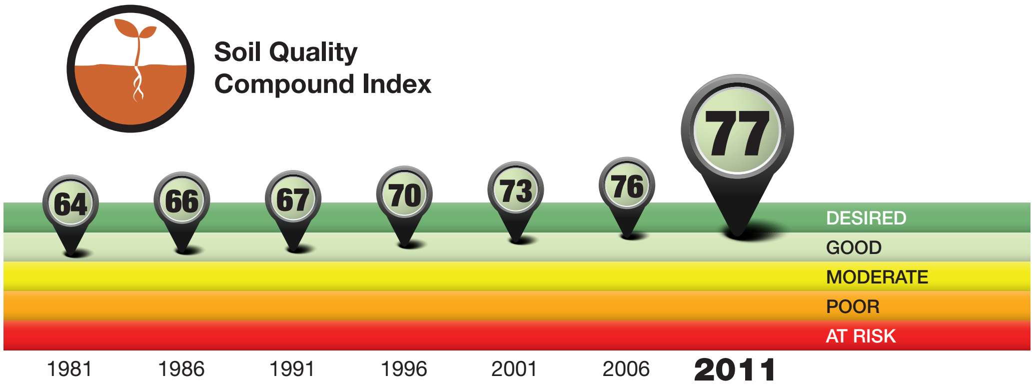

Figure E-2: Soil Quality Compound Index

Considering various aspects of soil quality together, as illustrated in the Soil Quality Compound Index (Figure E-2), agriculture's environmental performance has a 'Good' status, and has significantly improved over the 30-year period preceding 2011. This compound index is a weighted[7] average of the performance indices reported for the Soil Erosion, Soil Organic Carbon and Soil Salinization Indicators, plus findings from the Trace Elements Indicator (extrapolated from previous years, not reported in this publication[8]). As such it is a highly generalized statistical snapshot of soil health, both in terms of current state and over time.

Improvements to the Soil Quality Compound Index can be directly attributed to improvements in land management practices, such as increased adoption of reduced tillage and no-till practices, and the reduction in area under summerfallow.

The improved performance was driven by the Prairie Provinces where cultivated agriculture is extensive and is dominated by cereals and oilseeds. This agricultural region is most amenable to reduced-till and no-till practices. Increased soil cover resulting from these has led to a significant increase in soil organic matter. The reduction in tillage has also led to a reduction in soil erosion risk, notably tillage erosion, which has historically accounted for the majority of erosion losses (followed by wind and then water). The extensive reduction in area of summerfallow has also improved soil health, leading to a reduction in soil erosion – particularly from wind and water; and has also reduced salinization risk.

Generally, higher rainfall in Ontario, Quebec and the Atlantic Provinces compared to the Prairies supports more intensive agriculture and a different mix of crops. These regions have seen a shift away from pasture and forage production, following the decline in cattle production in 2006, towards row crops which offer less soil protection. However, as the majority of agricultural land is sited in the Prairies, where soil health is improving, the national picture is also one of improvement for soil health.

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7 All national "core" indicators, to include Soil Erosion, Soil Organic Carbon and Trace Elements have a weighted value of 1. In the case of Soil Salinization Indicator, which covers only the Prairie extent, its weighting is reduced to 0.81 to reflect the percentage of farmland area under coverage.

8 The Risk of Soil Contamination by Trace Elements Indicator was developed for the 1981 and 2006 Census years only and therefore does not have a Chapter designated to it in this publication. However, since these trace element values are not likely to change significantly from year to year at the scale of analysis used in this report, they have not been recalculated for 2011. Instead, the 2006 trace element values were extrapolated for use in the 2011 year, and were included in the calculation for the overall Soil Quality compound index.

Water Quality

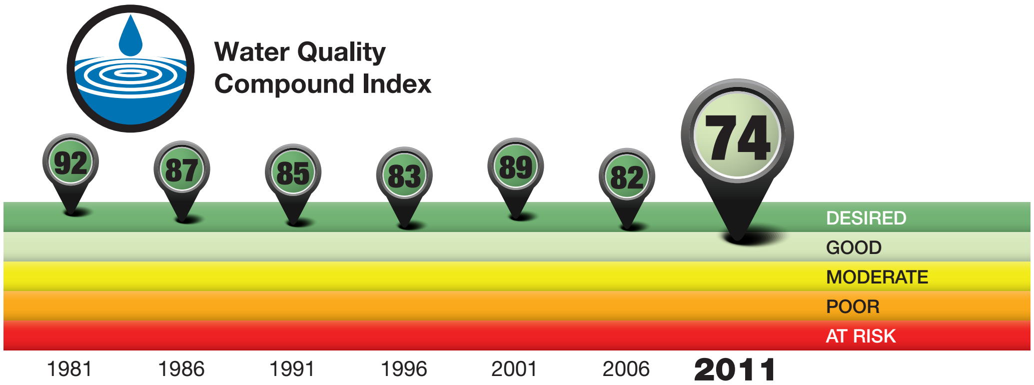

Figure E-3: Water Quality Compound Index

Considering various aspects of risks to water quality together (Figure E-3)[9], agriculture's environmental performance currently has a 'Good' status. It does however represent an overall decline from a desired state in 1981. This overall declining performance is mirrored by the individual indicator performance indices, which moved from 'Desired' status in 1981 to 'Good' status in 2011, with the exception of the Phosphorus Indicator, which moved from 'Desired' status to 'Moderate' status. The deterioration in the index can be attributed to increased application of **nutrients** (N and P) as **fertilizer** and manure as well as an increased use of **pesticides** across Canada.

The declining agri-environmental performance was observed in all regions of the country. In the case of nitrogen, the levels of residual soil nitrogen have increased steadily as inputs from fertilizer and manure in particular have increased at a faster rate than outputs from crop harvests, gaseous losses and **leaching**. This soil nitrogen is most readily available in the form of water-soluble **nitrates**, which are at risk of leaching to **ground water** and, where fields are tile-drained, into drainage water, which can then be directed into ditches, streams and rivers. Despite this increasing risk, the Nitrogen indicator remains in the 'Desired' category.

In the case of **phosphorus**, performance has declined quite dramatically from 'Desired' in 1981 to 1991, dipping to 'Good' in 1996, recovering to 'Desired' in 2001 and declining since that time. This report is the first time this indicator has been classified as 'Moderate', reflecting a combination of phosphorus source and transport. Increased surpluses in soil-phosphorus in all regions reflect national increases in fertilizer and manure application as well as increased concentration of livestock. Added to this increased source is the much higher than average runoff in 2011, following a very wet spring throughout the Prairies. This increased **runoff** increased risk by flushing much of the built-up soil phosphorus into surface waters.

While overall livestock numbers have decreased on a national scale, there is a growing trend towards larger operations, with higher concentrations of animals. A consequence of this increase is that on-farm manure capacity can grow to exceed the capacity of surrounding land to use it as fertilizer, sometimes leading to higher application rates. As a result, the Coliforms Index has deteriorated from 'Desired' in all preceding years, to 'Good' in 2011.

In the case of pesticides, the risk of water contamination has increased on about 50% of cropland over the past 30 years. The index has deteriorated from 'Desired' in all preceding years to 'Good' in 2011. The highest risk increases occurred in the Prairies between 2006 and 2011 where the area treated by fungicides doubled. This increase, as well as increases in herbicide use, can be attributed to the switch to reduced tillage and no-till which necessitates the use of pesticides to control weeds and diseases (reduced tillage systems are more susceptible to fungal

9 The Water Quality Agri-Environmental Performance Index combines indices for water contamination by nitrogen (N), phosphorus (P), coliforms and pesticides.

diseases). The increased risk can also be explained by a shift away from pasture and forage to cropping systems that require more pesticide inputs and, to a lesser extent to wetter weather in the Maritime Region in 2010.

Increased efforts are required throughout Canada to minimize the risk of nutrient, pesticide and **coliform** movement to surface water bodies and leaching beyond the rooting depth of vegetation. This is particularly so in higher rainfall areas of the country. This risk can be further reduced through practices such as regular soil testing and better matching agricultural inputs application to field conditions. Practices that mitigate surface runoff, such as establishing **riparian buffer** strips, **winter cover crops**, maintenance of surface residue, etc. will also contribute to a reduced risk to water quality.

Air Quality

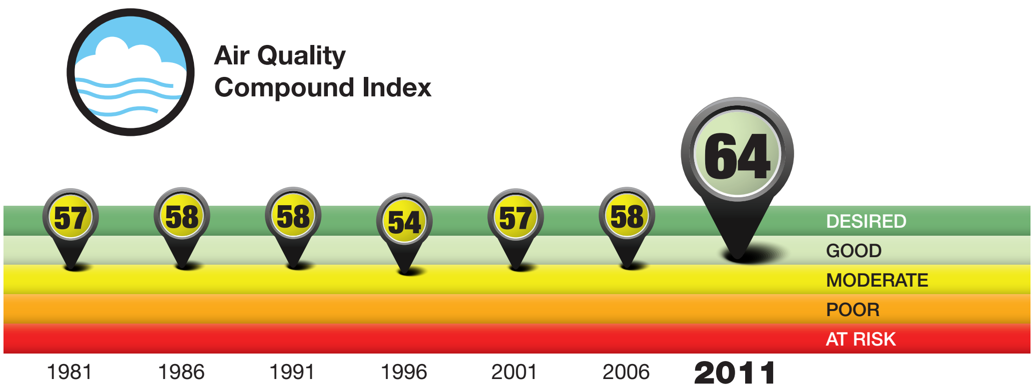

Figure E-4: Air Quality Compound Index

Considering various agricultural atmospheric emissions together (Figure E-4[10]), agriculture's environmental performance in air quality is 'Good', having been relatively stable between 1981 and 2006, and then significantly improving to 2011. This improvement is mirrored by improvements in all the individual performance indices within this theme.

Improvements in land management practices such as increased adoption of conservation and no-till practices, reduced use of summerfallow, and increased forage and permanent cover crops were primarily responsible for the improved agri-environmental performance for air quality. Adoption of these management practices, particularly in the Prairies, led to soils becoming a net sink for atmospheric **carbon**, which means more carbon is being **sequestered** in soil than is being emitted, leading to a reduction in overall **greenhouse gas (GHG)** emissions. The same practices have led to improvements in **particulate matter (PM)** emissions over the period of study. A decrease in numbers of livestock across the country between 2006 and 2011 is the primary reason for the improvements in the **ammonia** emissions performance index, which now sits at just above 1996 levels.

Land management practices that favour **sequestration** of carbon in the soil, such as reduced tillage and residue management practices to maintain soil cover, need to be continued and expanded in order to maintain and increase the amount of **carbon dioxide** removed from the atmosphere and stored in the soil. Similar practices that reduce the number of field operations and protect the soil surface from wind erosion are effective in minimizing PM emissions. Improved animal feeding strategies and more efficient use of N in agriculture are examples of **beneficial management practices (BMPs)** that can be used to mitigate emissions of **methane**, ammonia and **nitrous oxide**.

10 The Air Quality Agri-Environmental Performance Index combines indices for greenhouse gases (GHGs), particulate matter (PM) and ammonia emissions from agriculture.

Applications and Future Directions

In addition to the risk and state indicators in this report, increasing attention is being given to a third type of indicator; the commodity-specific intensity indicator, which can estimate resource-use efficiency, typically by comparing inputs and outputs of a given resource, such as water or fuel. Chapter 18, on Greenhouse Gas Emission Intensity of Agricultural Products presents calculations of the total GHG emissions that occur during the production of one unit of a given agricultural product for different regions of Canada. Findings for several products, to include major field crops, dairy products and beef are included.

To be viable, environmentally sustainable production systems must also be economically sustainable. AAFC is developing tools and approaches for linking indicators to economic models as a means of providing guidance for policy and program evaluation and development, and to answer commodity-specific questions on the economic sustainability of alternative land use or management practices that have been identified as environmentally beneficial. The Integrated Economic and Environmental Modelling Chapter (Chapter 19) describes how the indicators can be combined with economic models to inform policy and program development and evaluation. It provides examples of how the AEIs have been used recently, in providing Environment Canada with GHG emissions estimates for the agriculture sector and in conducting environmental assessments of business risk management programs.

01 Introduction

Authors:
R.L. Clearwater, T. Martin,
R. MacKay, A. Lefebvre.

The Canadian agriculture industry has evolved significantly over the past 30 years. Across Canada the number of farms has decreased while the average farm size, crop area and number of head of livestock per farm have all increased. Advances in technology and farming practices have allowed farmers to manage much larger operations with the same or less labour, making the structural adjustment towards intensification possible and leading to economies of scale which have helped to offset decreasing profit margins.

Producer demographics are also changing. According to Statistics Canada, for the first time in Census history, farmers in the 55-and-over age group represented the largest share of operators. Farmers are also increasingly comfortable using technologies and decision-support systems such as mobile applications to assist them in their work. This has been facilitated by a rapid growth in access to high-speed internet. **Precision farming**[1] is on the increase, helping to maximize efficiency on the farm.

Producers have been able to increase their efficiency and obtain higher yields from a finite amount of land, while operating in a highly competitive world market of unstable commodity prices. Meanwhile, they have faced a number of environmental, economic and social challenges, including droughts, floods, high energy prices, encroaching urban development and evolving buyer demands.

Farmers strive to meet global demand for commodities in the face of unstable prices and unpredictable weather. In recent years market factors have driven a shift away from livestock-based operations (which accounted for 50.9% of all farms in 2006, and 41.6% in 2011), towards crop-based operations (which increased from 49.1% of all farm types in 2006, to 58.4% of all farms in 2011). Canola has surpassed spring wheat as the leading crop in Canada, moving up from its third place position behind hay in 2006. This transition has been accompanied by an increase in **nitrogen fertilizer** consumption as well as in **pesticide** applications.

Scientific research has brought advances in technology such as new cultivars and machinery, and has enabled better production practices that use inputs more efficiently. These improvements have allowed producers to be more adaptable and innovative in their operations, and have led to the intensification of production. As agricultural production has become increasingly sophisticated and intensified, environmental pressures have become more complex. This has led to greater public and consumer scrutiny of food production methods and the emergence of some private sustainability standards, thus adding to the challenges producers face in achieving their economic objectives while managing their land in a sustainable manner. Fortunately, most producers understand the importance of managing **ecosystem** functions and services such as **nutrient** and water cycling, **carbon sequestration**, and pollination, and realize that stewardship of critical natural resources such as water, soil and **biodiversity** is essential in order to ensure the long-term success of their farms.

1 Words included in the glossary (at the end of this publication) are bolded in first instance they appear in each chapter.

Evaluating Environmental Performance: Agri-Environmental Indicators

Agro-ecosystems are human-managed ecosystems that produce food, fibre and other products for society. The manipulations required to produce these services include actions such as clearing, cultivating, seeding and harvesting, supplementing nutrients and natural precipitation and controlling weeds and pests, and can be undertaken in a variety of ways. Agro-ecosystems, like natural ecosystems, are dynamic, with a constant flow of energy, water and chemical elements entering and leaving the system in cycles.

Agricultural decision-makers require good information to properly understand and manage complex agri-ecological systems while taking into account economic and social factors. However, the long-term and complex nature of ecological research means that our understanding of these dynamic systems is evolving and requires effort to translate results into information meaningful to producers and the decisions they face.

In 1993, in response to a need for agri-environmental information, and to assess the impacts of agricultural policies on the environment, Agriculture and Agri-Food Canada (AAFC) began to develop a set of science-based environmental indicators specific to the agriculture and agri-food sector (McRae et al., 2000). This mandate was strengthened in 2003 when AAFC established the National Agri-Environmental Health Analysis and Reporting Program (NAHARP). **Agri-environmental indicators** (**AEIs**) aggregate a large amount of biophysical information such as soil types, climate and topography, and combine it with data on land use and crop and livestock management practices. The result is easy-to-understand measures that can inform agriculture sector stakeholders and other decision-makers about the following topics:

- the environmental performance of agriculture, i.e. management and conservation of natural resources and compatibility with the broader environment;
- how the environmental performance of agriculture changes over time;
- the impact of adopting environmentally **beneficial management practices**;
- the development of strategies and actions to safeguard areas and resources;
- the effectiveness of agricultural policies and programs.

This report, Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series—Report #4, builds on past efforts. Agri-environmental performance results and trends are now presented for the 30-year period from 1981 to 2011 for many of the indicators. With advances in research, most of the indicators have been refined and updated from previous reports and now have improved calculation methodologies. As part of Canada's commitment to open data, the data and methods are being made publicly available online at open.canada.ca.

Applications and Future Directions

The indicator results presented in this report are designed to provide a snapshot of the environmental risks and conditions in agriculture at regional and national scales. The report is intended for readers who want to learn about the environmental issues most important to the agriculture sector, and want to know whether the agriculture sector is moving towards or away from environmental sustainability. This information can be used as a report card for producers, consumers and the international community, as it points out areas where further efforts are required. It also provides valuable information to assist decision-makers in developing and evaluating agricultural policy.

For example, the indicators presented in this report are being used increasingly as environmental performance measures for Canadian policy and programming, as well as in international reports on global progress. The **Growing Forward 2** federal, provincial and territorial agreement on agricultural policy and programming uses the **greenhouse gas** emissions indicator, as well as the compound performance indices[2] for water quality, soil quality and biodiversity from this report as outcome indicators of the long-term environmental sustainability of Canadian agriculture. Both Canada's Federal Sustainable Development Strategy and AAFC's Departmental Sustainable Development Strategy similarly use selected indicators as measures of environmental sustainability. Environment Canada's Canadian Environmental Sustainability Indicators program, which provides data and information to track Canada's performance on key environmental sustainability issues, uses the water and soil quality indicators. The Organisation for Economic Co-operation and Development (OECD) report entitled *Environmental Performance of Agriculture in OECD Countries Since 1990* (OECD, 2008) summarizes the efforts made by member countries to develop a set of AEIs that are based on consistent and compatible methodologies. The development of environmental indicators that can be used at the international level is especially challenging because of differences in environmental conditions, economic activity, national priorities and the availability of data across countries. Canada actively contributes to the OECD's efforts in this area through AAFC's work on AEIs.

The AEIs are also useful to industry and commodity groups addressing the need for sustainability metrics, to gain or maintain market access. For example, the Soil Organic Matter Indicator model was instrumental in assuring Canadian canola access to the European **Biofuels** market. AAFC marketing specialists and research scientists are working with commodity groups and consortia, including the Canadian Roundtable for Sustainable Crops and the Canadian Roundtable for Sustainable Beef to make the indicator data sets and methodologies more directly suited to commodity-specific estimates of impact per unit of production, for example greenhouse gas emissions per litre of milk produced. Chapter 18, "Greenhouse Gas Emission Intensities of Agricultural Products" documents some progress in this direction.

Structure of the Report

In addition to this chapter, the introductory Section of this report includes chapters on methodologies for the assessments and the forces driving change in the indices. Section 2 presents indicators relating to Farmland Management and species habitat. Sections 3, 4, and 5 present indicators relating to Soil Quality, Water Quality, and Air Quality respectively. Section 6 discusses Applications and Future Directions for these indicators.

While the indicators presented in this report are shown individually, many, if not most of them are inter-related. Improvements to the Soil Cover, Soil Organic Matter and Soil Erosion Indicators, for example, relate to the trends towards **reduced tillage** and the reduction in **summerfallow** on the Prairies. These same land-use trends have also driven improvements in the Particulate Matter and Greenhouse Gas Indicators. Conversely, some of the declines in the national indicators stem from these same trends; the Pesticide Indicator for example, has shown a deteriorating trend, partly due to the increased volume of pesticides needed to manage weeds and diseases associated with reduced tillage or **no-till** systems. This demonstrates that tackling agri-environmental issues requires a holistic approach that considers the health of our water, air, soils and biodiversity collectively. As a report card of our agri-environment, this publication can help inform policy makers to target issues and regions where further efforts are needed.

References

McRae, T., C.A.S. Smith, and L.J. Gregorich (eds.), 2000. *Environmental sustainability of Canadian agriculture: Report of the agri-environmental indicator project*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Organisation for Economic Co-operation and Development, 2008. Environmental performance of agriculture in OECD countries since 1990. Retrieved on July 15, 2009 from http://www.oecd.org/document/56/0,3343,en_2649_33793_40374392_1_1_1_1,00.html

2 Refer to Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector" for a description of the compound performance indices, and how they are calculated.

02 Assessing the Environmental Sustainability of the Agri-Food Sector

Authors:
T. Martin, R.L. Clearwater,
T. Hoppe, W.D. Eilers

Summary

This report covers four key aspects of primary agriculture: farmland management, soil quality, water quality and air quality. This chapter explains how Agriculture and Agri-Food Canada (AAFC) uses **agri-environmental indicators (AEIs)**[1] to conduct comprehensive national assessments, and report on Canada's agri-environmental performance. It discusses methodologies common to the indicators, and explains the common presentation standards used across the indicator set. More detailed information on how specific indicators are calculated, and on the models or algorithms used, is found in each indicator chapter.

Agri-Environmental Indicators

AEIs can be used to assess the environmental sustainability of agriculture and are designed to be responsive to changing land use and management practices and to lend themselves to the analysis of large areas. They can be used to highlight improvements over time, and to identify specific regions where policy interventions might be focused.

It should be noted that each new AEI report replaces its predecessor, as model and data refinements result in new estimates for previous years. Therefore, it is important not to compare quantitative findings from two different reports. Note as well that the suite of indicators itself is subject to review. As such, some indicators found in past reports are not reported here. For example soil trace element concentrations, which were evaluated in Report 3, are not likely to change significantly from year to year, and as such are not evaluated in this report.

To be considered consistent and credible, all AEIs have to meet the following set of fundamental criteria:

RELEVANT

Indicators must relate to agri-environmental issues that governments and other stakeholders in the agriculture and agri-food sector are seeking to address.

SCIENTIFICALLY SOUND

Indicators must rely on methodologies that are scientifically sound, reproducible, defensible, and accepted, recognizing that their development may involve successive stages of improvement.

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

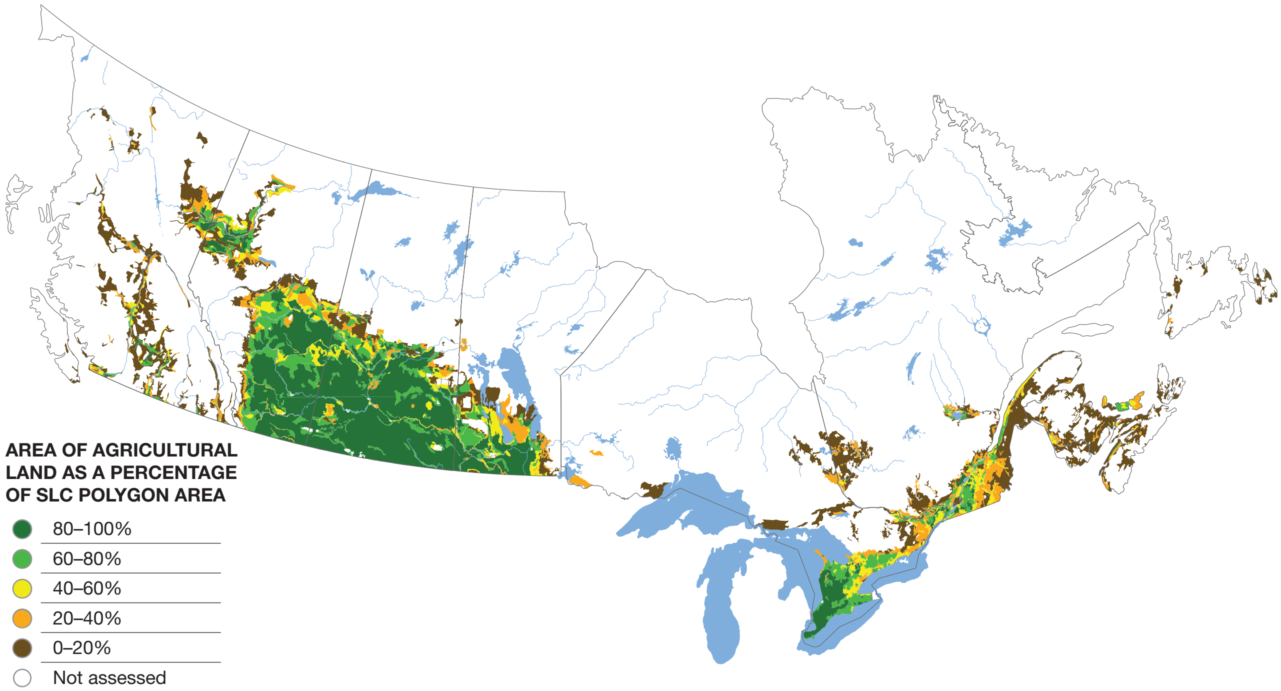

Figure 2–1: Proportion of agricultural land in Canada, 2011

UNDERSTANDABLE

The significance of the indicator values that are reported must be readily understood by a non-scientific audience.

CAPABLE OF IDENTIFYING GEOSPATIAL AND TEMPORAL CHANGE

Indicators should allow identification of trends over time and area.

FEASIBLE

Indicators should make use of existing data as much as possible and they should be economically efficient to develop.

The indicators typically fall into one of three categories:

1. *Risk indicators* are an estimate of the likelihood of a potential environmental impact.
2. *State indicators* estimate the actual presence and degree of an impact.
3. *Intensity indicators* estimate resource-use efficiency, typically by comparing inputs and outputs of a given resource, such as water or fuel.

Calculation Method

The AEIs are calculated using mathematical models or formulas that integrate information on soil, climate and landscape, mainly derived from the **Soil Landscapes of Canada (SLC)** (Soil Landscapes of Canada Working Group, 2007), with information on crops, land use, land management and livestock from the **Census of Agriculture** and other custom data sets from provincial agencies, private sector, and remote sensing. Results are generalized to provide a snapshot of an environmental condition on the landscape at a given time. The calculations and models for each indicator differ considerably, but all mathematical models and formulas have been adapted or developed from solid scientific knowledge and understanding of the interactions between various aspects of agricultural practices and the environment.

The data used to calculate AEIs are collected at various temporal and geographical scales and must be interpreted and integrated into a common geospatial framework for indicator calculation and mapping. The areas used for most of the primary agriculture indicator model calculations are the **polygons** of the SLC map series.

Figure 2–1 shows the proportion of agricultural land found in each soil polygon, based on earth observation. In fringe areas where agricultural activities are highly dispersed, SLC polygons may be omitted from some indicator calculations due to lack of verifiable information. Agriculture in the Yukon Territory, the Northwest Territories and Nunavut was also excluded from the study, for this reason.

A second framework, based on drainage area polygons derived from the National Drainage Areas (NRC, 2003), is used by some of the water risk indicators. This framework allows integration of soil and farm management information with the surface drainage network within these **watersheds**, to report risk to water quality from agricultural sources.

Summarized results from the Census of Agriculture, special surveys such as the Farm Environmental Management Survey (Statistics Canada, 2012) or combinations of these two sources are also presented in this report (Chapter 4 "Agricultural Land Use" and Chapter 5 "Farm Environmental Management") to complement the information provided by AEIs. These results are not considered indicators *per se*, but nevertheless offer important information that can help readers interpret the results of the indicators.

Understanding the Results

The AEIs communicate information in summary form about important issues from a biophysical perspective. However, their use is not strictly limited to showing present status and trends. Individual indicators may show an obvious change in risk but the complex nature of agriculture's interactions with the environment means that positive trends in one indicator may lead to negative trends in another, and therefore the indicators should not be interpreted in isolation. As well, there are broader questions to consider for the sector, such as the overall socio-economic and environmental costs and benefits associated with adopting alternative land use or management practices. As part of its efforts to develop AEIs, AAFC is also developing tools and approaches for linking these indicators to economic models as a means of providing guidance for policy and program evaluation and development. Use of the indicators in policy development is discussed in greater detail in Chapter 19 "Integrated Modelling".

Because the indicator results are expressed in different units (for example, **nitrogen** and **phosphorus** are calculated in kilograms, **greenhouse gases** in tonnes of emissions, and **coliforms** in units of population per hectare), common relative classes were developed to enable more comparisons between indicators, and to allow non-specialists to better understand the status and trends of the various indicators.

STANDARD CLASSIFICATION FRAMEWORK

A five-class rating system has been developed to interpret and compare the indicators. Each class has a general meaning in relation to environmental stability, or a given application from a policy perspective. Table 2–1 shows the rating system using terminology appropriate to the risk-focused indicators, for example the Soil Erosion and the Water Quality Risk indicators.

Maps depicting risk-based agri-environmental indicator results display colour-coded polygons based on the findings within the agricultural area of each polygon. For example, the colour red is used to indicate a high level of risk, and green is used to indicate low risk. The indicators that estimate state, for example the Air Quality Indicators, which estimate emission rates, use the same colour scheme, whereby green indicates a healthy state, yellow indicates moderate and red indicates an unhealthy state. The maps used in this report that show indicator results typically represent the most recent assessments of the conditions in question, which correspond to the status of the indicators based on 2011 Census of Agriculture data. In these maps, whole SLCs or other spatial polygons are assigned a value while the results apply only to the agricultural portion of the polygons. In addition, results per polygon are based on aggregated data and should not be attributed to any individual farm.

The trend that an indicator shows over time is just as important as the current condition or status of an indicator. Temporal trends are generally presented in tables that show the results for Canada and individual provinces for each year that the indicator was calculated. Maps are included in most chapters to show how indicator classes have changed over time, usually between 1981 and 2011.

Table 2–1: Description of indicator classes for risk indicators

Classes	Indicator Class Colour	Meaning	Implication
1. Very low risk	(dark green)	In general, this level of risk is negligible. Agri-environmental health is likely to be maintained or enhanced over time.	A more detailed analysis of the situation is warranted to understand various factors that have contributed to this rating. Some potential may exist to export policy and program approaches to areas of higher risk.
2. Low risk	(light green)	In many cases this level of risk may be acceptable. Agri-environmental health is at low risk of being significantly degraded.	Continued adoption of beneficial management practices to better match the limitations of the biophysical resource may improve sustainability in some areas. Specific (policy or program) actions are not necessarily warranted.
3. Moderate risk	(yellow)	Awareness of the situation is important. Agri-environmental health is at moderate risk of being significantly degraded.	The trend towards or away from sustainability needs to be assessed. More attention should be directed locally to promoting the adoption of beneficial management practices. This will better match the limitations of the biophysical resource and reduce this risk.
4. High risk	(orange)	Heightened concern is warranted. Under current conditions, agri-environmental health is at high risk of being significantly degraded.	A more thorough local assessment is probably warranted. Additional efforts and targeted actions are likely needed locally to better match management practices to the limitations of the biophysical resources.
5. Very high risk	(red)	Immediate attention is likely required. Under current conditions, agri-environmental health is at very high risk of being significantly degraded.	A more thorough local assessment is warranted. Concrete and targeted actions are likely needed locally to better match management practices to the limitations of the biophysical resources. It may be necessary to consider alternate land uses to reduce the risk.

AGRI-ENVIRONMENTAL PERFORMANCE INDEX

The agri-environmental performance index shows environmental performance state and trends over time, based on weighting the percentage of land in each indicator class[2], such that the index ranges from 0 (all agricultural land in the most undesirable category) to 100 (all land in the most desirable category[3]). Table 2–2 shows the index classes. The index uses the same five-colour scheme as the indicator maps whereby dark green represents a desirable or healthy state and red represents at risk or least healthy.

Table 2–2: Performance Index scale

Scale	Colour scheme	Class
80–100	(dark green)	Desired
60–79	(light green)	Good
40–59	(yellow)	Moderate
20–39	(orange)	Poor
0–19	(red)	At risk

These unit-less indices are used to present qualitative information on the performance of individual indicators over time. Because they apply a common method to enable direct comparisons between indicators, they can also be aggregated with other similar indices, to provide a snapshot of health within a given theme, such as water quality, air quality and soil quality. These compounded indices are weighted averages of those indicators within a given theme. They are calculated by applying equal weightings to national indicators, and partial weightings to those with less than national extent[4]. The indices are presented graphically at the beginning of each theme Section and each agri-environmental indicator chapter, and provide a basis for discussion of overall trends.

2 The equation is simply "(% in poor class times .25) plus (% in moderate class times .5) plus (% in good class times .75) plus (% in desired class)". As the percentage of land in the "at risk" class is multiplied by zero, it is not included in the algorithm. These class percentage values are reported in table form in all indicator chapters, rounded to no decimal places. The performance index values are derived from the original submitted data which were not rounded. Consequently applying this equation to the tables in this report may yield different values from those reported.

3 This scale of the indicators has changed slightly from previous reports. Past reports considered 0–20 to be "At risk"; 21–40 to be "Poor"; 41–60 to be "Moderate"; 61–80 to be "Good"; and 81–100 to be "Desired". All performance indices have been recalculated for all previous years using the new scale in this report.

4 All national "core" indicators have a weighted value of 1, In the case of Soil Salinization Indicator, which covers only the Prairie extent, its weighting is reduced to 0.81 to reflect the percentage of farmland area under coverage.

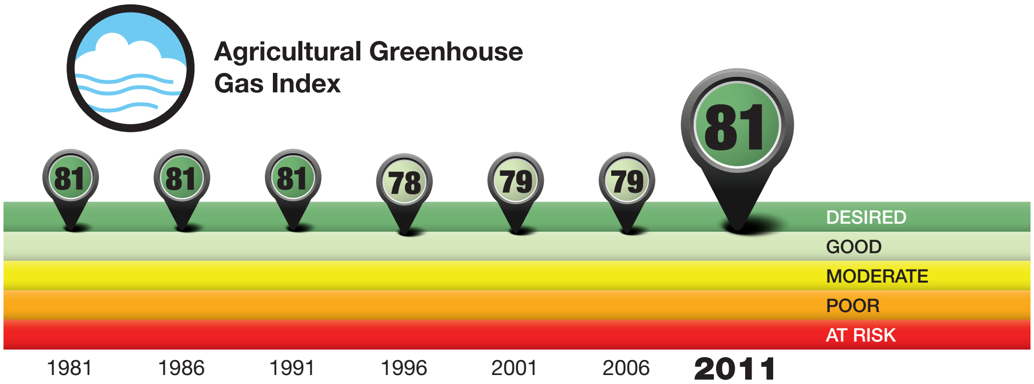

Figure 2–2: As with all indices, the Agricultural Greenhouse Gas Index figure, shown here, illustrates both current state and trends over time (1981–2011).

Figure 2–2 is an example of how the index information is displayed, showing both state and trend. The index classes are displayed on the Y axis, and the index value is given for each year. The X axis shows the years of reporting, making it possible to see whether performance has improved or declined.

Interpreting the Findings

Where feasible, this report uses terrestrial **Ecozones**, which are large generalized ecological units, and **Ecoregions**, which are more specific ecological units nested within them, as defined by the National Ecological Framework (Ecological Stratification Working Group, 1995) when interpreting AEI results, rather than reporting at a provincial scale. This is because Ecoregions describe areas of similar climate, physiography, soils, hydrology and vegetation, making them respond similarly under certain land management practices or to certain inputs, whereas provinces can include a variety of climatic or physiographic variables. Figure 2–3 shows those Ecozones and Ecoregions that are referenced in this report. Note that this is not an exhaustive list of agricultural Ecoregions as only those Ecoregions explicitly referenced in the report are labelled here.

Limitations

In developing AEIs, scientists assess the environmental performance of a complex system that is not fully understood, and must work within the limits of available data. Hence, the approach used for the development of the AEIs in this report is subject to the following general limitations. Additional limitations may apply to individual indicators which are described in each chapter, where applicable.

KNOWLEDGE GAPS

How we develop indicators depends on our understanding of the **ecosystem** processes involved. For some indicators, developing models and calculation methodologies has been underway for some time and is quite advanced while, for others, it is less developed. In some cases, the linkages between key issues are not fully understood, which may affect how the indicator results are interpreted. In addition, the boundaries of the five classes used for reporting results would ideally use science-based reference thresholds such as environmental quality standards. However, these are largely not available at a national scale. For most of the indicators, classes are based on expert knowledge and are subject to change as our knowledge improves over time.

Figure 2–3: **National Ecological Framework Ecozones and Ecoregions containing agricultural land, as referred to in this report**

SCALING-UP

In this publication, indicators are typically calculated using models that have been developed and tested at the field level, which provides a good theoretical foundation for assessment. However, the level of uncertainty in results increases when the field-tested models are used at broader scales. Due to this uncertainty, the results presented are limited to potential or relative risk assessments as opposed to determined, actual physical contributions to the environment in specific locations.

DATA ISSUES

All measured data used in calculating the indicators carry an intrinsic level of uncertainty. In addition, the required data may not always be available for all census years or for the whole country. This situation may occur because a particular parameter has not been consistently measured or surveyed (e.g. Census of Agriculture measurement of **no-till** and **conservation tillage** has only been conducted since 1991), or because data may be suppressed to protect producers' confidentiality (e.g. when there are too few instances of a particular farm activity in a given area). Alternative approaches are used to overcome these limitations and estimate the missing values, which are then used in the calculations, however data gaps can lead to skewed results. Indicators are often calculated using data that were not collected on the same spatial framework used to report the indicators, and reallocation of the data has to be performed. A prime example is the re-assignment of Statistics Canada Census of Agriculture data, which are aligned to political boundaries and cannot easily be linked to biophysical information such as that in the Soil Landscapes of Canada framework. A method based on the proportion of SLC polygon areas to Census framework area was devised to calculate and reassign the Census data to the SLC polygons (AAFC, 2004). Uncertainty is introduced through these interpolation methods, especially where agriculture is present in only a small proportion of the SLC polygon area.

Representative information on the soils and landscapes in the SLC polygons are key components for many indicators. However, data on specific soil properties or landscape characteristics are often based on limited or historic information, which can increase uncertainty.

RELIABILITY

Efforts have been made to validate the results of the indicators, however, very little independent experimental data are typically available with which to calibrate or validate the indicator model results. Though uncertainty analysis has been explored for some of the indicators, significant progress has not been possible. In this report we were unable to use statistical methods to determine the actual uncertainty associated with the indicator results.

Future Directions

Agri-food product retailers are increasingly requiring commodity groups and producers to demonstrate that products are produced in an environmentally sustainable manner. This has created a demand for indicators which identify environmental impacts or risks on the basis of a unit of production, for example per litre of milk, kilogram of beef, or tonne of grain, as discussed in Chapter 18 "Greenhouse Gas Emission Intensities of Agricultural Products". These indicators come under the broad banner of sustainability metrics, which includes life-cycle analyses, environmental footprints and intensity metrics. While continuing to address policy needs, ongoing environmental indicator development work at AAFC is focused on providing sustainability metrics and tools for major agricultural commodities.

References

Agriculture and Agri-Food Canada, 2004. *Census of agriculture: Soil landscapes of Canada (SLC), v.3 and Water survey of Canada sub-sub drainage area (WSCSSDA), v.5*, Re-allocation. Unpublished research data. Ottawa, ON Canada.

Ecological Stratification Working Group, 1995. *A National Ecological Framework for Canada*. Agriculture and Agri-Food Canada. Ottawa. Ontario.

Natural Resources Canada, 2003. *Fundamental drainage areas of Canada: National scale frameworks hydrology version 5.0*. Ottawa: ON, Canada: author.

Soil Landscapes of Canada Working Group, 2007. *Soil Landscapes of Canada v3.1.1 Agriculture and Agri-Food Canada*. (digital map and database at 1:1 million scale).

Statistics Canada, 2013. *Farm Environmental Management Survey 2011*. Catalogue no. 21-023–X. Ottawa, ON. Available from http://www.statcan.gc.ca/pub/21-023–x/21-023–x2013001-eng.htm

03 Driving Forces

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Summary

Globalization, technological innovations, decreasing profit margins and efforts to keep pace with domestic and worldwide demand for agricultural products are all factors that have spurred Canada's agriculture sector to increase its productivity and output. This has led to structural changes in the sector over the last century, some of which have had environmental implications. Supply challenges have emerged as producers struggle to adapt to increased climate variability and more frequent extreme weather events while also dealing with competition for available arable land and water. At the same time, producers face growing demands from purchasers for agricultural products with sustainability attributes. Over the years, Canadians have supported a widening array of domestic and international agreements and regulations designed to protect the environment.

The agriculture sector has responded to these driving forces by looking for ways to incorporate environmental considerations in on-farm decision making and policy development. The sector is adopting new technologies and new production and business practices. In addition, voluntary initiatives are being carried out to meet the growing demand for sustainably, and some provinces have passed regulations aimed at improving environmental outcomes. With the accumulating evidence of climate change impacts on agricultural production, there is an increasing need to adapt to changing climatic conditions.

Introduction

This chapter reviews some of the forces that have likely influenced the agriculture sector's environmental performance as measured by the **agri-environmental indicators**[1] presented in this report.

Agriculture is inextricably linked to the broader policy, economic and social contexts that exist around the world. Globalization, trade agreements, changing domestic and world demand, changing market structure, and technological innovations all influence the decisions agricultural producers make. Climatic and weather conditions are also major elements influencing crop and livestock production in the agri-food sector (Kandlikar and Risbey, 2000). Producers consider these forces and select production strategies that will enable them to achieve their desired outcomes most efficiently.

These outcomes include local environmental impacts and product attributes. Many producers are motivated by a sense of land stewardship to address the local impacts of their practices for the benefit of local communities. In addition, producers can sometimes increase their net revenue by adopting sustainable practices that decrease input costs or are directly compensated by purchasers of their products.

Producers influence the level of environmental risks and benefits that are associated with agricultural production, which can vary significantly depending on the management practices they implement and the local **ecosystems** concerned.

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

The complexity of the agriculture sector has increased over the past century, with changes occurring even more rapidly in recent years. New issues keep emerging as the sector continues to grapple with the effects of agricultural operations on the larger ecosystem. Driving forces will continue to evolve, and risks to the environment will remain present as production increases are achieved through more intensified use of agricultural land. Policy, technology and other means will be required to respond to these driving forces so that economic, environmental and social objectives can all be achieved.

Market Demand

The expanding world population, higher disposable incomes and increased life expectancies have boosted global demand for food. The world population, which stood at 7.2 billion in mid-2013, is projected to increase by almost 1 billion within the next 11 years, reaching 8.1 billion in 2025, 9.6 billion in 2050 and 10.9 billion by 2100 (United Nations, 2013). Since people are living longer, there is expected to be a significant increase in demand for food products with health-related attributes. In addition, consumer preferences are changing as a result of rising incomes in both developed and developing countries. In the case of developing countries, diets are shifting toward higher-value products including oilseeds, dairy and meat. In developed countries, there is a growing preference for products with sustainability attributes such as fair trade, organic, and food produced on farms that meet various environmental and animal welfare standards. In addition, industrial demand for non-food agricultural products (e.g. **biofuels**, bioenergy, biomaterials, and biochemicals) is growing. The rising global demand for food and non-food agricultural products has been accompanied by globalization of markets and trade liberalization, which has led to the removal of many export subsidies and import restrictions. This has made Canadian agricultural products more accessible to other countries while also opening up the possibility of trade barriers given the emerging sustainability requirements imposed by trading partners for continued access to certain markets.

Canada, with its large land base, limited population, ample water supplies and competitive industry, has successfully responded to the opportunities created by the increased demand for agricultural products, remaining a large net exporter of food (Figure 3–1). However, market forces can also have a negative effect on agriculture and agri-food production and trade. For example, the fluctuation of the Canadian dollar and the introduction of new international trade policies and regulations can adversely affect exports.

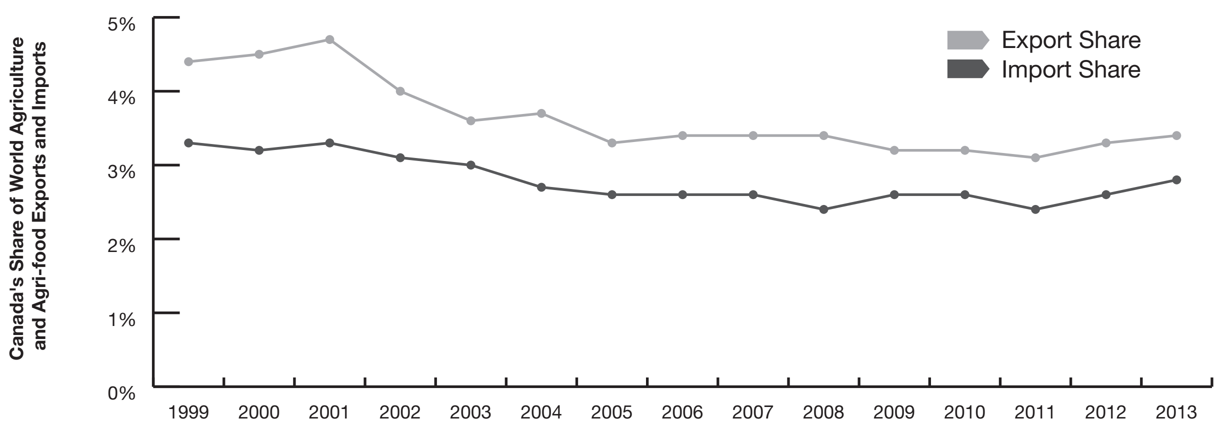


Figure 3–1: Canada's share of the world agri-food trade, 1999 to 2013 (Source: Global Trade Atlas and AAFC calculations)

Increased market demand has led to the intensification of agricultural land use over the past few decades. Between 1991 and 2013, there was a significant increase in agricultural output without a corresponding increase in land or water use. For example, the production of major grains and **oilseeds** increased roughly 57% during that period, while the area of **cropland** changed very little.

Intensification of production on a limited land base does not necessarily increase risks to agricultural resources or to the environment. **Beneficial management practices (BMPs)**, such as increased use of soil testing and judicious **nutrient** application, can reduce the likelihood that nutrients will leave fields and move into the air or water. While further intensification will be required to meet the food demands of a growing global population, the agricultural sector can mitigate the associated risks by implementing BMPs and new technologies, and by considering landscape function in order to protect the areas most at risk, such as **wetlands** and important habitat.

Some issues may reach a critical level as a result of the cumulative impacts of multiple sectors and/or land-use activities, exerting pressure on agriculture, regardless of its relative contribution. Species at risk, water quality and quantity, and **greenhouse gas (GHG)** emissions are all issues that are exposed to combined impacts which may lead to the threshold levels of use of some resources being reached.

Addressing Buyer Demands for Sustainable Attributes

Sustainable sourcing occurs when buyers take environmental considerations into account alongside the conventional criteria of price and quality when making purchasing decisions. In some sectors, this has manifested itself in consumer labelling changes, such as seafood certified by the Marine Stewardship Council and forestry products approved by the Forest Stewardship Council. In the agriculture sector, most of the pressure on the supply chain is driven directly by global corporations, such as food manufacturers and retailers, and is not visible to the consumer. Drivers include brand reputation, concerns about future supply of raw materials, costs and uncertainty related to securing capital, and the regulatory burden. Key capital market players are increasingly aware of the connection between environmental issues and companies' financial value and have been calling for greater environmental disclosure by companies. Reflecting this demand, voluntary sustainability reporting by corporations continues to grow each year as more and more corporations commit to using sustainably produced agricultural products. For example, McDonalds has made a commitment to begin purchasing verified sustainable beef in 2016. Since 2007, McCain Foods Canada has required that all its producers have an **environmental farm plan (EFP)** in place to ensure sustainable potato production. Both of these companies, along with more than 40 other food manufacturers and retailers, are also members of the Sustainable Agricultural Initiative (SAI) Platform, a non-profit organization dedicated to supporting the development and implementation of sustainable sourcing strategies.

Sustainability reporting has implications for the entire value chain. In the agriculture sector, farming is the largest source of many environmental impacts. Commodity groups, processors and retailers have responded to this market driving force by implementing a variety of systems that measure, reward and communicate their environmental performance. Essential to this reporting are metrics and data that help to measure impact per unit of production, such as **carbon footprint** tools, many of which can be derived from agri-environmental indicator data sets and methodologies.

Another significant challenge relates to the environmental requirements imposed by trading partners for continued access to certain markets, such as European Union (EU) requirements related to high-profile global environmental issues such as tropical deforestation and climate change. The Canadian agriculture sector recently faced a significant market access issue of this type, when the Canola Council of Canada was asked to provide specific data to the EU and to certify individual farms in order to help them gain access the EU **biodiesel** market. Market access issues will increase the demand for agri-environmental data at a variety of levels, from the farm scale to the national level, and will enhance comparability across different countries.

This is a rapidly changing area in which companies and trading partners are continually revising their approaches. There is general recognition that the proliferation of sourcing requirements has pushed up costs and increased the reporting burden for producers and processors.

Government Policy

Government policies operate at local, regional, provincial, national and international levels and have a strong influence on production decisions affecting the use of agricultural resources. Since the early 20th century, the primary objective of Canadian agricultural policy has been to increase output and promote income stability in a sector that has to cope with variable weather conditions, volatile commodity prices and strong international competition. Over the past few decades, government support has shifted to agricultural research focusing on ways to increase productivity and limit environmental impacts, long-term capital to finance growth and technology, income stability and trade liberalization.

Government income support peaked during the 1970s and 1980s, when the total amount of direct and indirect subsidies (the Producer Support Estimate, or PSE) reached about 30% of the value of production. Most developed countries ratified the Agreement on Agriculture in 1995 under the auspices of the World Trade Organization and agreed to reduce measures that distort trade. Canada has been a strong proponent of measures to reduce trade-distorting agricultural subsidies, since Canadian producers are considered to be highly competitive in most commodities. From 2012 to 2014, the PSE for Canada stood at a much lower level, about 11%, than in previous decades as a result of various reforms, such as the elimination of grain transportation subsidies and the decoupling of farm income safety nets from specific commodity production (OECD, 2015). The PSE for Canada is now significantly lower than the average value for member countries of the Organisation for Economic Co-operation and Development (OECD).

Not all government or commercial policies are geared to expanding production. Global pressures related to environmental issues such as climate change, ozone depletion, wildlife habitat and biological diversity have given rise to a number of international initiatives in which Canada is a participant. A wide range of policies and initiatives have been adopted both nationally and internationally with important implications for Canadian agricultural production and the environment. Examples of international environmental initiatives include:

- United Nations Framework Convention on Climate Change, which may affect agricultural greenhouse gas emissions;
- Montreal Protocol on Substances that Deplete the Ozone Layer, which eliminated the use of methyl bromide, an agricultural **fumigant**;
- United Nations Convention on Biological Diversity, which promotes conservation of crop and livestock biodiversity, habitats and species;
- North American Waterfowl Management Plan, which promotes conservation of wetlands within agricultural areas.

Canada's existing regulations pertaining to agriculture fall mainly under provincial and/or municipal jurisdiction. Producers increasingly face new or more stringent provincial and municipal regulations such as land zoning restrictions, requirements related to nutrient management plans, crop rotations and minimum **riparian buffer** widths, and a number of site-specific requirements for environmental protection (e.g. rules related to **pesticide** storage and manure storage facilities). Some of the Canadian environmental regulations that affect agriculture include:

- Canada's *Fisheries Act*, which protects fish and fish habitat and can affect management of agricultural watercourses, including irrigation and drainage canals;
- Canada's *Pest Control Products Act*, which regulates the use of pesticides based on environmental, human health and other factors;
- Prince Edward Island's *Watercourse and Wetland Protection Regulations* under the *Environmental Protection Act*, along with its *Agricultural Crop Rotation Act*, which set out requirements related to riparian buffer strip width and crop rotations, and which restrict cultivation of steeply sloped land;
- Quebec's *Agricultural Operations Regulation* under the *Environment Quality Act*, which requires producers to maintain nutrient management accounts and restricts application of excess manure.

In 2013, federal, provincial and territorial governments agreed to **Growing Forward 2** (**GF2**), an agricultural policy framework for the period 2013 to 2018. The investment under GF2 includes $2 billion (an increase of 50% from the previous framework, **Growing Forward**) for cost-shared programs delivered by provinces and territories (60% federal, 40% provincial/territorial), to ensure programs are tailored to meet regional needs. GF2 programs focus on innovation, competitiveness and market development to ensure Canadian producers and processors have the tools and resources they need to continue to innovate and capitalize on emerging market opportunities. GF2 is the cornerstone of agri-environmental policy in Canada and includes cost-shared programs that support voluntary on-farm environmental risk assessments, such as environmental farm plans (EFPs), in which environmental risks are identified and remedial action is encouraged through incentives for producers to adopt BMPs. These incentives are cost-shared, with producers contributing (often significantly) towards the cost of implementing and maintaining beneficial practices, with technical support from the provinces.

The federal-only AgriInnovation (AIP) and AgriMarketing (AMP) programs support industry initiatives and projects including some related to environmental parameters of sustainable sourcing.

In addition, a suite of Business Risk Management (BRM) programs help farmers manage risks related to severe market volatility and disaster situations. Governments also help the industry with its efforts to research, develop and implement new agricultural risk management tools.

Agriculture and Agri-Food Canada's role is to conduct research, provide funding for agri-environmental programs, provide market information, identify and promote environmental BMPs, reform trade policy and fulfill Canada's international agricultural commitments. To give producers an incentive to meet environmental goals and standards, some countries have made eligibility for farm program support contingent on environmental performance—a practice known as cross-compliance. While Canada's approach to date has consisted mainly of voluntary measures and incentives, starting with the 2013 program year, an individual province or territory may require participants to meet certain criteria before they are eligible to receive government contributions under AgriInvest—one of the BRM programs. The environment is one of the four thematic areas of the AgriInvest cross-compliance requirements.

Technological Change

At the farm level, the technological developments of the past 200 years have significantly altered the way in which producers use resources. This is particularly true of the technology explosion that marked the latter part of the 20th century. Noteworthy technological advances have included new farm implements such as air seeders, major improvements in information technology and genetic engineering and the advent of precision farming. Between 1991 and 2011, the percentage of total land prepared for seeding using no-till methods increased significantly (from 7% to 56%), producing many positive environmental effects: improved soil quality, reduced erosion, and reduced net GHG emissions through increased **carbon sequestration** in the soil. The proportion of farms using a computer to help manage the farm nearly doubled every five years from 1986 to 2001 and by 2011 stood at 60%. Among these farms, 93% use the Internet for their farm business and 75% have access to high-speed Internet.

The adoption of innovative technologies can occur rapidly when producers realize the benefits they offer. The use of GPS technology is a good example. In 2011, 47% of producers were using GPS technology for various applications that include yield mapping and soil sampling, as well as tracking systems using auto-steer equipped tractors to increase efficiencies. Among crop farms that used GPS technology, by far the most common use was for guidance or tracking systems (auto-steer), with an uptake rate of 90% in 2011, while yield mapping was used by 19% of the farms. GPS use also increases with farm size, with more than 80% of producers that manage 1,000 acres or more using GPS technology.

These developments have shifted the emphasis in agriculture away from physical labour to activities based more on knowledge and skills. Modern agriculture is characterized by a reduction in physical labour and a move towards specialization, concentration of production and consolidation of holdings. Specialization has spread through entire regions where specific crops are most profitable, and where farms previously supplied a wider range of crops to local markets. Since the prices for specialized crops tend to fluctuate, producers have also adapted by adding value through processing, introducing and developing markets and production practices for new crops, and becoming more involved in crop selling online or via market agents. For most commodities, distance to market is no longer the most important factor in deciding where production should take place.

The effect these technological changes are having on the sector's environmental performance is the subject of considerable debate. Some technologies have had unanticipated, adverse effects on the environment, such as the fumigant methyl bromide, which has been phased out because of negative effects on stratospheric **ozone**.

Other new technologies and practices have the potential to reduce environmental risks or have minimal adverse impacts, such as biological pest control, improved manure management, more efficient livestock diets and conservation tillage. **Biotechnology** and genetic engineering potentially offer considerable advantages to farmers for improving crop yields. Herbicide tolerance and insect resistance—the dominant traits of **genetically modified (GM)** crops—can help increase crop productivity and, in the case of insect-resistant-strains, can also reduce pesticide use. However, in Canada and elsewhere, there has been considerable debate about the merits of these technologies because of the uncertainty surrounding the long-term environmental and human health effects. In some instances, restrictions imposed by other countries have created market barriers for Canadian GM products.

Another emerging technology relates to the use of agricultural feedstocks for a number of bioproducts, such as biofuels. **Fossil fuel** prices and the desire to decrease GHG emissions have sparked interest in the domestic production of biofuels, which currently involves converting plant **biomass** (typically corn or canola in Canada) into ethanol, biodiesel, biogas and hydrogen. Current research is focusing on the next generation of biofuels that will be manufactured from the cellulose contained in **crop residues**. This technology will enable biofuel production that does not compete for future demands for food. Bioenergy can be generated from farm waste as well. Research is currently being carried out on **anaerobic digesters** that can convert agri-food waste and animal manure into biogas that can be used on-farm or, where suitable policies are in place, can be sold to electric utilities and natural gas companies. Emerging demand for various bioproducts such as biochemicals (e.g. aspartic acid from sugar beets) and biomaterials such as foams and **bioplastics** is creating new opportunities in bio-based manufacturing and value-added crops.

Climate Change

Temperature, moisture, and weather conditions greatly influence plant and animal productivity, input levels, management practices, yields and economic returns on Canadian farms. Climate change is expected to alter growing conditions and climate-related risks and opportunities. Adapting to weather is something farmers have always done; however, given the predicted increases in climate- and weather-related risks, the ability to adapt to future conditions will be critical for the ongoing development of the agri-food sector.

Research to date has identified a number of risks and some opportunities associated with climate change for the agri-food sector across Canada (Campbell et al., 2014). Climate change projections often focus on increases in temperature, which could be beneficial if they generate production opportunities from the extended growing season and increases in available heat units. More heat and a longer season should allow for increased flexibility in timing of operations and in choice of crops or varieties, particularly on northern margins. For instance, Quebec and Ontario producers have been able to expand grain production with plant cultivar development, and they expect to be able to expand their corn and soybean production to more northerly agricultural regions. Although the opportunity to extend agricultural production northward is appealing and often assumed to be possible, soil quality, moisture availability, and other constraints may impede such developments. In addition, excess heat beyond a certain threshold can reduce productivity for both crops and livestock and increase water demand, posing additional challenges for farmers. Other changes in climatic conditions projected for Canada include a small increase in total precipitation but with shifting patterns; more precipitation in the winter -and spring than in summer and fall; and more rain than snow. These changes are expected to impact regional hydrology and could lead to water challenges during the growing season, particularly in areas that depend on snowmelt to recharge streams through the summer. As well, climate change is expected have an effect on the frequency, magnitude, and extent of extreme events such as droughts and floods (Environment Canada, 2013) as well as on new pests and diseases. Climate is naturally variable and agricultural systems have evolved to cope with modest variations in conditions, but they are susceptible to extremes.

Despite the important economic consequences of climate change, it is often characterized as primarily an environmental issue with impacts being defined in terms of temperature zones, production conditions, growing season conditions, and/or yields. However, climatic and weather conditions pose risks for the financial viability of individual farm businesses, regional agricultural sectors, and rural communities, depending on agricultural activity. For example, drought or flooding induced by extremes in climate and weather can result in crop failures and subsequent financial hardships for agricultural producers. Also affected are agribusiness firms that supply inputs, process outputs, and provide services, and the institutions that fund support programs related to agricultural production. For example, a crop loss early in the growing season would result in less chemical inputs, less product available for processing, and less income to purchase equipment. It would also mean less income for farm-related upgrades or to retain farm workers, and would place greater strain on income support programs.

Ready for the Future

The environmental, technical and market challenges that drive agriculture have led farmers, the agri-food industry and government to build awareness, resilience and adaptive capacity. Many technologies and administrative tools have been created to prepare the agricultural industry for the future. For example, EFPs are voluntarily prepared by farm families to increase their environmental awareness about different aspects of their operations. Through this assessment process, farmers highlight their farm's environmental strengths, identify areas of environmental concern, and set realistic action plans to improve environmental conditions. Environmental cost-shared programs are available to assist in implementing projects. Governments are also carrying out numerous adaptation activities related to agriculture. These include monitoring and surveillance for animal diseases and plant pests, supporting research into developing pest- and drought-resistant crops and reviewing business risk management approaches. Research-led innovations can ensure that Canada capitalizes on the agricultural advantages it enjoys. We are already seeing the adoption of adaptation measures such as greater diversification and changes in farming practices aimed at increasing environmental sustainability (Oliver, 2013). These, along with many other innovations and developments, are building resilience within the Canadian agricultural sector against future changes and uncertainties.

References

Campbell, I.D., Durant D.G., Hunter, K.L. and Hyatt, K.D. (2014): Food Production. In: Warren, F.J. and D.S. Lemmen (eds.). *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*, Government of Canada, Ottawa, ON, p. 99-134.

Environment Canada. 2013. *Canada's sixth national report on climate change 2014 : actions to meet commitments under the United Nations Framework Convention on Climate Change*. Government of Canada; Ottawa, ON, Canada.

Kandlikar, M., and J. Risbey, 2000. *Agricultural impacts of climate change: If adaptation is the answer, what is the question?* Climatic Change 45: 529-539.

Oliver, S., 2013. *What does a changing climate mean for Canadian agriculture?* Canada 2020 Analytical Commentary: No. 02, March 2013.

Organisation for Economic Co-operation and Development (OECD). 2015. *Agricultural Policy Monitoring and Evaluation 2015*, OECD Publishing, Paris.

Reid, S., B. Smit, W. Caldwell, and S. Belliveau, 2007. *Vulnerability and adaptation to climate risks in Ontario agriculture.* Mitigation and Adaptation Strategies for Global Change. 12:609-637.

Smit, B., and O. Pilifosova, 2003. From adaptation to adaptive capacity and vulnerability reduction. In: Smith, J.B., R.J.T. Klein, and S. Huq (eds.). *Climate change, adaptive capacity and development*. London, England: Imperial College Press.

United Nations, Department of Economic and Social Affairs, Population Division, 2013. *World population prospects: The 2012 revision, Highlights and advance tables*. Working Paper No. ESA/P/WP.228.

Summary of agricultural statistics in Canada, 2011

Land Statistics

Total area	998,5 million ha
Total land area	909,4 million ha
Total farm area	64,8 million ha
Cultivated land	58%
Pastureland	31%
Other land	11%
Average farm area	315 ha

Farm Characteristics

Total number of farms	205,730
Total number of families (unincorporated)	150,745
Total number of operators	294,000
Average age of operators	54
Education level of operators	
University degree	13%
No university degree	87%

Major Agricultural Outputs

Cattle & calves	$6.3 billion
Dairy	$5.8 billion
Hogs	$3.9 billion
Canola	$7.7 billion
Poultry & eggs	$3.4 billion
Wheat	$4.1 billion
Potatoes	$1 billion
Corn	$2.1 billion

Livestock Population (number of animals)

Poultry	133 million
Cattle and calves	13 million
Pigs	13 million
Dairy cows	1 million

Farm Income

Total net cash income	$11.4 billion
Total cash receipts	$49.6 billion
Total operating expenses	$42.2 billion
Distribution of farms by revenue class	
Less than $10,000	21%
$10,000 to $49,000	28%
$50,000 to $100,000	12%
More than $100,000	38%

Food and Beverage Industry

Total number of establishments – December	6,112
Small (less than 50 employees)	83%
Medium (50 to 199 employees)	13%
Large (more than 200 employees)	4%
Total value of shipments	$91.3 billion
Food processing	$80.6 billion
Meat products	28%
Dairy products	16%
Grain and oilseed miling	12%
Bakery and tortilla products	10%
Other food	34%
Beverages	$10.7 billion

International Trade Statistics

Trade surplus	$9.4 billion
Exports	
Total agricultural exports	$40.4 billion
Primary	49%
Processed	51%
Major export markets	
U.S.	49%
China	9%
Japan	7%
EU	7%
Mexico	4%
Imports	
Total agricultural imports	$31.0 billion
Primary	29%
Processed	71%
Major import markets	
U.S.	60%
EU	12%
Mexico	4%
Brazil	3%
China	2%

Contribution to GDP (in 2007 Real Dollars)

Agri-food sector	$45.1 billion
Primary agriculture	$17.4 billion
Food processing	$27.7 billion

DATA SOURCES

The main source of statistics on land use, livestock populations, farm characteristics and farm income is: Statistics Canada, 2011. *Census of Agriculture.*
Food and beverage industry: Statistics Canada, 2011. *Annual Survey of Manufactures and Logging.*
International trade, import and export markets: Statistics Canada. 2011. *Canadian International Merchandise Trade Database and AAFC calculations.*
Contribution to GDP: Statistics Canada, Canadian System of National Accounts (CSNA) (and AAFC calculations)

Farmland Management

Summary

How farmland is managed is a primary determinant of agriculture's environmental performance. The **Census of Agriculture**[1] and the Farm Environmental Management Survey (FEMS) are two important surveys that provide useful information for determining how agriculture is changing over time and about activities and **beneficial management practices** (**BMPs**) that are being implemented to address the environmental risks associated with agriculture. The surveys provide the data for two key summaries that, while not indicators themselves, provide highly relevant information and trends related to the status of agriculture and agricultural practices.

- The Agricultural Land Use Chapter (Chapter 4) provides an overview of changes in land use, cropping and tillage practices, and livestock populations that occurred between 1981 and 2011 in Canada. This overview is based on data from the Census of Agriculture, which is used by the **agri-environmental indicators** to track practices and their effect on the environment. This is a key component for assessing agriculture's environmental performance.
- The Farm Environmental Management Chapter (Chapter 5) presents a summary of key findings from the 2011 FEMS questionnaire which gathered information on management practices used by producers in 2011. Producers were asked about manure storage and spreading, grazing practices, crop and **nutrient** management, **pesticide** application, wildlife damage, land and water management, waste management, and environmental farm planning.

Farmland management influences the environment in many ways, including the efficiency of resource use and conservation and the availability of wildlife habitat. The Soil Cover Indicator and the Wildlife Habitat Capacity on Farmland Indicator are reported on in this section of the report. Together, they feed into the **Biodiversity** Compound Index featured at the end of this summary.

1. The Soil Cover Indicator (Chapter 6) estimates the number of days in a year that agricultural soils are covered and protected from erosive forces. An increase in the number of soil cover days over time indicates an improvement in environmental sustainability since the soil is better protected from degradation and is less likely to contribute to water contamination and atmospheric emissions.
2. The Wildlife Habitat Capacity on Farmland Indicator (Chapter 7) assesses broad-scale trends in the capacity of the Canadian agricultural landscape to provide suitable habitat for populations of terrestrial vertebrates. Agricultural landscapes are dynamic, with both beneficial and detrimental land-cover changes driven by economic forces. It is the nature of these changes that ultimately determines the habitat capacity of a landscape, and the structure and viability of the wildlife populations that are present. Assessing the wildlife habitat capacity of farmland is an important step in understanding the impact of agriculture on the environment.

Two prevalent trends in Canadian agricultural production were discernable between 1981 and 2011—the consolidation of farmland into fewer farms, and the increasing intensity of production on those farms. Increases in intensity are reflected in the growth in **oilseed** and pulse crop areas, declines in the area of **summerfallow** and cereal grains, and increases in livestock numbers per farm.

The use of summerfallow across the Prairies has been declining since the early 1980s.The primary driver for the decline in summerfallow has been the increase in **reduced tillage** and **no-till**, which has been made possible through the availability of effective **herbicides** and the availability of planting equipment that can seed through **crop residue** on the surface.

The use of reduced tillage and no-till has increased steadily since the early 1990s, as part of the push to reduce fuel costs and improve soil health. Between 2006 and 2011, the total area of agricultural land on which **intensive tillage** was carried out declined by 30.9%. In 2011, no-till land management was applied on more than 50% of all agricultural areas prepared for seeding in Canada (Statistics Canada, 2011[2]). The decreased use of summerfallow coupled with the rise in reduced tillage and no-till resulted in a national-scale improvement in average levels of soil cover. From 1981 to 2011, average levels of soil cover in Canada increased by 7.6%.

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each Chapter or section.

2 Statistics Canada, 2011. *Table 004–0010 – Census of Agriculture, selected land management practices and tillage practices used to prepare land for seeding,* Canada and provinces, every 5 years, CANSIM (database).

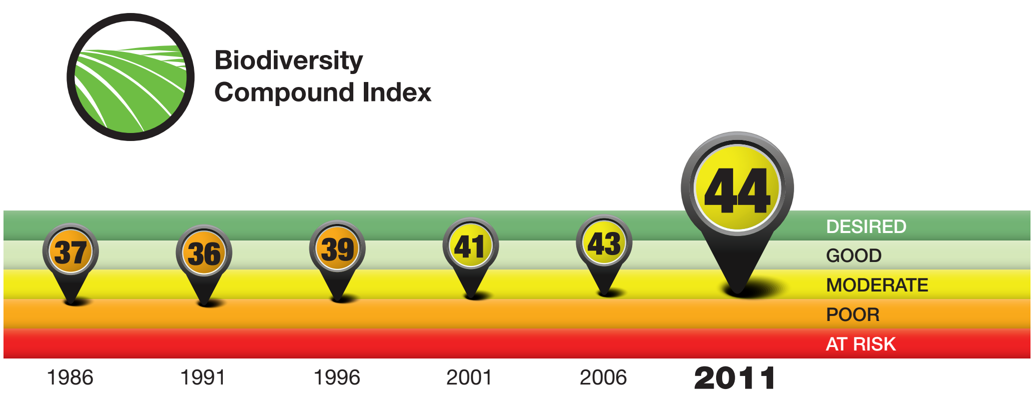
From 1986 to 1996, wildlife habitat capacity (WHC) was relatively stable; however, from 1996 to 2011 there was an overall decline in WHC at the national scale, despite the reduction in summerfallow (which offers limited capacity for wildlife) and the increase in soil cover. The decline in WHC was primarily due to the intensification of farming as well as the loss of natural and semi-natural land, which is largely a result of the shift away from pasture and forage production to annual cropping, especially in Eastern Canada.

For the most part, the 2011 results reflected the positive adoption of nutrient management practices by producers, such as soil nutrient testing, timing optimization, application and incorporation of solid and liquid manure and **fertilizer**, and increased manure storage capacity. However, there were some notable changes in fungicide use and decreases in the implementation of some erosion control practices, which were associated with an increase in the use of reduced tillage.

Total numbers of all major livestock categories increased over the 30-year period for the country as a whole. During this period, there were some noteworthy trends in the cattle industry. Since 1981, the beef cattle industry in Canada grew steadily, reaching a peak between 2001 and 2006. Since 2006, the beef herd size has been declining, mainly as a result of a decline in consumer demand for beef, but also as a holdover from the **Bovine Spongiform Encephalitis (BSE)** outbreak in 2003–2004. In contrast, between 1981 and 2011, the number of dairy cows declined steadily with a 46% drop over the 30 years and a 3.4% decline between 2006 and 2011. The primary reason for the general decline in dairy cattle numbers has been a dramatic increase in milk production per cow, which has been facilitated by the consolidation of dairy farms and improved feed efficiency.

Biodiversity Compound Index

The overall trend from 1981 to 2011 for biodiversity shows improvements across Canada, as depicted by the Biodiversity Compound Index below.



This compound performance index is a weighted average of the Soil cover and Wildlife Habitat Capacity performance indices.[3] As such, it is a highly generalized statistical snapshot of these two variables both in terms of current state and changes over time. More information on how performance indices are calculated can be found in Chapter 2 “Assessing the Environmental Sustainability of the Agri-Food Sector.”

3 All national “core” indicators, which include Soil Cover and Wildlife Habitat Capacity on Farmland, have a weighted value of 1.

04 Agricultural Land Use

Authors:
B. Daneshfar and T. Huffman

Status:
National Coverage, 1981 to 2011

Summary

Agricultural land use and management practices are key determinants of the current status of agri-environmental sustainability in Canada. Changes in these factors influence the direction of the trend in sustainability. Reliable information on agricultural land use and management practices is critical for assessing the agriculture sector's environmental performance.

From 1981 to 2011, there was an increase in the area planted to **oilseed** and pulse crops as well as in livestock numbers per farm. While production changes such as these tend to increase the level of environmental risk, over the past several decades the higher level of risk has been offset by environmentally beneficial trends, including the shift from **conventional tillage**[1] to **conservation tillage** and **no-till**, the widespread decline in the area devoted to **summerfallow**, and the decline in the number of dairy cattle.

This chapter provides a general overview of the situation and of trends related to livestock numbers, tillage practices and land use and crop area as an aid to understanding and interpreting the various **agri-environmental indicators** presented in this report, which address specific environmental issues in detail.

The Issue and Why it Matters

Agri-environmental sustainability depends on the widespread use of agricultural management practices designed to prevent or reduce the degradation of land, water and air. As an example, an increase in the area of row crops under no-till, or an increase in the amount of land used to grow hay, pasture or other perennial crops can lower the risk of soil erosion and improve the sustainability of soil resources. Conversely, an increase in the area of row crops grown under conventional tillage or without erosion-control measures boosts the risk of soil erosion and reduces sustainability. Similarly, changes in the number, type and location of livestock can have significant implications for air, soil and water quality. The level of environmental risk may increase or decrease depending on the specific management practices employed, such as the tillage and manure management methods used in crop and livestock production.

Reliable information on trends in agricultural land use and management practices over time is essential for assessing the ways in which the environmental sustainability of agriculture is changing. It is also important for understanding risks and opportunities, and for developing practices, policies, and programs that foster sustainable agricultural production. This information serves as both inputs to and a key to interpreting the agri-environmental indicators.

There are a number of drivers that influence agricultural land use, including farm consolidation and intensification, changing consumer preferences, and market demands. A good illustration of this is provided by the global market response to the **Bovine Spongiform Encephalitis (BSE)** outbreak, which led to an appreciable decline in beef and **forage** production from 2006 to 2011, and an increase in the area devoted to annual crops. These changes in turn affected other indicators and factors such as soil fertility, erosion risk, risk of water contamination, the agriculture sector's contribution to **greenhouse gas (GHG)** emissions, and the abundance of wildlife habitat.

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

Agricultural Land-Use and Management Information

This Chapter presents some of the key changes in land use, cropping practices, tillage practices and livestock populations that occurred between 1981 and 2011 in Canada, based on data from the **Census of Agriculture**. The potential environmental implications of these trends are identified and explored in more detail in the specific indicator chapters of this report.

LAND USE

The total area of farmland in Canada includes field crops, hay, fruit, vegetables and other specialty crops, pasture, rangeland, and **all other land** owned by producers, such as woodland, **wetland** and land with buildings, yards, gardens and lanes. Different land uses have potentially different environmental risks. To present an overview of long-term land-use trends for each province and for Canada as a whole, four Census land-use variables have been used in this report:

1. Area of **cropland** (includes hay; excludes summerfallow and pasture)
2. Area of summerfallow
3. Area of pasture (improved pasture and rangeland)
4. Area of "other land" (This encompasses the newly designated "woodlands and wetlands" category, which consists of woodlots, sugarbushes, windbreaks, marshes, bogs, ponds and sloughs; the "all other land" category includes idle land and land with farm buildings, barnyards, lanes, and home gardens.)

CROPPING PRACTICES

In addition to having land-use data, it is important to know the crop types that are grown in a given region and the associated temporal trends, because different crop types and cropping patterns typically have differing effects on the environment. Seven Census variables are presented:

1. Area of **cereal** grains (wheat, barley, oats and mixed grains)
2. Area of **oilseeds** (canola, mustard, flax, safflower and sunflower)
3. Area of corn (grain corn and silage corn)
4. Area of potatoes
5. Area of pulse crops (beans [including **soybeans**], lentils and peas)
6. Area of forage crops (alfalfa, tame hay and forage seed)
7. Area of other crops (all other crops such as sugar beets, vegetables, fruit, grapes and berries, etc.)

TILLAGE PRACTICES

When interpreting land-use trends, it is important to consider the management practices employed by agricultural producers. The practices considered in this Chapter relate to tillage and weed control, and include the distribution of conventional (intensive) tillage, conservation (reduced) tillage and no-till practices. These have been included in the Census of Agriculture since 1991 using six variables:

1. Area of cropland prepared for seeding using conventional (intensive) tillage (tillage practices that turn over the top 15 to 20 cm of soil, burying plant residues and exposing the soil, followed by secondary tillage to break up soil aggregates and produce a smooth, even seedbed);
2. Area of land prepared for seeding using conservation (reduced) tillage (tillage practices that break up the soil and kill weeds but do not turn the soil over, thus maintaining most of the **crop residue** on the surface);
3. Area of land prepared for seeding using no-till (management practice in which there is no tillage after one crop is harvested and the next crop is sown; all plant residues are maintained on the soil surface);
4. Area of summerfallow on which weeds are controlled by tillage only (the practice of fallowing traditionally includes periodic tillage during the growing season, which buries crop residue);
5. Area of summerfallow on which weeds are controlled by a combination of chemical applications and tillage (chemical and tillage weed control involves reduced tillage frequency or only spot cultivation);
6. Area of summerfallow on which weeds are controlled by chemicals only (no tillage).

LIVESTOCK

Data on the number, location and type of livestock, together with associated changes over time, are essential for assessing the relationship between agricultural production practices and the health of the environment. The crop and livestock sectors are closely connected, as the cropping systems used by many farms are determined by the feed and manure management requirements of on-farm livestock. In addition, efficient local production of some crop types encourages the development of specific livestock production systems. This relationship between land use and livestock production has significant implications for assessing and mitigating greenhouse gas emissions, soil erosion, surface water and **ground water** contamination, soil **carbon** depletion and air quality degradation. In this report, the number of animals in each of the five categories below has been used to identify relevant changes and trends:

1. Dairy cows
2. Beef cows
3. Pigs
4. Poultry
5. Sheep and goats

Limitations

One of the main concerns related to the analysis of land-use, crop, tillage, and livestock data is the tendency to interpret individual activities in isolation from other factors, including management practices that are being used but cannot be included, for lack of data. For example, an increase in confined livestock numbers could result in an increase in **methane** emissions and a higher risk of water contamination. However, if the increase in animal numbers is accompanied by improvements in air quality control and in manure storage and handling, the overall effect may be an improvement in environmental sustainability. Similarly, an increase in potato production may leave larger areas of soil unprotected over the winter; however, if **winter cover crops** are added to the potato rotation, the net effect may be an improvement in soil protection.

Another limitation to the numbers reported in this Chapter relates to changes in Census of Agriculture questions over time, and the possibility that the Census questions have been misinterpreted by respondents. For example, in 1981 the area of unimproved pasture was under-reported in the four western provinces, because it was aggregated with non-agricultural land-use classes such as marshes. Therefore the data were not directly comparable with previous years. This also affected the area of total farmland and "other land" categories for each of the western provinces and for Canada as a whole. The interpretation of livestock numbers may be problematic in the case of farm animals (e.g. poultry and hogs) that undergo more than one "cycle" per year. The Census reports the number of animals held on-farm at a specific point in time; however, if it is assumed that this total number of animals is resident at the farm throughout the year, the environmental impact may be overestimated if there are time periods between production cycles when there are fewer or no animals on-site. A more complete description of Census data quality and potential errors is provided by Statistics Canada (2011a).

Results and Interpretation

LAND USE

Based on the 2011 Census of Agriculture, total farm area (including cropland, pasture, forest, wetlands and all other land owned by agricultural producers) made up 7.2% of the total land base in Canada. Newfoundland and Labrador accounted for the lowest percentage (0.1%) and Prince Edward Island and Saskatchewan for the highest percentage (about 42%) (Statistics Canada, 2011b).

In Canada, cropland (including all annual field crops, alfalfa and tame hay, summerfallow, vegetables, fruits, nursery crops and sod) has traditionally accounted for the largest proportion (58% in 2011) of the more than 64 million hectares (ha) of agricultural land (farm area) reported in the 2011 Census of Agriculture (Statistics Canada, 2011c; Statistics Canada, 2011d). Total pasture, including tame or seeded pasture and natural grassland (rangeland), made up 31% of the total farm area, and the remainder (11.0%) consisted of "other land," which includes woodlands, wetlands, farmsteads, lanes and gardens (Figure 4–1).

Canadian agriculture is a dynamic industry in which changes in land use occur over time. Table 4–1 shows the magnitude and temporal variation in the ratio of the main agricultural land-use classes to total farmland in Canada (Statistics Canada, 2011c). Between 1981 and 2011, changes in the national farmland area were driven by trends in Manitoba, Saskatchewan, Alberta and British Columbia, which showed an increase in farmland area between 1981 and 2006, followed by a decline to 2011. These changes can be attributed to generally improving commodity markets and increasing cattle numbers to 2005, followed by increasing input costs which promoted a drive to increased economic efficiency and the abandonment of marginal land. In Eastern Canada, farmland area has gradually declined over the same time period due to conversion to urban use and the abandonment of poor quality land.

Over the period 1981 to 2011, cropland and tame pasture showed an overall increasing trend, and summerfallow exhibited an overall decreasing trend, at the national level (Figure 4–2). In Ontario, Quebec, Prince Edward Island and the Prairie Provinces, cropland has ranked as the major land-use class in every Census year since 1981 and has shown a slightly increasing trend in most regions and in Canada as a whole. Improved pasture (tame or seeded) area has been decreasing since 1981 in all provinces except Alberta, Saskatchewan and Manitoba, where it has been increasing.

Summerfallow is the practice of leaving a field without a crop for one year in order to control weeds and allow soil moisture levels to increase. In Canada fallowing is carried out almost exclusively in the Prairie region and primarily in the semi-arid grassland regions of southern Saskatchewan and Alberta. Although weed control during a fallow year has traditionally been carried out through repeated cultivation, the use of herbicides ("chem-fallow") has become much more common over the past 30 years. The use of summerfallow has been declining across the Prairies since the early 1980s, falling from around 10 million hectares in 1981 to around 2 million hectares in 2011 (Statistics Canada, 2011g). The downward trend in summerfallow area continued until 2011, with a decrease of approximately 40.5% recorded from 2006 to 2011. In 2011, summerfallow made up about 3% of the total farm area in Canada (Table 4–1) (Statistics Canada, 2011d). The decline in summerfallow has been driven primarily by the adoption of no-till, which has been made possible by the increased availability of effective herbicides and planting equipment that can effectively seed through crop residue on the soil surface. No-till offers several benefits: better retention of soil moisture, lower risk of soil erosion during fallow years, and reduced fuel use.

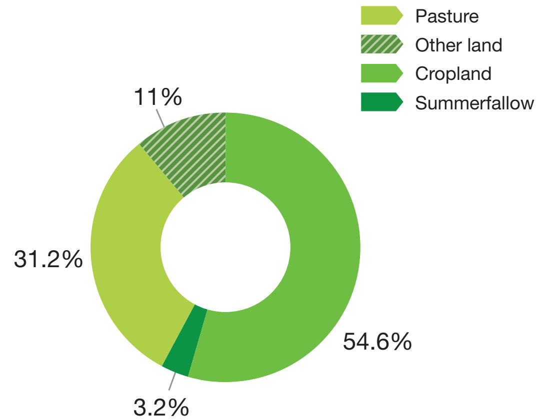


Figure 4–1: Percent of agricultural land use as a proportion of total farm area in 2011 in Canada (Statistics Canada, 2011d)

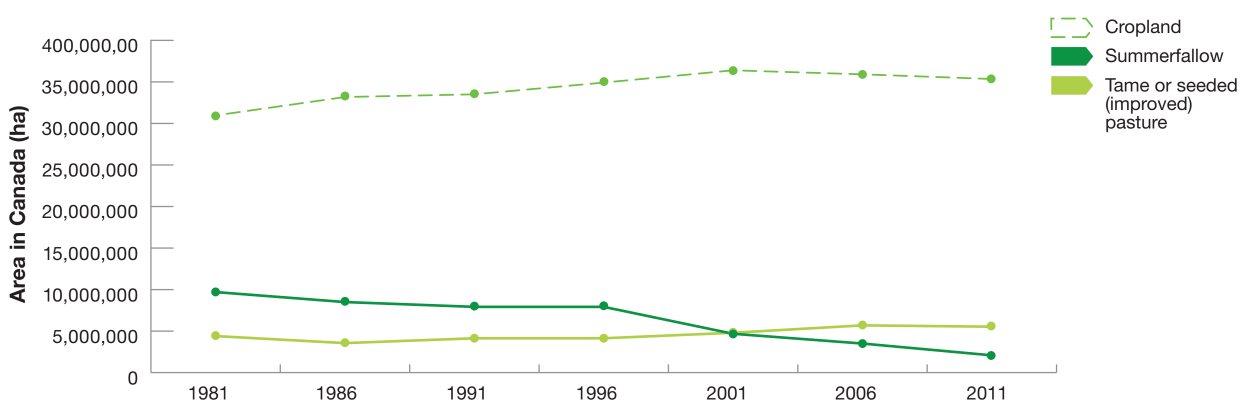


Figure 4–2: Temporal variation of use of farmland between 1981 and 2011 in Canada (Statistics Canada, 2011c)

Table 4–1: Agricultural land use as a share (percentage) of farmland, 1981 to 2011 (based on Statistics Canada, 2011c)

				Share of Farmland in Various Uses (%) ("-" indicates less than 1%)																											
	Area of Farmland (ha)			Cropland							Summerfallow							Pasture							Other Land						
Province	1981	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	2,178,596	2,835,458	2,620,889	26	24	23	23	24	21	23	3	3	2	2	1	1	1	59	51	53	56	56	62	62	12	22	21	20	19	17	15
Alberta	19,108,513	21,095,393	20,415,173	44	44	45	45	46	46	48	12	10	9	7	6	4	3	40	38	40	41	42	43	43	4	7	6	7	6	7	7
Saskatchewan	25,947,086	26,002,606	24,951,334	45	50	50	54	59	58	59	26	21	21	17	12	9	6	27	24	24	24	25	27	28	2	5	5	5	5	6	8
Manitoba	7,615,926	7,718,570	7,293,419	58	58	62	61	62	61	60	8	7	4	4	3	2	1	29	26	27	26	26	27	26	5	9	7	9	9	11	13
Ontario	6,039,237	5,386,453	5,129,202	60	61	63	63	67	68	71	1	1	1	-	-	-	-	24	19	19	18	15	14	13	15	19	17	18	17	18	16
Quebec	3,779,169	3,462,936	3,338,960	46	48	48	51	54	56	56	1	1	-	-	-	-	-	21	17	19	15	11	9	8	31	34	33	34	35	35	36
New Brunswick	437,888	395,228	380,116	30	32	33	36	39	39	38	1	1	-	-	-	-	-	20	14	16	13	12	11	10	49	53	52	51	49	50	52
Nova Scotia	466,023	403,044	411,815	24	26	27	29	32	31	29	1	1	-	-	-	-	-	20	16	17	14	14	14	11	55	56	56	56	55	55	59
Prince Edward Island	283,024	250,859	240,514	56	57	60	64	67	68	69	1	1	-	-	-	-	-	18	14	14	10	9	9	7	25	28	27	25	23	22	23
Newfoundland and Labrador	33,454	36,195	31,302	14	13	13	17	21	26	27	1	1	-	-	-	-	-	64	34	39	21	24	35	33	21	52	47	62	55	39	40
Canada	**65,888,916**	**67,586,741**	**64,812,723**	**47**	**49**	**49**	**51**	**54**	**53**	**55**	**15**	**13**	**12**	**9**	**7**	**5**	**3**	**31**	**28**	**30**	**29**	**30**	**31**	**31**	**7**	**10**	**9**	**10**	**9**	**10**	**11**

* This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011.

Table 4–2: Share of cropland in various uses, 1981 to 2011 (based on Statistics Canada, 2011e)

				Share of Farmland in Various Uses (%) ("-" indicates less than 1%)																																																
	Area of Cropland (ha)			Cereal Grains							Oilseeds							Corn							Potatoes							Pulse Crops &Soybeans							Forages							Other Crops						
Province	1981	2006	2011*	81	86	91	96	01	06	11	81	86	91	96	01	06	11	81	86	91	96	01	06	11	81	86	91	96	01	06	11	81	86	91	96	01	06	11	81	86	91	96	01	06	11	81	86	91	96	01	06	11
BC	568,241	589,803	607,176	30	22	22	22	17	15	17	4	8	7	5	4	4	6	2	2	2	2	2	2	2	1	1	1	1	1	1	-	-	-	-	1	1	-	1	58	62	63	64	70	71	66	5	5	5	7	6	6	7
AB	8,441,242	9,622,121	9,739,832	71	65	65	63	57	52	48	8	13	14	14	11	18	26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	3	3	4	20	21	20	21	27	26	22	-	-	-	-	-	-	1
SK	11,740,864	14,960,355	14,746,108	85	80	78	71	58	52	45	6	11	12	15	17	21	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	4	14	11	12	8	7	7	8	10	14	13	-	1	1	2	-	1	1
MB	4,420,369	4,701,355	4,341,760	67	64	62	60	52	45	38	15	17	18	19	21	25	33	2	1	1	1	1	2	3	-	-	-	1	1	1	1	1	2	3	2	4	6	8	13	14	15	16	20	21	18	1	3	1	1	1	1	1
ON	3,632,727	3,667,333	3,622,040	24	25	19	18	15	20	17	-	-	1	1	-	-	1	31	27	26	25	26	21	26	-	-	-	-	-	-	-	10	13	19	23	25	26	29	30	30	31	29	28	28	23	5	5	4	4	6	4	4
QC	1,756,038	1,941,166	1,881,255	20	20	20	16	17	16	13	-	-	-	-	-	-	1	14	17	20	21	26	24	24	1	1	1	1	1	1	1	-	-	2	6	8	9	15	61	59	53	50	42	44	41	4	3	4	5	5	5	5
NB	130,526	154,209	144,282	20	21	21	22	21	17	15	-	-	-	-	-	-	6	1	1	1	1	2	3	5	17	15	17	16	16	16	15	-	-	-	-	-	1	0	56	56	53	50	52	54	49	6	7	8	10	9	9	11
NS	112,782	125,742	121,322	16	13	12	10	9	7	6	-	-	-	-	-	-	-	4	4	3	4	5	6	8	1	1	2	2	2	1	1	-	-	-	-	1	1	3	65	64	64	58	58	60	55	13	17	19	27	26	26	27
PEI	158,280	171,494	166,349	46	-	41	37	36	32	27	-	-	-	-	-	-	-	2	1	1	1	1	2	3	16	17	20	26	25	23	21	-	1	2	1	2	3	13	33	34	33	32	33	37	31	3	47	2	3	3	3	4
NL	4,744	9,298	8,460	1	-	3	2	3	1	1	-	-	-	-	-	-	-	1	-	-	-	2	7	4	8	5	4	5	3	4	2	-	-	-	-	-	-	0	74	80	78	70	75	69	75	16	15	14	23	16	19	17
Canada	**30,965,812**	**35,942,878**	**35,378,585**	**66**	**63**	**62**	**58**	**49**	**45**	**39**	**7**	**8**	**11**	**13**	**13**	**17**	**24**	**5**	**4**	**4**	**4**	**4**	**4**	**5**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2**	**2**	**3**	**5**	**10**	**9**	**11**	**19**	**18**	**18**	**18**	**21**	**23**	**20**	**1**	**4**	**1**	**2**	**1**	**2**	**2**

Table 4–3: Proportion of cropland and summerfallow under different tillage practices, 1981 to 2011 (based on Statistics Canada, 2011g)

	% of cropland area in various tillage practices															% of summerfallow area in various practices														
	Conventional					Conservation					No-till					Tillage only					Tillage and chemical					Chemical only				
Province	**1991**	**1996**	**2001**	**2006**	**2011**	**1991**	**1996**	**2001**	**2006**	**2011**	**1991**	**1996**	**2001**	**2006**	**2011**	**1991**	**1996**	**2001**	**2006**	**2011**	**1991**	**1996**	**2001**	**2006**	**2011**	**1991**	**1996**	**2001**	**2006**	**2011**
British Columbia	83	65	65	55	39	12	24	21	26	33	5	10	14	19	28	66	65	65	62	68	31	29	30	23	27	3	5	6	15	6
Alberta	73	57	37	25	13	24	33	35	28	22	3	10	27	48	65	58	51	39	27	24	37	38	38	28	23	5	11	24	45	53
Saskatchewan	64	45	32	18	10	26	33	29	22	20	10	22	39	60	70	57	55	48	31	25	39	37	36	31	25	4	9	16	38	50
Manitoba	66	63	54	43	38	29	28	33	35	38	5	9	13	21	24	73	61	50	46	40	24	34	38	40	43	3	6	12	13	17
Ontario	78	59	52	44	37	18	22	22	25	30	4	18	27	31	33	66	53	65	68	74	26	38	24	23	19	8	9	11	9	7
Quebec	85	80	77	62	49	12	16	19	28	33	3	4	5	10	18	48	43	56	71	69	28	25	18	11	16	24	32	26	17	15
New Brunswick	85	80	82	78	68	12	18	15	17	24	2	2	3	5	7	79	72	71	76		14	8	17	18	14	8	20	12	6	-
Nova Scotia	88	77	71	66	60	8	20	20	20	22	4	3	8	14	17	72	62	69	78	59	19	26	19	17	34	9	13	12	4	8
Prince Edward Island	91	82	76	78	74	8	16	22	19	22	1	2	2	3	4	35	55	44	49	-	23	32	17	38	-	42	13	39	14	-
Newfoundland and Labrador	84	88	76	88	86	8	8	13	6	10	8	4	11	6	4	49	74	62	62	65	38	19	7	38	-	13	7	30	-	35
Canada	**69**	**53**	**41**	**28**	**19**	**24**	**31**	**30**	**26**	**25**	**7**	**16**	**30**	**46**	**56**	**58**	**54**	**46**	**31**	**26**	**38**	**37**	**36**	**31**	**25**	**4**	**9**	**18**	**38**	**49**

Table 4–4: Changes in livestock populations in Canada, 1981 to 2011 (based on Statistics Canada, 2011h)

	Beef Cows			Dairy Cows			Pigs			Poultry			Sheep & Goats		
Province	**1981**	**2011**	**% change**	**1981**	**2011**	**% change**	**1981**	**2011**	**% change**	**1981**	**2011**	**% change**	**1981**	**2011**	**% change**
British Columbia	233,911	195,920	-16	89,279	73,707	-17	254,895	89,067	-65	10,958,442	20,328,880	86	75,783	72,105	-5
Alberta	1,367,783	1,528,429	12	165,528	80,724	-51	1,199,397	1,397,711	17	10,358,078	12,866,849	24	211,861	231,823	9
Saskatchewan	946,049	1,124,948	19	84,619	28,029	-67	574,334	1,033,574	80	4,860,929	5,739,181	18	81,369	123,830	52
Manitoba	389,363	485,213	25	83,188	41,848	-50	874,995	2,845,360	225	7,257,002	8,836,707	22	41,047	75,980	85
Ontario	378,311	282,062	-25	552,748	318,158	-42	3,165,837	3,088,646	-2	38,727,767	51,770,766	34	297,037	469,067	58
Quebec	146,326	187,332	28	705,935	359,510	-49	3,440,724	4,096,678	19	24,756,269	34,716,344	40	125,232	311,449	149
New Brunswick	19,454	16,312	-16	28,050	18,534	-34	89,620	54,630	-39	2,329,911	3,232,595	39	14,133	10,210	-28
Nova Scotia	24,072	18,563	-23	36,237	21,935	-39	139,344	18,645	-87	3,544,852	5,068,065	43	44,391	28,912	-35
Prince Edward Island	11,038	10,207	-8	24,106	13,128	-46	116,843	53,649	-54	234,955	468,655	99	7,967	8,097	2
Newfoundland and Labrador	979	382	-61	2,660	6,153	131	19,076	1,144	-94	936,087	1,625,578	74	7,731	2,562	-67
Canada	**3,517,286**	**3,849,368**	**9**	**1,772,350**	**961,726**	**-46**	**9,875,065**	**12,679,104**	**28**	**103,964,292**	**144,653,620**	**39**	**906,551**	**1,334,035**	**47**

CROP TRENDS

As shown in Table 4–2, the most dramatic and consistent trend in Canada has been the diversification of crop production, with a steady decrease in the area planted to cereal crops (wheat, barley, oats, rye) and an increase in oilseed area (canola, soybean, flax, mustard, sunflower) and in the area in pulse crops and soybeans (Statistics Canada, 2011e). This trend has been driven by improved Canadian varieties and expanding global markets for oilseeds and pulses.

Based on the 2011 Census of Agriculture, in 2011 total canola area exceeded the area planted to spring wheat, making canola the dominant field crop in Canada. Manitoba and Saskatchewan posted the greatest decreases in spring wheat area. While canola area increased dramatically in the Prairie Provinces, soybean area increased 33.2% from 2006 to 2011 in Central Canada, reflecting the higher prices resulting from increased demand. Ontario is the largest producer of soybeans, with 62.3% of Canada's total production. New soybean varieties adapted to shorter growing seasons enabled Manitoba to double its soybean area between 2006 and 2011. Sunflower, another oilseed cultivated mainly in Manitoba, saw a reduction in area between 2006 and 2011 (Statistics Canada, 2006; 2011f). Cultivation of pulse crops (fava beans, lentils, field peas) has also increased in Canada. As an example, lentil area doubled between 2006 and 2011, with most of the crop being produced in Saskatchewan (96%) and a small proportion (3.8%) in Alberta.

A gradual uptrend in tame hay area was recorded between 1981 and 2006; however, the total area of tame hay declined by 14.0% between 2006 and 2011. This trend reversal is likely due to the declining livestock population (particularly cattle numbers) and to increases in market prices for oilseed crops. Feed grain (oats, barley and mixed grains) area also decreased by 26.0% between 2006 and 2011 in Canada (data not shown). Seventy-four percent of Canadian forage production takes place in Western Canada, and Alberta is still the dominant producer of tame hay and alfalfa (30.2% of total). Corn production, which is concentrated mainly in Ontario, Quebec and Manitoba, has fluctuated somewhat since 1981 but does not show a significant increasing or decreasing trend in Canada.

TILLAGE PRACTICES

During the last few decades many producers have sought to reduce their use of tillage as a means of cutting their fuel costs and improving soil health. The use of conservation tillage and no-till has increased steadily since the early 1990s (Table 4–3; Figure 4–3). No-till has become a common land management practice in situations where crop and soil conditions warrant, while tillage (conservation and conventional) is still used where surface residue buildup is a concern. Between 2006 and 2011, the total area of agricultural land on which conventional tillage was applied declined by 30.9%. In 1991, the first Census that asked for information on the distribution of tillage practices, 29.9 % of Canadian farms reported using either reduced (conservation) tillage or no-till, while by 2011 the corresponding proportion had risen to 72.5%. In 2011, 17.1% more Canadian farms reported using no-till than in 2006, and no-till methods were applied on more than 50% of all agricultural areas prepared for seeding in Canada (Statistics Canada, 2011g).

The no-till adoption rate in Manitoba, Saskatchewan and Alberta has remained very high. The primary drivers for no-till are better moisture retention, decreased erosion, the availability of herbicides, the availability of appropriate seeding equipment and reduced fuel use.

In Alberta, Saskatchewan and Ontario, the area of land on which no-till has been used has exceeded the area of conservation tillage since 2001, whereas in other provinces conservation tillage area has remained higher or equivalent to the no-till area (Statistics Canada, 2011g).

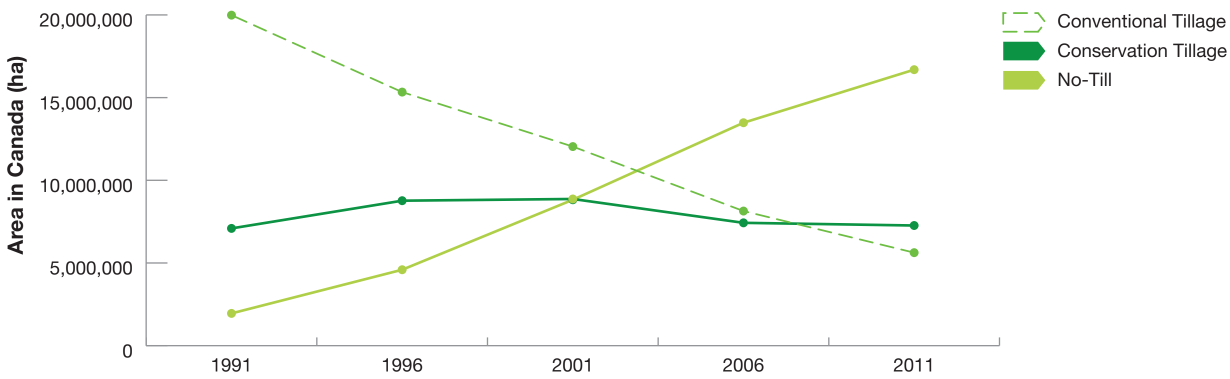


Figure 4–3: Temporal variation of tillage practices between 1991 and 2011 in Canada (Statistics Canada, 2011g)

LIVESTOCK

The beef cattle industry in Canada grew steadily between 1981 and 2001, reaching a peak in 2006. Since 2006, Canada's beef herd size (as represented by the number of beef cows) has been declining, primarily due to market hold-over effects from Canada's BSE crisis in 2003, but also due to a strong Canadian dollar and to changes in consumer preferences (Table 4–4) (Statistics Canada, 2011d). In contrast, the number of dairy cows declined steadily between 1981 and 2011, with a 46% drop being recorded over this 30-year-period and a 3.4% decline between 2006 and 2011. Saskatchewan posted the greatest decrease in dairy cattle numbers. Newfoundland and Labrador was the only province to show growth in dairy herd size since 1981. In 2001, there were 1,091,000 dairy cows in Canada, producing an average of 6,700 litres of milk per cow. In 2011, herd size in Canada decreased to approximately 987,000 dairy cows, producing an average of 7,800 litres of milk per cow, which represents a 16% increase in production per cow (Canadian Dairy Commission, 2015). The total number of pigs on farms in Canada increased from about 10 million in 1981 to approximately 13 million in 2011. The Atlantic Provinces and British Columbia recorded a decline in pig numbers, while numbers increased dramatically in Manitoba and Saskatchewan and moderately in Alberta and Quebec. In Ontario, pig numbers remained relatively constant (Statistics Canada, 2011d). The trend toward larger farms continued, with the average number of pigs per farm increasing from 1,414 in 1981 to 1,707 in 2011 (Statistics Canada, 2011i).

Between 1981 and 2011, the total number of poultry (laying hens and meat birds) in Canada increased by 39%, from around 100 million to around 140 million, with all provinces showing an increase. Ontario and Quebec were the dominant poultry producers throughout the period, although Newfoundland and Labrador, Prince Edward Island and British Columbia showed the greatest increases in production numbers with population increases of 74%, 99% and 86%, respectively.

Since 1981, the number of sheep, lambs and goats in Canada has increased by 47%, from 0.9 million to 1.3 million. Ontario and Quebec are the main producers, followed by Alberta. The largest increases occurred in Quebec (149%) and Manitoba (85%), while New Brunswick, Nova Scotia and Newfoundland and Labrador showed decreases over the period 1981 to 2011.

INTENSITY OF AGRICULTURE

Agricultural land-use intensity can be evaluated by looking at the ratio of cropland to total farm area (%) or, more simply, the proportion of farmland that is cropland, particularly annual cropland, as opposed to perennial crops such as forage, hay and pasture. An increase represents a growing proportion of farmland put into crop production and thus an increase in the average intensity of farming, while a decreasing ratio indicates a greater proportion of farmland in pasture and unproductive land and thus a decline in production intensity. Intensification of agriculture does not necessarily translate into increased risk for the environment as it could and often does indicate that agricultural production is being concentrated on soils and landscapes that are more environmentally suited for production.

The change in the ratio of Census cropland (annual field crops, alfalfa and tame hay, vegetables, fruit, nursery crops and sod) to total farm area between 1981 and 2011, as an indicator of changes in agricultural intensity, is shown in Figure 4–4. The map shows that between 1981 and 2011 an increase in agricultural intensity occurred across the major agricultural regions of Canada, particularly in Prince Edward Island, the Mixedwood Plains and most of the Prairies.

This trend toward increasing intensity was particularly pronounced in areas with the most productive land. On the Prairies, this trend is associated with the decrease in summerfallow. East of the Prairies, producers are converting grassland, pasture and idle land to more productive annual and specialty crops as cattle numbers in this region decline and as world grain and oilseed prices provide positive returns.

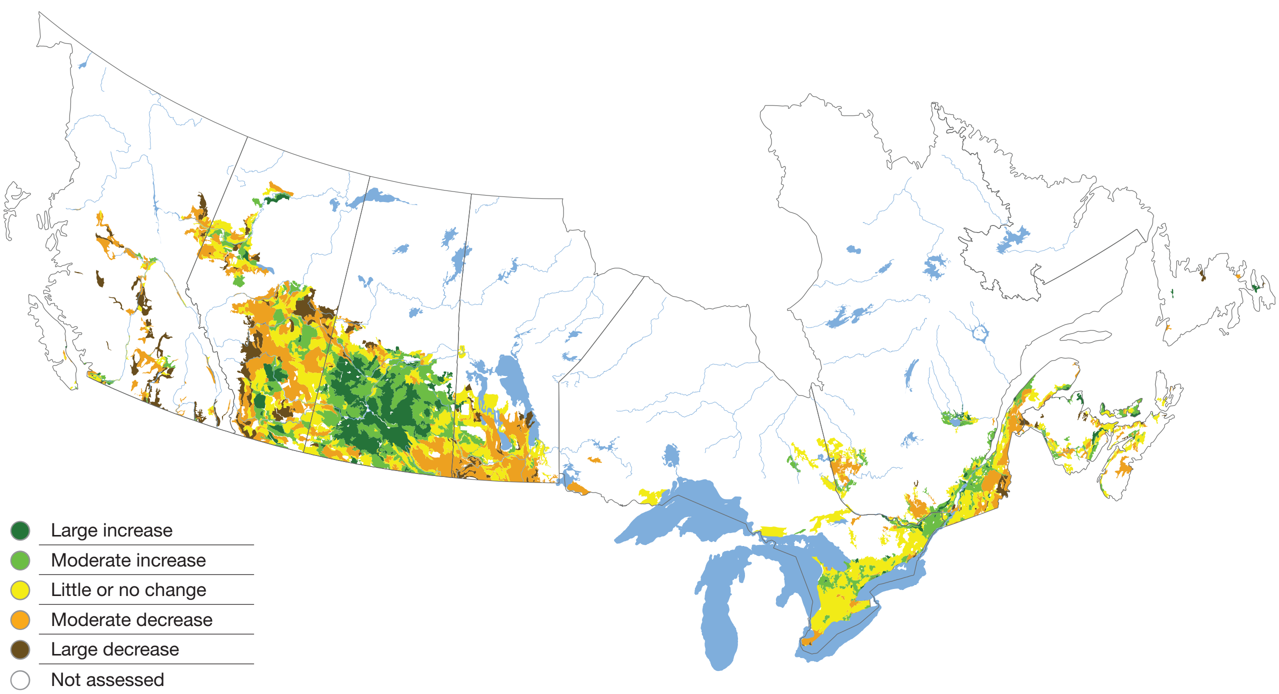


Figure 4–4: Change in agricultural land use intensity between 1981 and 2011 as defined by the ratio of cropland to total farm area. Based on the Census of Agriculture interpolated to Soil Landscapes of Canada (SLC).

Conclusion

The information on the status and trends of some major agricultural land uses and management practices presented in this Chapter should help to improve understanding of the indicator chapters that follow.

Both the intensity of production and the diversity of crops have been increasing in most areas of Canada. Land-use intensification is part of a global trend toward producing more from a limited agricultural land base, while diversification is attributable to the expanding market for alternative crops such as oilseeds and pulses.

In some cases, an increase in the intensity of production may place greater pressure on the environment and create sustainability challenges. However, there is considerable evidence of improvements in environmental stewardship, including the dramatic shift from conventional tillage to conservation tillage and no-till over the past several decades, the widespread decline in the area devoted to summerfallow, and the decline in the number of dairy cattle.

Identifying and mapping various aspects of agricultural land-use change and understanding the associated spatial-temporal trends aid in interpreting other agri-environmental indicators. Agricultural land-use change can also be a significant driver for the trends observed in agri-environmental indicators such as greenhouse gas emissions, the risk of water contamination and wildlife habitat suitability.

References

Canadian Dairy Commission, 2015. *Milk production*. Available at http://www.cdc-ccl.gc.ca/CDC/index-eng.php?id=3801)

Statistics Canada, 2006. *Census of Agriculture, Farm and Farm Operator Data* (*Catalogue no*. 95–629-x).

Statistics Canada, 2011a. *2011 Census of Agriculture, Data quality*. Available at http://www.statcan.gc.ca/ca-ra2011/dq-qd-eng.html

Statistics Canada, 2011b. *The Daily*. May 10, 2012. Available at http://www.statcan.gc.ca/daily-quotidien/120510/dq120510a-eng.htm).

Statistics Canada, 2011c. *Table 004–0002 – Census of Agriculture, total area of farms and use of farm land*, Canada and provinces, every 5 years, CANSIM (database).

Statistics Canada, 2011d. *Snapshot of Canadian agriculture*, 2011 Census of Agriculture (Catalogue no.: 95–640-X).

Statistics Canada, 2011e. *Table 004–0003 – Census of Agriculture; selected crop data*, Canada and provinces, every 5 years, CANSIM (database).

Statistics Canada, 2011f. *Census of Agriculture; Farm and farm operator data* (*Catalogue no.: 95–640-XWE*).

Statistics Canada, 2011g. *Table 004–0010 – Census of Agriculture, selected land management practices and tillage practices used to prepare land for seeding, Canada and provinces, every 5 years*, CANSIM (database).

Statistics Canada, 2011h. *Table 004–0004 – Census of Agriculture, selected livestock and poultry data, Canada and provinces, every 5 years*, CANSIM (database).

Statistics Canada. 2011i. *Table 003-0103 – Hogs statistics, number of farms reporting and average number of hogs per farm, semi-annual (number)*, CANSIM (database).

05 Farm Environmental Management

Authors:
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Summary

Farm management has a direct effect on agri-environmental performance. The practices a producer chooses to implement can affect economic realities on the farm and have direct effects on air, water and soil quality, both on and off the farm. Producers across Canada are applying practices that reduce the impacts of agricultural activities on the environment. Results from the 2011 Farm Environmental Management Survey (FEMS) show that producers across Canada are adopting **beneficial management practices (BMPs)**[1] with or without a formal **environmental farm plan (EFP)**, in order to manage manure, fertilizers and pesticides more efficiently and protect land and water resources.

For the most part, the 2011 survey results indicate continued positive adoption of **nutrient** management practices such as soil nutrient testing, optimization of the timing of nutrient and pesticide application, incorporation of solid and liquid manure and fertilizer, and increased manure storage capacity. Notable changes include an increase in fungicide use and an increase in **conservation tillage**. Conservation tillage was positively associated with a decrease in the implementation of some soil erosion practices. This can be explained by the fact that some soil erosion practices, such as **cover crops** and green manure, which are aimed at covering exposed soils, are not necessary in conservation tillage systems.

The 2011 survey also indicated that further improvements could be made in some areas where little progress has been observed since 2006—particularly in relation to manure management and livestock access to surface water. Producers with EFPs identified economic pressures as the primary impediment to the implementation of improved systems in these areas. Accordingly, incentives may be required to increase adoption rates for some practices.

This chapter examines the extent to which Canadian producers have made changes to their farm infrastructure and practices in order to manage environmental risks related to water quality, air quality and soil quality. While this chapter highlights some of the relationships between agricultural practices and environmental performance, it does not present an exhaustive list of all practices that can improve the sector's environmental performance.

1 Words included in the glossary (at the end of this publication) are bolded in first instance they appear in each chapter.

The Survey

In 2011, Statistics Canada, in partnership with Agriculture and Agri-Food Canada (AAFC), conducted the third FEMS to gather information on the management practices being implemented by producers. The voluntary survey was delivered to 20,000 crop and livestock producers across Canada (excluding the Yukon, the Northwest Territories and Nunavut) who reported more than $10,000 in gross receipts in the 2011 **Census of Agriculture**. Approximately 15,400 (77%) of these producers replied. The survey asked about manure storage and spreading, grazing practices, crop and nutrient management, pesticide application, wildlife damage, land and water management, waste management, and environmental farm planning. The 2011 FEMS built on previous surveys, conducted in 2001 and 2006, and now provides information for trend analysis on the adoption rates of some BMPs over a ten-year period. The information presented in this Chapter is a summary of key findings from the 2011 FEMS.

Environmental Farm Planning in Canada

Environmental farm planning is a voluntary, confidential self-assessment tool or process which is designed to help farmers enhance their environmental management by increasing their knowledge and awareness of agri-environmental risks and benefits. This is accomplished through interactions with support personnel (e.g. EFP facilitator or coordinator and EFP workshop) and technical experts (e.g. provincial agricultural staff, agrologists and agricultural engineers), as well as support materials (e.g. EFP workbooks, reference manuals and factsheets). Producers use the knowledge they acquire to identify the agri-environmental risks and benefits associated with their farming operations. The culmination of this process is the creation of an EFP, which includes a list of on-farm agri-environmental risks and an action plan detailing the BMPs required to mitigate those risks. A completed EFP is often a requirement for obtaining federal/provincial cost-shared funding to implement eligible beneficial management practices (BMPs) aimed at reducing on-farm agri-environmental risks.

The concept of environmental farm planning originated in Ontario in 1993 and quickly grew in popularity across Eastern Canada. By the late 1990s, provincially led EFP or equivalent programs were operating in Ontario, Quebec and Atlantic Canada, encouraging farmers to develop their own plans and promoting the adoption of BMPs. In April 2003, under the **Agricultural Policy Framework (APF)**, the National EFP Initiative defined a set of nationally consistent principles and program elements for EFP programs in Canada. This resulted in the creation of a federal/provincial/territorial partnership that designed and supported the implementation of an EFP program in all Canadian provinces and in the Yukon Territory by April 1, 2005.

EFPs are delivered provincially through Growing Forward 2 federal-provincial cost-share agreements. As a result, the EFP process is tailored to, and varies among individual provinces. Environmental farm planning enhances Canada's reputation and marketability as a supplier of safe, high-quality agricultural products that are produced in an environmentally responsible manner. A recent increase in demand by domestic and international buyers for sustainable agricultural products may influence the way EFPs will be used in the future. EFPs may play a greater role in educating producers and helping them demonstrate compliance with buyers' sustainable sourcing requirements. For example, since 2010 McCain Foods has required their potato producers and suppliers to have an EFP.

The Issue and Why it Matters

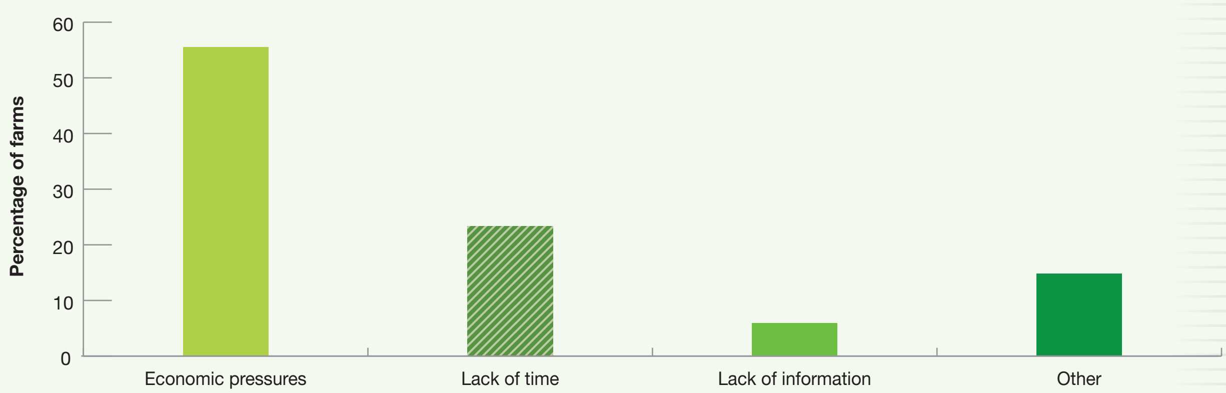
Producers across Canada have a direct influence on the environmental performance of the agriculture sector through the types of management practices they choose to implement in their operations. Management practices are selected for many reasons, including cost effectiveness, legacy infrastructure and historical practice. Many BMPs can help to maintain or improve productivity while mitigating or reducing environmental risks. In many cases, these practices provide environmental benefits such as water filtration and wildlife habitat.

The data collected from FEMS, which focuses on both livestock and crop operations, allow for the establishment of baselines, the identification of trends related to changing practices, and the development of updates for an expanded set of **agri-environmental indicators**. These indicators are needed to determine the present status of farm environmental management across Canada; identify areas that are most in need of environmental management efforts; and generate information to design effective and well-targeted policy and program responses that address current issues and reflect the changing way resources are being managed on today's farms.

EFP Highlight – Deterrents to BMP implementation

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

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



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

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

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

Limitations

Farm management practices and their potential environmental impacts vary regionally since agricultural production, soil and landscape characteristics, weather and other factors are not uniform across the country. This means that the effectiveness and acceptability of a management practice may vary from one region to the next. These biophysical differences are not addressed in the results presented in this Chapter and, therefore, by themselves, the findings are insufficient to assess environmental performance. A more comprehensive assessment of the sector's environmental performance is provided by the agri-environmental indicators described in this report.

It should be noted that since the last survey was conducted, changes were made to the questionnaire in order to reduce the burden on respondents, provide clarity and improve the quality of responses. As a result, direct comparisons between the different survey years cannot be made for all questions. As well, some changes were made to improve analysis methods between surveys. As a result, some of the data from different survey years may not be directly comparable. Notable changes include the introduction of a new section on perennial crops; the addition of rankings to decision factors for manure, fertilizer and pesticide application (in previous surveys, respondents could check off as many factors as they wanted); changes to manure incorporation categories; discontinuation of reporting of setback distances around **wetlands** in 2011.

Results and Interpretation

ENVIRONMENTAL FARM PLANNING

Awareness of on-farm environmental issues and how to manage them is the first step toward improving environmental performance. The EFP process has become a key source of information and education for producers in Canada. It enables them to learn about agri-environmental issues, apply this knowledge to identify farm-specific potential environmental risks, and develop an action plan to mitigate those risks. The implementation of BMPs can contribute to better farm environmental performance and improved agricultural sustainability. Based on the results of the 2011 FEMS, 35% of farms in Canada had a formal written EFP, which accounts for 50% of the agricultural land area and represents a 7% increase in the number of farms with formal EFPs since 2006. In addition, 2% of farms were in the process of developing an environmental farm plan.

Producers across Canada have actively participated in EFP programs, as depicted in Figure 5–2, which shows the provincial percentages of farms with EFPs. In Quebec, there is a significantly higher proportion of producers participating in the EFP program than in other provinces, likely because of provincial legislation that targets nutrient and manure management issues, along with programs to encourage EFP implementation that have been in place since the mid-1990s.[4] Quebec's EFP participation appears to have reached a plateau, whereas participation in all other provinces was on the rise. In 2011, participation in EFP programs continued to be higher in Eastern and Central Canada, where there is a longer history of environmental farm planning, than in Western Canada.

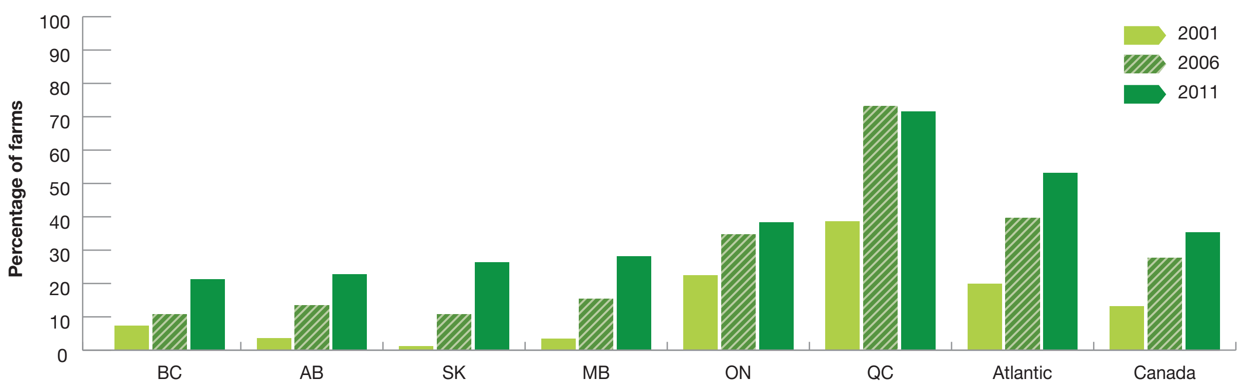


Figure 5–2: Percentage of farms with an environmental farm plan, by province[3]

3 Atlantic Provinces include New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador.

4 Quebec values may be over-reported; they include farms with a plan agroenvironnemental de fertilisation (PAEF)

The following sections provide details on practices implemented on Canadian farms in 2011 for the management of nutrients, pesticides, and land and water resources. Additionally, some EFP trends are showcased in highlight boxes throughout this chapter.

NUTRIENT MANAGEMENT

Nitrogen (N), phosphorus (P) and potassium (K) are nutrients that are essential for plant growth. Healthy soils contain these nutrients, but not always in the amounts required by crops; hence, supplementing with manure or fertilizers is often necessary to maximize productivity and economic returns. However, adding nutrients to soils beyond crop needs can pose environmental risks. Over-application and improper timing or placement of manure and fertilizers, or reduced nutrient uptake due to drought or crop damage, can result in the accumulation of excess nutrients in the soil and their subsequent loss to the environment. Excess N can volatilize into the air, contributing to atmospheric **greenhouse gas (GHG)** emissions and poor air quality, and both N and P can be transported by water into **ground water** or surface water bodies, potentially causing excessive growth of algae and aquatic plants and resulting in **eutrophication**. Although some loss of nutrients is inevitable, there are a number of BMPs that can be implemented to manage nutrients and reduce the risk of loss to the environment. Nutrient loss to the environment also represents an economic loss for producers since the nutrients are not available to meet the needs of the crop.

Soil nutrient testing provides valuable information that producers can use to match crop nutrient requirements with nutrient levels in soil and nutrients applied in the form of manure and commercial fertilizers. This can help to maximize productivity and make the most efficient use of resources while reducing the risk of losses to the environment. The more frequently soil tests are conducted, the more opportunities a producer has to fine-tune nutrient applications in order to optimize crop growth. Figure 5–3 shows that, on the whole, soil testing frequency has remained fairly constant since 2006, although considerable improvements were made between 2001 and 2006. The number of farms that did not carry out soil tests has been reduced by almost half since 2001 and represents 13% of farms and 12% of total acreage. Annual soil testing has varied the least over time, with about 20% of farms carrying out testing annually, which represents 28% of the total Canadian **cropland** acreage in 2011. The most common soil testing frequency is still every two to three years: 37% of producers conducted testing at this rate, accounting for approximately 34% of the total cropland acreage in 2011.

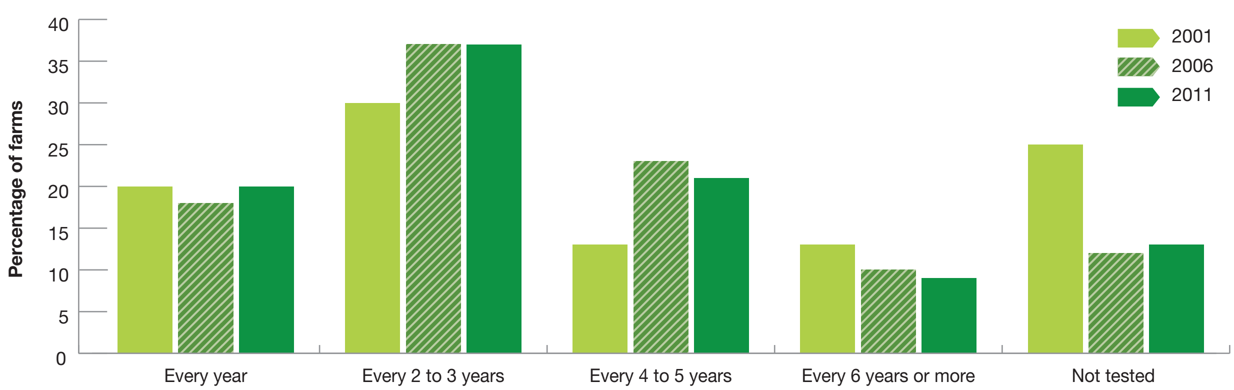


Figure 5–3: Frequency of soil nutrient testing on Canadian farms

MANURE

Manure storage and application is one of the most significant environmental challenges for livestock producers. Spreading manure to supplement crop nutrients provides a use for this inevitable by-product of livestock production. However, suboptimal storage and application of manure can lead to increased environmental risks.

Manure can be solid, liquid or semi-solid, depending on the type of livestock and how the manure is managed before entering storage. Typically, beef and poultry operations store solid manure, while hog and dairy operations store liquid or semi-solid manure. The different manure types require different storage methods, each of which presents unique challenges. A primary goal for manure storage is to retain as many nutrients as possible for subsequent spreading on cropland. Nutrient loss during storage may occur through **volatilization, runoff** from exposed solid manure piles and **leaching** into the soil below the manure storage facility. The optimal storage system for solid manure includes a covered impermeable pad with runoff containment. The optimal system for liquid and semi-solid manure consists of a covered and impermeable tank or pit, above or below ground level.

EFP Highlight – BMP Adoption Trends

Producers are increasingly concerned about the impact of their production practices on the environment (Figure 5–4):

- Producers with an environmental farm plan (EFP) in 2011 were more likely to have adopted a variety of BMPs.
- One of the recommended BMPs for farmers who apply both manure and fertilizer is to modify their fertilizer application rates based on the nutrient content of the manure they are spreading, thus avoiding over-fertilization. The 2011 FEMS reported that farmers with an EFP are about 20% more likely to adopt this practice.
- Farmers with EFPs were also more likely to implement **riparian buffers** to protect water bodies, to use GPS technology and other **precision farming** techniques, and to test their solid manure for nutrient content before applying it to the land.
- While many factors (e.g. cost savings, improved efficiency or regulations) can influence the adoption of practices that have positive environmental outcomes, there is a clear trend toward increased adoption of BMPs, either with or without a formal EFP.

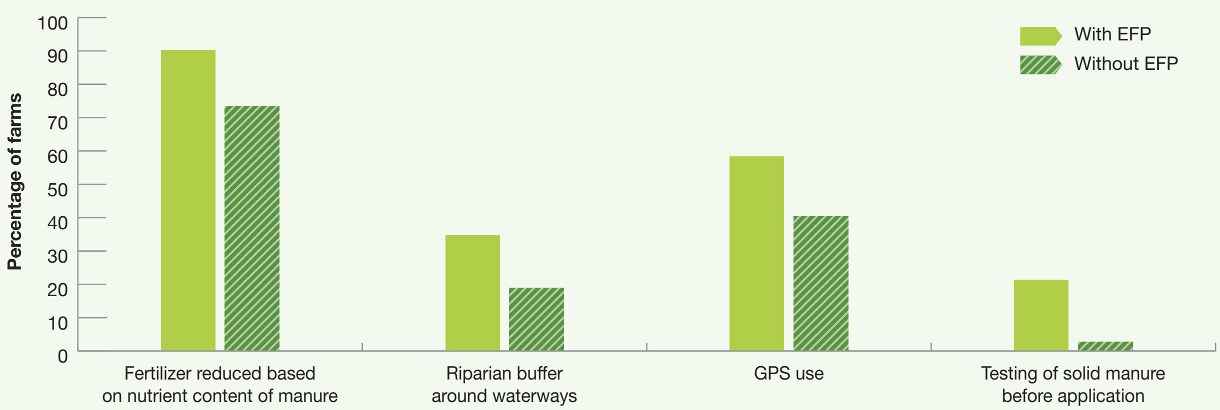


Figure 5–4: Percentage of farms implementing beneficial management practices, 2011

The 2011 edition of the FEMS identified three common storage locations for solid manure. On any given farm, more than one location may be used. Manure piles are usually located near livestock buildings, and manure bedding packs are located in barns, pens or corrals. The environmental risks associated with solid manure storage depends more on how the stored manure is managed than on where it is stored. The key to reducing nutrient loss is to use storage systems with covers, impermeable bases and/or runoff containment.

In 2011, 59% of farms storing manure on bedding packs in barns kept all of it on an impermeable pad. Thirty-five percent of farms with manure piles near livestock buildings kept all of the piles on an impermeable pad. However, only 17% of farms with manure bedding packs in outdoor corrals, pens or feeding sites used impermeable pads. This situation indicates that there is still room for improvement.

Common storage options for liquid and semi-solid manure include earthen lagoons and tanks or pits located outside or below a slatted barn floor. Each of these storage systems presents challenges that need to be addressed with a view to ensuring environmental sustainability. Earthen lagoons have a large storage capacity; however, they must be constructed properly to avoid leakage and are difficult to cover owing to their large surface area. Tanks and pits are more easily covered but are costly to construct and generally have smaller storage capacity. Figure 5–5 illustrates the frequency of use of different liquid or semi-solid manure storage systems by different types of livestock farms.

Based on the 2011 FEMS results, only 26% of producers covered their liquid and semi-solid manure storage facilities. While this is up slightly from 22% in the 2001 survey, the low percentage suggests that there may be further barriers to adopting this type of practice and that additional efforts are needed to improve adoption rates.

The rate, method and timing of manure application and incorporation can influence the total amount of nutrients lost in runoff or through volatilization. There are several factors that producers consider when determining the amount of manure to apply to crops. Tables 5–1 and 5–2 list the top five decision factors as reported in the 2011 FEMS.

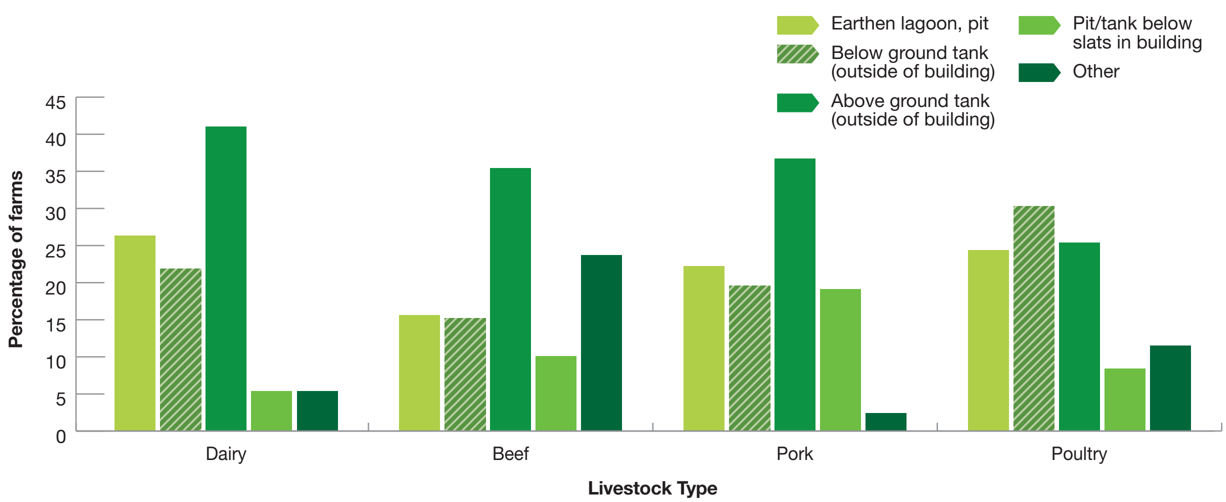


Figure 5–5: Percentage of farms with different types of liquid or semi-solid manure storage, by livestock sector

Table 5–1: Top five factors used to decide how much solid manure to apply[5]

Decision Factor	Overall Rating
The quantity of fertilizer used in past, or based on experience	2.14
Nutrient requirements of crop grown or carryover nutrients from last crop	1.83
Amount of land available to receive manure	1.71
Soil moisture, temperature or other growing conditions	1.67
Nutrient content of manure	1.50

Table 5–2: Top five factors used to decide how much liquid manure to apply[5]

Decision Factor	Overall Rating
Nutrient requirements of crop grown or carryover nutrients from last crop	2.48
Soil testing or plant analysis	2.37
Quantity of fertilizer used in past or based on experience	2.36
External sources of information (crop advisor, fertilizer dealer, provincial recommendations, neighbours etc.)	2.23
Soil moisture, temperature or other growing conditions	2.22

In the case of liquid manure, the decision factors that were ranked highest by producers in relation to liquid or semi-solid manure were crop nutrient requirements, followed by soil testing or plant analysis. Note that historical use (practices used in the past) ranked third. These results indicate that producers are carefully considering factors that can help them successfully manage nutrient inputs.

A quick comparison between Table 5–1 and Table 5–2 shows that the overall ratings are consistently higher for liquid manure. This suggests that management of liquid manure receives more careful consideration than solid manure. The reasons for this could include more limited storage capacities for liquid manure, regulatory requirements, and the fact that liquid manure has a more consistent nutrient content and can be easier to apply than solid manure.

The method used to apply manure also influences the risk of nutrient loss to the environment. Nutrient losses from solid manure can be reduced by spreading, followed by immediate incorporation of manure into the soil, where feasible, such as on annually-cropped fields or during the establishment year of a perennial crop such as grass or alfalfa. While **perennial forage** is a preferred crop for utilizing and storing nutrients from manure sources, opportunities for incorporation are limited on established stands, requiring specialized equipment such as low disturbance injectors or aerators to place manure beneath the surface.

In the case of liquid and semi-solid manure, the optimal practice consists of injecting the manure directly into the soil. This is often feasible even in established perennial forage stands by using equipment with narrow openers. Other methods for applying liquid manure such as using a low dribble bar (below crop canopies) or **broadcasting** with immediate incorporation may also be acceptable. These management practices reduce the risk of surface runoff and nutrient loss to the air, reduce odours and place nutrients in immediate proximity for crop uptake. The least beneficial practice for both solid and liquid manure consists of spreading the manure and leaving it on the soil surface, thereby exposing the nutrients to the air and causing significant nutrient loss and odour, as well as increasing the potential for runoff into **waterways**. It is difficult to make definitive statements about the use of manure incorporation, because in the case of spreading without incorporation, the 2011 FEMS did not ask producers to specify whether this practice occurred on annual crops or perennial forages.

5 Producers were asked to rate the importance of each factor as "high," "medium" or "low." An overall rating calculation was applied in order to provide a single weighted value for each decision factor based on percentage of responses for each priority rating. To this end, the priority ratings were given numeric values as follows: high = 3, medium = 2, low = 1 and none = 0.

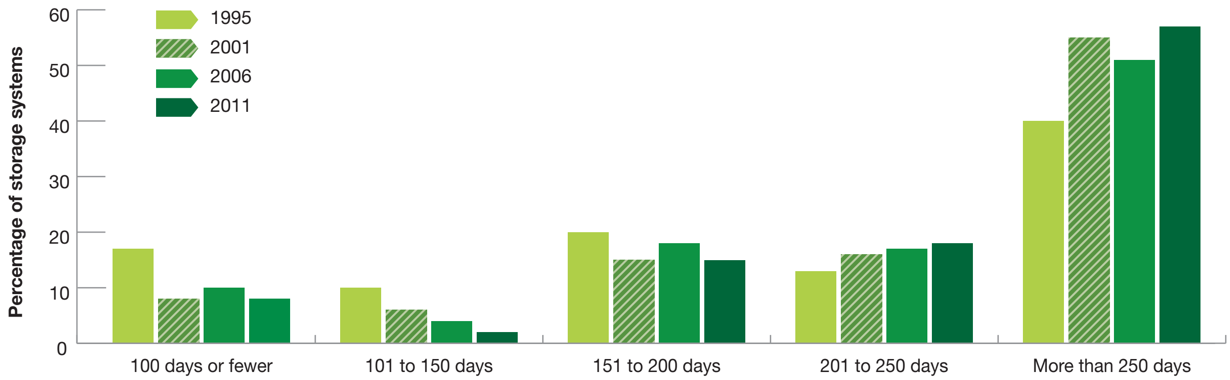


Figure 5–6: Change in liquid manure storage capacity since 1995[6]

Timing is also a very important factor. The longer the time between manure application and incorporation, the greater the risk of nutrient loss through volatilization or runoff caused by precipitation. More specifically, volatilization losses are usually greatest during the first day after application. Since manure incorporation also helps to reduce odour, immediate or same-day incorporation is optimal. In 2011, same day manure incorporation was done by 29% of farmers with solid manure, and 34% of farmers with liquid manure. Also in 2011, 41% percent of farmers incorporated solid manure within 1-2 days, while 45% percent of farmers incorporated liquid manure within 1-2 days. These statistics demonstrate that a good proportion of farmers are considering timing when incorporating their manure. However, there is room for improvement when it comes to solid manure, given that in 2011, 32% of producers delayed incorporation more than five days, compared to only 6% for liquid manure[7].

The time of year or the crop-growth stage when manure is applied influences nutrient loss and ultimately environmental performance, as a crop's ability to use nutrients varies throughout the growing season. Ideally, nutrients are added to the soil so that they will be available when crops need them most and nutrient uptake is the highest. Spreading manure during the winter is a poor practice, and is usually associated with insufficient on-farm manure storage capacity. This practice poses a high risk of nutrient runoff which may contribute to water contamination. Winter spreading is discouraged through regulation in many provinces, and only a small percentage of producers carry out this practice.

As manure storage capacity increases to meet the demands of increased manure production, so does the producer's flexibility to spread manure at the optimal time. Therefore, increasing storage capacity to accommodate increased manure production is a beneficial practice. Storage capacity for liquid manure has been increasing since 1995 (Figure 5–6).

FERTILIZER

Mineral fertilizers are the primary source of nutrient inputs on Canadian farms. In 2011, 69% of producers growing crops applied mineral fertilizer, which corresponds to 84% of Canada's crop area. Fertilizers represent a significant economic investment by producers[8], and efficient application helps to ensure a maximum return on this investment. Good nutrient management practices ensure efficient fertilizer application, thereby supporting the production of high-quality crops with optimal yields

6 2006 results include both liquid and semi-solid manure; the 1995 and 2001 results are for liquid manure only.

7 Due to changes in survey questions between survey years, direct comparisons to previous surveys, and trends over time could not be made.

8 Over the 2003-2013 period fertilizer and lime was the second largest farm operating expense, preceded by commercial feed costs (AAFC, 2015). Collectively, fertilizer and lime costs amounted to $3.6 billion in 2010, comprising 8.4% of total farm operating expenses that year (Statistics Canada, 2014).

and minimal nutrient loss to the environment. As with nutrients from manure, excess nutrients from fertilizer can be lost from farmland through leaching, runoff or volatilization, potentially contributing to contamination of surface waters and ground water (see Chapter 11 "Nitrogen" and Chapter 12 "Phosphorus") and emissions of **ammonia** (a precursor of airborne **particulate matter**) (see Chapter 16 "Ammonia" and Chapter 17 "Particulate Matter") and **nitrous oxide** (a greenhouse gas) (see Chapter 15 "Agricultural Greenhouse Gases").

As is the case for manure application, the methods used for fertilizer application affect the risk of nutrient loss. The results of the 2011 FEMS show that there has been little change in fertilizer application methods since 2001. Applying fertilizer with the seed at planting remains the most common practice (Figure 5–7). Subsurface application with the seed (e.g. using granular fertilizers with air seeders) or banding of fertilizer in a separate band during the seeding operation lowers the risk of runoff and volatilization and reduces the number of equipment passes. This also helps to reduce GHG emissions (less fuel is used) and represents an increase in time efficiency for producers. In addition, post-plant top-up applications—usually associated with liquid fertilizer application to crops with large nutrient demands and a higher rate of return—have risen since 2001. This practice is used above all in Central and Eastern Canada, where more of the land is planted to nutrient-demanding crops such as corn and potatoes. While a post-plant top-up treatment requires an extra field operation, this approach is beneficial if used to more accurately match nutrient additions with crop requirements based on early season growing conditions and growth projections as well as on more current weather forecasts. In 2011, there was a decrease in the use of fertilizer broadcasting and as well, most producers that continued to use broadcasting reported that they incorporated fertilizer afterwards (68%). Both of these results represent positive trends.

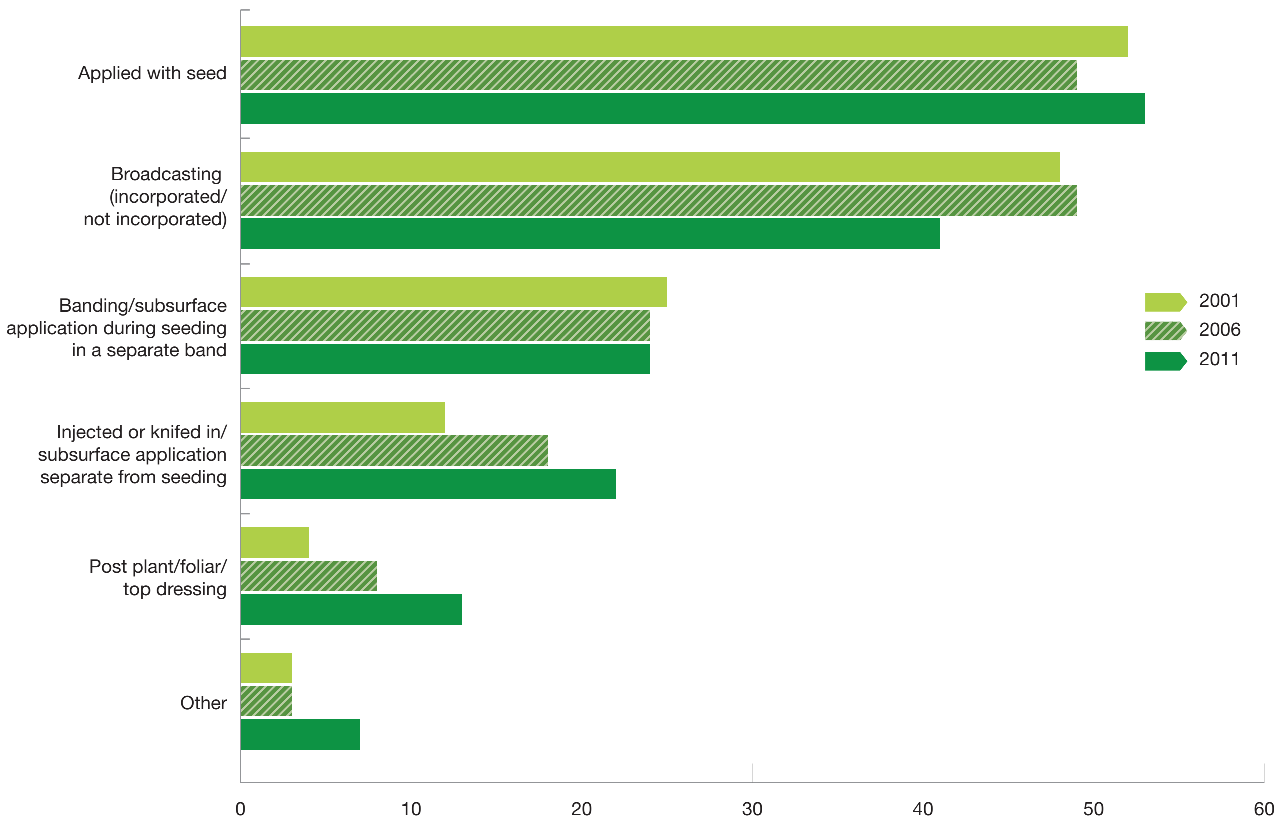


Figure 5–7: Fertilizer application methods on Canadian crop farms in 2001, 2006 and 2011[9]

9 Percentages may add up to more than 100% because producers were asked to "check all that apply."

Table 5–3: Top five factors used to decide how much fertilizer to apply

Decision Factor	Overall Rating
Amount used in past or based on past experience	2.41
Nutrient requirements of crop grown or carryover nutrients from previous crop	2.34
Cost of fertilizer or crop prices	2.19
Soil testing or plant analysis	2.09
Soil moisture, temperature or other growing conditions	2.04

Most producers use more than one fertilizer application method for a variety of reasons. For example, only a limited amount of nitrogen can be safely applied with the seed at planting because of the risk of seedling burn. The preferred method may be to apply fertilizer during the seeding operation on most cropland; however, a separate broadcasting application may be used on certain areas of land that are too wet for heavy equipment at seeding time.

Producers consider many factors when determining the amount of fertilizer to apply. The most common decision factor is the amount of fertilizer used in the past. This may not be an ideal approach, unless soil conditions and crop requirements were taken into consideration in the past. All of the other top-ranked factors (see Table 5–3) contribute to both maximum crop nutrient utilization and reduced nutrient losses as part of sound economic management.

Farms that spread manure, which can be a rich source of nutrients, typically require less fertilizer than those that do not. Producers who do not reduce their fertilizer use to offset the manure applied may increase the risk of nutrient loss to the environment in addition to incurring higher economic costs. In 2011, 84% of producers reduced their fertilizer use to offset the nutrients added to the soil in the form of manure. In spite of a 5% decrease from 2006, this result represents a substantial improvement over 2001 (43%).

PESTICIDES

Agriculture is vulnerable to pests that feed on crop plants or compete for the same resources as crops. There are three primary types of pests: insects, weeds and fungi. Producers may choose to apply pesticides—insecticides, herbicides and fungicides—to protect their investment and maintain their crop yields. More information about pesticides and pesticide use in Canada can be found in Chapter 14 "Pesticides".

Although pesticides that are less toxic to non-target organisms have been developed in recent years, these products continue to pose risks to the environment. Applying pesticides under certain conditions can produce drift to non-target areas, reduce effectiveness in target areas and affect air quality. Pesticides may also be transported to water bodies and soil, potentially affecting non-target organisms and, in some cases, beneficial organisms. In addition to posing environmental risks, pesticide drift or transport away from the target organism represents an economic loss to farmers and a loss of operational efficiency.

In 2011, 71% of producers reported using pesticides on their operation, a 5% decrease since 2006. In 2011, 69% of crop producers applied herbicides (likewise down by 5% since 2006) on land corresponding to 71% of the total crop area in Canada, approximately the same percentage as in 2006[10]. Insecticides were applied by 15% of producers (similar to the proportion in 2006) on land representing 9% of the total crop area. Twenty-three percent of crop farmers applied fungicides, up from 16% in 2006, on land accounting for 21% of the total crop area in Canada, a 14% increase since 2006. Chapter 14 "Pesticides" reports a near doubling of fungicide use on the Prairies between 2006 and 2011, a situation that is attributed to the

10 These statistics report on the number of operators applying pesticides and not the volume of pesticide applied, which has been increasing. For more information on pesticide-use trends use see Chapter 14 "Pesticides".

wetter-than-usual weather in 2010 and the shift to reduced tillage systems, both of which increase the risk of fungal diseases such as fusarium blight.

Pesticide use trends can vary significantly from one region to another given the diverse nature of the sector. As noted in Chapter 14 "Pesticides," the expansion of pesticide use is likely related to the increased use of reduced tillage systems on the Prairies, since these systems are more likely to lead to problems with weeds, insect pests and fungal disease. The prospect of increased revenue based on higher commodity prices in 2011 may also have prompted producers to increase their pesticide use to achieve higher crop yields and meet quality targets.

Producers consider many factors when deciding whether to apply pesticides and when to apply them. Ideally, pesticides are applied only when necessary, such as before the economic injury threshold is reached. The decision factors most widely used to determine the timing of pesticide applications in 2011 were crop condition or growth stage; weather conditions; and personal experience, historical pattern or regular scheduling. Basing decisions on crop condition and weather conditions is a beneficial practice, but relying on past experience or using regularly scheduled applications may lead to suboptimal outcomes since this involves making a decision without checking the crop. Another beneficial practice, described as "detection of pests, field scouting, or regional pest data" in the FEMS, was the fourth-ranked factor.

A formally certified pesticide applicator is knowledgeable about optimal application methods and timing, application equipment and the environmental risks associated with pesticides. Some provinces require that a certified applicator make all pesticide applications. In 2011, 53% of farms used a certified specialist for all pesticide applications and 9% of farms used a certified specialist for some pesticide applications. These percentages have remained relatively constant over the last two surveys.

Calibrating the pesticide sprayer is also an important practice which ensures that pesticides are applied at the intended rate. Sprayers should be calibrated at various times during the crop season, for example, prior to switching to a different type of pesticide. Figure 5–8 shows that, in spite of a slight decline since 2006, most farmers are calibrating their sprayers at the start of each growing season. Twenty-one percent of producers re-calibrated between pesticide applications, down slightly from 2006.

Part of the reason for the above decreases is that additional calibration options were used in the 2011 survey. Based on these new options, 21% of producers calibrate before every use and 22% of producers use certified applicators to apply their pesticides. Calibrating before every use, calibrating between different pesticide applications and using custom operators ensures more efficient pesticide use, potentially reducing the risk of loss to the environment. However, because of the changes to the list of options in the questionnaire, it is difficult to identify the trend since 2006.

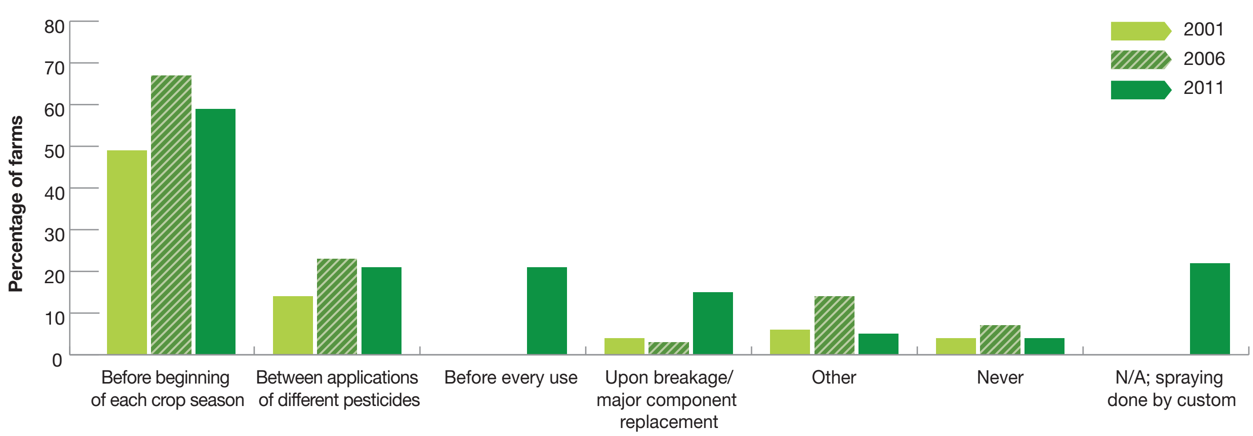


Figure 5–8: Change in pesticide sprayer calibration frequency since 2001[11]

11 2006 percentages may add up to more than 100% since respondents were asked to "check all that apply."

Table 5–4: Most commonly used alternative methods for pest control or reduction of pesticide use in 2011

Method	Percentage of farms
Rotating crops to disrupt pest cycles	59
Using tillage implements	38
Planting crop varieties that are pesticide resistant	33
Using lures/traps	32
Mowing (for perennial weed control)	28

As part of their efforts to reduce pesticide use, many producers are using **integrated pest management**, a decision-making process that uses multiple practices to suppress pests effectively, economically and in an environmentally sound manner (see the "Integrated Pest Management" text box in Chapter 14 "Pesticides"). In 2011, 59% of producers reported using crop rotations as a pest control method; the second and third most popular alternatives to applying pesticides were tillage and planting pesticide-resistant crop varieties, respectively (Table 5–4). These results are encouraging, as they suggest that producers are actively managing their operations to reduce their use of pesticides. However, it should be noted that the practice of planting pesticide-resistant crop varieties does not necessarily reduce pesticide use. It can make specific pesticides more effective in controlling pests while ensuring that they do not damage the crop.

LAND AND WATER MANAGEMENT

Healthy soil and clean water are critical to farm operations since they are essential for crops and livestock and support wildlife habitat. In addition to managing agricultural inputs such as manure, fertilizer and pesticides, Canadian producers manage their land and water resources in a sustainable manner that supports the continued productivity of their operations.

Key benefits of sustainable land and water management include the reduction of erosion and loss of productive soil, as well as the protection of water resources. Based on the 2011 FEMS results, producers are implementing fewer BMPs specifically targeted at reducing erosion than in 2006. For instance, 25% of producers reported using permanent perennial forages on erodible land, as opposed to 34% in 2006. Only 15% reported using cover or companion crops, compared to 23% in 2006, and only 9% reported using post-harvest **winter cover crops** or green manure, compared to 11% in 2006. However, the declining use of these practices may not be cause for concern. Over the same time period, the use of **reduced tillage** and **no-till** increased. This practice may not be applicable or compatible with some of the above land management practices. Therefore, despite the reduction in some BMPs that help to reduce soil erosion, the risk of soil erosion has actually declined. For further information on soil erosion, refer to Chapter 8 "Soil Erosion."

LIVESTOCK ACCESS TO WATER

Most farms in Canada have some surface water for at least part of the year, including permanent or seasonal wetlands, streams, dugouts or ponds. The quality of this surface water may be compromised as a result of agricultural activities that lead to soil erosion, nutrient and pesticide runoff or contamination by livestock.

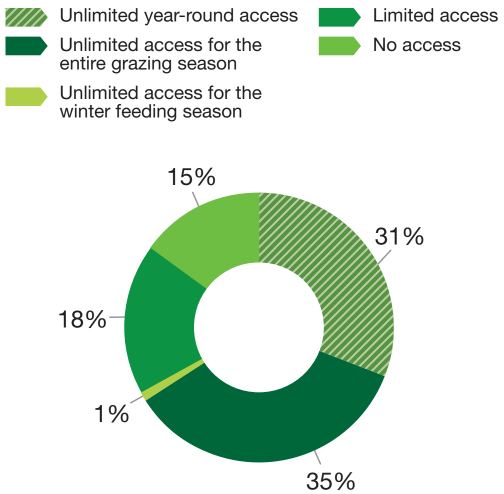


Figure 5–9: Percentage of beef and dairy farms providing various degrees of access to surface water in 2011[12]

Direct access to surface water by grazing livestock can result in streambank erosion and a reduction in bank stability, and can lead to contamination of the body of water with sediments as well as nutrients and **pathogens** from manure. Controlling or restricting livestock access to surface water helps to prevent streambank degradation and protect water quality. In many cases, this can be accomplished by merely limiting access to the water body (especially when combined with appropriate rotational grazing strategies); however, in some sensitive regions, elimination of access may be required or desirable. According to the 2011 FEMS survey, only 15% of beef and dairy farms with grazing land adjacent to surface water prevented all access to surface water, while an additional 18% allowed limited access and 35% allowed unlimited access during the grazing season (Figure 5–9). These results are similar to those reported in the last survey; however, there was a positive reduction in the number of respondents allowing unlimited access for the entire grazing season (down from 47% in the 2006 survey). Access to surface water remains a key area that producers need to address in order to significantly improve their environmental performance.

RIPARIAN MANAGEMENT PRACTICES

Management practices such as maintaining setback distances for crops near surface water, stabilizing shorelines and creating riparian buffer areas with perennial vegetation can reduce the risk of water contamination and improve **biodiversity** and wildlife habitat. As Table 5–5 shows, 54% of producers are maintaining buffers on all cropland adjacent to waterways, and an additional 11% of producers are protecting some of their waterways (for a total of 65%). Waterways are the most frequently protected riparian areas, followed by permanent wetlands and seasonal wetlands. Producers are least likely to maintain riparian buffers around seasonal wetlands (sloughs, potholes, etc. which have water only part of the season) as these areas can be used for agricultural purposes during drier summer periods and during drought years. Producers in some provinces are required by regulation to maintain riparian setbacks or buffers around waterways, which is likely reflected in the results. The results nonetheless indicate that there remains room for improvement.

12 Based on beef and dairy farms with grazing land adjacent to surface water.

Table 5–5: Farms maintaining riparian buffer areas on cropland with surface water bodies, 2011

	Maintained riparian buffer on all cropland (% of farms)	Maintained riparian buffer on some cropland (% of farms)
Seasonal wetlands	22	34
Permanent wetlands	41	53
Waterways	54	65

Conclusion

Farm production is not static over time. Changes in cropping and livestock production are driven by multiple factors including changes in consumer preferences and demand, market access, weather fluctuations and climate change. The Farm Environmental Management Survey seeks to describe some of the BMP adoption trends that influence the sector's environmental performance. The survey data are used to determine the extent to which these practices are being used across the country and to track changes over time. Furthermore, survey data are used in the models for the Coliforms and Phosphorus Indicators (refer to Chapter 12 "Phosphorus" and Chapter 13 "Coliforms), in the pasture and spreading component. The FEMS summary presented here aids the interpretation of producers' actions and associated agri-environmental trends. This information can enhance the assessment of the sector's environmental performance and help to inform government programs and policy, as well as commodity groups and farmer organizations.

References

Agriculture and Agri-Food Canada, 2015. An Overview of the Canadian Agriculture and Agri-Food System 2015. Catalogue No. A38-1/1-2015E.

Statistics Canada, 2013. Farm Environmental Management Survey 2011. Catalogue no. 21-023-X.

Ottawa, ON. Available from http://www.statcan.gc.ca/pub/21-023-x/21-023-x2013001-eng.htm

Statistics Canada, 2014. Feeding the Soil puts food on your plate. Online catalogue number 96–325–X201400113006 Ottawa Ontario, Available from http://www.statcan.gc.ca/pub/96–325–x/2014001/article/13006–eng.htm

Statistics Canada, 2007. Farm Environmental Management Survey 2006. Ottawa, ON.

06 Soil Cover

Authors:
T. Huffman and J. Liu

Indicator Name:
Soil Cover

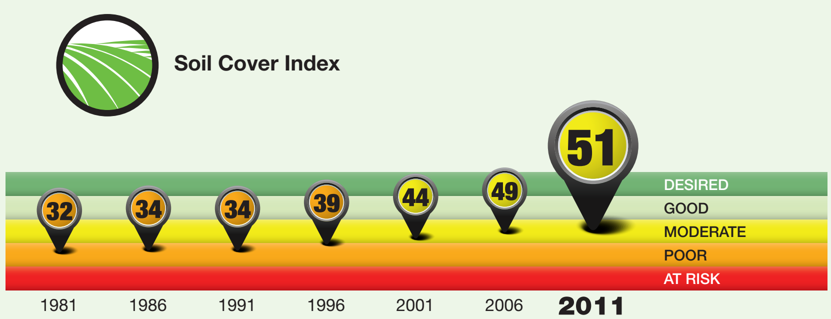
Status:
National Coverage,
1981 to 2011

Summary

Agricultural soils that are covered by vegetation, **crop residue**[1] or snow are partially protected and are less susceptible to degradation processes that affect bare soils, such as wind and water erosion, organic matter depletion, structural degradation and loss of fertility. The amount of time soil is covered during a year depends on many factors such as the type of crop (perennial crops generally provide more cover than annual crops) and the amount of **biomass** it produces, the harvest practices used and the type and timing of field operations, especially tillage. The Soil Cover Indicator summarizes the effective number of days in a year that agricultural soils are covered. An increase in the number of soil cover days over time indicates an improvement in environmental sustainability, since the soil is more protected from degradation and less likely to contribute to water contamination and atmospheric emissions. The Soil Cover Indicator assesses the broad-scale *state* and *trend* of soil cover levels within the Canadian agricultural landscape.

Soil Cover Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign single values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of soil cover on farmland in Canada was 'Moderate'. The index illustrates an upward trend, from an index value of 32 in 1981 to a higher value of 51 in 2011, demonstrating a steady improvement and an increase in soil cover over this 30-year period. From 1981 to 2011 average levels of soil cover in Canada increased by 7.6%. This national-scale improvement came about primarily as a result of widespread adoption of reduced (conservation) tillage and no-till, as well as decreases in the use of summerfallow in Manitoba, Saskatchewan and Alberta. However, these improvements were offset to a considerable degree by increases in low-cover crops such as potatoes, canola and soybeans.

The index tends to aggregate and generalize trends. Specific findings, as well as regional variations and interpretations, are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector".

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

Soil cover has been increasing on agricultural lands in Canada. The national average increased from 268.5 soil cover days in 1981 to an average of 288.8 soil cover days in 2011. The greatest increase occurred in the Prairie Provinces, particularly in Saskatchewan. This improvement can mainly be attributed to a reduction in **summerfallow**, along with a shift to **reduced-tillage** and **no-till** practices in this region. While shifts from pasture and **forage** production to annual cropping in other parts of the country have led to a reduction in soil cover days, the overall trend has been one of improvement on a national scale.

The Issue and Why it Matters

In **agro-ecosystems**, bare soil is more susceptible to soil degradation processes such as wind and water erosion, loss of organic matter, breakdown of **soil structure** and loss of fertility. The result of these degradation processes negatively impacts crop quality and yield; soil that is of marginal quality limits the types of crop that can be grown and requires more inputs, resulting in higher costs and reduced competitiveness to the producer. In extreme cases, soil degradation can result in the loss of agriculturally productive land. The issue of soil degradation is of concern not only from the perspective of soil quality, but also from a broader environmental perspective. Higher levels of erosion can increase the risk of contamination of **ground water** and surface water by solids, **nutrients** and chemicals, while increased oxidation of **soil organic matter** in bare soils contributes to **greenhouse gas** emissions. Bare soil also generally provides poor wildlife habitat and therefore can impact **biodiversity**.

The type of crop grown determines row spacing, the growth rate and the amount of biomass produced, and thus has a strong influence on the amount of soil cover produced in a given year. Perennial field crops such as hay offer good soil coverage year-round, while annual crops such as wheat or corn may leave soil exposed after planting or after fall tillage. In addition, crops such as beans, peas, canola and potatoes tend to have shorter periods with a full canopy and leave lower levels of residue after harvest. Residue management, such as the method, timing and frequency of tillage, also has significant implications for soil cover. **Intensive tillage** (also referred to as conventional tillage) practices typically involve incorporating most of the crop residue into the soil to leave a clean surface for seeding, while reduced tillage and no-till leave more crop residue on the soil surface and thus provide greater cover. As well, tillage done in the fall after harvest exposes soil for a greater length of time than tillage done in the spring just before planting.

Soil productivity and climatic or weather conditions also influence soil cover by affecting the vigour of crop growth and thus the amount of canopy and crop residue available as cover. The same crop grown under different climatic regimes generally provides different amounts of canopy and residue cover depending on the intensity of vegetative growth. Similarly, the number of days in a year in which soil is protected against wind and water erosion by snow cover varies widely in Canada.

The removal of crop residue (straw and stover) by burning or baling can have a negative effect on soil cover, but since burning is no longer a common practice in Canada and baling generally only occurs in areas where straw is plentiful, neither of these practices has a significant effect on national soil cover estimates. In addition, straw removed by baling is typically used as livestock bedding and much of this is eventually returned to the field with manure, thus limiting the overall and long-term effects of this management practice. Recent studies which involved modelling different residue harvest scenarios for bioenergy demonstrated that removing up to 40% of crop residue has little effect on soil cover, except in the **Brown** and **Dark Brown soil** zones in southern Saskatchewan and Alberta (Huffman et al., 2013). Currently, permanent removal of crop residue through baling or burning is generally restricted to flax fields in Manitoba, and the practice of burning straw has declined dramatically due to environmental concerns and improvements in the ability of field machinery to till and plant in heavy residue.

Overall, the primary factor that influences change in agricultural soil cover over time is land management. Adopting reduced tillage and no-till practices, reducing the amount of summerfallow and converting land from annual crops to perennial crops are practices that tend to increase soil cover, whereas increased tillage, greater harvesting of crop residues and expanded production of annual crops tend to lower soil cover values.

Soil cover has implications for a number of environmental processes and conditions relating to overall soil health, including organic matter content and soil susceptibility to erosion, as well as for broader environmental issues such as wildlife habitat and water and air quality. Soil cover also has implications for land productivity, crop yield and quality.

Bare soils are susceptible to breakdown of structure and erosion during **runoff** events or high winds, which affects the longer-term sustainability of crop production. During the 1930s, catastrophic soil loss occurred in some regions of the Prairies, in great part due to the imported European practices of deep plowing and summerfallowing. The resultant lack of soil cover, coupled with drought and strong winds, led to the loss of millions of tonnes of soil and the introduction of **dryland** farming techniques better suited to the region. Fortunately, significant and ongoing improvements, predominantly in reduced tillage and no-till practices, as well as in the reduction of summerfallow, have occurred over the past 30 years, particularly in the Prairie Provinces.

Areas of land with high soil cover offer habitat and food for wildlife and are generally favourable to biodiversity. Soil cover helps to keep soil in place, reducing erosion and the associated loss of nutrients and **pesticides** to waterbodies, reducing negative water quality impacts and financial losses to producers. Soil cover also affects air quality, as abundant soil cover prevents the breakdown of soil organic matter from beneath the surface, reducing the amount of oxidation and the release of **carbon dioxide** into the atmosphere. Soil cover helps to maintain the health and productivity of soils, a critical factor in terms of food quality and food supply security.

The Indicator

The Soil Cover Days (SCD) model has been improved and new information, including data from the 2011 **Census of Agriculture**, has been incorporated since the analysis was performed for the previous Agri-Environmental Indicator report (Eilers et al., 2010). All previous Census years have been re-calculated, resulting in some slight differences in reported values. In the event of a discrepancy between the findings in the two reports, this latest report should be used.

The SCD model is relatively easy to understand and can be implemented at a variety of scales, including the individual farm level. The model can be used to assess and demonstrate changes in the sustainability of Canada's soil resources that have occurred as a result of changes in management practices.

The Soil Cover Indicator summarizes the number of days per year that agricultural land is covered in a typical crop production cycle (Huffman et al., 2012). One soil cover day (SCD) can be achieved with 100% cover for one day, 50% cover for two days, 10% cover for 10 days, and so on. The indicator considers the soil cover provided by crop canopy, crop residues on the soil surface, and snow. As an example, a perennial hay crop typically has more than 300 SCDs per year since very little soil is exposed at any given time. By contrast, a soybean crop in an area of low snowfall and with no **winter cover crop** may have fewer than 150 SCDs.

To estimate the number of SCDs, an annual calendar was developed which includes dates of typical field activities and soil cover amounts for each crop and each tillage practice within each **ecoregion**. The Soil Cover Indicator takes into account the following variables:

- the day on which significant changes in soil cover occur (e.g. planting, harvesting, tillage) and the percentage of soil cover upon completion of the operation;
- the duration (number of days) and percentage of soil cover between operations;
- canopy development and decline between planting and harvest;
- the **decomposition** of residue;
- the total number of days of snow cover greater than 2 cm;
- multiple cuts and grazing on hay and pasture.

A series of SCD calendars have been developed for all crops and ecoregions in Canada using data from field studies (Wall et al., 2002), extension bulletins (Agriculture and Agri-Food Canada, undated), published literature (Steiner et al., 1999) and consultation with local agronomy experts. For crops that cover a small area, procedures were generated by extrapolating from known values for similar areas, crops and management practices.

Crop areas and tillage distribution data were obtained from the Census of Agriculture for 1981, 1986, 1991, 1996, 2001, 2006 and 2011. An area-weighted average SCD value was calculated for each **Soil Landscape of Canada (SLC) polygon**, for each province and for the whole country.

The indicator results can be expressed as the mean annual number of soil cover days or the proportion of cropland falling into each of five soil cover classes for each Census year between 1981 and 2011. An increase in the number of SCDs or in the proportion of land in the high cover classes over time indicates an improvement in sustainability and a declining likelihood that soils will become degraded or contribute to the degradation of the surrounding environment.

Limitations

A number of assumptions and limitations are inherent in the SCD methodology. The use of “typical” cropping practices and long-term climatic averages (for snow cover) means that local (sub-ecoregion) variations in cropping practices, dates and weather conditions are not accounted for. Also, since the Census of Agriculture is the only national source of tillage information and it does not provide a breakdown of tillage practices based on specific crops, the same distribution of intensive tillage, reduced tillage and no-till is used for all crops within an SLC polygon. Since reduced tillage and no-till have been widely used only over the past 25 to 30 years and data on tillage practices have been collected in the Census only since 1991, we assumed that all tillage on both crops and summerfallow was intensive in 1981 and 1986.

Results and Interpretation

Tillage practices, the frequency of perennial crop harvests, the use of summerfallow, snow-cover and soil-climatic growing conditions vary across the agricultural regions of Canada, and these are reflected in the different average SCD values estimated for each region (Figure 6–1 and Table 6–1).

Table 6–1 and Figure 6–2 also illustrate soil cover trends by province between 1981 and 2011. And Figure 6–3 gives a spatial illustration of the extent of these changes across the country over the same time period.

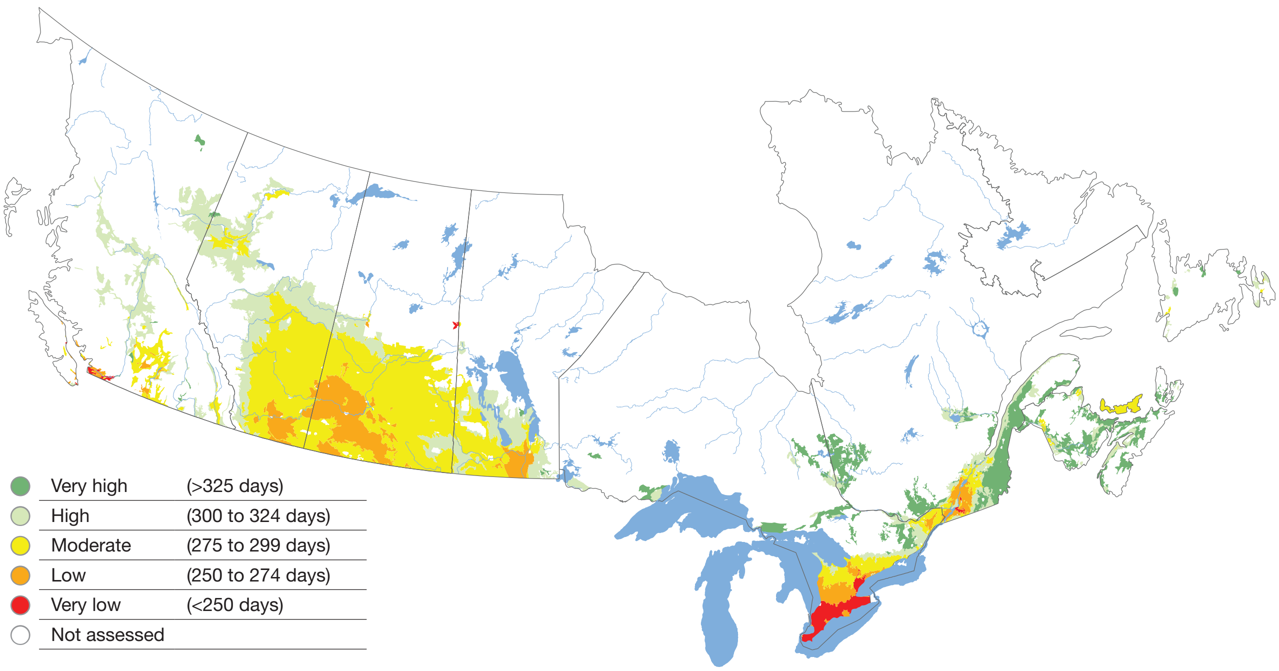


Figure 6–1: Soil cover days in Canada, 2011

Table 6–1: Area-weighted mean annual soil cover days (SCDs) for each province and for Canada, 1981 to 2011

	1981	1986	1991	1996	2001	2006	2011
BC	291.2	299.6	300.8	301.3	302.2	300.0	298.0
AB	273.4	276.4	277.6	282.3	287.0	291.7	292.4
SK	252.0	254.3	255.1	261.5	268.1	278.0	283.2
MB	274.4	278.2	279.2	282.2	284.8	290.0	291.7
ON	271.6	272.6	271.7	275.1	275.3	276.2	273.9
QC	312.0	313.5	311.3	310.7	306.6	308.6	308.9
NB	323.9	328.1	325.9	325.8	325.3	326.6	325.8
NS	326.1	328.5	329.1	329.8	328.1	328.9	330.1
PE	289.9	292.0	292.0	289.0	287.5	288.7	287.5
NL	294.4	323.5	319.7	333.5	329.5	314.0	316.6
Canada	**268.5**	**271.2**	**271.6**	**276.4**	**280.6**	**286.7**	**288.8**

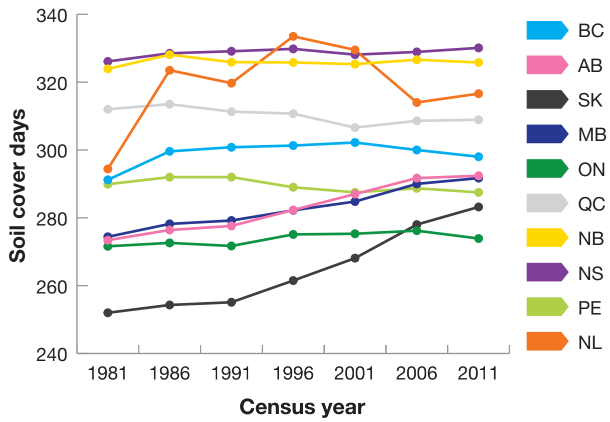


Figure 6–2: Soil cover in Canada, 1981 to 2011

The adoption of reduced tillage has had a positive influence on soil cover for all crops in all regions of Canada, with an especially pronounced effect in Western Canada and the Prairies, and in all years under study (Table 6–2, Figure 6–4). In the Prairie Provinces, the adoption of reduced tillage and no-till and a decline in the frequency of summerfallow contributed significantly to the increase in soil cover. Over the 30-year period under study, increases in the area of annual crops in Eastern Canada, as well as national increases in low-cover annual crops such as canola, potatoes and soybeans, negatively influenced soil cover (Figure 6–5). For example, between 1981 and 2011 the percentage of cropland devoted to annual crops increased from 55.3% to 62.2% in Prince Edward Island, from 32.1% to 52.6% in Quebec and from 59.0% to 70.3% in Ontario, while the total area of potatoes, canola and soybeans in Canada increased from 2 million hectares to 11 million hectares.

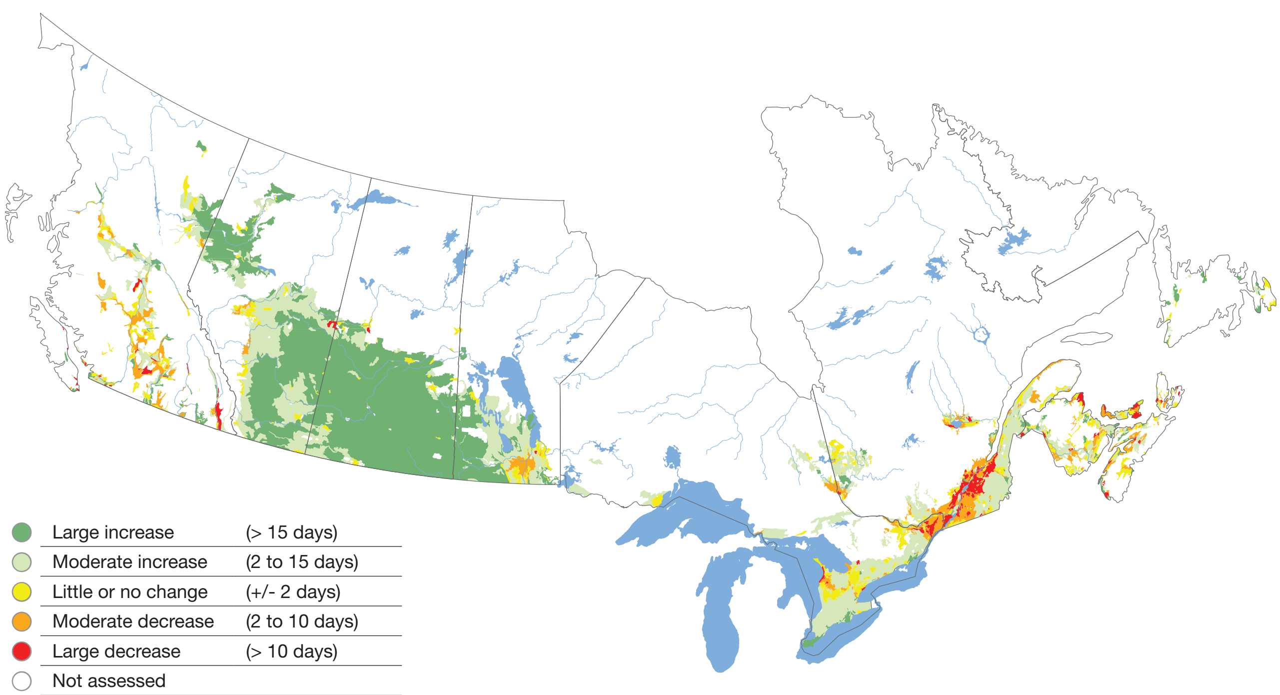


Figure 6–3: Change in soil cover in Canada by soil landscape unit, 1981 to 2011

Table 6–2: Annual average SCDs under different tillage practices for selected crops and regions in Canada

Crop	Tillage practice	Region: Prince Edward Island	Region: Southwestern Ontario	Region: Southern Manitoba	Region: Southern Alberta/ Saskatchewan
		Average Annual SCDs			
Cereal Grain	Intensive	239	214	244	222
	Reduced	271	245	263	245
	No-till	309	283	300	283
Canola	Intensive	195	155	245	219
	Reduced	231	176	254	233
	No-till	292	275	275	249
Hay	Intensive	n/a	n/a	n/a	n/a
	Reduced	n/a	n/a	n/a	n/a
	No-till	312	236	318	315
Summerfallow	Intensive	n/a	n/a	203	178
	Reduced	n/a	n/a	244	219
	No-till	n/a	n/a	287	251

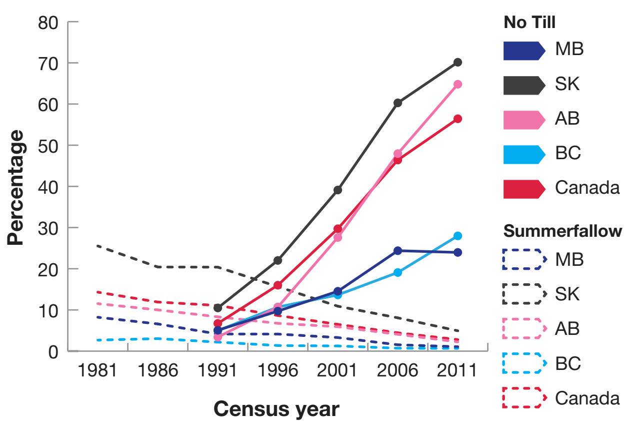


Figure 6–4: Trends in summerfallow and no-till in Western Canada and the Prairies, 1981 to 2011. Note that Census data for tillage practices are available from 1991 onwards only.

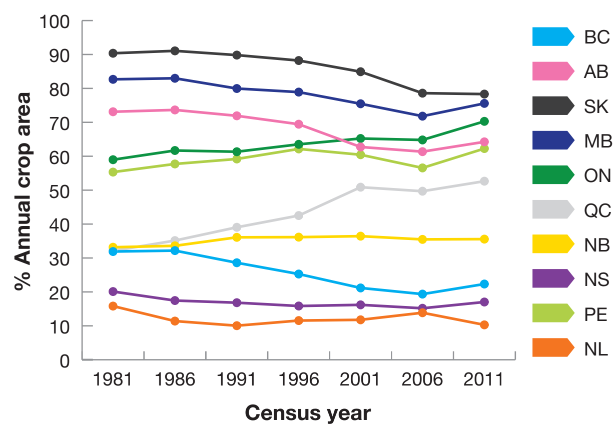


Figure 6–5: Trends in annual crops, 1981 to 2011

Provincial average SCD values over the study period ranged from a low of 252 in Saskatchewan in 1981 to a high of 333.5 in Newfoundland and Labrador in 1996 (Table 6–1). The national average increased over the 30-year period from 268.5 SCDs to 288.8 SCDs (Table 6–1), with the greatest increases occurring in Saskatchewan (12.4%), Newfoundland and Labrador (7.5%), Alberta (6.9%) and Manitoba (6.3%). Smaller increases occurred in British Columbia (2.3%), Nova Scotia (1.2%), Ontario (0.8%) and New Brunswick (0.6%), while average SCD decreased by about 1% in Prince Edward Island and Quebec. The national increase in SCD over the period from 1981 to 2011 was driven primarily by the Prairie Provinces and is attributable to their large agricultural area and relatively large increases in soil cover as a result of reductions in tillage and summerfallow area (Figure 6–3, Figure 6–4). Ontario, Quebec and Prince Edward Island showed generally steady but modest improvements up to 2006, followed by a slight decline which was associated with shifts from perennial to annual crops. New Brunswick and Nova Scotia showed very little change, but their average soil cover values tended to be consistently the highest in the country due to the high proportions of perennial crops. British Columbia showed a relatively dramatic improvement early in the study period (1981–1986) due to a reduction in tillage; however, little change occurred from 1986 to 2001 and soil cover has followed a downward trend since 2001. The recent decline can be attributed to a significant increase in the reported area of thinly vegetated rangeland in the dry, low-snowfall interior mountain valleys. Newfoundland and Labrador showed an overall improvement in soil cover over the study period, but wide fluctuations from one Census year to the next due to changes in crop distribution on a relatively small farmland base.

In order to get a picture of the spatial variability in soil cover across the country, we defined *Very High* soil cover as being greater than 325 days per year, *High* as 300 to 324 days, *Moderate* as 275 to 299 days, *Low* as 250 to 274 days and *Very low* as fewer than 250 days. The proportion of farmland in each of these classes by province and by year is presented in Table 6–3, the 2011 spatial distribution, calculated on the basis of SLC polygons, is shown in Figure 6–1. About 4% of Canadian farmland was in the *Very High* soil cover class in 1981, and that declined to 3% by 2011, while the proportion of land in the *High* class rose from 8% in 1981 to 21% in 2011 and the proportion in the *Moderate* class rose from 23% in 1981 to 57% in 2011. These increases were the result of a decrease in the proportion of land in both the *Low* (from 41% to 17%) and *Very low* classes (from 24% to 2%). Newfoundland and Labrador, Quebec, New Brunswick and Nova Scotia had the highest percentages in the *Very High* soil cover class, while Ontario had the highest proportion in the *Very low* soil cover class.

Table 6–3: Percentage of farmland by soil cover class[1], 1981 to 2011

Class	Very high (>325)							High (300 to 325)							Moderate (275 to 300)							Low (250 to 275)							Very low (<250)						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	0	3	1	2	1	4	1	42	56	64	62	67	61	62	41	28	26	29	24	28	23	14	10	5	5	5	6	11	4	3	3	3	3	1	3
Alberta	0	0	0	0	0	0	0	6	13	14	20	25	30	29	39	38	38	47	56	58	63	42	36	38	29	17	12	8	13	13	10	4	2	0	0
Saskatchewan	0	0	0	0	0	0	0	0	0	0	2	2	5	7	8	11	12	18	34	52	69	48	45	45	55	51	43	24	44	44	43	26	14	1	0
Manitoba	0	0	0	0	0	0	0	8	14	13	15	15	25	32	29	35	38	50	63	58	52	63	51	49	34	21	15	16	0	0	0	0	1	1	0
Ontario	4	7	7	6	7	5	6	17	16	16	22	16	21	15	32	30	30	23	26	25	27	18	18	18	22	22	23	25	29	30	30	28	29	27	28
Quebec	39	45	39	40	37	31	37	37	31	34	33	26	37	29	13	12	14	11	15	20	14	11	12	13	15	14	11	19	0	0	0	1	7	1	1
New Brunswick	56	70	66	67	66	74	56	38	23	27	27	19	19	30	6	7	7	6	15	7	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nova Scotia	72	77	78	77	71	76	72	20	16	15	21	22	21	23	7	6	7	2	7	2	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Prince Edward Island	0	0	0	0	0	0	0	20	25	21	14	0	9	1	65	60	75	66	83	91	98	15	15	4	20	17	0	1	0	0	0	0	0	0	0
Newfoundland and Labrador	0	59	36	86	61	20	23	31	23	57	13	37	68	64	59	15	8	1	3	13	14	10	3	0	0	0	0	0	0	0	0	0	0	0	0
Canada	**4**	**4**	**3**	**4**	**3**	**3**	**3**	**8**	**11**	**11**	**15**	**16**	**20**	**21**	**23**	**24**	**25**	**31**	**42**	**49**	**57**	**41**	**37**	**37**	**37**	**30**	**24**	**17**	**24**	**24**	**23**	**14**	**9**	**3**	**2**

1 This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding the numbers may not sum exactly to 100%

The spatial distribution of changes in soil cover in Canada between 1981 and 2011 is shown in Figure 6–3. Most of the central Prairie region, where reductions in tillage and summerfallow area have been significant, has seen increases of more than 10 days, while the agricultural fringe areas, which are characterized by a greater proportion of perennial crops, less opportunity for reduced tillage and lower summerfallow levels, have seen only minor changes or more moderate increases. The rest of the agricultural regions in Canada have undergone moderate to slight decreases or increases, with the exception of several areas in southern British Columbia and the St. Lawrence Lowlands in eastern Ontario and western Quebec, which showed decreases of greater than 10 days. These areas underwent significant changes in crop distribution, with relatively large shifts from perennial to annual crops during the period under study.

Response Options

Changes in average soil cover within a region are influenced by changes in both tillage practices (intensive vs. reduced vs. no-till) and crop distribution. Thus, although the adoption of reduced tillage may increase soil cover for a specific crop (Table 6–2), a shift from intensive tillage on a high-residue crop such as cereal grain to reduced tillage on a lower-residue crop such as canola could result in a decrease in SCDs.

Of perhaps even greater importance than the adoption of reduced tillage in improving soil cover is the application of practices to enhance soil cover during the production of inherently low-residue crops such as potatoes, canola, soybeans, vegetables and nursery crops. These crops have increased in area since 1981 and can be expected to continue to expand. Planting a green manure crop or a winter cover crop where feasible as soon as possible after harvesting would provide a greater degree of soil cover for these crops during the long period between harvesting in the fall and planting in the spring. This may become especially important if climatic changes reduce the number of days of soil protection afforded by snow or if extreme weather events become more common in the spring before planting, when the soil is particularly vulnerable to degradation through erosion.

The desire for greater soil cover also has some research implications in terms of developing suitable companion and overwinter crops as well as cold-germination varieties of crops for use under no-till; and in terms of developing equipment that can better maintain surface residue while performing production operations satisfactorily. Another promising area of research may be the development of crops with a greater mass of more durable foliage.

Since the early 1980s the trend in the level of soil cover has been generally positive. However, the increase in soil cover has slowed almost universally from a high rate of change in the early to mid-1990s to a much more modest increase since then. This is indicative of the increasing technical challenges that are encountered as the rate of adoption of reduced tillage practices levels off. This trend is indicative of the need for continued efforts to adjust and develop beneficial practices to address changing trends in cropping practices, such as recent increases in intensive low cover row crops. Such efforts are needed in order to keep pace with changing practices trends that are resulting in lower soil cover.

References

Agriculture and Agri-Food Canada (AAFC), 2008. *Interpolated Census of Agriculture to soil landscapes, ecological frameworks and drainage areas of Canada.* Agriculture and Agri-Food Canada, National Land and Water Information Service. Retrieved June 9, 2009 from www.agr.gc.ca

Agriculture and Agri-Food Canada (AAFC), Undated. *Managing crop residues on the prairies*. Crop Residue Survey on the Prairies. Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration. Retrieved June 9, 2009 from www.agr.gc.ca

Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds.), 2010. *Environmental sustainability of Canadian agriculture: Agri-environmental indicator report series – Report #3*. Agriculture and Agri-Food Canada, Ottawa, Ontario.

Huffman, T., J. Liu, D.R. Coote, and M. Green, 2013. *The effect on soil quality of integrating perennial crops into cropping systems in response to demand for bioenergy feedstock*. Invited presentation, Water, Food, Energy and Innovation for a Sustainable World. ASA, CSSA and ASSA International Annual Meetings, Tampa, FL, Nov 3-6, 2013.

Huffman, T., D.R. Coote, and M. Green, 2012. *Twenty-five years of changes in soil cover on Canadian Chernozemic (Mollisol) soils, and the impact on the risk of soil degradation*. Canadian Journal of Soil Science. 92: 471-479.

Statistics Canada, 2011. *About the Census of Agriculture*. Retrieved June 25, 2012 from http://www.statcan.gc.ca/ca-ra2011/index-eng.htm

Steiner, J.L., H.H. Schomberg, P.W. Unger, and J. Cresap, 1999. *Crop residue decomposition in no-tillage small-grain fields*. Soil Science Society of America Journal. 63: 1817–1824.

Wall, G.J., D.R. Coote, E.A. Pringle, and I.J. Shelton (eds.), 2002. *RUSLEFAC – Revised universal soil loss equation for application in Canada: A handbook for estimating soil loss from water erosion in Canada*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Wischmeier, W.H., and D.D. Smith, 1965. *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: Guide for selection of practices for soil and water conservation.* In: Agriculture Handbook No. 282. Washington, D.C.: U.S. Department of Agriculture.

07 Wildlife Habitat

Authors:
S.K. Javorek, M.C. Grant and S. Fillmore

Indicator Name:
Wildlife Habitat Capacity on Farmland

Status:
National Coverage, 1986 to 2011

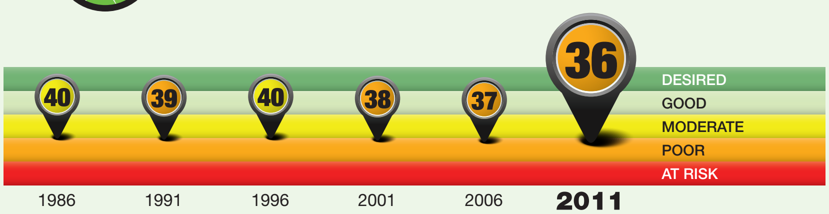
Summary

Canada's diverse agricultural landscape provides habitat for close to 600 species of birds, mammals, reptiles and amphibians. Although these **agro-ecosystems**[1] support many of Canada's native wildlife species, shifting economic factors drive dynamic land-use change which can have both beneficial and detrimental impacts on wildlife.

Wildlife Habitat on Farmland Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.

Wildlife Habitat on Farmland Index



State and Trend

As illustrated by the performance index, in 2011 the state of the environment from the standpoint of wildlife habitat capacity on farmland in Canada was 'Poor'. Between 1986 and 1996, wildlife habitat remained stable on 97% of Canadian farmland; however, there was a decline in habitat capacity between 1996 and 2011, as illustrated by the drop in index values. In the last 15 years, the majority (85%) of Canada's farmland has maintained its habitat capacity, and a small proportion (1%) has seen an increase. However, 14% of farmland has seen an actual decrease in capacity over that period, representing a decline in habitat availability or suitability. This decline is primarily attributable to the loss of natural and semi-natural land and the intensification of farming. Within some regions, most notably the Mixedwood Plains Ecozone, the loss of perennial hay and pasture habitat was a major contributor to WHC decline.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

Agriculture can have a positive effect on wildlife by increasing **landscape heterogeneity** or a negative effect through the loss, alteration or fragmentation of habitat. The vast majority of wildlife species (close to 90%) associated with agricultural land depend upon natural or semi-natural land-cover types, such as woodlands, **wetlands** or grasslands, to provide essential breeding and feeding habitat. In sharp contrast, only 3% of the identified wildlife species could fulfill both breeding and feeding requirements on annual **cropland** alone. This indicates that the existence of viable wildlife populations on farmland is tied to the availability of natural and semi-natural cover types within the Canadian agricultural landscape. The Wildlife Habitat Capacity (WHC) on Farmland Indicator assesses the overall *state* and *trend* of the Canadian agricultural landscape from the standpoint of the availability of suitable habitat for populations of terrestrial vertebrates.[2]

In 2011, most of the agricultural land in Canada provided Low (46.1% of land) or Very low (47.9%) values for wildlife, with just 4.5% of land in the Moderate category, 1.3% in the High category and 0.2% in the Very High category. The distribution of these categories generally corresponds to areas with a high proportion of agriculture, such as the Prairies and Mixedwood Plains **ecozones**, where agricultural land use accounts for 90% and 60% of land cover, respectively, and where natural and semi-natural land cover comprises a relatively small percentage of the agricultural landscape. In the last 15 years, the majority (85%) of Canada's farmland has maintained its habitat capacity, and a small proportion (1%) has seen an increase in capacity. However, 14% of farmland has seen an actual decrease in capacity over that period, predominantly driven by the loss of natural and semi-natural land cover, as well as by conversions from pasture and **forages** to annual crops, following the decline in livestock production, particularly since 2006. Most of these declines occurred in the Mixedwood Plains region of eastern Canada. The Prairies, which account for the majority of Canada's agricultural lands have had pockets of decline, but have remained relatively stable in terms of their ability to provide wildlife habitat. It is important to note that for this indicator, the main objective is for the majority of agricultural working landscapes to provide a stable or improved level of habitat capacity, thus avoiding further significant habitat degradation.

The Issue and Why it Matters

Approximately 8% of Canada's landmass is used for agriculture; this land is comprised of cultivated lands, haylands and grazing lands, as well as associated natural and semi-natural cover types such as wetlands, woodlands, **riparian areas** and grasslands. There are 579 identified species of birds, mammals, reptiles and amphibians that use this mosaic of land cover for feeding, breeding or shelter. Each of these species has unique habitat requirements which must be satisfied in order for viable populations to exist.

Although agricultural landscapes can support many of Canada's **native species**, agricultural land use is dynamic and changes can have major impacts on wildlife. Wildlife habitat on farmland is degraded through the conversion of natural and semi-natural areas to cropland, increased use of chemical inputs, drainage of wetlands, removal of **shelterbelts** and natural field barriers to accommodate larger machinery, and sometimes through an increase in livestock density. These changes can lead to habitat fragmentation and the loss of landscape heterogeneity.

Natural habitat within the agricultural landscape is extremely important for wildlife as it fulfills both breeding and feeding habitat requirements for the vast majority (89%) of species associated with farmland. In contrast, only 3% of species could fulfill their breeding and feeding requirements on annual cropland alone, and 19% of species could meet these requirements on all cropland (annual and perennial crops and **tame hay**). The value of cropland for wildlife increases when other land-cover

2 For the purposes of this indicator, wildlife refers to terrestrial vertebrates only and does not extend to invertebrates or plants.

types (primarily **all other land**[3] and **unimproved pasture**[4]) are present in the agricultural landscape, since 35% of species utilize cropland for a single habitat requirement (either breeding or feeding). Similarly, 30% of species could use unimproved pasture for both breeding and feeding habitat, but when other land-cover types are present to meet partial habitat requirements, 49% of species could then be supported by this land-cover type. This shows that the value of certain cover types may vary depending on the presence of complementary habitats that fulfill partial life-history requirements. The maintenance of heterogeneous agricultural landscapes that include a suitable amount and spatial arrangement of natural and semi-natural land cover is of most benefit to wildlife.

Since a large percentage of the terrestrial area within some ecozones of Canada (e.g. the Prairies) is devoted to agricultural use, planning at the provincial or national level is essential to accommodate the needs of a wide range of species found in such areas and to support the management of Canada's **biodiversity**. Conservation and enhancement of wildlife habitat in agricultural areas is particularly important, since some of the species in Canada that use farmland as habitat are classified as at risk (CESCC, 2011; Javorek and Grant, 2010) under provincial and/or federal species at risk legislation. This may lead to increased public or regulatory pressure on producers to alter their management practices in order to protect and conserve important habitat features on their farms. Currently, half of the terrestrial vertebrates listed as species at risk use farmland within part of or across their feeding and breeding ranges. The Migratory Birds Convention, a treaty signed with the United States to protect migratory birds, can also have implications for the management of agricultural lands.

Agriculture benefits from the important **ecosystem services** provided by wildlife, including crop pollination and natural pest control. The provision of wildlife habitat in agricultural regions, through the creation or maintenance of buffers, woodlots or wetlands, for example, can also provide other benefits such as improved soil and water quality, efficient **nutrient** cycling and **carbon sequestration**. Nonetheless, public efforts to conserve and restore habitat capacity on private lands must consider the realities of the working landscape, including production and economic factors in the agricultural sector. Several initiatives exist (administered both provincially and through non-governmental funding sources) to compensate farmers for their efforts towards the provision or enhancement of ecosystem services in targeted areas that contribute to the public good.

The Indicator

The Wildlife Habitat Capacity on Farmland Indicator provides a multi-species assessment of broad-scale trends in the capacity of the Canadian agricultural landscape to provide suitable habitat for populations of terrestrial vertebrates.

It is important to note that for this indicator, the main objective is for the majority of agricultural working landscapes to provide a stable or improved level of habitat capacity, thus avoiding further significant habitat degradation.

3 The All Other Land category is an older (pre-2006) Census category that includes areas of all other land on a farm, including idle land, woodlots, marshes, and wetlands, as well as land containing farm buildings, barnyards, lanes and home gardens. Since 2006, it has been split into two new distinct categories: "Woodlands and Wetlands," which incorporates woodlots, sugarbush, windbreaks, marshes, bogs, ponds and sloughs; and a new "All other land" category which now only encompasses idle land, as well as land containing farm buildings, barnyards, lanes, and home gardens. For consistency in calculating this indicator, the original All Other Land designation has been maintained.

4 Unimproved Pasture includes natural land for pasture

The WHC of the Canadian agricultural landscape was investigated from 1986 to 2011 at five-year intervals to coincide with the Canadian **Census of Agriculture**, which is the source of the land-cover data used for indicator calculation. The analysis was restricted to land reported in the Census; therefore, non-agricultural land, such as forested and urban lands, was not included.

METHODOLOGY

Land-cover information at the **Soil Landscapes of Canada (SLC) polygon** level was obtained from the Census. A habitat association matrix was constructed to link each of 579 species (including 363 birds, 136 mammals, 42 amphibians and 38 reptiles) to the 15 land-cover types reported in the Census. These cover types consist of cereals, winter cereals, **oilseeds**, corn, soybeans, vegetables, berries, fruit trees, other crops (including potatoes, millet, caraway, ginseng and coriander), pulses, **summerfallow**, tame hay**, improved pasture**, unimproved pasture, and all other land. Habitat use by individual species was spatially linked to the Census land-cover data by adjusting each species' natural habitat range to the SLC polygons. Both primary and secondary habitat used for breeding and feeding was included in the indicator calculation.

For each species whose habitat range included a given SLC polygon, the percentages of land corresponding to land-cover types used for breeding and for feeding were averaged to determine the species-specific habitat availability (SSHA) for that SLC polygon.

A single value for potential wildlife habitat capacity (WHC) on farmland was created for each SLC polygon by taking the average of all SSHA values calculated for that SLC polygon.

The state of WHC on agricultural land in Canada for 2011 was determined by classifying these potential WHC values into five categories, based on the national distribution of habitat capacity scores from all reporting SLC polygons. These classes are *Very low* (< 26.0), *Low* (26.0 to 42.5), *Moderate* (42.6 to 59.5), *High* (59.6 to 76.0), and *Very High* (>76.0).

Trends for 1986 to 1996, 1996 to 2011 and 1986 to 2011 were determined through analysis of variance, followed by pairwise comparison of means to detect significant changes ($p<0.001$) in habitat capacity for SLC polygons among years.

The methodology has been revised for this report. Previous versions applied weightings to habitat use based on habitat value (e.g. Primary, Secondary, Tertiary). This approach has been discontinued for Report 4 due to the challenges involved in applying a single habitat-use value, such as primary, to a broad category such as "all other land." All previous years have been re-calculated in this report. In the event of any discrepancies between this report and its predecessors, the approach used in the present report takes precedence.

Limitations

Calculation of the indicator is limited by the lack of resolution within the Census "all other land" category, which, for the purpose of this indicator,[5] encompasses **idle land**, woodlots, marshes and wetlands, as well as land containing farm buildings, barnyards, lanes and home gardens. The use of such a broad category may cause overestimation or underestimation of species-specific habitat availability. In order to counter this limitation, a remote sensing component is being developed to better distinguish these habitat types. The integration of earth observation data will also enable researchers to analyse the important influence of landscape pattern and configuration (to include heterogeneity, connectivity and fragmentation), factors that are not addressed by the existing model. Once finalized, it will improve the model outputs, and better capture the state and trend of habitat on farmland.

Agricultural landscapes are dynamic, with beneficial and detrimental land-cover changes often happening concurrently. Analyses conducted at broad national or provincial scales can lead to a counterbalancing of the effects of land-cover change on wildlife, and mask habitat changes at regional or local scales. Therefore, it is important to interpret the trends carefully, since relatively small local changes in natural and semi-natural land cover, which are not captured with broad-scale assessment, can have a major impact on wildlife.

It should be kept in mind that wildlife populations are opportunistic and adaptive. The indicator does not currently relate changes in wildlife habitat capacity to the responses of wildlife populations.

The WHC category rankings are based on their relative value among all reporting SLC polygons, and not on biologically derived habitat classification rankings. The indicator currently looks only at agricultural land and thus does not incorporate the influence of other, adjacent land-use types (for example, forestry) on wildlife.

Results and Interpretation

POTENTIAL WILDLIFE USE OF AGRICULTURAL LAND

Figure 7–1 shows the number of wildlife species using each of the cover types for breeding and feeding on agricultural land in Canada. "All other land" ranked highest, followed by unimproved pasture (natural land for pasture), showing the importance of these natural and semi-natural land-cover types for wildlife. Perennial cropland, including improved pasture, tame hay, and orchard crops, ranked next but had a markedly lower number of associated species which find such land suitable as either breeding or feeding habitat. Annual field cropland, including grains, cereals, oilseeds, pulses and horticultural crops, among others, was characterized by a comparatively low value for wildlife, especially in terms of breeding habitat. Summerfallow also had a comparatively low wildlife value.

NATIONAL RESULTS AND INTERPRETATION

In 2011, the average wildlife habitat capacity on farmland in Canada was *Low*. Wildlife habitat capacity on the majority of farmland in Canada fell in the *Very low* (47.9%) and *Low* (46.1%) categories, with 4.5% *Moderate*, 1.3% *High* and 0.2% *Very High* (Table 7–1).

In 2011, the majority of farmland in the *Low* and *Very low* WHC categories was found in western and central Canada (Figure 7–2). The distribution of these categories generally corresponds to areas with a high proportion of agriculture, such as the Prairies and Mixedwood Plains ecozones, where agricultural land use accounts for 90% and 60% of land cover, respectively, and where natural and semi-natural land cover comprises a relatively small percentage of the agricultural landscape. In areas where agriculture is the dominant type of land cover, agricultural land-use and land-management decisions can have a major impact, positive or negative, on wildlife habitat availability.

5 An explanation is provided in a footnote on page 3 and also in the Glossary section at the end of this publication.

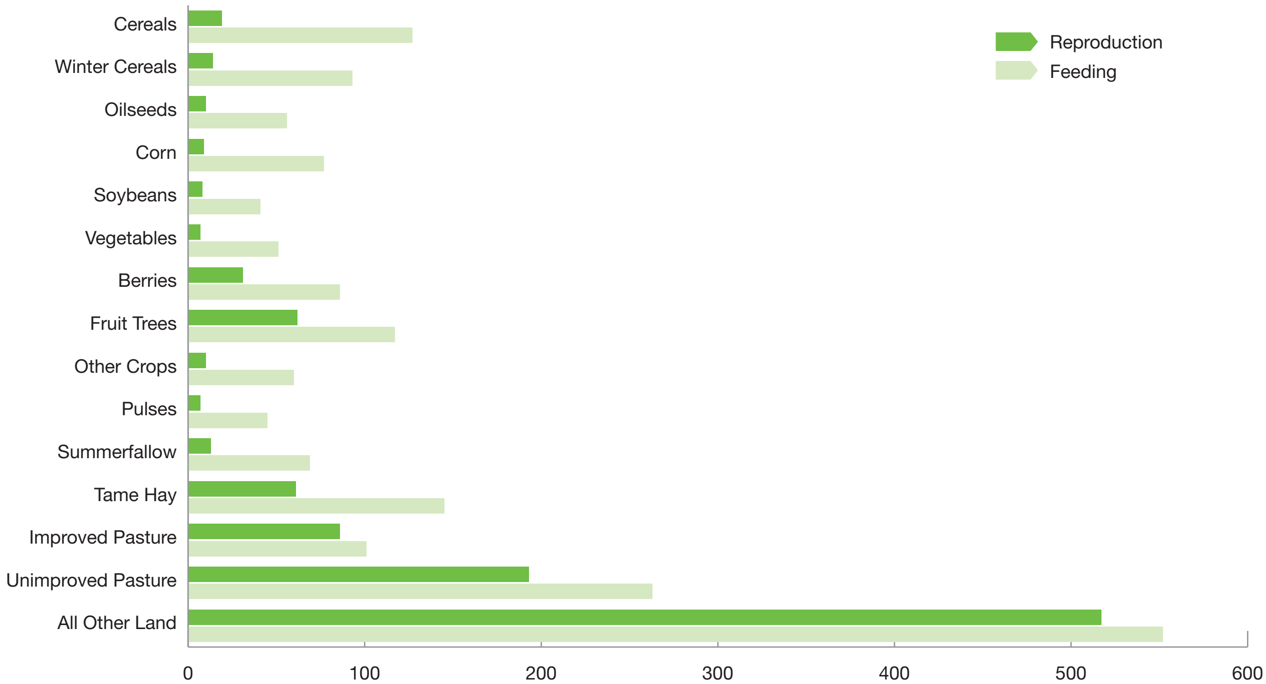


Figure 7–1: The number of wildlife species using each of the cover types for breeding and feeding on agricultural land in Canada

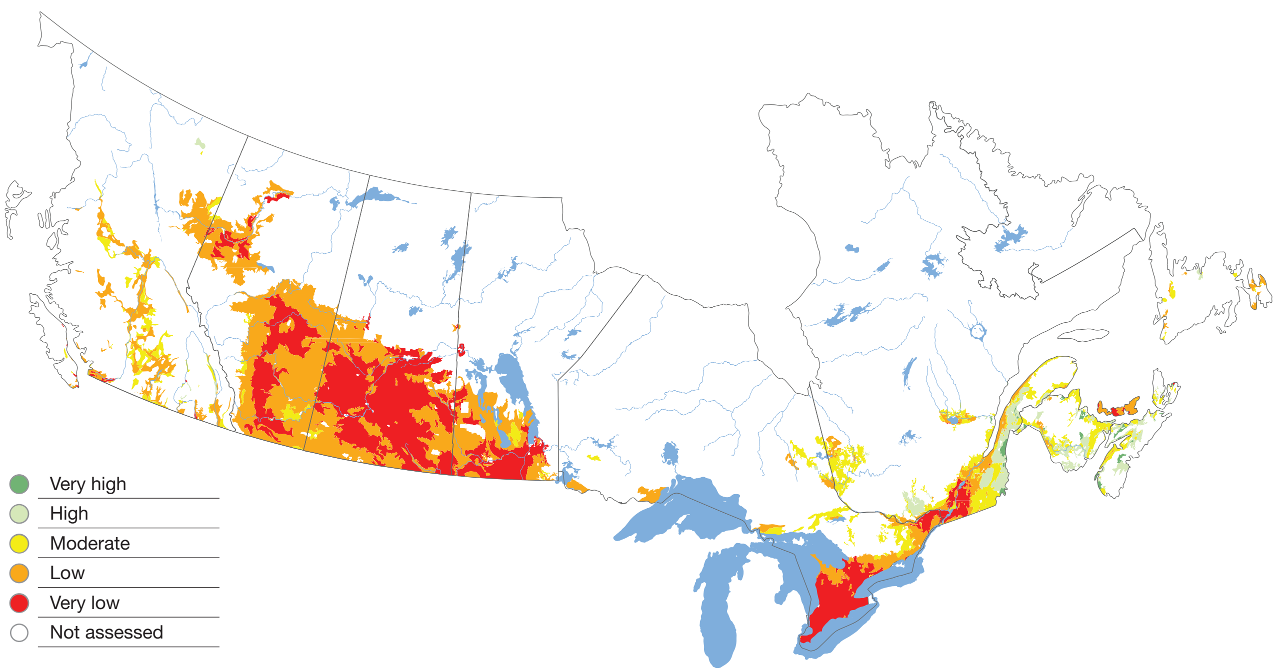


Figure 7–2: Wildlife habitat capacity for terrestrial vertebrates using agricultural land for breeding and feeding, 2011

Table 7–1: The percentage (%) of farmland per class for breeding and feeding terrestrial vertebrates in 1986, 1991, 1996, 2001, 2006 and 2011

Class	Very High						High						Moderate						Low						Very Low					
Year	1986	1991	1996	2001	2006	2011	1986	1991	1996	2001	2006	2011	1986	1991	1996	2001	2006	2011	1986	1991	1996	2001	2006	2011	1986	1991	1996	2001	2006	2011
British Columbia	0	0	0.1	0	0	0	1.9	1.1	0.8	0.2	0.4	1.2	46.8	53.4	58.3	53	25	19.9	49.9	44.2	39.8	45.9	72.3	75.1	1.4	1.3	1	0.9	2.3	3.7
Alberta	0	0	0	0	0	0	0	0	0.3	0	0	0	4	3.5	5.8	3.6	3.5	2.2	76	78.2	76.5	74.9	71.5	64.7	20.1	18.3	17.4	21.5	25	33.2
Saskatchewan	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.5	0.5	0.4	0.4	0.5	41.7	38.9	41	36	37.6	34.5	57.5	60.6	58.5	63.6	62	65
Manitoba	0	0	0	0	0	0	0	0	0	0	0	0	3.2	0.2	0.4	2.7	3.3	2.7	59.2	57.6	58.4	57.2	53.9	44.1	37.6	42.1	41.1	40.2	42.6	53.2
Ontario	0	0	0	0	0	0	1.2	0.7	2.7	0.9	0.2	0.3	16.3	12.3	12.2	11.8	9.6	6.2	44	43.3	41.4	37	35.5	28.9	38.5	43.6	43.8	50.2	54.7	64.6
Quebec	0.4	0.2	1.2	0.6	1.3	1.8	10.7	9.9	15.9	18.8	10.5	15.5	46.1	45.1	36.4	33.4	35.8	29.3	31.4	31.1	32.1	29.4	31.9	31.2	11.4	13.6	14.4	17.7	20.5	22.2
New Brunswick	2.6	0.6	1.5	1.7	0.8	4.1	54.4	42.5	45.4	44.8	37.6	31.1	38.9	51.3	47.9	41.9	48.9	53.4	4.2	5.5	5.1	11.6	12.7	11.4	0	0	0	0	0	0
Nova Scotia	3.8	4.5	9	10.8	4.7	17.1	62.4	63.6	58.7	43.6	43.7	42.4	31.3	31.7	30.8	42.2	47.4	33.1	2.5	0.2	0.8	3.5	3.9	7	0	0	0	0	0.2	0.3
Prince Edward Island	0	0	0	0	0	0	0	0	0	0	0	0	25	24.2	14.1	15.7	0	1.5	75	72	81.7	84.3	75.4	70	0	3.8	4.1	0	24.6	28.5
Newfoundland and Labrador	2.1	2.1	10.5	9	0.2	0	45	20	63.8	29	4.3	10	35	68.5	24.5	57.4	51.5	24.4	17.7	9.5	1.2	4.7	42.4	64	0.2	0	0	0	1.7	1.6
Canada	**0.1**	**0**	**0.1**	**0.1**	**0.1**	**0.2**	**1.5**	**1.2**	**1.8**	**1.6**	**1**	**1.3**	**7.9**	**7.1**	**7.6**	**6.8**	**5.8**	**4.5**	**53.7**	**52.9**	**53.2**	**50.4**	**50.9**	**46.1**	**36.9**	**38.7**	**37.3**	**41**	**42.2**	**47.9**

Farmland with *Moderate* to *High* WHC was generally associated with mixed farming in the Atlantic Maritime Ecozone, and with rangelands in the Montane Cordillera and Pacific Maritime ecozones. Much of the farmland in the Atlantic Maritime Ecozone was characterized by significant amounts of natural and semi-natural land. With the exception of a few regions (Saint John River Valley, Annapolis-Minas Lowlands and parts of Prince Edward Island), agriculture was a minor component of the broader landscape. In many areas of the Montane Cordillera and Pacific Maritime ecozones, rangeland represented a significant component of agricultural land. The relatively high value of unimproved pasture as wildlife habitat compared to cropland contributed to the *Moderate* WHC ranking assigned to agricultural land in parts of these ecozones.

From 1986 to 2011, WHC was constant on 82.1% of agricultural land, decreased on 16.5% and increased on 1.4% (Figure 7–3, Table 7–2). The net result of these changes was a decrease in the proportion of agricultural land in the *Moderate* (7.9 to 4.5%) and *Low* (53.7 to 46.1%) categories and an increase in the *Very low* (39.9 to 47.9%) category (Figure 7–4, Table 7–2). The rate of WHC decline was not constant over the 25 years considered. From 1986 to 1996, WHC was relatively stable, remaining constant on 97.0% of farmland, decreasing on 1.1% and increasing on 1.8%. From 1996 to 2011, WHC decreased steadily, so that while habitat remained stable on the majority (85.3%) of farmland and improved on 0.8%, it declined on 13.9% of farmland.

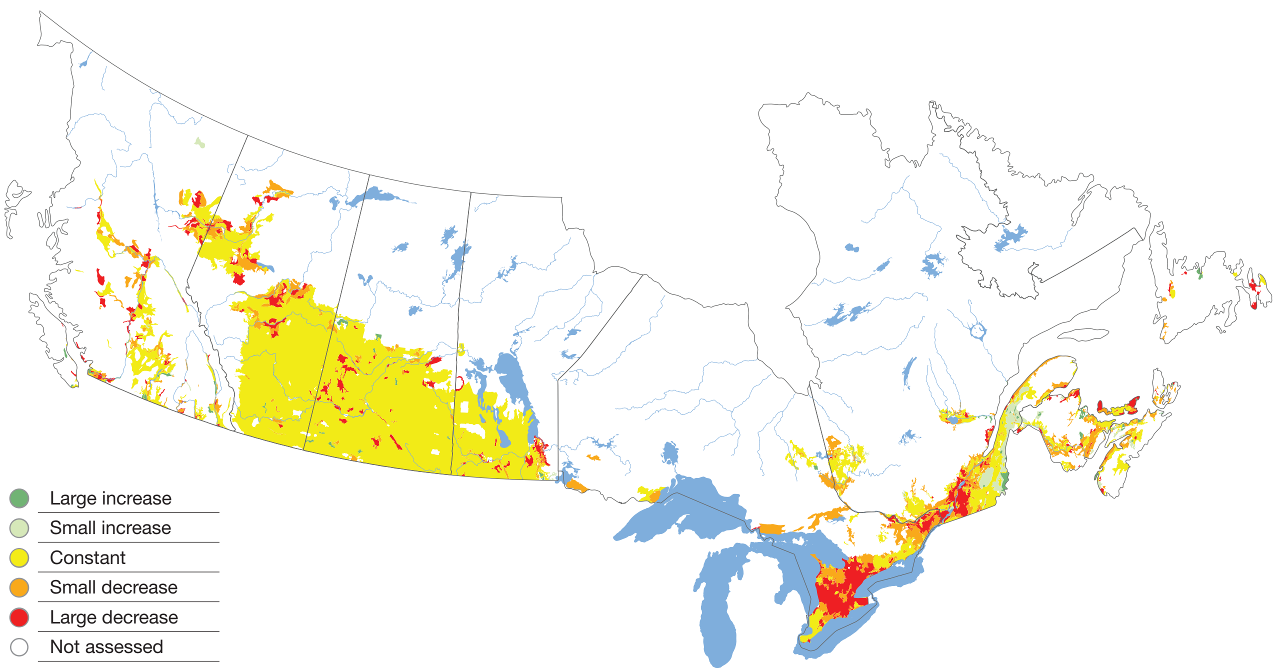


Figure 7–3: Change in wildlife habitat capacity on farmland for breeding and feeding terrestrial invertebrates, 1986–2011

Table 7–2: Share of agricultural land per wildlife habitat capacity class, 1986–1996, 1996–2011 and 1986–2011

Class	Large Increase			Small Increase			Constant			Small Decrease			Large Decrease		
Year	1986–1996	1996–2011	1986–2011	1986–1996	1996–2011	1986–2011	1986–1996	1996–2011	1986–2011	1986–1996	1996–2011	1986–2011	1986–1996	1996–2011	1986–2011
British Columbia	0.7	2.2	2.8	0.4	1.2	1.3	97.9	63.6	57.4	0.6	23.2	23.7	0.5	9.8	14.9
Alberta	1.5	0.2	0.1	0.2	0.0	0.0	97.5	92.8	90.0	0.8	3.8	5.8	0.1	3.2	4.1
Saskatchewan	0.5	0.3	0.6	0.3	0.0	0.0	99.0	95.1	94.3	0.1	1.1	1.3	0.1	3.5	3.8
Manitoba	0.5	0.6	0.2	0.1	0.1	0.1	98.7	92.0	93.4	0.3	1.3	1.6	0.3	6.1	4.7
Ontario	0.9	0.2	0.2	1.3	0.1	0.0	96.1	33.3	22.4	1.7	36.6	32.1	0.0	29.9	45.3
Quebec	2.1	0.9	2.0	11.8	4.1	12.5	79.1	56.5	38.7	6.6	21.4	25.3	0.5	17.0	21.5
New Brunswick	1.7	5.0	6.0	5.8	6.4	6.1	64.3	57.6	36.5	28.1	24.2	40.4	0.2	6.7	11.0
Nova Scotia	4.0	3.5	9.0	19.7	19.0	11.9	68.9	45.7	42.3	6.3	27.0	32.2	1.0	4.8	4.5
Prince Edward Island	0.0	1.5	1.5	0.0	0.0	0.0	89.8	64.5	52.6	9.8	22.8	9.2	0.4	11.2	36.7
Newfoundland and Labrador	41.1	0.0	6.8	12.8	0.0	0.0	38.1	20.2	33.0	3.9	4.7	9.3	4.1	75.2	50.9
Canada	**0.9**	**0.4**	**0.6**	**0.9**	**0.4**	**0.8**	**97.0**	**85.3**	**82.1**	**0.9**	**7.1**	**7.7**	**0.2**	**6.8**	**8.8**

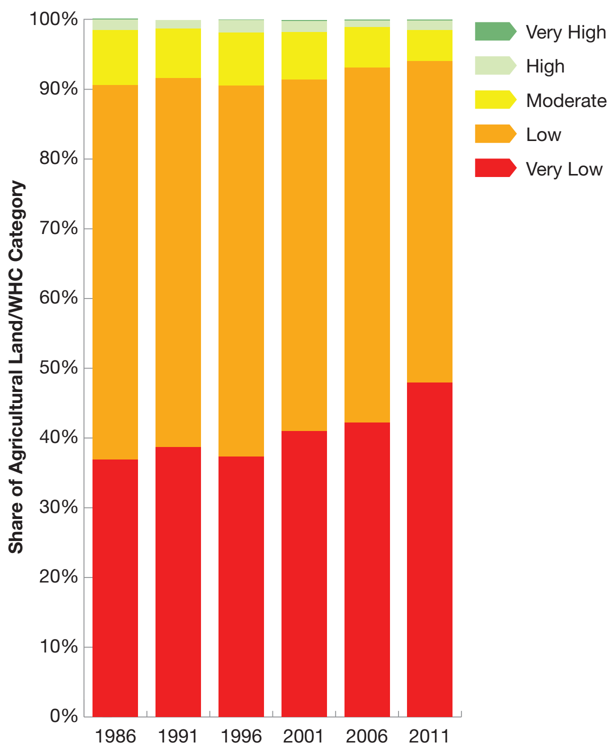


Figure 7–4: The national share of farmland in each wildlife habitat capacity (WHC) class, 1986 to 2011

Declines in "all other land" occurred at a low but relatively continuous rate across Canada from 1986 to 2011, resulting in a loss of about 2 million hectares of land considered to have a high capacity to support wildlife. This has been a major factor in WHC decline. Shifts in the type of crops planted also affected WHC, since crop types with higher habitat suitability were often replaced with crops with lower suitability. Specifically, the share of cereals has declined, while the share of oilseeds, soybeans and potatoes (included in other crops) has increased, particularly since 1996.

At the regional level, changes in Canadian farming practices across the Prairie region led to a dramatic reduction in summerfallow from 1986 to 2011. A portion of this land shifted to tame hay and improved pasture production. The replacement of species-impoverished summerfallow (especially in terms of breeding habitat) by cover types more suitable as wildlife habitat has had a positive impact on the wildlife habitat capacity rating. Reductions in cattle herd sizes in Ontario and Quebec since 2001 have led to a reduction in pasture and hayland, and dramatic increases in soybean production, which has contributed to the WHC decline in these regions. These areas can be clearly seen in Figure 7–3.

Response Options

It is recognized that biologically diverse agro-ecosystems tend to be healthy, resilient and productive, providing a strong foundation for **sustainable agriculture**. However, farming is a business driven by markets and commodity prices which can make it challenging to balance high productivity with the long-term health of the agro-ecosystem as a whole. Conserving habitat for wildlife poses a particularly difficult challenge because the most profitable agricultural land uses may compete with the natural and semi-natural land-cover types that are required to maintain viable populations of many species of birds, mammals, reptiles and amphibians within the agricultural landscape. It is important to note that for this indicator, the main objective is for the majority of agricultural working landscapes to provide a stable or improved level of habitat capacity, thus avoiding further significant habitat degradation. However, maintaining this stability may be not possible as demand for food and conflicting land-use pressures evolve. Habitat loss and fragmentation caused by wetland drainage, woodland clearing and cultivation of marginal land are key drivers of declining wildlife habitat availability on farmland. Given that most agricultural land in Canada is privately owned, the activities and decisions producers make can have a major impact on wildlife habitat.

Most producers understand the production/ conservation conundrum and seek meaningful solutions within the economic realities of their livelihood which is dependent on farming. The development and delivery of a suite of **beneficial management practices (BMPs)** designed to improve wildlife habitat on farmland can provide guidance and decision support to producers' conservation efforts. Through **environmental farm planning** activities, producers learn about the impacts their farming operations can have on wildlife and about the BMPs they can implement to address these issues. These BMPs include managing riparian areas and woodlots; converting marginal cropland to **permanent cover**; planting or maintaining shelterbelts and hedgerows; delaying haying; and conserving wetland, wetland buffers, and natural and semi-natural lands. All these practices can have a substantial, positive impact on wildlife.

A number of species that are endangered or at risk are native to natural grasslands. Once grasslands have been cultivated, it can take decades or centuries for them to revert to their natural state. Maintaining grassland areas for grazing, combined with management practices conducive to restoring their natural state, represents an economically viable way to have a significant positive impact on wildlife habitat suitability in regions where natural grasslands are found.

Conservation strategies at the farm scale can be most successful when they are aligned with conservation targets established at a broader landscape scale such as a **watershed**, municipality, provincial, or even national level. Initiatives with attainable wildlife habitat objectives can inform land-use planning and options to maintain or enhance wildlife on agricultural lands in a way that is compatible with farming activities.

References

Javorek, S.K., and M.C. Grant, 2010. *Wildlife Habitat*. In: Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds.). *Environmental sustainability of Canadian agriculture: Agri-Environmental indicator report series. Report No. 3.* Ottawa, ON, Canada: Agriculture and Agri-Food Canada; p. 36–43.

Canadian Endangered Species Conservation Council (CESCC), 2011. *Wild species 2010: The general status of species in Canada*. National General Status Working Group.

Soil Quality

Summary

Soil quality is defined as the soil's fitness to support crop growth without resulting in soil degradation or otherwise harming the environment (Acton and Gregorich, 1995[1]). Severe soil degradation can prevent crop growth and can contribute to a decline in other environmental parameters, such as water or air quality. Soil quality can be degraded by natural processes such as erosion, **salinization**,[2] loss of **soil organic carbon (SOC)** and the accumulation of trace elements. Each of these processes is influenced by agricultural practices.

Erosion removes topsoil, reduces soil organic matter and contributes to the breakdown of soil structure, which can result in low crop productivity, inefficient use of cropping inputs and adverse off-farm impacts on the environment. The combined effects of wind, water and tillage erosion must be managed to maintain soil health.

Losses of SOC contribute to degraded soil structure, increased soil vulnerability to erosion and lower fertility, ultimately leading to lower yields and reduced sustainability of soils. SOC change is an indicator of soil health and is an estimate of the amount of **carbon dioxide** (**CO_2**) (a **greenhouse gas**) that is either removed from the air and **sequestered** as SOC in agricultural soils or emitted back to the atmosphere through decomposition.

Soil salinization results when the natural movement of water in the soil leads to the accumulation of salts in portions of the landscape. Accumulations of soluble salts at high enough levels can inhibit the ability of plants to absorb water and nutrients, subjecting the plants to drought-like conditions, thus reducing crop yields.

To assess the risks and trends in the effect of land-use practices on soil quality, three agri-environmental indicators have been developed:

1. The Soil Erosion Risk Indicator (Chapter 8) presents the combined risk of water, wind and tillage erosion when climate, soil, topography and farming practices are considered.
2. The Soil Organic Matter Indicator (Chapter 9) assesses how organic carbon levels are changing over time in Canadian agricultural soils.
3. The Risk of Soil Salinization Indicator (Chapter 10) estimates the risk of soil salinization associated with changes to land use and management practices in the Prairie Provinces.

A fourth indicator, The Risk of Soil Contamination by Trace Elements Indicator, was developed for the 1981 and 2006 Census years only and therefore does not have a separate chapter devoted to it in this section. However, since trace element values are not likely to change significantly from year to year at the scale of analysis used in this report, they have not been recalculated for 2011. Instead, the 2006 trace element values were extrapolated for use in the 2011 year, and were also included in the calculation for the overall Soil Quality Compound Index.

1 Acton, D. F. and L.J. Gregorich, 1995. *The health of our soils: toward sustainable agriculture in Canada.* Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa, ON.

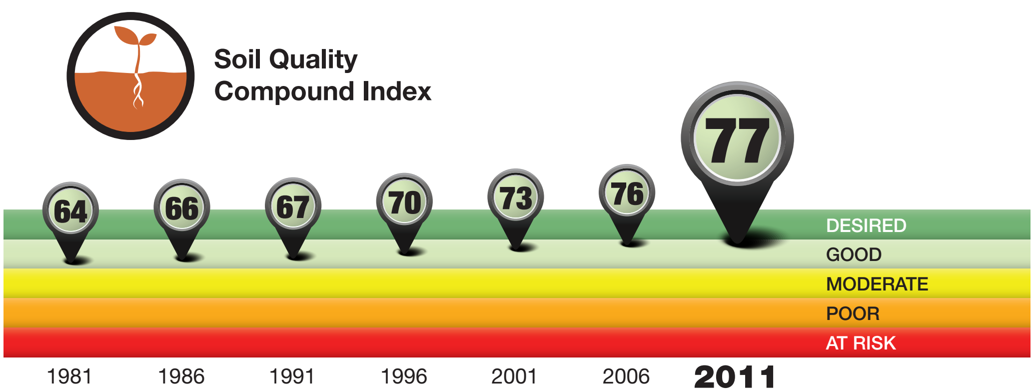
2 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter or section.

Trends in soil health from 1981 to 2011 show consistent improvements across Canada.

- **Erosion.** Soil loss from the combined effects of wind, water and tillage decreased in most provinces of Canada between 1981 and 2011. Over that period, the proportion of cropland in the *Very low* risk class increased from 29% to 61%. Much of this change is due to a reduction in wind and tillage erosion in the Prairie Provinces. The decrease in all forms of erosion across Canada has been largely due to the widespread adoption of **conservation tillage**, particularly **no-till** systems.
- **Soil Organic Carbon.** In the Prairies, SOC is increasing primarily due to a reduction in tillage intensity and **summerfallow** area. This trend holds promise for correcting past practices that caused soil degradation and left many Prairie soils with very low SOC levels. In contrast, in regions of Canada east of Manitoba, SOC is generally decreasing due to the steady conversion of tame pastures and hayland to annual crops. For Canada as a whole, improvements in farm management have resulted in a dramatic shift in the role of soils from CO_2 source to **sink**. In 1981, Canadian agricultural soils represented a net source of 1.2 megatonnes (Mt) of CO_2 per year, but became a net sink of 11.9 Mt per year in 2011.
- **Salinization.** From 1981 to 2011 there has been an 8% increase in the land area included in the *Very low* and *Low* risk classes. Over the same 30-year period, the land area in the *Moderate*, *High* and *Very High* risk classes decreased from 15% to 8%. These improvements are largely attributable to a 7-million-hectare (ha) decrease in summerfallow area (a 78% reduction from 1981 to 2011), and a 4.8-million-ha increase in the area of **permanent cover** (a 14% increase from 1981 to 2011). A reduction in risk has been observed in all Prairie Provinces, with the greatest decline recorded in Saskatchewan, where the area of summerfallow decreased by more than 5 million ha and the area of permanent cover increased by more than 3 million ha.

Soil Quality Compound Index

Generally, trends from 1981 to 2011 for soil health show improvements across Canada, as depicted by the Soil Quality Compound Index below.



This compound performance index is a weighted[3] average of the performance indices reported for the Soil Erosion, Soil Organic Carbon and Soil Salinization Indicators discussed in the following three chapters, plus the Trace Elements Indicator findings extrapolated from previous years, as noted earlier in this summary. As such, it is a highly generalized statistical snapshot of soil health, both in terms of current state and changes over time. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

3 All national "core" indicators, which include Soil Erosion, Soil Organic Carbon and Trace Elements, have a weighted value of 1. In the case of the Soil Salinization Indicator, which covers only the Prairies, the weighting is reduced to 0.81 to reflect the percentage of farmland area that is covered.

08 Soil Erosion

Authors:
D.A. Lobb, S. Li and
B.G. McConkey

Indicator Name:
Soil Erosion Risk Indicator
(integrating the risks of wind, water and tillage erosion)

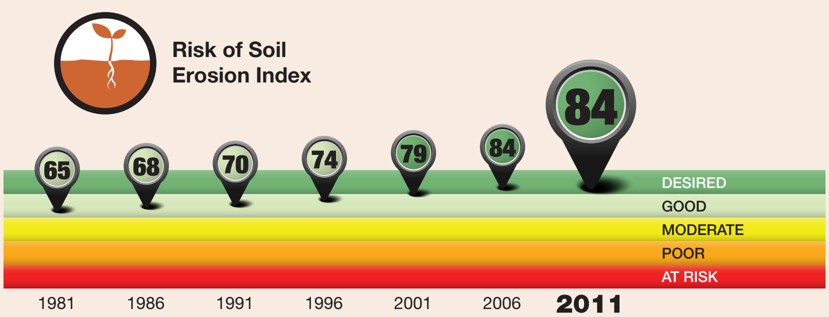
Status:
National Coverage,
1981 to 2011

Summary

Soil erosion—the movement of soil from one area to another—occurs through the natural forces of wind and water and through forces produced by tillage. Wind and water erosion which occurs naturally on **cropland**[1] can be accelerated by some farming activities (e.g. **summerfallow** or **row cropping**). Farmland soil erosion is also caused directly by the practice of tillage, which results in the progressive downslope movement of soil.

Risk of Soil Erosion Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign single values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of the environment from the standpoint of the risk of soil erosion on farmland in Canada was 'Desired'. The index illustrates an upward trend, from an index value of 65 in 1981, to a value of 84 in 2011, representing a declining risk of soil erosion across the country. These improvements came about primarily as a result of widespread adoption of reduced tillage and no-till, as well as decreases in the use of summerfallow in the Prairie Provinces, making soils less vulnerable to the effects of wind and tillage erosion in particular.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector".

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter

Healthy soils are fundamental to the sustainability of agriculture in Canada. Erosion removes topsoil, reduces **soil organic matter** content and contributes to the breakdown of **soil structure**. This has an adverse effect on soil fertility and movement of air and water into and from the soil surface, ultimately impacting crop yields and profitability. Yields from severely eroded soils may be substantially lower than those from non-eroded soils in the same field. Erosion can also have significant adverse environmental and economic impacts off-farm, through the physical transport and deposition of soil particles leading to the release of **nutrients**, **pesticides**, **pathogens** and toxins. Management of the combined effects of wind, water and tillage erosion is essential to maintain soil health. The Soil Erosion Risk Indicator assesses the *state* and *trend* of the risk of soil erosion by water, wind and tillage in the Canadian agricultural landscape.

Soil loss due to the combined effects of wind, water and tillage erosion decreased in most provinces between 1981 and 2011. Over that period, the proportion of cropland in the *Very low* risk class increased from 36% to 74%, with most of this change occurring between 1991 and 2006. The improvement in soil erosion risk reflects the reduction in the risk of wind and tillage erosion (decrease of 11% and 22%, respectively, compared to 1% for water erosion). Much of this improvement is attributable to the shift to **reduced tillage** and **no-till** practices.

The Issue and Why it Matters

Soil erosion can pose a significant threat to the sustainability of agriculture in Canada and around the world. Since the process of erosion impacts the organic-rich, topmost layer of soil, it typically results in decreased soil fertility and inefficient use of cropping inputs, as well as productivity and profitability losses due to reduced crop yields and quality. In extreme cases, severe degradation can result in land being permanently lost to agriculture.

The transport and deposition of nutrients, pesticides, pathogens and toxins attached to soil particles also contributes to water and air quality degradation. Water **runoff** and soil erosion are the primary mechanisms involved in the transport of agricultural pollutants to surface waters. Therefore, an understanding of soil erosion is essential for addressing the risks that agricultural activities pose to water resources.

There are three main forms of soil erosion: wind erosion, water erosion and tillage erosion (see text box on types of erosion). The combined effects of wind, water and tillage erosion pose a more serious threat than each of these forms of erosion on its own. Prudent management of wind, water and tillage erosion is critically important and very complex because the practices used to control one type of erosion may exacerbate another type, and because the level of erosion risk is affected by multiple variables, including cropping systems, climate and topography. Identifying the landscapes and factors that pose the greatest risk is an important step in targeting and developing localized management approaches where they are most needed, in order to maintain soil health and reduce environmental degradation and economic losses. This approach will enable Canada to maintain the sustainability of its agricultural lands and be a competitive global supplier of agriculture and food products.

The Indicator

The SoilERI model was used to assess the risk of soil erosion due to the combined effects of wind, water and tillage erosion on cultivated agricultural lands. Calculated at the **Soil Landscapes of Canada (SLC) polygon** scale, this indicator and its component indicators for wind, water and tillage erosion reflect the characteristics of the climate, soil and topography and respond to changes in farming practices over the 30-year period from 1981 to 2011.

Since the analysis was performed for the previous Agri-Environmental Indicator report (Eilers et al., 2010), the SoilERI model has been modified and new data, including data from the 2011 **Census of Agriculture**, have been incorporated. All previous Census years have been re-calculated, resulting in differences in reported values. In the event of a discrepancy between the findings in the two reports, this latest report should be used.

Soil erosion was calculated using landform data and the associated topographic data in the National Soil Database. Each SLC polygon is characterized by one or more representative landforms, and each landform is characterized by hillslope segments (upper, middle and lower slopes and depressions). Each hillslope segment is characterized by a slope gradient and slope length. Hillslope segment data were revised for the current indicator analysis in order to better reflect

Types of Erosion

WATER EROSION

Rainfall and runoff are the driving forces behind water erosion. Not only does the loss of topsoil cause land degradation but the eroded soil is carried in runoff to agricultural drains, ditches and other waterways. Suspended soil particles in the runoff increase the turbidity (cloudiness) of the water, exacerbate sediment buildup in waterways and reservoirs, and release nutrients and pesticides into the water.

WIND EROSION

Although wind erosion is a concern in many areas of Canada—from the sandy soils along the Fraser River in British Columbia to the coastal areas of the Atlantic Provinces—it is in the Prairie region that the potential for wind erosion is the greatest. This can be explained by the dry climate and the vast expanses of cultivated land which have little protection from the wind.

TILLAGE EROSION

Many farm implements move soil, and on sloping land this movement is influenced by gravity, which causes more soil to be moved during downslope tillage compared to upslope tillage. Even when tillage is done across the slope, more soil will be moved downslope than upslope. The resulting progressive downslope movement of soil and its accumulation at the base of hills is called tillage erosion. Evidence of tillage erosion is found on hilly land across Canada. This form of erosion is most severe on land that has many short, steep slopes and in areas where intensive cropping and tillage practices are used. Although distinct from wind and water erosion, tillage erosion influences wind and water erosion by exposing the subsoil which is often more sensitive to these erosion processes, and by delivering soil to areas of the landscape where water erosion is most intense. As such, tillage erosion also contributes to the off-site environmental impacts of soil erosion by wind and water.

the topographically complex nature of landforms and the influence of landform on erosion processes. The use of these revised data has contributed to differences in indicator results between this analysis and previous analyses.

The risk of soil erosion by wind, water and tillage was calculated as the amount of soil loss for all segments of a given landform. However, the highest rates of soil loss due to wind and tillage erosion are recorded on upper slopes, whereas the highest rates due to water erosion are on mid-slopes. The SoilERI was assessed as the cumulative soil loss rate for the slope segment with the greatest rate of loss, because the slope segment with the highest rate of loss largely determines changes in management. For analysis and reporting purposes, the erosion rates were summed across areas to the SLC polygon, provincial, regional and national levels.

The Water Erosion Risk Indicator (WatERI) was estimated using a model developed to combine features of the Universal Soil Loss Equation (USLE) and the Revised USLE (RUSLE2). This model accounts for rainfall/runoff, crop type and area, landform, and soil **erodibility.**

The Wind Erosion Risk Indicator (WindERI) was estimated for the agricultural regions of Manitoba, Saskatchewan and Alberta using a modified version of the Wind Erosion Equation. The model incorporates soil factors related to soil texture and landform, a vegetation factor based on **crop residue** levels, and wind speed and rainfall after seeding, when residue levels are lowest and wind speeds are high.

The Tillage Erosion Risk Indicator (TillERI) was calculated as the product of tillage **erosivity** and landscape erodibility. Erosivity values are assigned based on the characteristics of the tillage operations carried out within the various **agro-ecosystems** across Canada, and based on experimental data. Landscape erodibility values are calculated for each landform as a function of slope length and gradient characteristics.

The erosion indicator calculation estimates the rate of soil loss in tonnes per hectare. These values are reported in five classes:

- *Very low* (less than 6 t ha^{-1} yr^{-1})
- *Low* (6 to 11 t ha^{-1} yr^{-1})
- *Moderate* (11 to 22 t ha^{-1} yr^{-1})
- *High* (22 to 33 t ha^{-1} yr^{-1})
- *Very High* (greater than 33 t ha^{-1} yr^{-1})

Areas in the *Very low* risk class are considered capable of sustaining long-term crop production and maintaining agri-environmental health under current conditions. The other four classes represent increasingly unsustainable conditions that call for soil conservation practices to support crop production over the long term and to reduce risk to soil quality.

Limitations

The results obtained from the soil erosion risk models, when interpreted at provincial and national scales and over the seven Census years, are considered to provide reasonably accurate spatial and temporal trends. They are subject to limitations, however, which affect their accuracy and certainty. As such, they should not be interpreted as quantitative estimates of actual erosion rates in any particular year. The limitations of this approach include the following:

- Landforms are represented in the National Soil Database by simple two-dimensional hillslopes. As such, the landform data reflect neither the topographic variety and complexity that exist in real landscapes nor the effect of fence lines, tree lines, roadways, ditches and drainage ways on the slope. For many landforms, the use of these data overestimates soil loss associated with water erosion and underestimates soil loss associated with tillage erosion.
- The SoilERI represents the slope position with the greatest soil loss, that is, the upper or mid-slope areas of a landscape. The values are averages for slope segments of representative landforms; therefore, specific areas may be at greater risk than indicated by the risk class assessment.
- The SoilERI is a simple sum of the estimated soil losses due to wind, water and tillage erosion; it does not take into account interactions that occur over time among erosion processes.
- Wind and water erosion indicators do not take into account the following erosion control practices: **grassed waterways**, **strip cropping**, **terracing**, **contour cultivation** and cropping, **winter cover crops** and **shelterbelts.**

- The water erosion indicator does not include gully erosion that occurs in locations where runoff concentrates. The water erosion risk indicator value should also be considered less accurate for locations where significant erosion occurs when soils are frozen. In particular, the erosion risk associated with rainfall occurring on a thawed soil layer overlying frozen soil is likely underestimated.
- The tillage erosion indicator only considers soil erosion that occurs along the length of hillslopes. It does not include cross-slope erosion or planing or scalping caused by tillage equipment.
- Wind erosion may be significant in some years on exposed sandy and peaty soils outside of the Prairie Provinces, but these situations were not considered.

Results and Interpretation

In 2011, 74% of cropland area was in the *Very low* risk class (Figure 8–1). This is a considerable improvement over 1981, when only 36% was in this risk class. The total combined cropland area in all other risk classes decreased by 60% during this time period, falling to 26% in 2011. The integrated erosion risk indicator results (Figure 8–1) are less positive than the results from the individual component indicators for water, wind and tillage erosion (Figures 8–3, 8–4 and 8–5, respectively, and Tables 8–2, 8–3 and 8–4 respectively), but better reflect the actual risk of soil degradation by erosion.

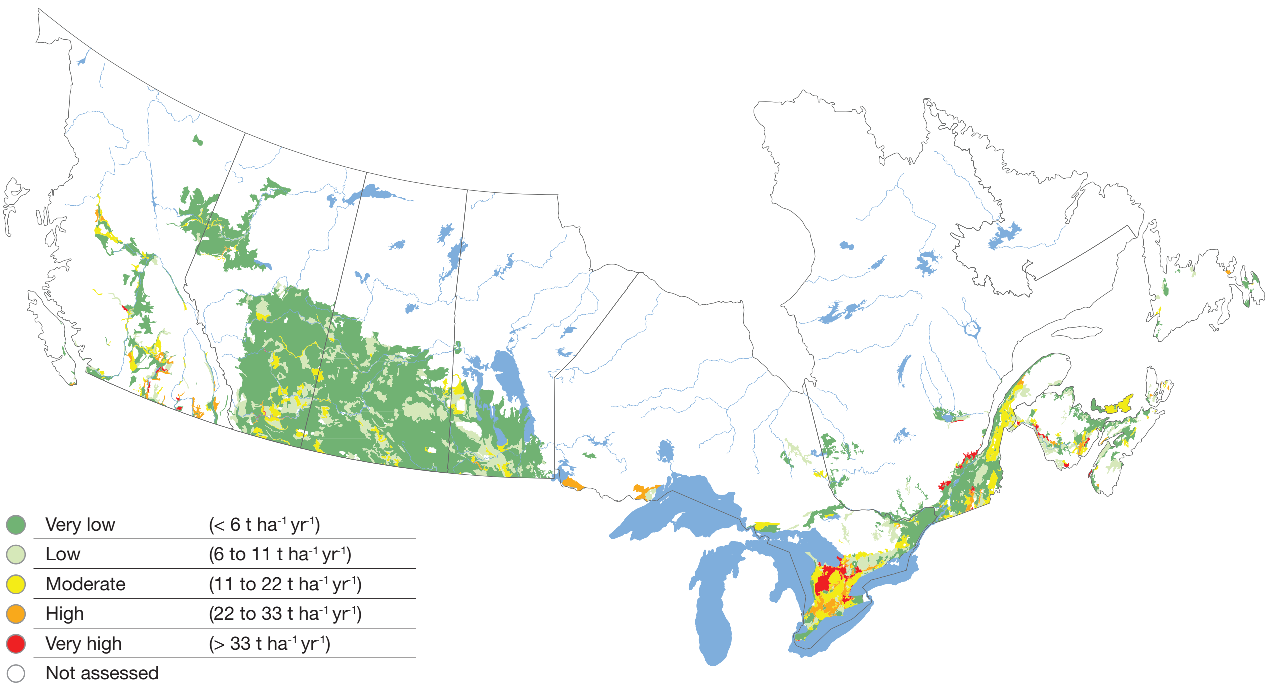


Figure 8–1: Integrated risk of soil erosion (water, wind and tillage erosion combined) in Canada, 2011

The risk of soil erosion on Canadian cropland steadily declined between 1981 and 2011 (Figure 8–2, Table 8–1). Most of the decrease in risk occurred between 1991 and 2006. The improvement in soil erosion risk reflects the reduction in wind and tillage erosion risk (decrease of 11% and 22%, respectively, compared to 1% for water erosion).

The decrease in all forms of erosion across Canada is largely attributable to the widespread adoption of **conservation tillage**, particularly no-till systems. No-till is now the most common tillage practice used for cereal crops in the Prairies. Changes in the share and mix of crops grown were less of a contributing factor. Crops such as corn, potatoes and beans that are typically produced using more **intensive tillage** (making them more erosive) increased their share of cropland area from 5% in 1981 to 11% in 2011. Southern Ontario has the largest amount of area in the higher erosion risk classes due to its high proportion of these types of row crops. However, improvements in conservation tillage techniques (permitting a minimum amount of tillage) have reduced tillage intensity. Therefore, although the share of cropland planted to such crops has risen since 1981, the average tillage intensity associated with the crops has decreased, with the result that no notable increase in risk has been recorded in this region.

The decline in overall erosion risk is also attributable to a decrease in summerfallow use on the Prairies, from 24% in 1981 to 6% in 2011, and to an increase in high-residue crops requiring very little tillage (e.g. alfalfa and hay), from 14% in 1981 to 18% in 2011. The increase in the cultivation of alfalfa and hay was particularly noticeable in the Fraser Basin and Plateau, the Peace River Lowlands and eastern Vancouver

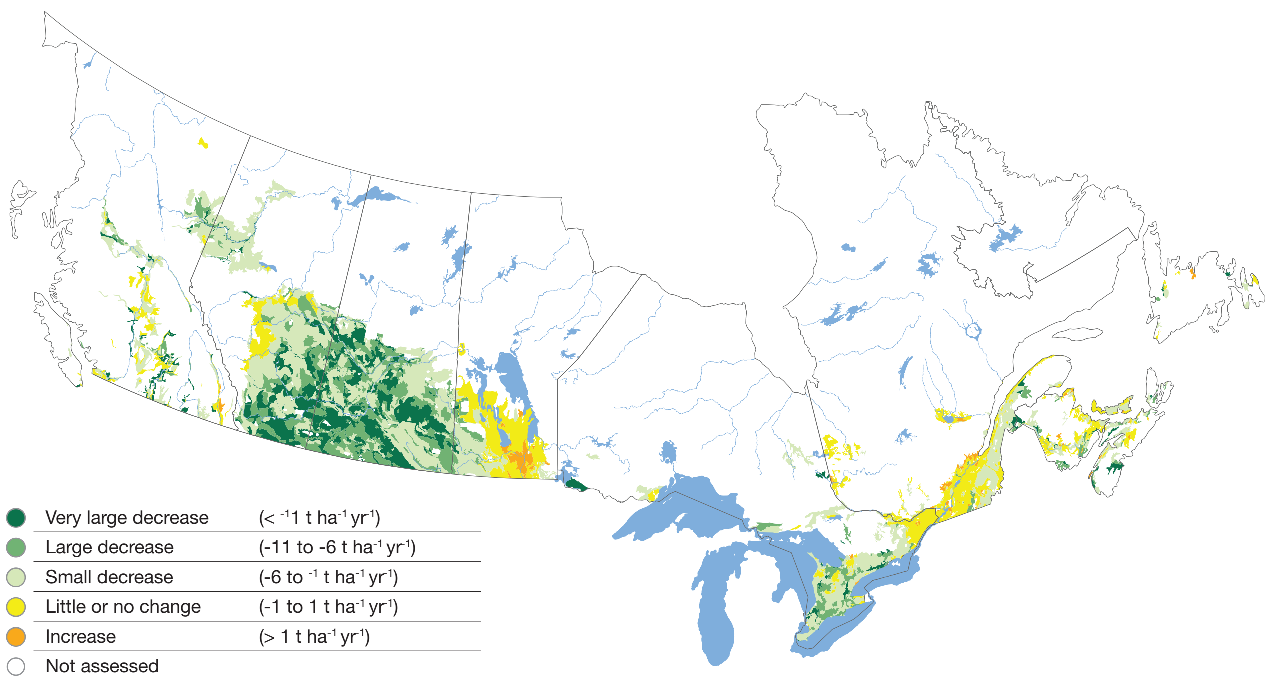


Figure 8–2: Change in integrated risk of soil erosion (water, wind and tillage erosion combined) in Canada, 1981 to 2011

Island, where the proportion of these crops rose by 15% between 1981 and 2011. Although most crops have seen a reduction in tillage intensity, the adoption of no-till in cereals has had the greatest influence in terms of reducing soil erosion risk owing to the large share of cropland devoted to cereals on the Prairies.

Among the cropping systems found across Canada, the highest risk of soil erosion is associated with potato and sugar beet production in the Atlantic Maritimes, which requires intensive tillage and is not conducive to the adoption of conservation tillage practices. The cropping system that presents the next highest risk of erosion is corn and soybean produced with **conventional tillage**. However, in this case there is considerable potential to reduce the erosion risk through conservation tillage. On landscapes across Canada, the highest risk of soil erosion is associated with slopes of 10% or more, especially in Eastern Canada, where there is an inherently high risk of water erosion owing to the climatic conditions. Soil erosion is of particular concern in situations where cropping systems involving a high erosion risk are paired with soil landscapes with high erosion risks. This is the case for a significant proportion of the cropland in southern Ontario and in Atlantic Canada. However, there are areas in every province that present risks of unsustainable soil erosion, including the steep slopes of the Hand Hills region of southern Alberta, the very dry and loamy soils of windy southern Saskatchewan, and the steep slopes of the Manitoba escarpment.

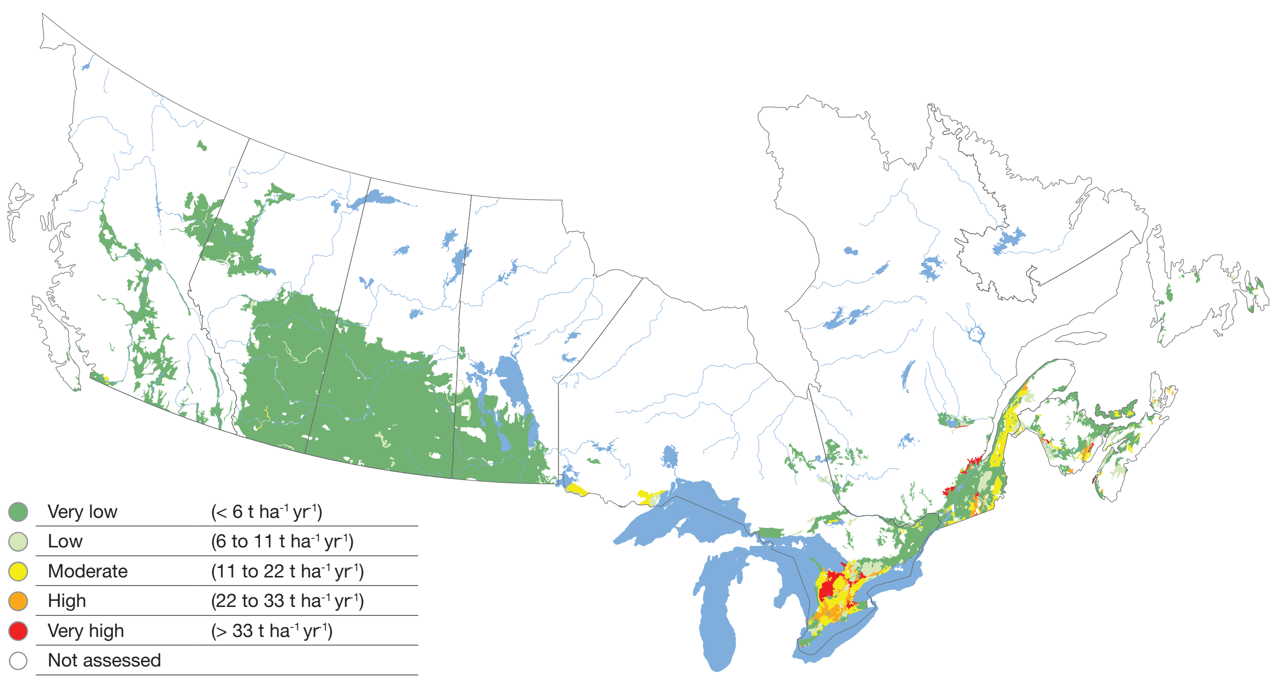


Figure 8–3: Risk of soil erosion by water in Canada, 2011

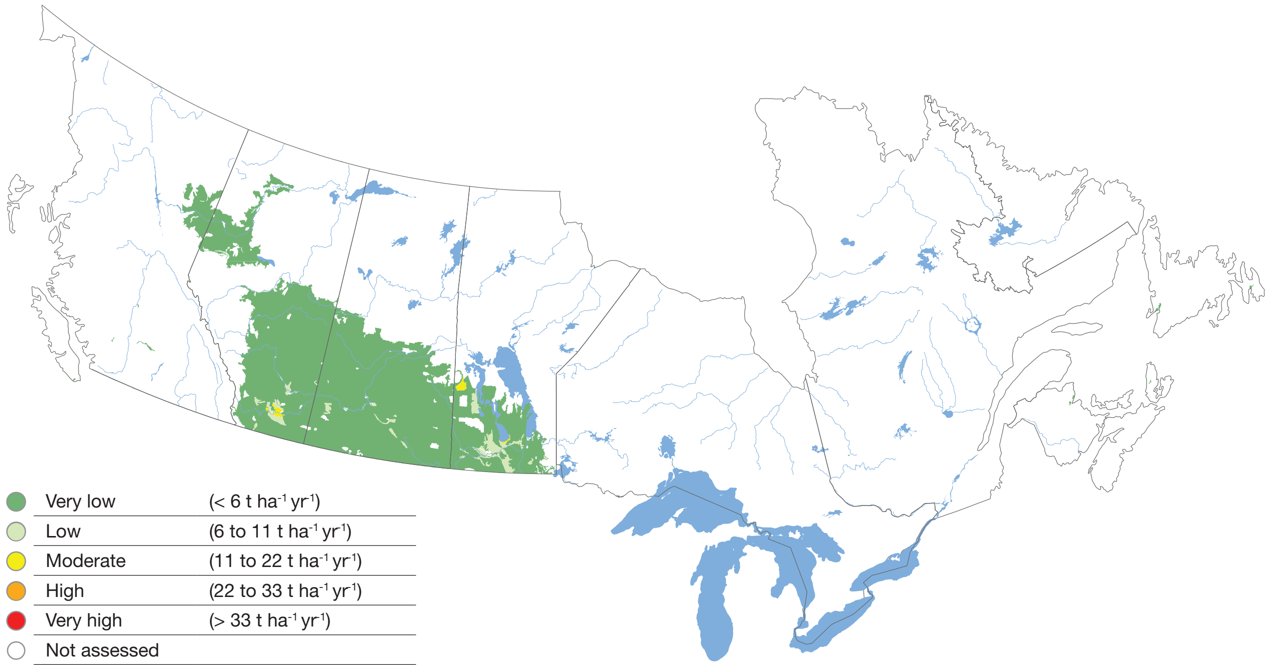


Figure 8–4: Risk of soil erosion by wind in Canada, 2011

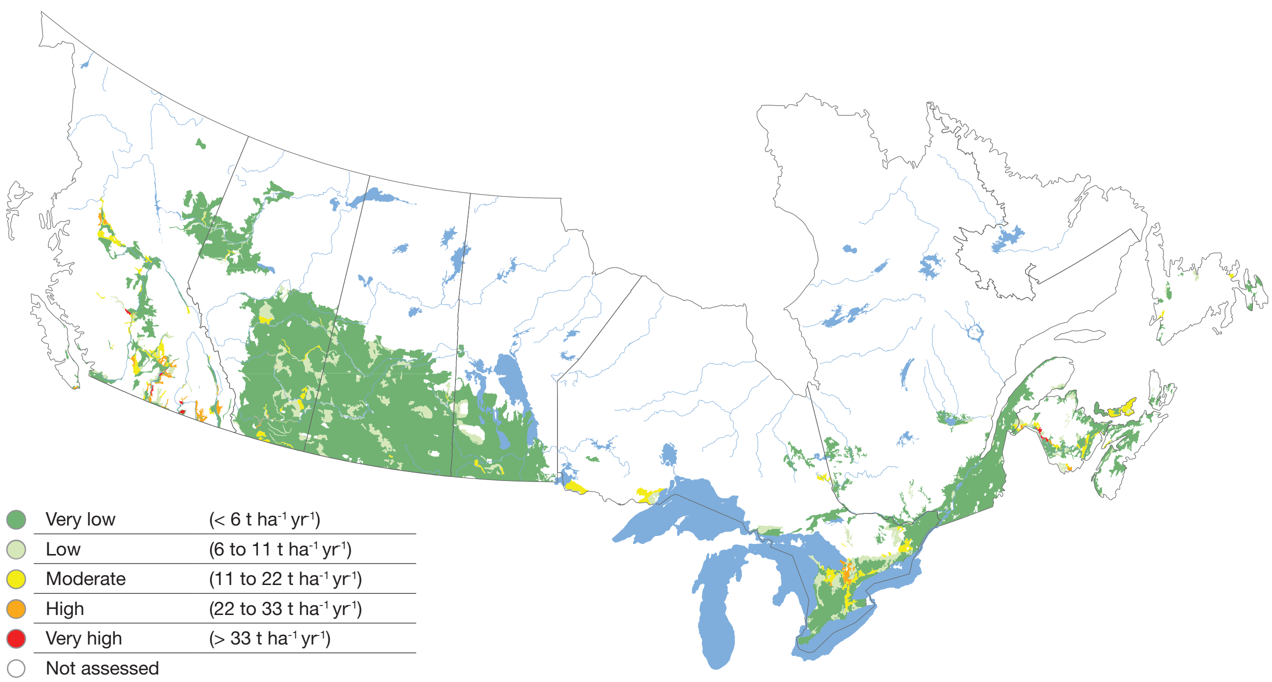


Figure 8–5: Risk of soil erosion by tillage in Canada, 2011

Table 8–1: Percentage of cropland in Canada in overall Soil Erosion (water, wind and tillage erosion combined) risk classes[2], 1981 to 2011

Class	Very Low (<6 t ha^{-1}yr^{-1})							Low (6 to 11 t ha^{-1}yr^{-1})							Moderate (11 to 22 t ha^{-1}yr^{-1})							High (22 to 33 t ha^{-1}yr^{-1})							Very High (>33 t ha^{-1}yr^{-1})						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	41	46	51	62	69	78	86	39	34	33	28	21	13	8	13	15	10	6	7	4	3	2	2	2	1	1	1	1	4	3	4	3	2	3	2
Alberta	53	55	57	60	71	77	87	16	14	18	18	15	13	9	19	19	16	13	12	8	4	7	9	8	6	2	1	0	5	3	2	1	1	0	0
Saskatchewan	22	25	29	46	57	67	78	38	37	35	21	19	26	19	26	29	28	27	22	8	3	8	4	4	5	3	0	0	6	5	4	1	0	0	0
Manitoba	48	46	53	55	56	54	67	28	32	32	31	30	36	23	23	21	14	13	14	9	9	1	1	0	1	1	0	0	1	1	0	0	0	0	0
Ontario	27	27	28	28	30	32	32	12	11	13	14	13	16	15	21	20	19	22	21	29	28	23	26	21	23	24	12	14	17	16	19	13	11	11	11
Quebec	72	74	74	76	72	74	77	15	15	14	13	14	14	13	9	9	8	10	10	8	7	3	2	2	1	3	2	2	1	1	1	1	1	1	1
New Brunswick	35	36	35	36	33	40	37	37	36	37	37	39	33	36	6	4	6	8	6	11	13	8	12	10	9	11	7	6	14	11	11	10	11	9	8
Nova Scotia	30	33	42	45	47	56	64	42	47	43	45	43	35	29	23	17	13	8	7	8	5	4	2	1	1	2	1	1	1	1	1	1	1	0	0
Prince Edward Island	19	25	24	20	24	25	22	5	0	0	5	0	0	0	76	75	76	75	76	75	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Newfoundland and Labrador	41	37	35	39	32	46	45	12	14	10	5	15	5	32	8	24	26	32	30	19	5	19	8	10	12	7	19	15	20	17	20	12	16	11	3
Canada	**36**	**38**	**41**	**51**	**58**	**65**	**74**	**28**	**27**	**28**	**21**	**18**	**22**	**16**	**23**	**24**	**22**	**21**	**17**	**10**	**7**	**8**	**6**	**6**	**6**	**4**	**2**	**2**	**6**	**5**	**4**	**2**	**2**	**1**	**1**

Table 8–2: Percentage of cropland in Canada in Water Erosion risk classes[3], 1981 to 2011

Class	Very Low (<6 t ha^{-1}yr^{-1})							Low (6 to 11 t ha^{-1}yr^{-1})							Moderate (11 to 22 t ha^{-1}yr^{-1})							High (22 to 33 t ha^{-1}yr^{-1})							Very High (>33 t ha^{-1}yr^{-1})						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	94	93	94	95	96	100	99	1	2	6	5	4	0	0	5	5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Alberta	97	97	97	97	98	98	99	2	2	2	2	1	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saskatchewan	97	97	97	98	98	98	99	2	2	2	2	2	2	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manitoba	98	99	99	99	99	99	99	1	1	1	1	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ontario	31	33	33	34	34	38	36	12	11	13	13	13	13	12	18	17	16	18	18	28	28	22	25	22	25	25	11	14	16	14	17	10	10	10	10
Quebec	77	79	80	80	76	79	81	10	10	9	9	12	10	10	9	8	8	9	8	8	7	3	2	2	1	3	2	2	1	1	1	1	1	1	1
New Brunswick	50	51	47	48	44	53	49	34	32	36	37	39	31	35	8	8	7	6	8	7	9	7	8	8	6	6	7	5	1	1	2	3	3	1	2
Nova Scotia	61	66	72	78	77	79	79	21	22	19	15	16	14	14	13	9	6	5	5	5	5	4	2	1	1	2	2	1	1	1	1	1	1	0	0
Prince Edward Island	89	90	91	90	91	90	88	0	0	0	0	0	0	1	10	10	9	10	9	10	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Newfoundland and Labrador	69	69	73	72	70	68	82	12	15	23	8	10	7	14	16	15	2	18	19	15	4	2	1	2	1	0	1	0	1	1	1	0	1	9	0
Canada	**90**	**91**	**91**	**91**	**91**	**92**	**92**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

2 This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding, the numbers may not sum exactly to 100%.

3 This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding, the numbers may not sum exactly to 100%.

Table 8–3: Percentage of cropland in Canada in Wind Erosion risk classes[4], 1981 to 2011

Class	Very Low (<6 t $ha^{-1}yr^{-1}$)							Low (6 to 11 t $ha^{-1}yr^{-1}$)							Moderate (11 to 22 t $ha^{-1}yr^{-1}$)							High (22 to 33 t $ha^{-1}yr^{-1}$)							Very High (>33 t $ha^{-1}yr^{-1}$)						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alberta	85	84	89	93	96	97	97	10	11	7	4	3	2	2	4	5	3	3	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Saskatchewan	86	87	88	92	95	98	99	11	11	10	7	4	1	1	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manitoba	83	82	85	87	88	89	84	13	15	13	11	11	10	13	5	3	3	2	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Canada	**85**	**85**	**88**	**92**	**94**	**96**	**97**	**11**	**11**	**9**	**6**	**5**	**3**	**3**	**3**	**3**	**2**	**2**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 8–4: Percentage of cropland in Canada in Tillage Erosion risk classes[5], 1981 to 2011

Class	Very Low (<6 t $ha^{-1}yr^{-1}$)							Low (6 to 11 t $ha^{-1}yr^{-1}$)							Moderate (11 to 22 t $ha^{-1}yr^{-1}$)							High (22 to 33 t $ha^{-1}yr^{-1}$)							Very High (>33 t $ha^{-1}yr^{-1}$)						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	55	58	59	72	77	81	87	31	29	29	17	14	11	7	8	8	6	7	5	3	3	2	2	2	1	1	2	1	4	3	4	3	2	2	2
Alberta	71	72	73	76	82	87	93	14	14	13	10	8	8	6	7	7	7	9	8	5	1	6	6	6	4	1	1	0	1	1	1	1	1	0	0
Saskatchewan	64	63	63	66	69	76	87	7	7	7	7	18	22	12	23	24	24	25	12	2	0	5	6	6	2	0	0	0	1	0	0	0	0	0	0
Manitoba	73	72	76	76	89	93	93	16	16	15	15	4	5	6	11	11	8	9	7	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Ontario	53	52	53	56	65	62	76	31	34	34	32	24	28	15	8	5	7	8	8	7	7	7	7	5	4	3	3	2	1	1	1	0	0	0	0
Quebec	90	92	92	93	94	94	97	9	8	7	6	5	5	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New Brunswick	65	67	68	70	67	68	70	12	10	9	8	10	10	9	3	6	11	11	10	13	14	12	11	5	4	5	2	1	7	6	7	7	8	7	6
Nova Scotia	65	64	67	71	77	86	91	27	29	26	26	21	13	8	7	7	6	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Prince Edward Island	24	31	24	25	24	31	29	10	4	9	10	9	4	11	66	65	66	65	67	66	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Newfoundland and Labrador	65	60	59	66	64	62	66	5	11	5	5	3	21	20	14	16	21	16	22	13	11	8	10	13	12	2	4	2	8	3	1	1	8	1	1
Canada	**67**	**67**	**68**	**70**	**76**	**80**	**89**	**13**	**13**	**12**	**11**	**14**	**15**	**9**	**15**	**15**	**15**	**16**	**10**	**4**	**2**	**5**	**5**	**5**	**3**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

4 This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding, the numbers may not sum exactly to 100%.

5 This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding, the numbers may not sum exactly to 100%.

Response Options

An integrated approach is needed to ensure that the combined soil losses from all forms of erosion are maintained at sustainable levels. This is critical for preserving soil health. While there are many practices that farmers can implement to reduce soil erosion, the appropriateness of a given practice depends on the type of farming system involved, climatic conditions, and certain characteristics of the land, such as soil texture and slope.

In general, all forms of soil erosion can be reduced by using a less intensive tillage method. Lower intensity tillage helps to decrease the amount and extent of soil movement and hence tillage erosion. It also reduces the degree of incorporation of crop residue, allowing this surface layer to provide protection against the erosive forces of wind and water. Since tillage practices vary in their effectiveness in reducing wind, water and tillage erosion, it is important to select a tillage method that is suited to the characteristics of the landscape. Reducing tillage intensity on hilly land, particularly in areas with short, steep slopes, is an effective way to reduce all forms of erosion. On level farmed landscapes, tillage erosion is less of a problem and soil texture and structure take on greater importance. A tillage method that maintains crop residue on the soil surface for protection against wind and water erosion should be favoured on such landscapes. While tillage erosion is quite predictable, unusually intense storms may occur periodically and cause extensive erosion if the soil does not have adequate protection from wind and water. Therefore, when deciding which erosion risk to address, producers should keep in mind that overprotection for expected weather conditions may be beneficial during intense weather events. Producers should select practices that help to minimize wind, water and tillage erosion over the long term. In doing so, they must consider the physical and environmental characteristics of the landscape, the climatic conditions, the type of crop concerned and the cropping system. Measures for managing each type of erosion are discussed further in the sections below.

WATER EROSION

Water erosion can be controlled by improving the soil structure and protecting the soil against the impacts of rainfall and flowing water, and by managing the land to reduce the amount of flowing water and its erosivity. Management practices for water erosion include:

- using conservation tillage and including **forages** in rotations;
- planting row crops across the slope;
- strip cropping;
- inter-seeding row crops with other crops; and
- growing cover crops.

More research needs to be done on alternatives to no-till in situations where this practice is not viable, such as intensive production of horticultural or potato crops. Where water erosion is severe, conservation tillage and cropping systems might not be sufficient to control erosion and runoff. In such cases, alternative erosion control practices include establishing terraces to reduce slope steepness and length, and establishing permanent small earthen berms or diversions running along the contours. Gully erosion is a problem that usually requires engineering solutions such as constructing grassed waterways or other erosion control structures. In areas of high precipitation where there is inherently greater risk of water erosion, low-residue crops and crops with considerable soil exposure, such as potatoes and horticultural and row crops (corn and soybean), are particularly vulnerable to water erosion. Policy and conservation programs should be targeted at these areas to reduce the risk.

WIND EROSION

In all areas of Canada, wind erosion can be managed effectively by keeping the soil covered with crop plants and crop residues. Soils with surface textures characterized by **loamy sand** or sand have the greatest inherent erosion risk. Planting **perennial forages** is the most practical response option. However when sandy soil areas are planted to annual crops, a complete no-till approach is necessary to minimize the erosion risk. Shelterbelts should also be considered for these areas. For other soil textures, a conservation tillage or no-till approach, combined with the application of solid manure, can be used to reduce the erosion risk. Planting a cover crop of spring or winter cereals following a potato or sugar beet crop, will help to mitigate wind erosion.

TILLAGE EROSION

Tillage erosion can be addressed by modifying tillage practices. Only by eliminating tillage can this form of erosion be completely stopped. An example of this would be using a no-till system for annual crops or growing perennials that require no tillage. However, even practices such as seeding and **fertilizer** injection can cause significant levels of soil movement and tillage erosion. Many cropping systems, such as potato production, will always involve some form of soil disturbance, leading to soil movement and erosion. In these production systems, it is important to select suitable tillage implements and carry out tillage operations in a way that minimizes erosion. Implements that move less soil overall and move the soil over a shorter distance, as well as those that operate at a uniform speed and depth, will generate less tillage erosion. In hillier landscapes, contour tillage may cause less erosion than tilling up and down hillslopes, particularly if greater uniformity of tillage depth and speed can be achieved by tilling along the contours. With contour tillage, the rollover **moldboard plough** can be used as a conservation tool by ensuring that the furrow is thrown upslope. The upslope movement of soil by the moldboard plough may offset the downslope movement caused by other tillage operations. Efforts to reduce tillage erosion should be focused on landscapes that are hilly and therefore more susceptible to such erosion.

Reducing all forms of soil erosion is a considerable challenge. Although some practices can reduce the soil loss caused by more than one form of erosion, other practices will reduce one form of erosion while exacerbating another form. Tillage practices that are effective in reducing wind and water erosion are not necessarily effective against tillage erosion. For example, the chisel plough leaves more crop residues on the soil surface than the moldboard plough, providing more protection against wind and water. At the same time, the chisel plough can move soil over a much greater distance and cause more tillage erosion. Shelterbelts and water diversion terraces help to reduce wind and water erosion, but the addition of field boundaries or obstacles within a landscape results in more extensive tillage-induced soil loss. The high-disturbance direct seeding approach used in some no-till cropping systems can cause as much tillage erosion as the mouldboard plough because the soil is moved over great distances and with great variability. Clearly, an integrated approach to managing soil erosion is essential in order to minimize soil loss.

References

Ali, G., C. Baldwin, and C. English, 2013. *Upscaling of soil erosion indicator models in a Canadian prairie watershed. A case study on the applicability of the NAHARP erosion indicator models at the watershed level – Final report*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Baldwin, C., and D.A. Lobb, 2012. *Field assessment of soil erosion and validation of WindERI. Technical supplement*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds.), 2010. *Environmental sustainability of Canadian agriculture: Agri-Environmental indicator report series – Report #3*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Huang, Q., and D.A. Lobb, 2013. *Uncertainty analysis for the soil erosion risk indicators. Technical supplement*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Huffman, T., D.R. Coote, and M. Green, 2012. *Twenty-five years of changes in soil cover on Canadian Chernozemic (Mollisol) soils, and the impact on the risk of soil degradation*. Canadian Journal of Soil Science. 92: 471-479.

Huffman, T., J. Liu, D.R. Coote, and M. Green, 2013. *The effect on soil quality of integrating perennial crops into cropping systems in response to demand for bioenergy feedstock*. Invited presentation. Water, Food, Energy and Innovation for a Sustainable World. ASA, CSSA and ASSA International Annual Meetings, Tampa, FL, Nov 3-6, 2013.

Li, S., and D.A. Lobb, 2009. *Role of topographic data on the accuracy and uncertainty of NAHARP indicators. Technical supplement*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Li, S., B.G. McConkey, M.W. Black, and D.A. Lobb, 2008. *Water erosion risk indicator (WatERI) methodology*. In: Soil erosion risk indicators: Technical supplement. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Li, S., D.A. Lobb, and B.G. McConkey, 2008. *Soil erosion risk indicator (SoilERI) methodology*. In: *Soil erosion risk indicators: Technical supplement*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Lobb, D.A., S. Li, K.H.D Tiessen, G.R. Mehuys, T.E. Schumacher, J.A. Schumacher, J. Mollinedo, D.J. Pennock, J. Liu, and T. Yates, 2008. *Tillage erosion risk indicator (TillERI) methodology*. In: Soil erosion risk indicators: Technical supplement. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

McConkey, B.G., S. Li, and M.W. Black, 2008. *Wind erosion risk indicator (WindERI) methodology*. In: Soil erosion risk indicators: Technical supplement. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Statistics Canada, 2011. *About the Census of Agriculture*. Retrieved June 25, 2012 from http://www.statcan.gc.ca/ca-ra2011/index-eng.htm

Steiner, J.L., H.H. Schomberg, P.W. Unger, and J. Cresap, 1999. *Crop residue decomposition in no-tillage small-grain fields*. Soil Science Society of America Journal. 63: 1817-1824.

Wall, G.J., D.R. Coote, E.A. Pringle, and I.J. Shelton (eds.), 2002. *RUSLEFAC – Revised universal soil loss equation for application in Canada: A handbook for estimating soil loss from water erosion in Canada*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Wischmeier, W.H., and D.D. Smith, 1965. *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: Guide for selection of practices for soil and water conservation.* In: Agriculture Handbook No. 282. Washington, D.C.: U.S. Department of Agriculture.

09 Soil Organic Matter

Authors:
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Indicator Name:
Soil Organic Carbon Change

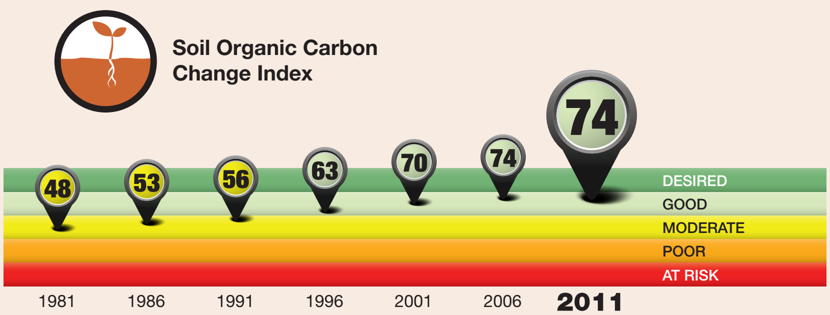
Status:
National Coverage,
1981 to 2011

Summary

Carbon (C)[1] is the basic building block of all living things and is critical to soil health and fertility. The Relative Soil Organic Carbon (RSOC) Indicator estimates soil organic carbon (SOC) levels across the country relative to a soil-specific baseline level, while the SOC Change (SOCC) Indicator assesses how organic carbon levels in Canadian agricultural soils are changing over time. Together, they provide a useful picture of soil health and an estimate of how much **carbon dioxide (CO_2)** has been removed from the atmosphere by plants and **sequestered** as SOC in agricultural soils. They assess both the state and the trend of organic carbon levels in Canadian agricultural soils.

Soil Organic Carbon Change Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign single values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of SOC change resulting from farming activities in Canada was 'Good'. The index illustrates an improving trend, representing an increase in SOC between 1981 and 2011. In the Prairies, SOC is increasing primarily due to a reduction in tillage intensity and summerfallow area.

The index tends to aggregate and generalize trends. Specific findings, as well as regional variations and interpretations, are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector".

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

In 2011, the average SOC content of farmland soils in Canada was increasing. Canadian agricultural soils removed 11.9 million tonnes of CO_2 from the atmosphere in 2011. In the Prairies, SOC is increasing primarily due to a reduction in tillage intensity and **summerfallow** area. This increasing trend holds promise for correcting past practices that caused soil degradation and left many Prairie soils with very low SOC levels. Conversely, in regions of Canada east of Manitoba, SOC is generally decreasing, primarily due to the ongoing conversion of **tame pastures** and hayland to annual crops.

The Issue and Why it Matters

Carbon is the basic building block of life and the main component of **soil organic matter**. It is captured from the air as CO_2 by plants during **photosynthesis**. Some of this C is stored in plant tissues and in the tissues of animals that directly or indirectly consume the plants. After the death and subsequent **decomposition** of these plants and animals, most of this carbon is quickly lost to the atmosphere; however, a small portion of organic C is transformed into soil organic materials that are less easily decomposed. Over time, soil organic matter builds up in the soil until a steady-state level of soil organic matter (SOM) is reached. At this point, new organic C additions from decayed plant and animal tissues are balanced by losses of organic C as a result of decomposition. Note that, in this text, the terms SOC and SOM are used somewhat interchangeably, as SOM is typically estimated to contain 58% carbon by mass (SOC=0.58*SOM).

Soil organic matter strongly influences many important aspects of soil quality and is a key component of good soil health. Along with plant roots, it holds soil particles together and stabilizes the **soil structure**, making the soil less prone to erosion and improving the ability of the soil to store and convey air and water. Good soil structure is important for maintaining soil tilth (workability) and permeability. SOM stores and supplies many **nutrients** needed for the growth of plants and soil organisms. SOM also binds potentially harmful substances, such as heavy metals and **pesticides**, thereby reducing their adverse environmental effects. Lastly, it acts as a storage reservoir (**sink**) for CO_2 captured from the atmosphere.

Losses of SOM contribute to degraded soil structure, increased soil vulnerability to erosion and lower fertility, ultimately leading to lower crop yields and reduced sustainability of the soil.

The health of Canada's soil resources is closely tied to the management practices that are used in crop and livestock production. The SOCC and the RSOC are key indicators of soil health. By assessing SOC trends in Canada, we can improve our understanding of the key drivers of soil health and the associated risks and opportunities. This knowledge is important for maintaining the land's productive capacity now and into the future, thereby ensuring the profitability and sustainability of the agriculture sector.

The SOCC and RSOC indicators are essential tools which are used to understand trends in agricultural **greenhouse gas** (**GHG**) emissions in Canada and to support Canada's annual GHG reporting efforts under the United Nations Framework Convention on Climate Change (see Chapter 15 "Agricultural Greenhouse Gases"). Canada's National Inventory Report tracks total GHG emissions and removals of carbon resulting from changes in agricultural and forestry land-use activities in the Land Use, Land-Use Change and Forestry sectors (Environment Canada, 2014). The SOCC and RSOC indicators highlight the linkages between changes in land management practices, such as conversion to **no-till**, reduction in summerfallow and conversion of **perennial forages** to annual crops, and the subsequent sequestration or release of carbon dioxide.

Agri-environmental indicator (AEI) data on SOC and erosion are being used by agriculture industry stakeholders to meet requirements for demonstrating sustainability criteria to buyers, including those for international market access.

The Indicator

The SOCC Indicator has been developed to assess how organic carbon levels in Canadian agricultural soils are changing over time. The indicator is based on the method used for Canada's National Inventory Report (Environment Canada, 2014). The indicator uses the Century model (NREL, 2007) to predict the rate of change in organic C content in Canada's agricultural soils associated with the effects of land management changes since 1951. These include changes in tillage and summerfallow frequency and shifts between annual crops and perennial hay or pasture. While the indicator includes land-use changes such as clearing of forests for agriculture or the conversion of native grassland to **cropland**, it does not include the loss of C from above-ground forest **biomass**. Where there were no changes in land use or land management, it was assumed that SOC did not change.

The change in SOC is a useful indicator of long-term, generalized trends in soil health. The indicator also serves to estimate how much CO_2 is removed from the atmosphere by plants and stored (or sequestered) as SOC in agricultural soils. Thus, in addition to indicating changes in soil health, the change in SOC provides an indication of potential reductions in atmospheric CO_2, which can offset greenhouse gas emissions.

The SOCC Indicator results are given as the percentage of total cropland that falls into each of five SOC change classes expressed in kilograms per hectare per year (kg ha^{-1} yr^{-1}). Negative values represent a loss of SOC and positive values, a gain of SOC. The five classes are defined as follows: large increase (gain of more than 90 kg ha^{-1} yr^{-1}), moderate increase (25 to 90 kg ha^{-1} yr^{-1}), negligible to small change (-25 to 25 kg ha^{-1} yr^{-1}), moderate decrease (-25 to -90 kg ha^{-1} yr^{-1}) and large decrease (loss of more than -90 kg ha^{-1} yr^{-1}).

If soil is well managed over a long period of time, the SOC content will stabilize and essentially remain constant over time. An increase in SOC is not necessarily better than a stable situation. However, if soil degradation has occurred in the past, a significant increase in SOC is clearly desirable, as it is indicative of improvements in soil health and function. A loss of SOC represents a release of CO_2 into the atmosphere and so is not desirable. Therefore, the preferred values for this indicator range from no loss of SOC from agricultural soils having high organic matter to C accumulation in soils that are currently low in organic matter.

In addition to knowing how quickly C is accumulating in the soil, it is useful to have a means of assessing soil health and function, which varies across different climates and soil types. A complementary indicator, the Relative Soil Organic Carbon (RSOC) Indicator, was developed as a measure which can be used to compare the current SOC level across different regions and for different farming practice. This indicator is calculated using the Century model with data from the Canadian Soil Information Service (CANSIS) (Soil Landscapes of Canada Working Group, 2010) and changes estimated by the SOCC Indicator. RSOC is expressed as the ratio of the current SOC level to a modelled baseline SOC value for an extensively grazed permanent grass pasture. This baseline SOC level is consistent with good soil health and function; however, it cannot be assumed to represent an attainable level of SOC for the wide diversity of cropping systems and management practices that exist within the agricultural sector. For many cropping systems, achieving the baseline SOC level is neither feasible nor necessary.

The resultant RSOC values are ranked as *Very low* (<0.55), *Low* (0.55 to 0.7), *Moderate* (0.7 to 0.85), *High* (0.85 to 1.0) and *Very High* (>1.0). Since farmland planted to annual crops generally has lower SOC levels than cropland under continuous pasture, the RSOC values are expected to fall into the moderate class when few periods of **forages** or pasture are included in the cropping cycle and when there are no organic matter additions from **cover crops**, green manures or animal manures. Areas with *Low* or *Very low* RSOC values represent opportunities to increase C sequestration through the adoption of appropriate management practices. Areas that have low RSOC values combined with a decline in SOC present the greatest risk of soil degradation.

Limitations

The SOCC Indicator does not take soil erosion into consideration. Soil erosion causes a decline in SOC because it removes part of the surface layer of soil which is enriched in SOC. Therefore, even relatively low rates of soil erosion can have significant effects on SOC status. As a result, when considered at the field-level, SOC change in this report is biased toward smaller losses and larger gains.

The RSOC Indicator should be considered more uncertain than the SOCC Indicator because of uncertainties related to the SOC values in the CANSIS database.

Results and Interpretation

For Canada as a whole, improvements in farm management have resulted in a dramatic shift from stable SOC levels (additions=losses) during the mid-1980s to a situation where the majority of cropland had increasing SOC levels in the mid-1990s and through to 2011 (Figure 9–1, Table 9–1). Across Canada, 72% of the agricultural land is in the *Large* or *Moderate Increase* classes. Thanks to the enhanced management practices adopted during this period, cropland soils have become a larger sink for atmospheric CO_2. Canadian agricultural soils represented a net source of 1.2 megatonnes (Mt) of CO_2 per year in 1981, but became a net sink of 11.9 Mt of CO_2 per year in 2011.[2]

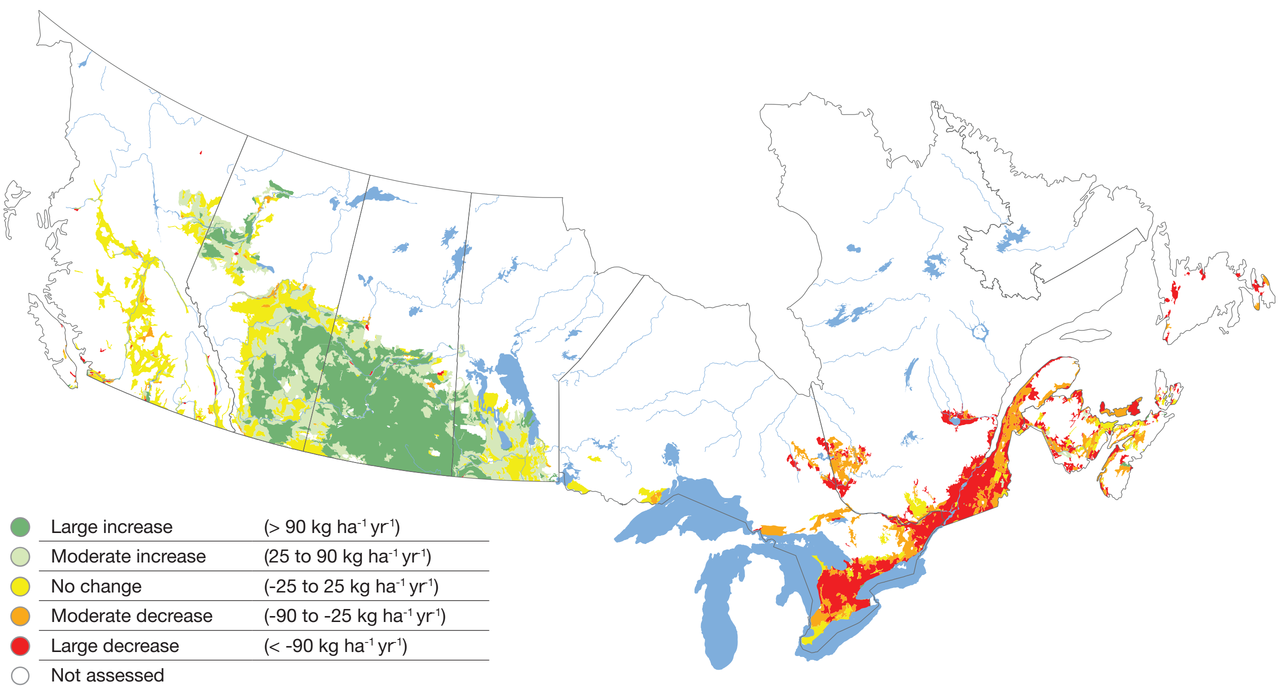


Figure 9–1: Soil organic carbon change (kg ha^{-1} yr^{-1}) in Canada in 2011

2 The sink of -11.9 Mt CO_2 in 2011 is strictly the amount of carbon sequestered in soil. This Figure does not include changes in carbon stocks (losses) associated with changes in living biomass and dead organic matter resulting from the conversion of forestland to cropland. When these other changes are included, and including N_2O and CH_4 emissions, the net sink for 2011 is approximately -5 Mt CO_2e (Environment Canada, 2014)

Table 9–1: Percentage* of land in SOC change classes

	Share of Cropland in Different Soil Organic Carbon Change Classes (%)																																			
Class	Large Increase More than 90 kg ha^{-1} yr^{-1}							Moderate Increase 25 to 90 kg ha^{-1} yr^{-1}							Negligible to small change -25 to 25 kg ha^{-1} yr^{-1}							Moderate Decrease -25 to -90 kg ha^{-1} yr^{-1}							Large Decrease More than -90 kg ha^{-1} yr^{-1}						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	0	0	0	1	1	2	2	0	2	5	11	12	15	15	69	70	79	78	76	73	75	28	23	14	9	9	7	6	3	5	2	2	2	3	2
Prairie mean	**1**	**2**	**3**	**8**	**35**	**53**	**56**	**18**	**39**	**47**	**69**	**50**	**35**	**31**	**78**	**57**	**49**	**22**	**15**	**12**	**13**	**3**	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Alberta	0	0	0	2	17	32	37	24	32	42	62	58	46	41	72	64	56	34	24	21	21	3	4	2	1	1	1	1	0	0	0	0	0	0	0
Saskatchewan	0	0	1	11	53	75	79	1	38	47	78	42	22	18	94	60	52	11	5	3	3	4	2	1	0	0	0	0	0	0	0	0	0	0	0
Manitoba	7	9	18	17	24	32	30	59	59	60	58	52	50	44	34	32	22	25	24	19	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Central Canada mean	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**15**	**16**	**15**	**13**	**11**	**13**	**12**	**36**	**36**	**31**	**32**	**28**	**27**	**24**	**50**	**48**	**54**	**54**	**61**	**59**	**64**
Ontario	0	0	0	0	0	0	0	0	0	0	1	0	0	0	12	13	14	16	15	18	17	23	27	26	29	28	29	26	65	60	60	54	56	53	56
Quebec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	23	16	7	2	2	2	61	54	43	39	27	24	18	19	23	41	54	71	74	80
Atlantic mean	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**2**	**1**	**1**	**2**	**37**	**32**	**28**	**20**	**13**	**15**	**14**	**53**	**54**	**54**	**60**	**62**	**61**	**49**	**8**	**14**	**16**	**16**	**23**	**22**	**34**
New Brunswick	0	0	0	1	0	0	0	2	3	4	5	3	1	3	88	70	62	31	23	21	20	10	22	30	60	52	60	49	0	4	4	4	22	19	28
Nova Scotia	0	0	0	3	1	1	4	0	0	0	3	1	3	2	27	30	28	36	20	30	28	68	58	56	42	53	44	40	4	12	15	16	24	23	26
Prince Edward Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81	79	74	77	80	81	56	19	21	26	23	20	19	44
Newfoundland and Labrador	1	2	2	0	0	0	0	2	1	0	0	0	0	0	45	29	30	1	0	0	1	25	27	20	36	33	10	47	26	42	48	62	67	90	52
Canada mean	**1**	**1**	**2**	**7**	**30**	**44**	**46**	**15**	**32**	**39**	**58**	**42**	**30**	**26**	**68**	**52**	**45**	**22**	**16**	**14**	**15**	**9**	**8**	**6**	**5**	**5**	**4**	**4**	**7**	**7**	**7**	**7**	**8**	**8**	**9**

* due to rounding, the values may not sum exactly to 100%.

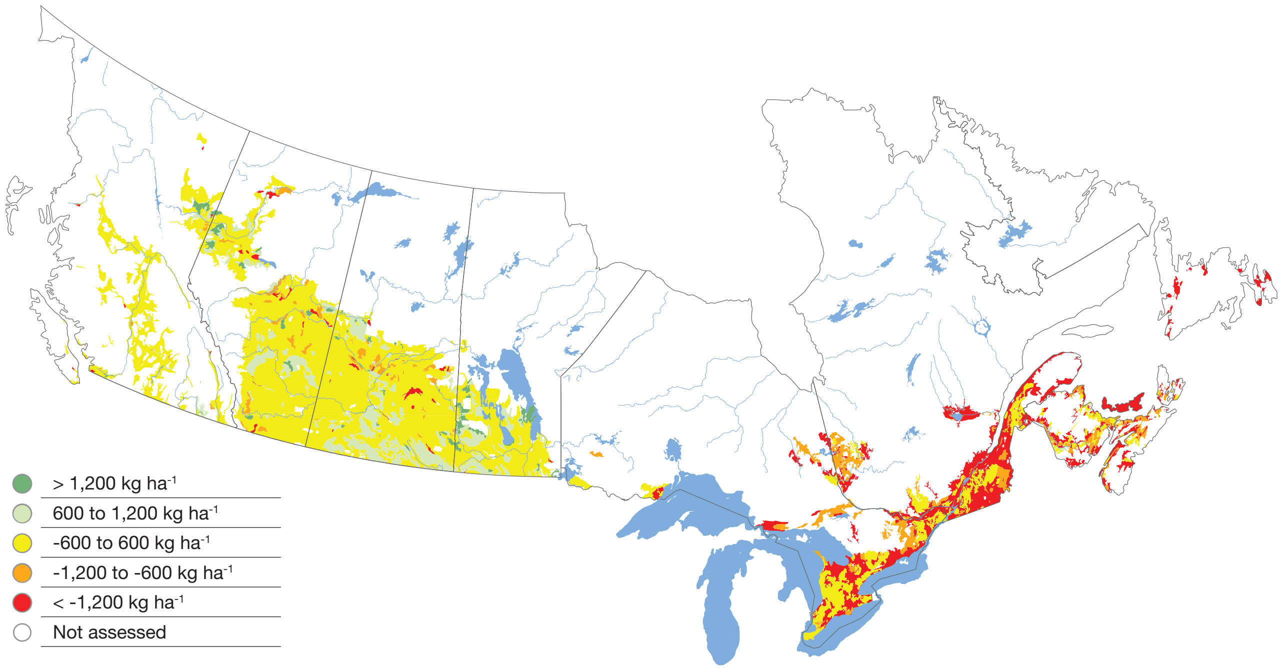


Figure 9–2: Cumulative SOC change (kg ha^{-1}) from 1981 to 2011 due to land-use changes (e.g. forest to agriculture) and shifts between annual and perennial crops

From Ontario eastward, there was an overall loss of SOC from 1981 to 2011 due to the reduction in the area of hayland and pasture and the corresponding increase in the area of annual crops (Figure 9–2). This shift in land use reflects a reduction in the demand for feed associated with the declining cattle populations in those provinces. The Prairie Provinces have seen major increases in SOC over time due to reductions in tillage and summerfallow (Figure 9–3). Ontario and Quebec have recorded moderate increases in SOC as a result of the adoption of **conservation tillage**, while other provinces in eastern Canada have shown limited increases because conservation tillage has not been implemented to the same extent owing to their cooler and wetter climatic conditions.

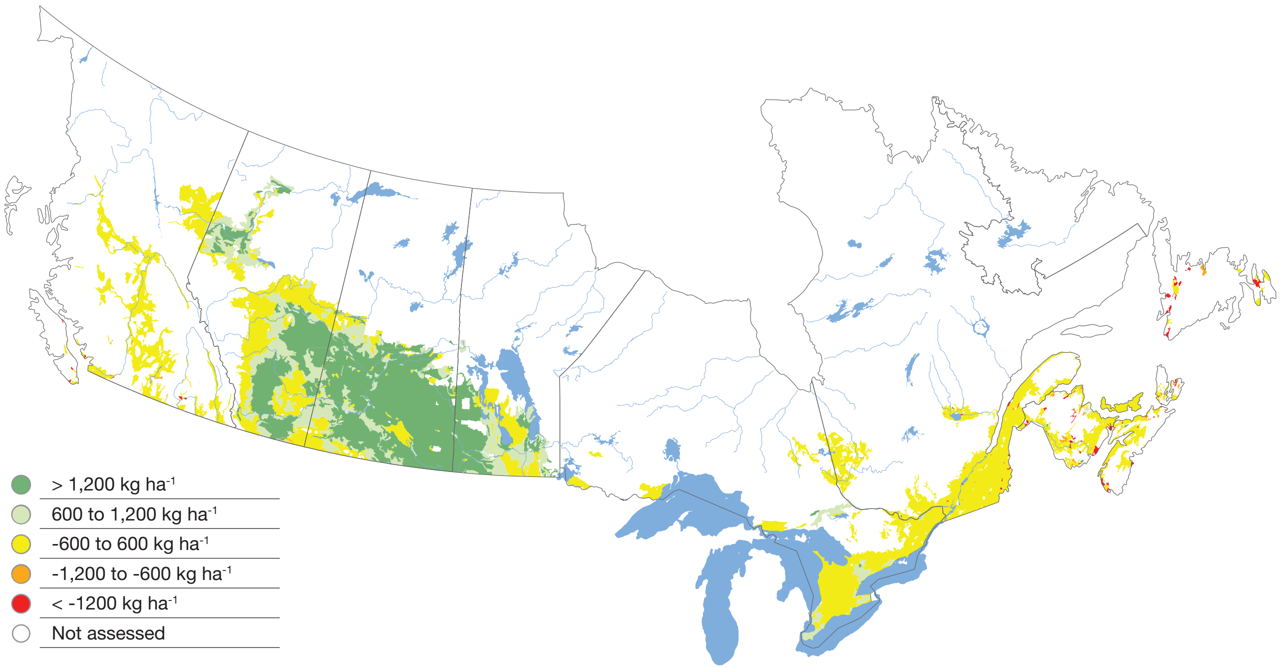


Figure 9–3: Cumulative SOC change (kg ha^{-1}) from 1981 to 2011 due to changes in tillage and summerfallow

Table 9–2: Average rates of SOC change and RSOC levels for the provinces and for Canada

Class	Soil Organic Carbon Change (kg ha^{-1} yr^{-1})							Relative Organic Carbon (Current SOC/modelled baseline SOC)	
Year	1981	1986	1991	1996	2001	2006	2011	1981	2011
BC	-19	-19	-9	0	-2	2	6	0.77	0.79
Prairie mean	**9**	**21**	**26**	**47**	**71**	**92**	**97**	**0.79**	**0.79**
AB	11	13	20	36	55	66	69	0.78	0.79
SK	-1	19	23	55	88	119	128	0.77	0.77
MB	39	44	49	50	58	72	66	0.89	0.90
Central Canada mean	**-91**	**-89**	**-96**	**-97**	**-114**	**-109**	**-115**	**0.73**	**0.68**
ON	-107	-100	-103	-95	-99	-92	-98	0.62	0.57
QC	-59	-65	-82	-102	-145	-144	-152	0.95	0.91
Atlantic mean	**-47**	**-56**	**-59**	**-60**	**-74**	**-86**	**-85**	**0.70**	**0.65**
NB	-12	-23	-25	-38	-58	-83	-79	0.77	0.73
NS	-39	-56	-61	-43	-72	-82	-64	0.59	0.53
PE	-81	-78	-80	-82	-80	-74	-92	0.72	0.69
NL	-132	-143	-155	-225	-211	-288	-274	0.90	0.83
Canada mean	**-6**	**4**	**9**	**26**	**45**	**62**	**64**	**0.78**	**0.78**

The mean RSOC Indicator value for Canada's agricultural land in 2011 was 0.78 (Table 9–2). While the majority of land in the Prairies, British Columbia, Quebec and much of Atlantic Canada have RSOC values in the *Moderate* to *High* range (Table 9–3), significant areas with low RSOC ratios (<0.7) are present in southwestern Ontario, the south-central Prairies, large portions of the Peace River region of Alberta and British Columbia, and parts of the Atlantic Provinces (Figure 9–4).

Together, the RSOC and SOC provide information on the overall risk of SOC degradation. The combination of SOC and RSOC classes used to define the SOC degradation risk classes is shown in Table 9–4. Areas having RSOC values in the *Low* to *Very low* classes combined with declining SOC (i.e. those cells highlighted in red) are considered to be at high risk of soil degradation and raise the greatest concern about soil quality in terms of SOC. These areas can be seen in Figure 9–5, and are also listed in Table 9–5.

Table 9–3: Share of land (percentage) in each RSOC class in 2011

	RSOC Class				
Class	Very high	High	Mod.	Low	Very low
BC	1	39	33	20	8
Prairies	**4**	**36**	**34**	**23**	**4**
AB	1	34	40	22	2
SK	3	32	33	25	7
MB	15	53	17	14	0
Central Canada	**12**	**5**	**15**	**26**	**42**
ON	1	2	14	30	54
QC	37	12	19	17	15
Atlantic Canada	**2**	**3**	**46**	**29**	**20**
NB	1	8	59	26	6
NS	3	0	7	26	63
PE	0	0	66	34	0
NL	25	16	39	18	1
Canada	**5**	**32**	**31**	**23**	**9**

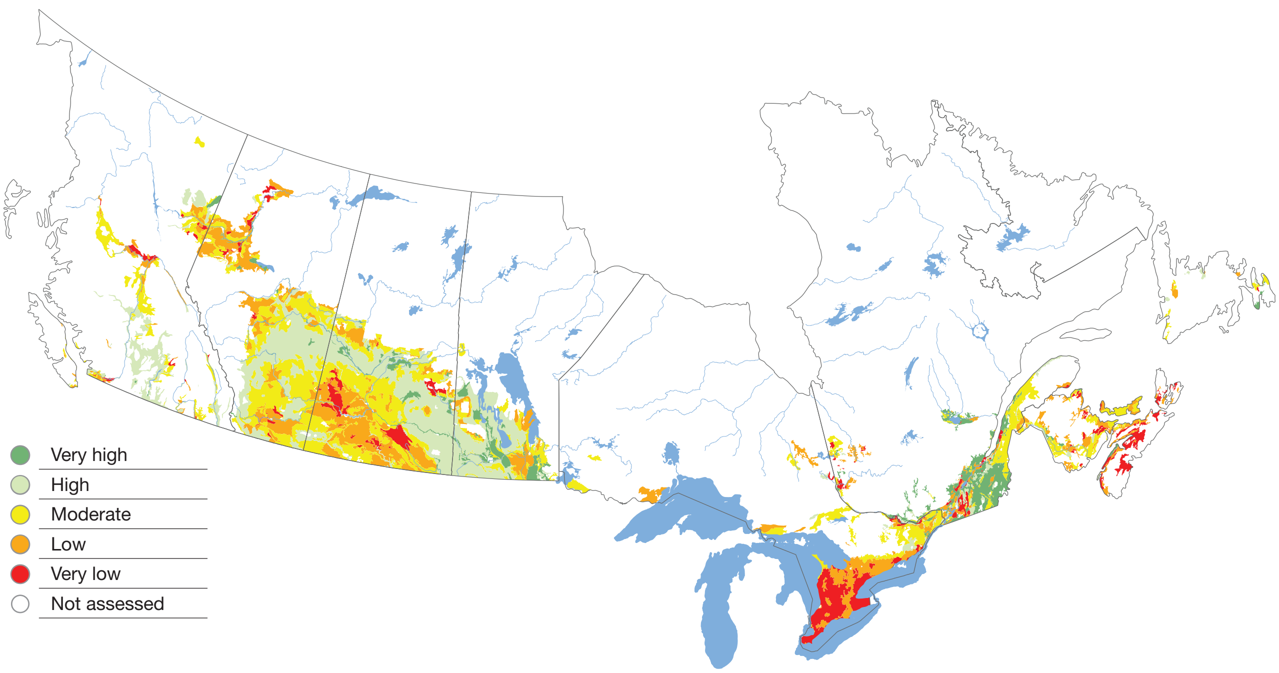


Figure 9–4: Relative soil organic carbon (RSOC) values for Canada in 2011

Table 9–4: SOCC/RSOC class combinations used to define SOC degradation risk

SOCC	SOC Degradation Risk – ROC: Very low	Low	Moderate	High	Very high
Large decrease	High	High	High	Moderate	Moderate
Moderate decrease	High	High	Moderate	Moderate	Low
No change	Moderate	Low	Low	Low	Low
Moderate increase	Low	Very Low	Very Low	Very Low	Very Low
Large increase	Very Low	Very Low	Very Low	Very Low	Very Low

Soil degradation risk: High; Moderate; Low; Very Low

In 2011, more than half the cropland in Central Canada could be considered to be at a *High* or *Very High* risk of degradation (Table 9–5), while 38% of the land in Atlantic Canada was in the higher risk classes.

Degradation of soil structure, as reflected in poor soil tilth and infiltration, is likely to be the first sign that SOC levels are lower than desired. The effects of degradation are most noticeable on sandy and clayey soils. Soils with low RSOC have the greatest potential for improvement through the adoption of enhanced management practices that increase SOC levels. In the Prairie Provinces, 27% of the land was in the *Very low* and *Low* RSOC classes, and almost all of this land had increasing SOC levels. Virtually none of the land with *Low* to *Very low* RSOC values on the Prairies had decreasing SOC levels.

In eastern Canada, the majority of land with *High* and *Very High* RSOC values is also losing SOC. This situation is not as worrisome from a soil health standpoint as is the loss of SOC combined with *Low* RSOC values. The loss of SOC from soils with *High* RSOC values is associated with shifts in farming from a cattle- and forage-based system to grains and **oilseeds**.

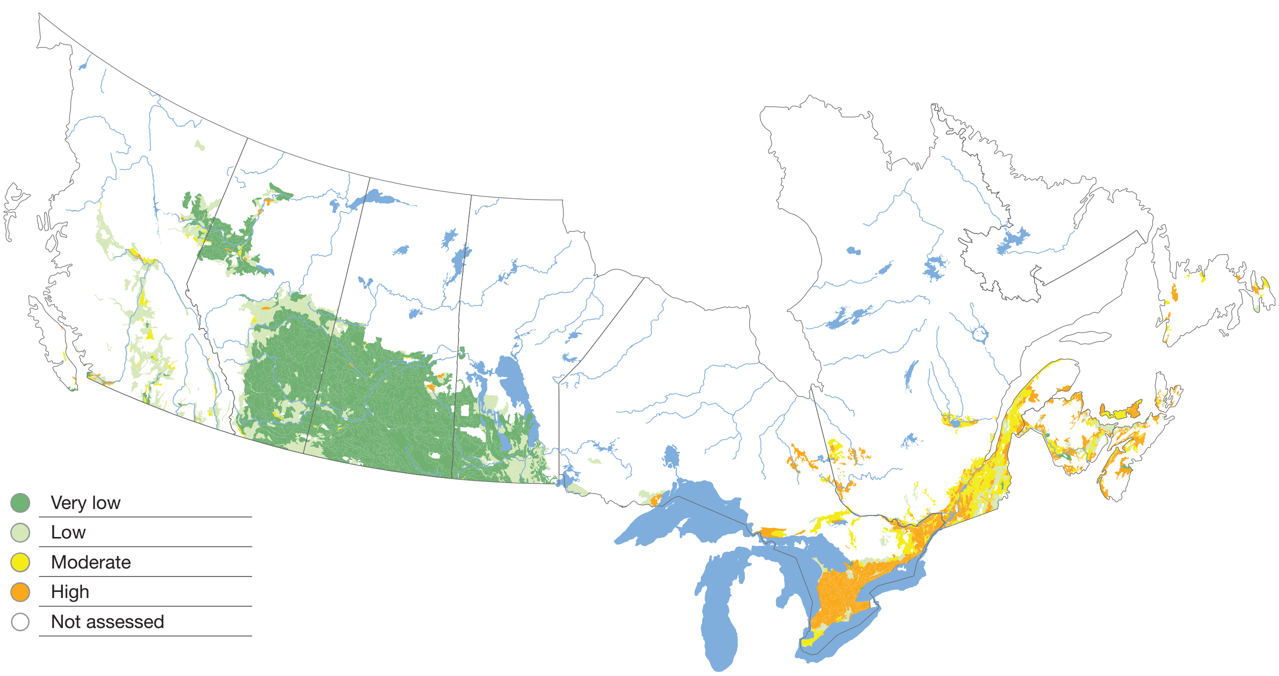


Figure 9–5: Soil organic carbon degradation risk in 2011

Table 9–5: Share of land (percentage) in each RSOC class/SOCC combination in 2011[3]

	SOC change class																								
	More than 90 kg ha^{-1} yr^{-1} RSOC class					25 to 90 kg ha^{-1} yr^{-1} RSOC class					-25 to 25 kg ha^{-1} yr^{-1} RSOC class					-25 to -90 kg ha^{-1} yr^{-1} RSOC class					loss more than -90 kg ha^{-1} yr^{-1} RSOC class				
	Very Low	Low	Mod	High	Very High	Very Low	Low	Mod	High	Very High	Very Low	Low	Mod	High	Very High	Very Low	Low	Mod	High	Very High	Very Low	Low	Mod	High	Very High
British Columbia	nil*	0	1	1	0	1	5	5	4	0	4	12	22	30	0	1	1	2	1	nil	0	1	0	0	nil
Prairie	**3**	**15**	**17**	**20**	**2**	**1**	**5**	**11**	**12**	**2**	**0**	**3**	**5**	**3**	**1**	**0**	**0**	**0**	**0**	**0**	**nil**	**0**	**0**	**0**	**nil**
Alberta	0	11	13	12	0	1	7	17	15	0	1	4	9	6	0	0	0	0	nil	nil	nil	nil	0	nil	nil
Saskatchewan	6	21	24	26	2	1	3	7	6	1	nil	0	2	1	0	0	nil	0	0	0	nil	0	nil	0	nil
Manitoba	nil	2	3	22	3	nil	2	10	24	7	nil	10	4	7	5	nil	nil	nil	nil	0	nil	nil	nil	0	nil
Central Canada	**0**	**nil**	**nil**	**nil**	**0**	**0**	**0**	**nil**	**0**	**0**	**5**	**3**	**3**	**1**	**1**	**10**	**7**	**3**	**1**	**2**	**26**	**15**	**8**	**4**	**9**
Ontario	0	nil	nil	nil	nil	0	0	nil	nil	nil	7	5	5	1	0	14	9	2	1	nil	32	15	7	1	1
Quebec	nil	nil	nil	nil	0	nil	nil	nil	0	0	nil	nil	0	0	1	0	1	6	1	8	14	15	11	10	26
Atlantic	**1**	**0**	**nil**	**nil**	**nil**	**0**	**1**	**1**	**0**	**nil**	**4**	**5**	**5**	**0**	**nil**	**10**	**5**	**32**	**2**	**1**	**5**	**18**	**8**	**1**	**1**
New Brunswick	nil	nil	nil	nil	nil	0	1	1	1	nil	1	7	11	1	nil	3	7	34	5	0	3	10	12	1	1
Nova Scotia	3	1	nil	nil	nil	1	0	1	nil	nil	15	8	5	nil	nil	30	9	1	0	nil	14	7	0	0	3
Prince Edward Island	nil	nil	nil	0	0	nil	nil	nil	0	0	nil	nil	nil	0	0	nil	nil	56	0	0	0	34	10	0	0
Newfoundland and Labrador	0	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	1	nil	nil	nil	26	nil	21	1	18	12	15	3
Canada	**2**	**12**	**14**	**16**	**1**	**1**	**4**	**9**	**10**	**1**	**1**	**3**	**5**	**4**	**1**	**1**	**1**	**1**	**0**	**0**	**4**	**2**	**1**	**1**	**1**

3 Nil indicates no land in combination, 0 indicates less than 0.5% of land in that combination

Response Options

Soil health with respect to SOC is generally improving. The adoption of practices such as reduced summer-fallow and **reduced tillage** are valuable ways to correct low SOC levels. Some significant declines in SOC have occurred. The decline in SOC in regions east of the Prairies is the inevitable result of the conversion of pastures and hayland to more intensive annual crops. As this trend has persisted for at least five decades, a continual loss of SOC has occurred.

In cases where low-residue horticultural or root crops are grown on farmland with relatively low SOC levels, it is important to include crops that produce abundant residues in the rotation. Spreading manure on soils with very low SOC is an approach that can increase SOC and improve soil health and productivity quickly.

The clearing of trees and shrubs to add land for farming continues to a limited extent and causes losses of carbon in all provinces. Similarly, some minor conversion of native grassland to cropland causes SOC loss and is evident in Alberta and Saskatchewan. The long-term merits of breaking this often marginal land for crops needs to be considered carefully.

Approaches for managing SOC need to be tailored to the SOC status of the area concerned. In the case of soils with relatively low SOC levels due to past management practices, a comprehensive analysis should be carried out to identify the methods that can be used to increase SOC levels. Slowing or reversing the loss of SOC is particularly important for soils that have low RSOC values. Minimizing erosion is a prerequisite for increasing SOC on these soils. Other suitable methods may include using cover crops, periodic use of perennial forages, incorporation of manure, and reducing tillage.

In soils with relatively high SOC, there is a need to prevent detrimental losses of SOC. Minimizing soil erosion on these soils is the most effective way to maintain SOC levels. Returning **crop residues** to the soil and having some high residue crops in the rotation are also important for maintaining SOC levels.

References

Alberta Agriculture and Rural Development, 2014. *Carbon contracting: 2012 changes to the Alberta carbon market.*

Environment Canada, 2014. *National Inventory Report 1990-2012: Greenhouse gas sources and sinks in Canada*. Submission to the United Nations Framework Convention on Climate Change. Available at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8108.php

National Resource Ecology Laboratory (NREL), 2007. *Century.* Retrieved June 9, 2009 from http://www.nrel.colostate.edu/projects/century/

Soil Landscapes of Canada Working Group, 2010. *Soil Landscapes of Canada version 3.2*. Agriculture and Agri-Food Canada. (digital map and database at 1:1 million scale).

The Management and Reduction of Greenhouse Gases Act. Available at http://www.qp.gov.sk.ca/documents/english/FirstRead/2009/Bill-95.pdf

10 Soil Salinization

Authors:
M.D. Bock

Indicator Name:
Risk of Soil Salinization Indicator

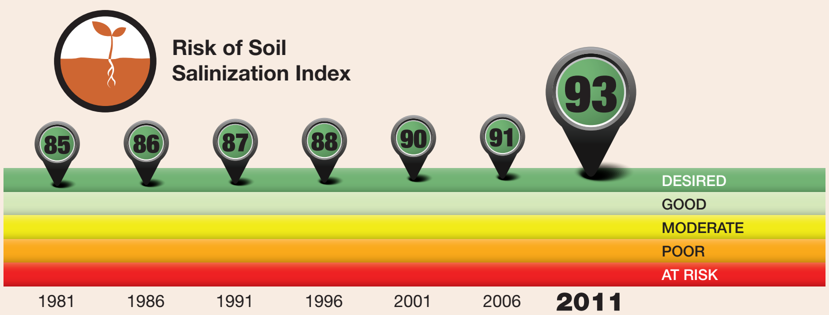
Status:
Provincial Coverage (Alberta, Saskatchewan, Manitoba), 1981 to 2011

Summary

The accumulation of soluble salts in portions of the landscape can contribute to localized soil degradation on the Canadian Prairies. **Salinization**[1] occurs most rapidly in arid regions after wetter-than-normal years because water tables become elevated. Soluble salts become concentrated near the soil surface as soil water is removed by transpiration and evaporation. Plants differ in their response to high levels of soluble salts. High soluble salt concentrations can impair a plant's ability to absorb water and **nutrients**, and some of the elements present in saline soils can be toxic. These factors can reduce the yield of agricultural crops, and, in extreme cases, can result in unproductive soils.

Risk of Soil Salinization Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign single values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of the environment from the standpoint of the risk of salinity on farmland in the Canadian Prairies was 'Desired'. The index illustrates an upward trend, from an index value of 85 in 1981, to an even higher value of 93 in 2011, representing a declining risk of soil salinity across the Prairies. These improvements came about primarily as a result of widespread adoption of reduced tillage (conservation tillage) and no-till, as well as decreases in the use of summerfallow in Manitoba, Saskatchewan and Alberta.

The index tends to aggregate and generalize trends. Specific findings, as well as regional variations and interpretations, are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector".

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1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

Production management systems that affect the quantity and flow of water and soluble salts through the soil can contribute significantly to soil salinization within agricultural **ecosystems**. The practice of **summerfallow**, for example, increases the amount of water stored in the root zone, which may result in an elevated water table and increased levels of soluble salts at or near the soil surface in susceptible areas of the landscape. By contrast, the use of **permanent-cover** crops and continuous-cropping practices reduces the amount of soil moisture that moves from the root zone to the water table, thereby reducing the potential for soil salinization. The Risk of Soil Salinization (RSS) Indicator has been developed to assess the state and trend of the risk of **dryland** soil salinization on the Canadian Prairies as a function of changing land use and management practices.

In 2011, 85% of the land area in the agricultural region of the Canadian Prairies was rated as having a *Very low* risk of salinization. The land area at risk of soil salinization deceased between 1981 and 2011 in all three Prairie Provinces, with the greatest decrease in risk occurring in Saskatchewan. These improvements were largely attributed to a 7-million-hectare (ha) decrease in summerfallow area (78% reduction from 1981 to 2011), and a 4.8-million-ha increase in the area of permanent cover (a 14% increase from 1981 to 2011).

The Issue and Why it Matters

Dryland soil salinization is a natural process that occurs in regions where moisture deficits are common (potential **evapotranspiration** exceeds precipitation) and where the soils and **ground water** may naturally have higher concentrations of mineral salts such as sodium, calcium and magnesium sulphate. Saline soils occur sporadically in other regions of Canada, but it is on localized areas in the Prairie region that salinization can pose a significant risk. The process of dryland soil salinization begins in portions of the landscape where snowmelt and precipitation exceed the requirements of the established plant community. Where this occurs, soil water moves down through the root zone, carrying the soluble salts to the water table. Once in the ground water, the dissolved salts can be transported to other parts of the landscape where regional ground-water flow is towards the surface. These conditions typically occur because of low-lying depressions or the shape of the underlying bedrock. As this water is transpired or evaporated, the salts are concentrated at or near the soil surface or in nearby water bodies (Figure 10–1). Over time, the process of salinization typically produces observable white salt crusts on the soil surface or crystalline precipitates within the soil profile.

High levels of root-zone salinity generally result in poor seed germination, reduced plant growth and significantly lower yields of agricultural crops. Growth and yields of most crops will be affected to some degree under conditions of weak soil salinity. As salt concentrations in the soil water increase, plants experience drought-like conditions and lose their ability to absorb sufficient water. Secondary causes of reduced growth and yield include the inability to absorb sufficient nutrients, the toxic effects of specific ions, and the adverse physical or nutritional conditions often associated with saline soils.

Under conditions of moderate to severe salinity, yield reductions of at least 50% are common for most **cereal** and **oilseed** crops. Salt concentrations may become so severe that even the growth of salt-tolerant plants is no longer possible. However, sensitivity to salt concentrations varies with crop type (Henry et al., 1987) and with different stages of development. For example, barley is more tolerant than wheat of weakly saline soils; bromegrass and sweet clover are tolerant of moderately saline soils; and sugar beets are sensitive to low levels of salinity during the germination and emergence stages of growth.

The soil salinization process is influenced by natural environmental factors including water deficits, topography, the inherent salt content of the soil parent material and underlying geologic formations, and hydrologic conditions. Although saline soils occur naturally in some landscapes, it is widely recognized that land-use practices can significantly influence (positively or negatively) both the degree of salinity and the areal extent of saline soils by altering natural hydrologic pathways. Agricultural practices such as **continuous cropping** or growing **perennial forages** in upland areas limit the amount of water **leaching** through the soil, thereby preventing the occurrence of salinization in lower-slope positions of the landscape. Conversely, summerfallow and irrigation result in excess soil moisture and can exacerbate salinity in susceptible areas by elevating the water table and contributing additional dissolved salts to ground water. Land-use practices that result in more efficient use of precipitation where it falls, for example, growing deep-rooted perennial crops, have been shown to reduce ground-water salinity and decrease the extent of salt-affected areas (Holzer et al., 1995).

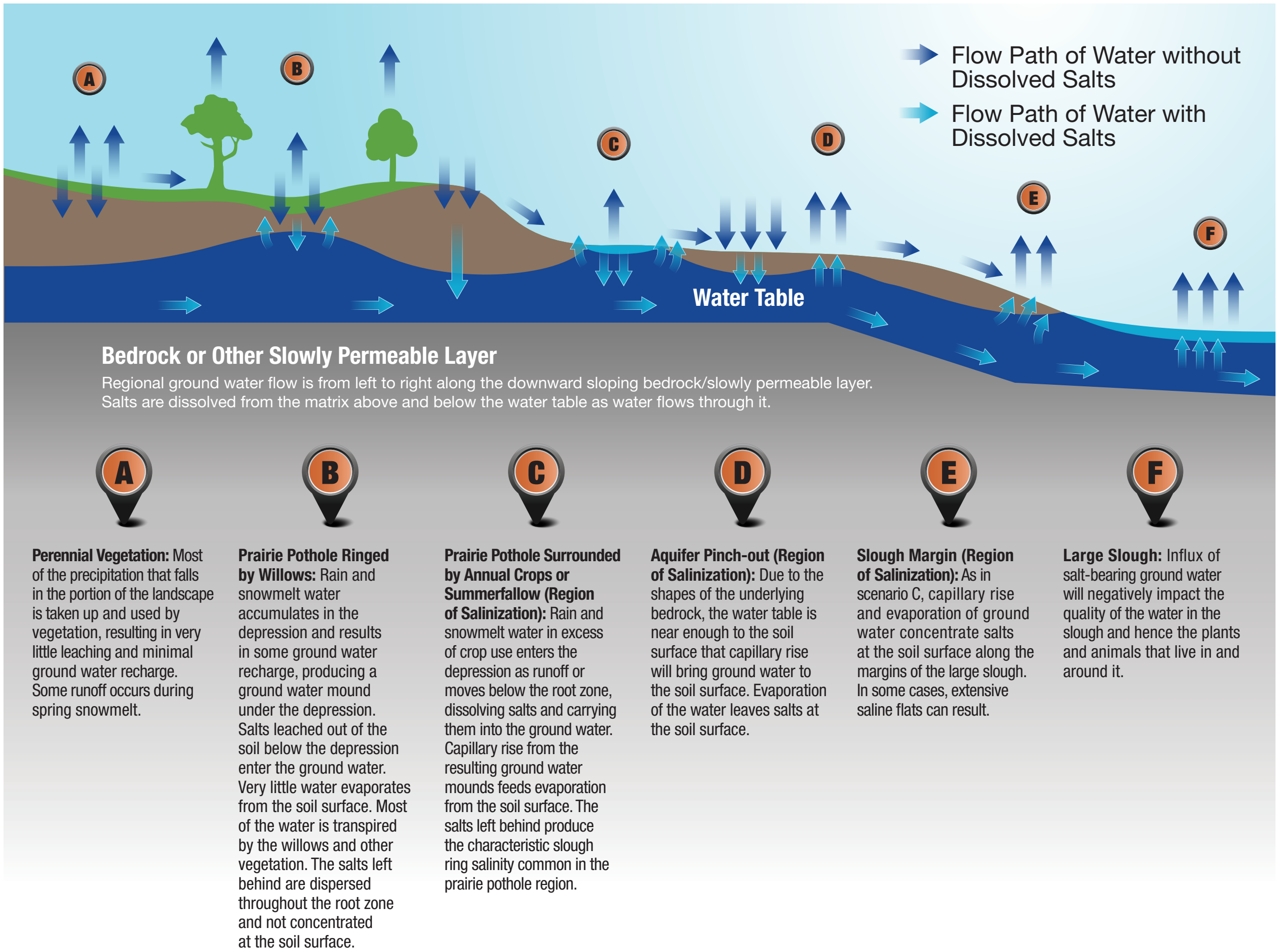


Figure 10–1: Conceptualized water and salt redistribution in a regional landscape, illustrating potential dryland soil salinization processes (Wiebe et al., 2010)

Wiebe et al. (2006, 2007) estimated that in agricultural regions of the Canadian Prairies approximately 1 million ha of surface soils are affected by moderate to severe soil salinity. Deterioration of local and potentially regional surface water and shallow ground-water resources has been attributed to the influx of soluble salts from dryland salinization (Miller et al., 1981). In 1998, annual income losses to Canadian farmers as a result of soil salinity were estimated at $257 million (Forge, 1998).

Dryland salinization not only reduces the crop yields but also limits the range of crops that can be grown, thereby reducing the potential economic returns to farmers. If soil landscapes susceptible to salinization are not managed properly, land that was once agriculturally productive may become non-productive.

Also, valuable ground-water resources may come under threat as the levels of dissolved salts increase (Vander Pluym, 1982). Under anticipated future climate change scenarios, the potential risk of soil salinization on the Canadian Prairies could increase due to increases in soil moisture deficits (Florinsky et al., 2009). An awareness of at-risk agricultural land is needed, as well as an understanding of land-use practices that can mitigate potentially negative impacts on valuable land and water resources. This will help Canada to continue to play an important role in minimizing salinity risks and enable it to meet global food demand while maintaining a highly productive and sustainable agricultural landscape.

The Indicator

The Risk of Soil Salinization (RSS) Indicator assesses and tracks changes in the potential for further development of salinity associated with changes in agricultural land use and management practices. The RSS is derived by calculating a unitless Salinity Risk Index (SRI) which combines weightings for factors that control or influence the salinization process. The following factors are used in the calculation:

- soil salinity status within the landscape, derived from a compilation of presence and extent of moderate-to-severe soil salinity across the Canadian Prairies (Wiebe et al., 2006; 2007);
- topography—including slope steepness and slope position;
- soil drainage;
- growing season climatic moisture deficits; and
- land use, based on the relative amounts of permanent cover, annual crops, and summerfallow, from the **Census of Agriculture** for 1981, 1986, 1991, 1996, 2001, 2006, and 2011.

The first four index factors are assumed to remain constant over each five-year reporting period, whereas changes in land use result in changes in the index value. Salinity experts developed a weighting for each factor based on the factor's influence on the process of soil salinization. For example, land under summerfallow was considered to be at highest risk, while land under permanent cover was associated with the lowest risk. Annual **cropland** was deemed to be at an intermediate risk. The weightings of the land-use factor were determined by the relative proportions of summerfallow, permanent cover and annual cropland in each **Soil Landscapes of Canada** (**SLC**) **polygon**.

The index values are expressed in five classes of risk which were established through consultation with salinity experts in each of the Prairie Provinces. Since individual soil and landscape combinations have a variable risk of salinization, an area-weighted SRI value was also calculated for each SLC polygon and used to assign a risk class to the polygon for mapping purposes.

Limitations

The soil, landscape and climate factors used in the indicator calculation are held constant so that the assessment of the risk of soil salinization will reflect the impact of current and evolving land use and cropping practices. In the calculation, long-term average climate data were used to quantify moisture deficits. However, moisture deficits during the growing season vary from year to year. Therefore, significant yearly variation in the risk of salinization due to weather variability is not taken into account in the indicator. The indicator has been developed for dryland agricultural systems and therefore assumes that inputs of water occur through precipitation. This risk assessment does not evaluate the risk of salinization for farming systems using irrigation. Additionally, non-agricultural uses of land such as roads, ditches and traffic corridors which influence the flow of surface and subsurface water and can affect soil salinization are not currently reflected in this broad-scale analysis.

The various land use and cropping practices reported in the Census of Agriculture were combined into three categories: cropland, permanent cover and summerfallow. The water-use efficiency of different crops varies significantly and, therefore, theoretically influences the salinization process differently. However, since insufficient data are available to categorize salinity risk according to crop type, all crops were included in the generic *Cropland* category. Similarly, the *Permanent cover* category encompasses both **improved** and **unimproved pasture**, all hay and forage crops, and all other land-use categories from the Census.

The practice of reducing salinization risks requires improvements in the spatial and temporal assessment of risk, refinement and further development of **beneficial management practices** (**BMPs**), and improvement in BMP implementation. More spatially detailed and up-to-date data on soil landscapes and on salinity occurrence and extent, as well as climate and land-use, should be incorporated into the RSS model in order to improve its responsiveness and more effectively target the use of appropriate BMPs.

Salinization occurs most rapidly in arid regions after wetter-than-normal years because water tables become elevated. Including more real-time weather data for both annual precipitation and growing-season aridity should improve the assessment of risk compared to the current methodology, which uses only 30-year normals for growing-season aridity. Research is required to determine how best to incorporate such real-time data. The use of more spatially detailed land-use data (e.g. Annual Crop Inventory mapping) in conjunction with Census of Agriculture data should be investigated as a means of improving the effectiveness of the model.

Results and Interpretation

Two of the primary conditions required for dryland salinization—water deficits and inherent salt content of soils and/or ground water—occur to a significant extent only in the Prairie Region of Canada. Therefore, the RSS Indicator is calculated only for the agricultural regions of Manitoba, Saskatchewan and Alberta (Figure 10–2). The pattern of distribution of land at risk of soil salinization generally aligns with soil zone boundaries, especially in Saskatchewan and Alberta, where the majority of the at-risk land is in the more arid **Brown** and **Dark Brown soil** zones. Although the agricultural region of Manitoba corresponds primarily to the more humid **Black soil** zone, significant areas have high natural risk factors for salinization, such as relatively level landscapes and poor drainage as well as near-surface saline ground water.

Across the Prairies, the land area at risk of soil salinization deceased between 1981 and 2011 (Table 10–1). Over this period, the land area in the *Low*, *Moderate*, *High* and *Very High* risk classes decreased by 11%, 4%, 1% and 2%, respectively, while at the same time the area in the *Very low* risk class increased by 19%. In 2011, 85% of the land area in the agricultural region of the Canadian Prairies was rated as having a *Very low* risk of salinization. Although the provincial trends differed from Census to Census, the risk of soil salinization decreased from 1981 to 2011 in all three Prairie Provinces. The greatest increase in the land area in the *Very low* risk class over this time period occurred in Saskatchewan (30%), while the smallest increase occurred in Manitoba (7%). Across the Prairies, only three SLC polygons showed an increase in risk over the seven Census periods: two increased from *Very low* risk to *Low* risk and one from *Moderate* risk to *High* risk (Figure 10–3). In Manitoba and Alberta, the risk class of the majority of the SLC polygons remained unchanged, while a significant number of polygons (32% and 22%, respectively) showed an improvement in risk by one or more classes. Saskatchewan showed the greatest decrease in salinization risk between 1981 and 2011, with a majority of SLC polygons (60%) showing an improvement in risk by one or more classes.

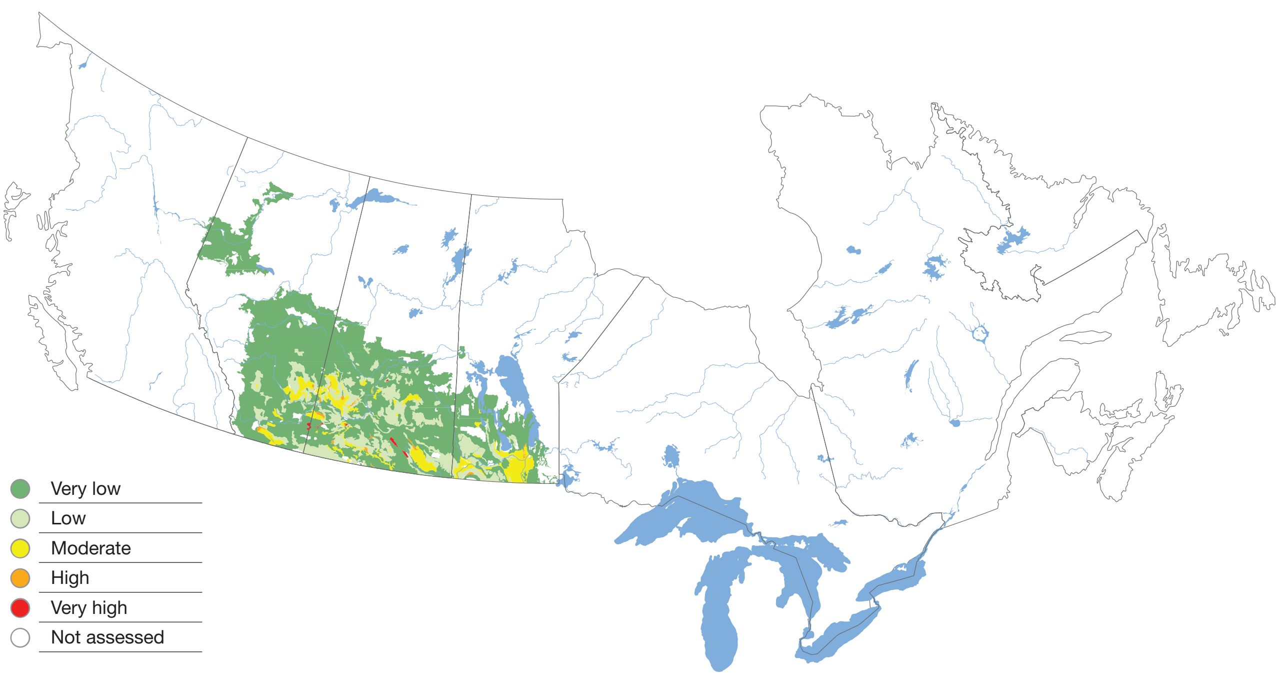


Figure 10–2: The risk of dryland soil salinization on the Canadian Prairies, based on land-use practices in 2011

Table 10–1: Percentage of agricultural area in each RSS class[2], 1981 to 2011

Class	Very Low							Low							Moderate							High							Very High						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
Alberta	81	82	85	86	86	89	91	12	12	9	9	9	7	6	4	4	4	3	3	2	2	2	1	1	1	0	1	1	1	1	1	1	1	1	1
Saskatchewan	53	56	56	61	69	75	83	28	26	26	24	20	15	9	11	11	11	9	5	4	3	2	2	2	2	3	3	2	6	5	5	4	3	3	2
Manitoba	65	63	69	66	69	72	72	8	11	9	11	10	10	11	18	17	16	17	17	15	15	7	7	5	5	4	3	2	3	2	1	1	1	0	0
PRAIRIES	**66**	**67**	**69**	**71**	**75**	**80**	**85**	**19**	**18**	**17**	**16**	**14**	**11**	**8**	**9**	**9**	**9**	**8**	**6**	**5**	**5**	**3**	**3**	**2**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**2**	**2**	**1**

2 Due to rounding, the values may not exactly sum to 100%

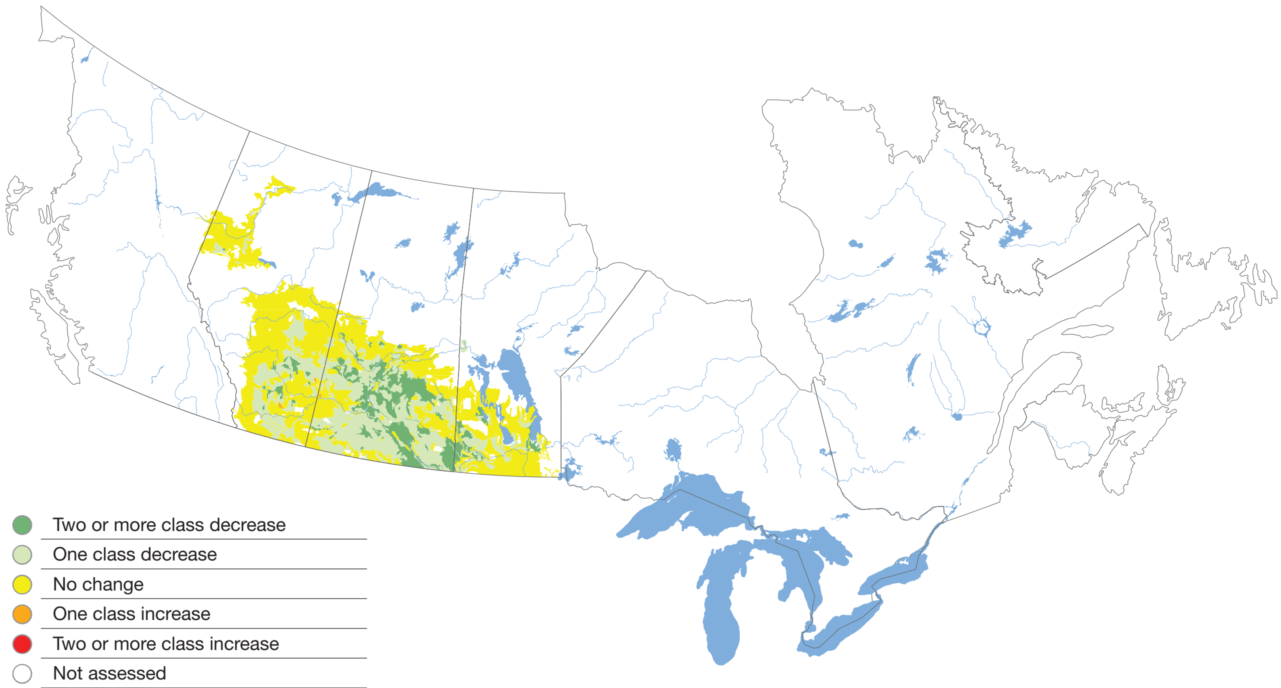


Figure 10–3: Change in salinization risk class due to changes in land use practices between 1981 and 2011

The Prairie-wide declining trend in the risk of soil salinity from 1981 to 2011 is largely due to changes in land-use practices, particularly the decrease in summerfallow and the increase in the area of permanent cover. Since 1981, the area of summerfallow has decreased across the Prairies by over 7 million ha (78% reduction) (Figure 10–4). Decreased use of summerfallow as a management option was consistent across the three Prairie Provinces, with the reduction in area ranging from 77% for Alberta and 78% for Manitoba to 84% for Saskatchewan. In Saskatchewan, more than 5 million fewer ha were under summerfallow in 2011 than in 1981. Permanent cover increased by 4.8 million ha (14%) in the Prairies over the same period, with Saskatchewan accounting for the largest proportion of the change (over 3 million ha), particularly since 1996 (Figure 10–5). The decline in summerfallow throughout the Prairie Region is the result of a number of factors, including the adoption of management practices (increased use of chemical fertilizers, extended crop rotations, continuous cropping) that maximize plant production and ensure more efficient use of available moisture; the use of chemical herbicides as an alternative to cultivation for weed control; the conversion of marginal land to permanent cover or pasture; and greater awareness among producers of the potential long-term degradation effects of summerfallow and **conventional tillage** practices.

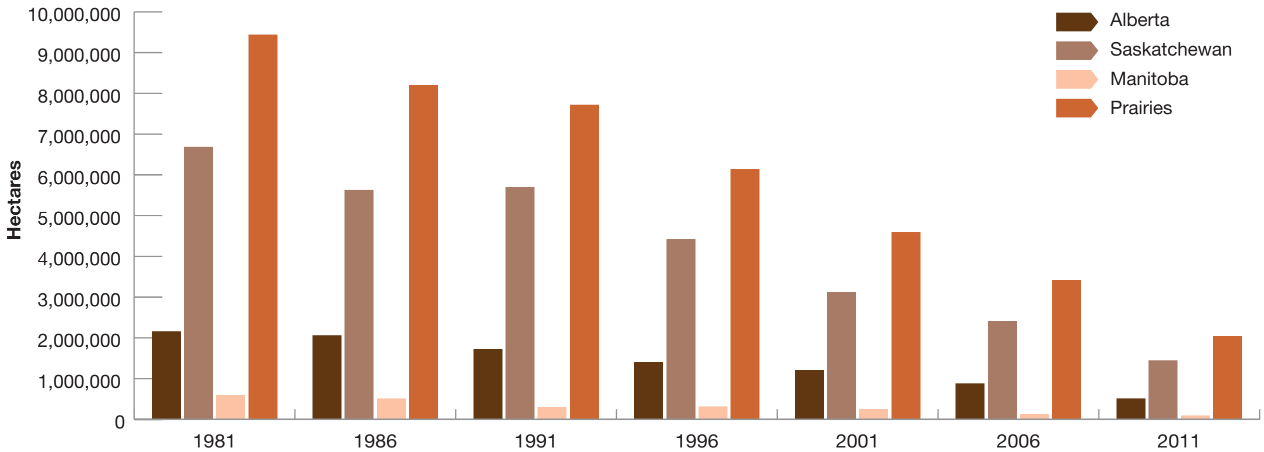


Figure 10–4: Area of summerfallow on the Canadian Prairies, 1981 to 2011

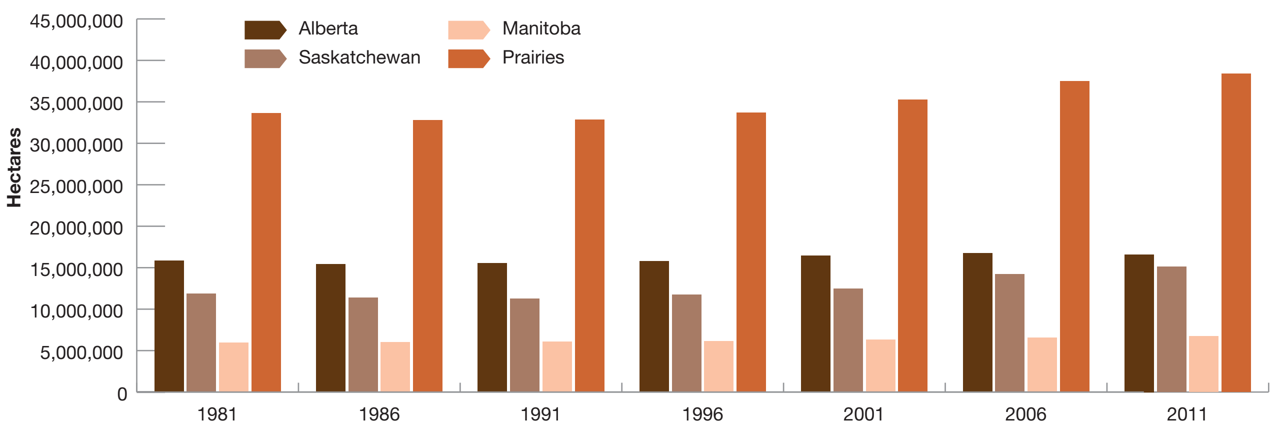


Figure 10–5: Area of permanent cover/perennial crops on the Canadian Prairies, 1981 to 2011

Response Options

While salinization risk has decreased across the Prairies over the last few years, it is still a localized issue of concern for some producers, particularly when water tables are elevated after wetter-than-normal years. The process of salinization is inextricably linked to soil-water conditions, and reducing the risk of salinization and improving existing saline soils requires appropriate soil-water management. BMPs that reduce the overland redistribution of excess water within the landscape and increase the amount of precipitation used by plants where it falls are most effective in controlling the movement of soluble salts throughout the landscape, and thereby preventing soil salinization. These land and water management practices include:

- reduced use of summerfallow;
- increased use of perennial forages, pastures and tree crops;
- snow management (preventing large drifts), to evenly distribute snow and reduce ponding in the spring;
- increased use of no-till and **minimum-till** to encourage more uniform infiltration of precipitation; and

- effective use of inputs such as **fertilizers** and manure to support healthy crop growth and maximize water uptake.

In areas of the landscape where high water tables are already a concern and pose a salinization risk, practices that lower the water table should be incorporated into management activities. These include:

- planting deep-rooted, high-moisture-use perennials to help dry out the subsoil and draw down the water table;
- incorporating more salt-tolerant crops in rotations where salinity is becoming a problem, to maximize water use and reduce salt movement to the soil surface;
- establishing interceptor perennial forage or tree crop strips to reduce ground-water flow to the area at risk;
- using strategic subsurface (plastic) tile drainage to remove water and salts;
- using appropriate surface drainage to reduce recharge; and
- monitoring depth of ground water in sensitive areas to aid in land-use planning and to allow for the implementation of appropriate BMPs.

Reduced (**conservation**) **tillage** practices can improve the distribution of snowmelt water and can reduce the need for summerfallow; however, this approach may also increase ground-water recharge via intact root channels. More information is needed on the effect of conservation tillage on hydrology to better assess its impact on salinization risk.

Soil salinity is a localized problem, and is more readily monitored today with advances in electrical conductivity measurement methods; however, there is room to further reduce the risks. More emphasis on salinity tolerance in crop breeding programs would provide producers with a wider range of cropping options for at-risk areas. Since ground-water flow often crosses property lines, the effective monitoring and management of salinization risk may require coordinated effort between conservation districts and government agencies. Better information on the extent and degree of soil salinization in Canada and its cost to Canadian agriculture would increase the motivation for such activities.

References

Florinsky, I.V., R.G. Eilers, B.H. Wiebe, and M.M. Fitzgerald, 2009. *Dynamics of soil salinity in the Canadian Prairies: Application of singular spectrum analysis*. Environmental Modelling and Software. 24: 1182-1195.

Forge, F., 1998. *Agriculture soil conservation in Canada*. [Online] Available at http://publications.gc.ca/Collection-R/LoPBdP/MR/mr151-e.htm.

Henry, L., B. Harron, and D. Flaten, 1987. *The nature and management of salt-affected land in Saskatchewan*. Agdex 518. Regina, SK, Canada: Saskatchewan Agriculture.

Holzer, J., M.R. Miller, S.K. Brown, R.G. Legare, and J.J. Von Stein, 1995. *Dryland salinity problems in the Great Plains Region of Montana: Evolution of hydrogeology aspects and control programs*. In: Proceedings of the International Association of Hydrogeologists – Congress XXVI: Dryland Salinity Workshop, Edmonton, AB, Canada.

Miller, M.R., P.L. Brown, J.J. Donovan, R.N. Bergatino, J.L. Sonderegger, and F.A. Schmidt, 1981. *Saline seep development and control in the North American Great Plains: Hydrogeological aspects*. Agricultural Water Management. 4: 115-141.

Vander Pluym, H., 1982. *Salinity in western Canada.* In: Proceedings of the First Annual Western Provincial Conference on Rationalization of Water and Soil Research and Management: Soil salinity. Lethbridge, AB, Canada.

Wiebe, B.H., R.G. Eilers, W.D. Eilers, and J.A. Brierley, 2006. *The presence and extent of moderate to severe soil salinity on the Canadian Prairies.* Poster presented at the 49th Manitoba Soil Science Society Annual Meeting, Winnipeg, MB, Canada.

Wiebe, B.H., R.G. Eilers, W.D. Eilers, and J.A. Brierley, 2007. *Application of a risk indicator for assessing trends in dryland salinization risk on the Canadian Prairies*. Canadian Journal of Soil Science. 87: 213-224.

Wiebe, B.H., W.D. Eilers, and J.A. Brierley, 2010. *Soil salinity*. Pages 66-71 in Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds.). *Environmental sustainability of Canadian agriculture: Agri-environmental indicator report series – Report #3.* Ottawa, ON: Agriculture and Agri-Food Canada.

Water Quality

Summary

Many inputs are used in agriculture to help meet the ever-increasing demand for food, fibre and energy. The plant nutrients **nitrogen** (**N**)[1] and **phosphorus** (**P**) are added to agricultural crops in the form of **fertilizers** and manure to increase yields. **Pesticides** are applied to crops to prevent losses in crop yield and quality. The potential exists, however, for these inputs to find their way into the broader environment, particularly into ground water and surface water bodies.

Nitrogen and phosphorus are essential nutrients required by all plants for growth. The loss of N and P to the broader **ecosystem** represents an economic loss to producers and has potential environmental impacts as the nutrients enter the surrounding environment. Excess N can be lost to the atmosphere as nitric oxide (NO), **nitrous oxide** (**N_2O**) (a **greenhouse gas**),[2] nitrogen gas (N_2) or **Ammonia** (**NH_3**).[3] Most residual soil N is in a water soluble form as **nitrate** (**NO_3^-**), and is at risk of **leaching** into ground water as well as nearby water bodies, where high levels in surface water can contribute to algae growth and **eutrophication** and have been linked to human health impacts. Similarly, P may be transported in a dissolved form or bound to soil particles. Excessive P in surface water can also contribute to eutrophication of rivers and lakes and to algal blooms, which reduce water quality and lead to limitations on water use.

Animal manure is a valuable organic fertilizer. However, manure applied on agricultural land can become a source of **pathogens** that may be released to the environment, including viruses, bacteria and protozoa. Water contamination by these pathogens can lead to increased costs for water treatment, loss of use of recreational waters, constraints to the expansion of the livestock industry and potential negative human health effects.

Pesticides are applied to crops in order to reduce losses from weeds, insects and diseases. There is concern, however, that these inputs may move into the broader environment and eventually contaminate ground water and surface waters, with potential environmental and human health implications.

To help quantify the risk to water quality associated with changes in agricultural management practices over time, five agri-environmental indicators have been developed:

1. The Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N) (Chapter 11) estimates the relative risk of agricultural N reaching ground water or surface water bodies in Canadian **watersheds**.
2. The Residual Soil Nitrogen Indicator (RSN) (also in Chapter 11) estimates how efficiently N is managed by providing the estimate of excess N remaining in the soil after harvest. The RSN Indicator is a valuable indicator in its own right, in that it estimates national soil nitrogen levels; however, for the purpose of this report, its chief function is to generate input data for IROWC-N.
3. The Indicator of the Risk of Water Contamination by Phosphorus (IROWC-P) (Chapter 12) estimates the relative risk of agricultural P reaching surface water bodies in Canadian watersheds. The indicator estimates both the source levels of P and the likelihood of transport.
4. The Indicator of the Risk of Water Contamination by Coliforms (IROWC-Coliform) (Chapter 13) assesses the relative risk of pathogens from agricultural sources contaminating surface water bodies using **coliforms** as a marker.
5. The Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest) (Chapter 14) estimates the relative risk of pesticides reaching ground water or surface waters in agricultural areas in response to agricultural management practices and chemical properties of the pesticides.

While the risk of water contamination was not considered to be high on a national basis in Canada in 2011, all of the indicators showed a trend toward increasing risk between 1981 and 2011.

- **IROWC-N and RSN.** While the majority of farmland (75%) is at very low risk of N contamination, over time there has been a gradual shift of land to higher risk classes for both the RSN and IROWC-N indicators, as increases in N inputs (primarily from fertilizer and manure) have outpaced N outputs (primarily from crop removal at harvest).

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter or section

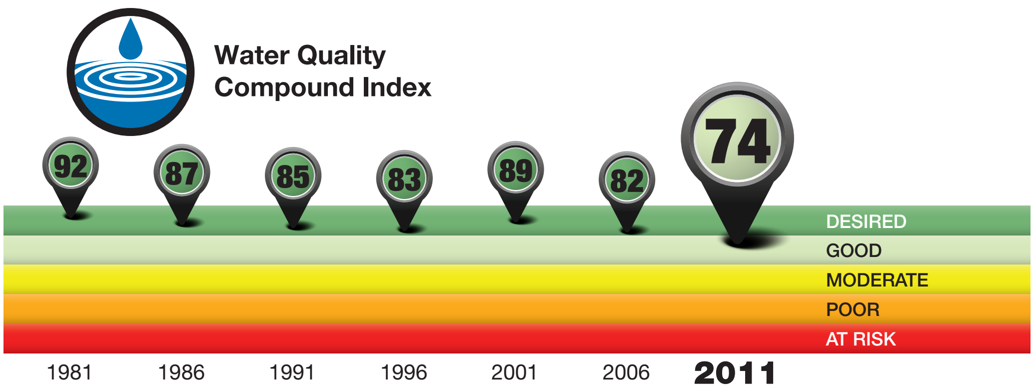
2 Refer to Chapter 15 "Agricultural Greenhouse Gases"

3 Refer to Chapter 16 "Ammonia"

- **IROWC-P.** Between 1981 and 2011, 50% of the 280 agricultural watersheds under study moved to higher risk classes, representing a decline in this indicator. The increased use of mineral fertilizers as well as greater concentration of livestock production has continued to create regional P surpluses, increasing the risk of agricultural soil P release and transport to surface water bodies.
- **Coliforms.** The area of farmland in the *Very low* IROWC-Coliform risk class decreased from 77% in 1981 to 41% in 2006, and then rose to 46% in 2011, indicating a fluctuating, but generally deteriorating trend over time. *High* to *Very High* risk classes for coliform contamination characterized watersheds in Quebec, Alberta and Ontario in 2011, comprising 5% of Canadian farmlands. These are watersheds where regionally concentrated livestock feeding operations and coliform transport factors pose a significant risk to water quality. In contrast, many watersheds in Eastern Canada and the Maritimes have seen improvements in this indicator, resulting from shifts in land-use from pasture and forage production to annual cropping.
- **Pesticides.** In 2011, 71% of Canadian cropland was in the *Low* or *Very low* risk category. However, from 1981 to 2011, the level of risk increased on 50% of agricultural land, primarily due to an increase in the area treated with pesticides. Much of this increase took place between 2006 and 2011, owing to a dramatic reduction in beef and forage production and a shift to cropping systems requiring greater use of pesticides and, to a lesser extent, to wet weather in 2010 in the Maritimes.

Water Quality Compound Index

The overall trend from 1981 to 2011 for water quality shows deterioration across Canada, as depicted by the water quality compound index below.



This compound performance index is a weighted average of the four Indicators of Risk of Water Contamination[4] discussed in the following four chapters. As such, it is a highly generalized statistical snapshot of all the results of the Nitrogen, Phosphorus, Coliforms and Pesticides Indicators, both in terms of current state and changes over time. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

4 All national "core" indicators, which include IROWC-N, IROWC-P, IROWC-Coliform and IROWC-Pest, have a weighted value of 1. As RSN forms part of the calculations for IROWC-N, it has zero weight in calculating the compound performance index for water quality.

11 Nitrogen

Summary

Nitrogen (**N**)[1] is an essential **nutrient** that supports and sustains crop growth and productivity. Crop yields are adversely affected when insufficient quantities of **inorganic** N are present in the root zone. However, adding N in excess of crop requirements can lead to losses from the soil. Over-fertilization is not only an economic issue (since nitrogen is an expensive input), it can cause environmental problems, as some reactive forms of N can have a negative impact on air quality (for example, **ammonia**[2] and **nitrous oxide**[3] emissions) and water quality (**nitrate** contamination of surface and **ground water**) (Rochette et al., 2008; Sheppard et al., 2010; De Jong et al., 2009).

The Residual Soil Nitrogen (RSN) Indicator provides an estimate of the amount of inorganic N that is left in the soil at the end of the growing season, which may be susceptible to loss (Drury et al., 2007, 2010). In many respects, RSN is also an efficiency indicator. The second indicator—the Risk of Water Contamination by Nitrogen (IROWC-N)— is an estimate of the amount of nitrogen that can be lost from the soil by **leaching;** hence, it is one of the water quality metrics used to evaluate agricultural sustainability (De Jong et al., 2007, 2009). It is important to note that IROWC-N examines risk of nitrate leaching to ground water as well as risk to surface water from nitrates in leached **tile drainage** water. These tile drainage losses can be very large (as much as 20-30 kg N/ha) as the leached water percolates through the soil to the tile drains, and out to drainage ditches (Drury et al. 1996, Drury et al., 2009, Drury et al. 2014). The Indicator does not consider inorganic nitrogen loss in surface runoff, as this is considered to be relatively minor (< 3 kg N ha^{-1}), even in regions with high N application rates that receive high annual precipitation. This is due to the highly soluble nature of inorganic N (nitrate in particular); the timing of the surface runoff (most surface runoff occurs in the non-growing season which is well after N application); and the method of application (nitrogen fertilizer and manures are often incorporated into the soil).

The RSN and IROWC-N indicators provide estimates of the inorganic N status of Canadian soils and associated risk to surface and ground water across the many climatic regions in Canada over six Census periods from 1981 to 2011. In general, the RSN and IROWC-N risk levels have increased over time because N inputs, from fertilizer and manure, have increased at a faster rate than N use by crops and other losses (outputs). In growing seasons with adverse weather patterns such as excess or insufficient rain, N uptake by crops may be reduced which results in lower N outputs and greater RSN and IROWC-N risk levels.

Residual soil nitrogen levels on farmland in Canada were in the *Moderate* risk class in 2011. The Canada-wide increase in RSN is mainly the result of increased **fertilizer** use across the country, particularly since 1996. On a national basis, N inputs have almost doubled over the past 30 years, whereas N outputs have increased by 63%. The higher increase in N inputs compared to N outputs over time has boosted RSN values by more than 150%. Twenty-eight percent of farmland was in the *High* and *Very High* risk categories, with most of this land located in Quebec, Nova Scotia and Manitoba. The only provinces with a majority of agricultural land in the *Low* or *Very low* risk categories were Saskatchewan, British Columbia and parts of Alberta; however, these provinces all had pockets of land in higher risk classes.

The majority of farmland in Canada presented a *Very low* risk of water contamination by N in 2011; however, over the past 30 years, the risk of annual N loss through leaching has increased by 36% and the N concentration in leached water has increased by a factor of 2.8. Since 1981, the proportion of farmland in the *Very low* risk class has decreased gradually, from 88% to 75%, while the proportion of land in the *Low* risk class increased from 2% to 16%.

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

2 The issue of agricultural ammonia emissions is discussed in more detail in Chapter 16 "Ammonia"

3 The issue of nitrous oxide emissions is discussed in more detail in Chapter 15 "Agricultural Greenhouse Gases"

Residual Soil Nitrogen

Authors:
C.F. Drury, J. Yang, R. De Jong,
T. Huffman, K. Reid, X. Yang,
S. Bittman and R. Desjardins

Indicator Name:
Residual Soil Nitrogen Indicator

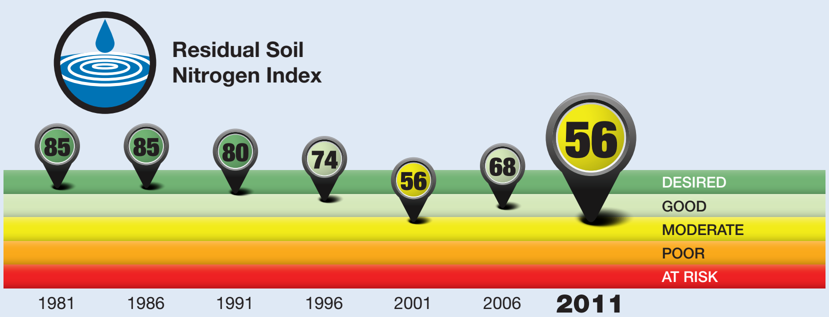
Status:
National Coverage,
1981 to 2011

The Issue and Why it Matters

Nitrogen is the most commonly applied nutrient for crop production. Increasing amounts are being added to farmland in the form of fertilizer and manure in order to optimize crop yields and meet the growing demand for food, animal feed and fibre. However, when nitrogen is applied in excess of crop needs, it can remain in the soil after harvest as residual soil nitrogen (RSN) and can subsequently be lost from the soil through leaching into ground water or through gaseous losses to the atmosphere. Most RSN is in the form of nitrate (NO_3^-), which is soluble in water and can readily move through the soil profile into the ground water, or enter surface waters through **runoff** and tile drainage (Drury et al., 1996; 2009). Figure 11–1 presents a conceptual view of the nitrogen cycle on agricultural land. High NO_3^- levels in surface waters can be detrimental to aquatic life (Guy, 2008), and high NO_3^- levels in potable water can lead to human health issues (Chambers et al., 2001). Wet soil conditions can lead to **denitrification,** a bacterial process whereby NO_3^- is converted and lost to the atmosphere as nitric oxide (NO), nitrous oxide (N_2O) (a **greenhouse gas**), or nitrogen gas (N_2). The

Residual Soil Nitrogen Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of residual soil nitrogen levels on farmland in Canada was 'Moderate' as indicated by a value of 56. The index illustrates a deteriorating trend Canada-wide, particularly from 1996 onwards, which is mainly attributable to increased fertilizer use across the country.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

loss of N from the soil through leaching or denitrification also represents an economic loss to producers because of the high cost of applying fertilizer or manure to supplement N.

The amount of RSN in a given area is determined by a number of factors that also affect crop growth and yields, including uncontrollable weather factors, insect pests, plant pathogens, weeds, and soil physical problems such as soil compaction, which reduces the soil's capacity to hold water and can lead to poor aeration. RSN can also be affected by the rate or timing of **nitrogen mineralization** from soils especially after they have received organic N from either manure or legume crop residues. If mineralization occurs after the crop has reached maturity, the resulting inorganic N may remain in the soil after harvest. This buildup of nitrate through mineralization presents a challenge for N management. Excess precipitation that occurs subsequently, during the fall, winter and early spring, will increase the risk of leaching. The use of **cover crops** is a **beneficial management practice** (**BMP**) that can be used to capture RSN in the fall through crop uptake and thereby minimize N leaching losses.

There is also a need to evaluate and quantify the effectiveness of agricultural management practices that are implemented to maximize N use efficiency and reduce losses. An optimal match between crop N requirements and the amount and timing of N application can minimize losses from the agricultural system and mitigate negative impacts on the environment. Controllable factors that can affect N uptake and crop production include the method and timing of manure and fertilizer application as well as the application rates.

The Indicator

The RSN Indicator is estimated as the difference between total N inputs to agricultural soils (fertilizer and manure, N fixation by leguminous plants, wet and dry **atmospheric deposition**) and total N outputs, which consist of harvested crops and gaseous losses including ammonia, nitrous oxide and nitrogen gas (N_2). This is illustrated in the diagram of the nitrogen cycle (Figure 11–1). The RSN Indicator provides an estimate of the amount of N remaining in the soil at the end of the growing season. (Note that the N leaching losses were not included in the RSN indicator as the majority of these losses occur in the period between growing seasons. Nitrogen leaching loss is the focus of the IROWC-N section).

The Canadian Agricultural Nitrogen Budget (CANB) Model was derived to estimate the RSN Indicator in agricultural regions across Canada on the basis of **Soil Landscape of Canada** (**SLC**) (Soil Landscape of Canada Working Group, 2005) **polygons** (Yang et al., 2007, 2013). Findings for this report are derived from CANB version 4.0, which includes several enhancements relative to older versions used in past reports. RSN was estimated for each year from 1981 to 2011 using annual data, where available (e.g. yields and fertilizer sales), and by interpolating the **Census of Agriculture** data between Census years (e.g. crop area and livestock number). When both fertilizer and manure N sources are present in a given SLC polygon, the model divides the N inputs between fertilizers and manure based on the crop type. Estimates of manure N losses from storage and land applications are based on livestock type, type of manure storage, and typical times and methods of application and incorporation of manure into the soil. The mineralization of organic N from manure and legume crop residues is estimated for the current year, as well as for the second and third years after application.

Farmland was assigned to *Very low* risk (0 to 9.9 kg N ha^{-1}), *Low risk* (10-19.9 kg N ha^{-1}), *Moderate* risk (20 to 29.9 kg N ha^{-1}), *High* risk (30 to 39.9 kg N ha^{-1}) and *Very High* risk (> 40 kg N ha^{-1}) classes based on the RSN level in the soil at the end of the growing season (Table 11–1). Using this modelling approach, the agricultural regions where N is used very efficiently (*Very low* and *Low* RSN areas) can be identified, as can those that need to be monitored (*Moderate* RSN areas), and those that may require remedial action because they pose an environmental risk (*High* and *Very High* RSN areas). RSN Indicator data compiled over a long time period (> 30 years) can be used to identify general trends over time and pinpoint areas of concern, such as agricultural regions with chronically high levels of inorganic N in the soil.

Although the RSN Indicator provides a way of estimating how efficiently N is used in soils, it does not provide estimates of the environmental consequences associated with elevated RSN levels. Surplus N may remain in the soil over the winter and be used by the next crop or it may be lost to the environment. A second agri-environmental indicator, the Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N), has been developed to estimate the leaching losses of nitrate (NO_3^-) from agricultural soils. In this report, the IROWC-N results are presented after the RSN results.

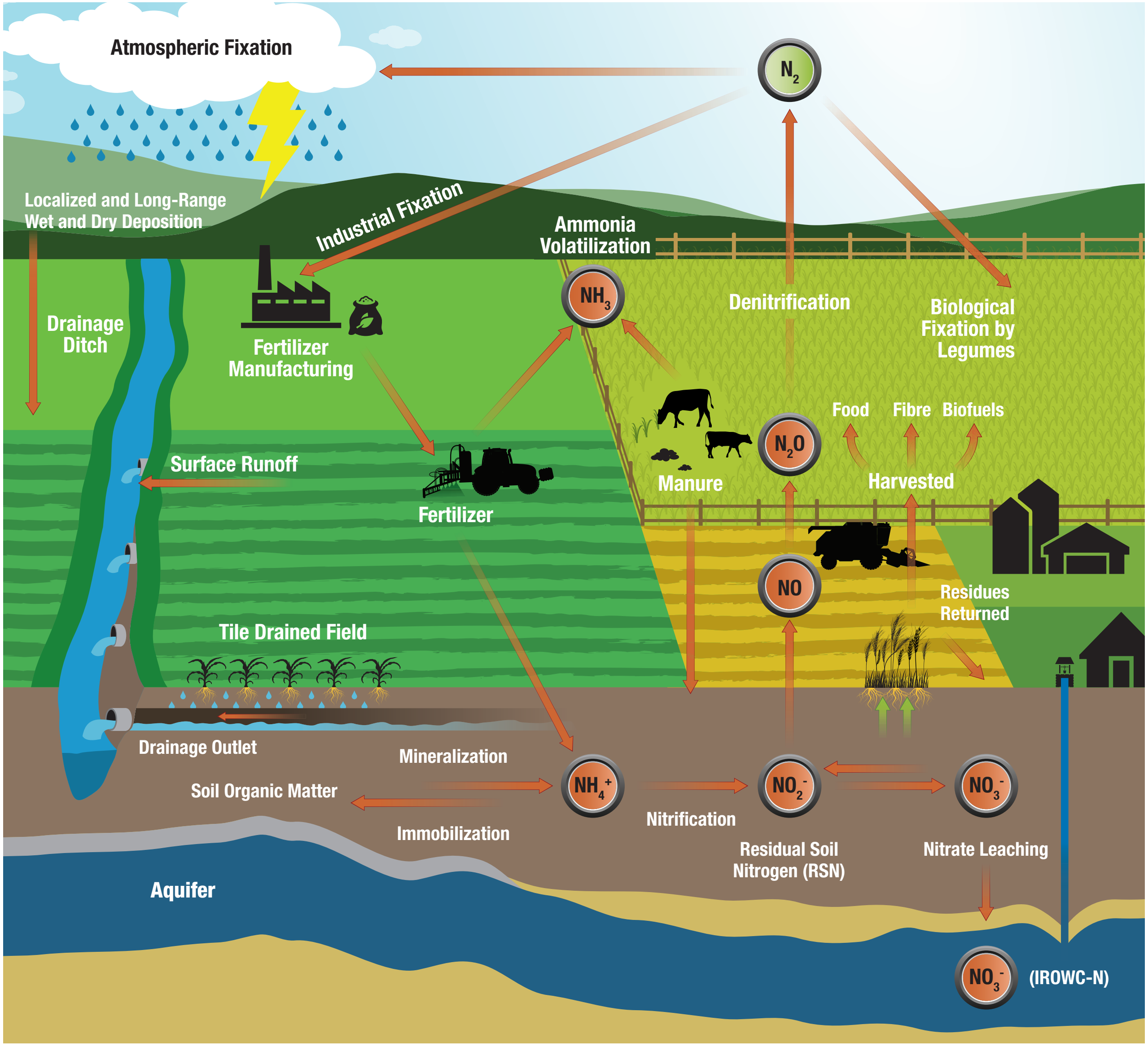


Figure 11–1: Conceptual view of the nitrogen (N) cycle in agricultural soils. RSN is the residual soil N level in the top 60 cm of soil after harvest.

Limitations

The RSN Indicator was calculated at the SLC polygon scale. This requires that most input and output data sets (crop area, animal numbers, climatic data and fertilizer N application) be allocated to the SLC polygon scale before the model is run. The structure of SLC input data limits the use of data from other scales (i.e. farm, township or **watershed**). Crop yield data sets affect the estimation of N outputs, which could be improved by (i) capturing the yields at the SLC polygon level instead of at the coarser scale of the Census of Agriculture Regions (the former has more than 3,000 polygons compared to 60 to 70 Census of Agriculture Regions) and (ii) including pasture and alfalfa yield estimates in surveys. This is especially important as pasture and alfalfa are grown on more than 40% of Canadian farmland.

Results and Interpretation

Agricultural practices and climatic growing conditions vary across the agricultural regions of Canada, and this variability is reflected in the different average RSN values estimated for these regions (Table 11–1 [2011 values] and Figure 11–2). In 2011, the majority of farmland in Canada was in the *Moderate* (28%) and *Low* risk (24%) classes. Twenty-eight percent of farmland was in the *High* and *Very High* risk categories, with most of this land located in southwestern Manitoba, southern Ontario, the St. Lawrence Lowlands (Quebec) and Atlantic Canada. The only regions with a majority of agricultural land in the *Low* or *Very low* risk categories were Saskatchewan, southern Alberta and British Columbia; however, these regions also contained pockets of higher risk.

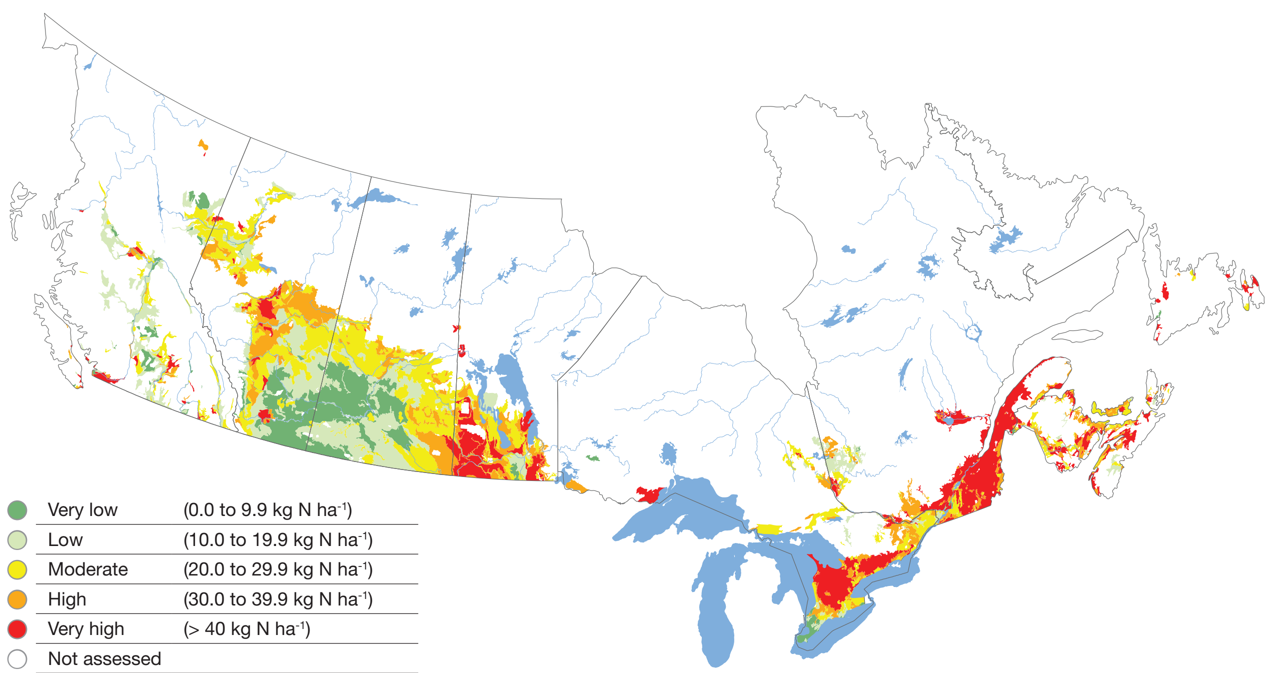


Figure 11–2: Residual Soil N (RSN) levels on Canadian farmland in 2011

Table 11–1: Percentage (%) of farmland in the various RSN classes[1] from 1981 to 2011

Class	Very low							Low							Moderate							High							Very high						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	47	37	15	12	3	11	20	27	35	49	47	27	53	40	12	16	21	25	36	26	28	6	3	6	7	22	3	6	8	9	9	8	11	8	7
Alberta	55	79	57	31	15	32	21	37	17	30	37	27	31	27	8	4	12	20	31	26	30	0	0	2	10	18	9	18	0	0	0	1	8	2	4
Saskatchewan	100	100	100	93	31	45	28	0	0	0	7	57	46	31	0	0	0	0	12	9	32	0	0	0	0	1	1	9	0	0	0	0	0	0	0
Manitoba	79	25	3	9	0	9	3	19	72	40	11	4	8	8	2	3	52	65	25	48	20	0	0	5	13	53	31	26	0	0	0	2	19	3	44
Ontario	1	1	5	6	0	12	11	8	8	5	3	0	6	8	13	6	9	12	3	19	19	22	15	13	14	5	16	22	56	70	68	65	92	47	41
Quebec	2	2	0	1	0	2	0	9	5	2	3	0	12	2	25	15	5	13	0	11	13	39	22	15	19	4	22	13	26	56	78	64	96	54	72
New Brunswick	0	1	0	0	0	0	1	35	7	0	3	0	0	2	47	33	3	14	2	3	32	16	47	28	51	8	11	35	3	13	69	33	90	87	30
Nova Scotia	0	0	0	0	2	0	0	9	2	0	6	1	1	6	47	27	3	24	3	7	22	30	38	24	34	2	8	25	14	33	73	36	92	85	47
Prince Edward Island	0	0	0	0	0	0	0	51	3	0	0	0	0	5	49	54	5	10	0	0	38	0	43	55	61	0	2	43	0	0	41	29	100	98	15
Newfoundland and Labrador	51	1	17	4	1	14	9	16	4	13	10	10	12	5	9	17	17	16	8	9	14	7	48	16	17	12	14	11	17	30	38	53	69	52	61
Canada	**69**	**71**	**61**	**50**	**18**	**31**	**20**	**16**	**16**	**16**	**18**	**34**	**33**	**24**	**6**	**3**	**11**	**16**	**19**	**20**	**28**	**4**	**3**	**3**	**7**	**13**	**9**	**15**	**6**	**8**	**9**	**8**	**16**	**8**	**13**

* This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding the numbers may not sum exactly to 100%.

Table 11–2: N inputs, N outputs and RSN (kg N ha^{-1}) by Census year, 1981 to 2011

Class	N input							N output							RSN						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	61.1	59.6	61.4	63.1	68.7	56.3	61.2	42.7	41.1	39.5	40.8	38.5	33.8	39.6	18.4	18.5	21.9	22.4	30.3	22.6	21.6
Alberta	43.7	43.0	46.7	56.1	61.4	61.1	70.9	34.4	37.5	37.1	40.2	38.1	44.6	50.5	9.4	5.5	9.6	15.8	23.3	16.5	20.4
Saskatchewan	19.4	23.6	22.5	38.6	45.1	51.1	64.9	19.2	23.5	22.4	35.3	31.5	40.2	47.2	0.2	0.1	0.1	3.3	13.7	10.9	17.7
Manitoba	45.7	58.8	68.0	76.8	83.2	84.9	90.5	38.6	46.4	47.3	52.4	49.3	58.3	54.9	7.0	12.4	20.8	24.4	34.0	26.6	35.6
Ontario	124.0	136.9	137.2	140.4	144.9	152.3	155.3	82.4	90.5	94.0	96.0	84.9	115.0	119.6	41.6	46.4	43.2	44.4	60.1	37.3	35.7
Quebec	111.0	132.1	128.3	140.1	153.5	143.5	162.3	77.3	87.2	77.9	96.0	89.4	101.3	110.4	33.7	44.9	50.4	44.1	64.2	42.2	51.8
New Brunswick	88.9	101.8	105.5	111.0	127.9	130.2	110.9	64.0	69.3	62.3	72.8	75.8	77.2	76.5	24.9	32.5	43.2	38.2	52.1	53.0	34.4
Nova Scotia	96.3	110.1	113.6	126.6	122.8	127.7	111.7	65.9	72.2	65.0	87.3	63.9	68.8	70.3	30.3	37.9	48.6	39.3	58.9	59.0	41.4
Prince Edward Island	90.2	104.3	110.8	123.3	133.6	146.3	128.4	70.7	74.7	71.7	86.8	75.4	89.7	96.9	19.5	29.6	39.1	36.5	58.2	56.6	31.4
Newfoundland and Labrador	50.5	83.8	75.3	112.8	106.6	101.0	105.3	31.4	43.5	41.7	68.4	53.5	50.1	55.5	19.1	40.3	33.6	44.5	53.1	50.9	49.7
Canada	**44.4**	**48.4**	**49.8**	**61.5**	**67.5**	**69.9**	**80.8**	**35.0**	**39.1**	**38.2**	**46.2**	**42.2**	**51.4**	**57.2**	**9.4**	**9.3**	**11.6**	**15.3**	**25.3**	**18.4**	**23.6**

1 This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding the numbers may not sum to exactly 100%

Figure 11–3 shows the change in risk classes between 1981 and 2011. The map clearly shows a national trend towards increasing risk associated with elevated residual N levels in farmland soils across Canada. The amount of land in the *Very low* risk class decreased from 69% to 20% in Canada between 1981 and 2011. This decrease occurred as a result of an 8% increase in land in the *Low* risk class, a 22% increase in land in the *Moderate* risk level, an 11% increase in land in the *High* risk class and a 7% increase in land in the *Very High* risk class (Table 11–1). Several factors contributed to the higher RSN values. For example, in 1981, there were 9.71 million hectares (ha) of land under summerfallow (98% of this land area was located in the Prairie Provinces); this land did not receive any inputs from fertilizer, manure or biological N fixation by legume crops. By contrast, in 2011, there were only 2.09 million ha of summerfallow (78.5% reduction from 1981) and most of the converted area previously under summerfallow consisted of annual and perennial crops, which receive N inputs from fertilizers, manure and/or biological N fixation. With the higher N inputs to this land, there was an increased risk of residual soil N after crop harvest.

In 1981, most areas of the Prairies were in a *Very low* risk class. By contrast, in 2011 there was a considerable amount of farmland with *Low* and *Moderate* RSN values in Saskatchewan and eastern Alberta, as well as some land with *High* and *Very High* values in Manitoba, the southeast corner of Saskatchewan, and central Alberta. The risk levels in Eastern Canada have generally increased; in 1981, much of the land within the St. Lawrence Lowlands and southern Ontario, as well as areas within the Atlantic Provinces were considered to be at *Moderate* and *High* risk. In 2011, most of these regions were at the *High* or *Very High* risk classes—indicating an increase in risk by one or two classes (Figures 11–2 and 11–3). Very few regions exhibited a declining risk over this 30-year period. However, southwestern Ontario and some pockets of land in southern Quebec did have improved RSN risk values in 2011 compared to 1981. This may be attributable in part to the more favourable climatic conditions that prevailed in these regions in 2011, promoting greater N utilization by the crops.

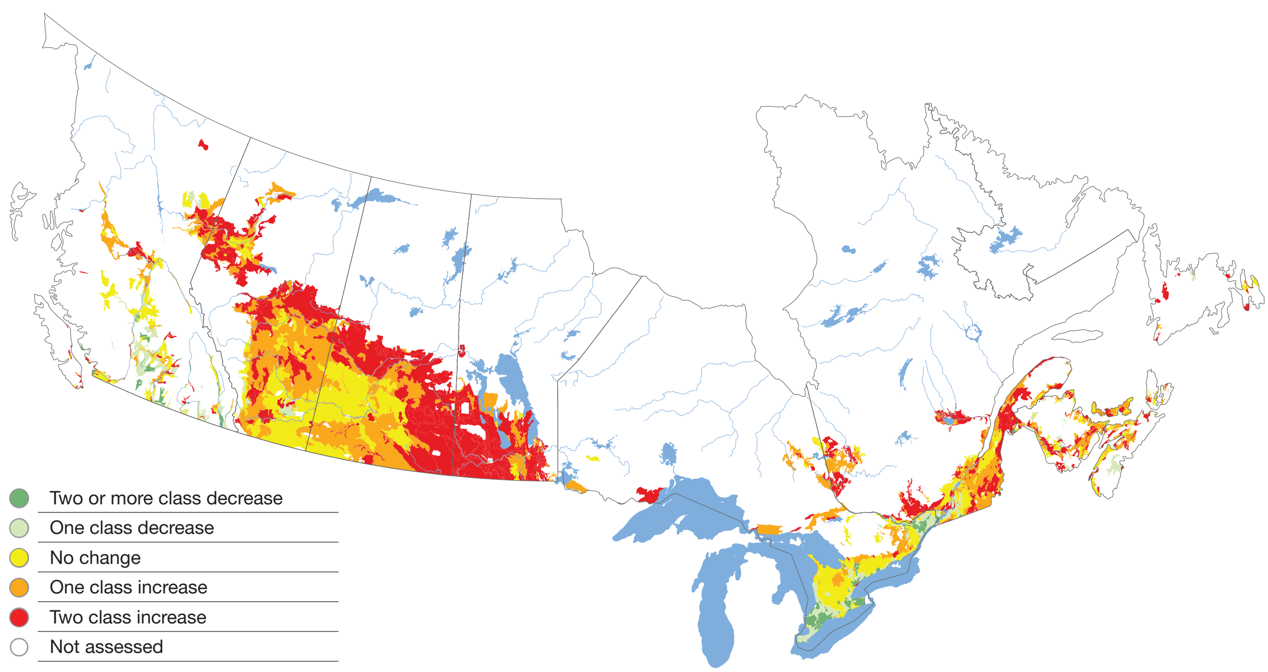


Figure 11–3: Changes in RSN levels on Canadian farmland, 1981 and 2011[2]

2 The five RSN risk classes are very low risk (0 to 9.9 kg N ha^{-1}), low risk (10-19.9 kg N ha^{-1}), moderate risk (20 to 29.9 kg N ha^{-1}), high risk (30 to 39.9 kg N ha^{-1}) and very high risk (≥ 40 kg N ha^{-1}).

The N inputs and outputs on Canadian agricultural land increased steadily from 1981 to 2011 (Figure 11–4). There is a greater year-to-year variation in N outputs than N inputs. This is primarily due to the variation in yields occurring in response to changes in climatic conditions. For example, in years with excess growing season precipitation, crop yields may be depressed because of damage to roots caused by poor soil aeration. Conversely, in growing seasons with droughts (e.g. many regions of Canada experienced a large-scale drought in 2001–2002) crop yields may be limited by a lack of water. Crop N uptake and removal from the field represents 95% of the Canadian N output during the growing season (annual range for the period from 1981 to 2011 was from 94.4 to 95.5%), Hence variations in yield dramatically impact N output and RSN values. The net effect of these changing levels of N inputs and outputs over time has been a steady increase in RSN, from a low of 9.4 kg N ha^{-1} in 1981 to a peak level of 25.3 kg N ha^{-1} in 2001, followed by a decline to 23.6 kg N ha^{-1} in 2011.

On a national basis, average N inputs have almost doubled over the past 30 years, from 44.4 kg N ha^{-1} to 80.8 kg N ha^{-1},whereas average N outputs increased by 63% from 35 kg N ha^{-1} in 1981 to 57.2 kg N ha^{-1} in 2011 (Table 11–2). The greater increase in N inputs compared to N outputs over time has resulted in an increase of RSN values from 9.4 kg N ha^{-1} in 1981 to 23.6 kg N ha^{-1} in 2011 (> 150% increase). The RSN value of 25.3 kg N ha^{-1} recorded in 2001 was primarily attributable to the low level of N outputs that year caused by the reduction in yields and crop N uptake associated with droughts in many regions in Canada.

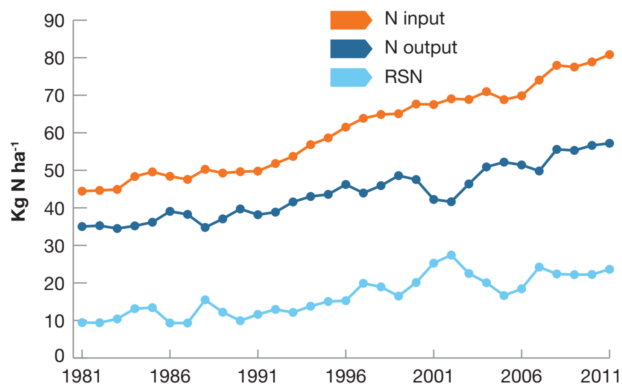


Figure 11–4: The estimated N input, N output and residual soil N in Canadian soils, 1981 to 2011

Water Contamination by Nitrogen

Authors:
C.F. Drury, J. Yang and R. De Jong

Indicator Name:
Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N)

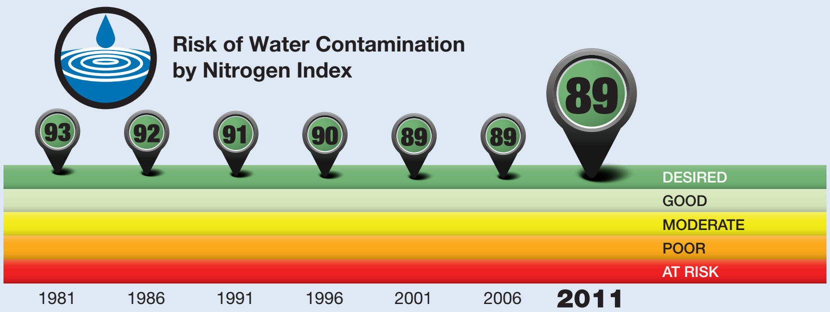
Status:
National Coverage, 1981 to 2011

The Issue and Why it Matters

Incomplete nitrogen (N) uptake by crops inevitably results in some inorganic N remaining in the soil at the end of the growing season. (See preceding section on Residual Soil Nitrogen). There is a risk that this excess N will be lost to the environment, and the level of risk is dependent on a number of factors including climate, soil type and topography. Equal amounts of residual N in two different locations may not pose the same level of risk to the contamination of surface waters (through tile drainage) or ground water through nitrate leaching. Knowledge of land-use practices and landscape conditions is critical in order to identify the areas with the

Risk of Water Contamination by Nitrogen Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the risk of water contamination by nitrogen on farmland in Canada was *Very low*, which corresponds to the 'Desired' category as indicated by a value of 89. The index illustrates a fairly stable, yet slightly deteriorating trend, from a high index value of 93 in 1981 to 89 in 2001, which subsequently plateaued and then remained stable until 2011. While this indicator has remained in the 'Desired' category, more and more farmland has been moving from lower risk categories to higher risk categories, and some pockets of farmland are now in the *High risk* and *Very High* risk classes.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

highest risk levels and to develop targeted management plans. The environmental risk is greatest when large surpluses of N are present in the soil, especially between cropping seasons in regions that receive considerable precipitation. Most of the residual inorganic N, which is in the form of nitrate, is water soluble and can readily leach through the soil into ground water or can move from tile drains into ditches, streams and lakes (Drury et al., 1996). High nitrate levels in surface waters contribute to algae growth and **eutrophication** and have been linked to human health impacts (Chambers et al., 2001). There is considerable public interest in human health issues relating to N, and Canadians remain concerned about the safety of their drinking water and food supply.

The Indicator

The Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N) establishes a link between the quantity of inorganic N remaining in the soil at harvest (Residual Soil Nitrogen, or RSN) and subsequent climatic conditions during the winter (De Jong et al., 2007; De Jong et al., 2010; Yang et al., 2007a, 2007b). A simplified conceptual model of soil N components and flow in **agro-ecosystems** illustrates the biophysical principles behind the indicator (Figure 11–1 – in RSN section). RSN is calculated by taking the difference between N inputs and N outputs. Inputs consist of additions of fertilizer and manure to farmland, fixation of N by leguminous plants, and atmospheric dry and wet deposition of N. The outputs from the system include N removal in the harvested portion of crops, N lost in gaseous form to the atmosphere (denitrification and ammonia volatilization), and N leached into ground water that was not captured by the RSN model. This nitrate-N leaching is what the IROWC-N attempts to estimate.

Because agro-ecosystems are complex, computer simulation techniques are the most practical methods for assessing the environmental sustainability of Canadian agriculture. The IROWC-N Indicator utilizes RSN data (preceding section) as an input, incorporates the climatic factors influencing crop growth, and examines the impact of the agricultural water cycle on water storage, water loss and nitrate leaching loss from soils. The water budget component is critical from a crop productivity perspective (insufficient water can decrease crop growth and yields, whereas excess water can damage or kill roots and reduce nutrient uptake and yields). Water also plays a role in transporting soluble nutrients such as nitrate from the crop zone. The model accounts for water loss in surface runoff, but does not account for N losses in surface runoff as these N losses are generally believed to be small compared to N losses that occur through tile drainage which impacts surface waters, and deep percolation which impacts ground water (Drury et al., 1993, 1996, 2009, 2014).

The IROWC-N Indicator is expressed as the proportion of agricultural land that falls into each of five risk classes (Table 11–3). These classes are derived from a combination of two components:

1. N leached from the soil profile during the winter period (N_{lost}, expressed in kg of N per hectare (ha) of land)
2. Nitrate-N (NO_3-N) concentration in drainage water (N_{conc}, expressed in mg of N per Litre (L) of water)

The nitrate-N concentration classes are related to the Canadian drinking water guideline of 10 mg NO_3-N per L (Canadian Council of Ministers of the Environment, 1999). In addition, the lower concentration limit of 5 mg N per L is rounded up from the Canadian long-term exposure limit for aquatic life in fresh waters (4.7 mg NO_3-N per L) (Guy, 2008). These two factors have been used to derive the IROWC-N classes, as they both reflect the potential environmental impacts of N losses.

IROWC-N RISK CLASSES

The IROWC-N risk class is a function of two criteria—the nitrate concentration and the nitrate loads (Table 11–3). The cut-off points for the nitrate concentrations in drainage water correspond to the quality guideline for fresh water (rounded to 5.0 mg N L^{-1}) and the drinking water guideline (10 mg N L^{-1}). N loss levels are grouped into four categories (0 to 4.9 kg N ha^{-1}; 5 to 9.9 kg N ha^{-1}; 10 to 19.9 kg N ha^{-1}; and ≥ 20.0 kg N ha^{-1}).

Table 11–3: IROWC-N classification based on the annual nitrate loss and the annual N concentration in water

	Annual N concentration (mg of N/L)		
Annual N lost (kg N/ha)	0 – 4.9	5.0 – 9.9	≥ 10.0
0 – 4.9	Very low	Very low	Low
5.0 – 9.9	Very low	Low	Moderate
10.0 – 19.9	Low	Moderate	High
≥ 20.0	Moderate	High	Very high

Legend
- Very high
- High
- Moderate
- Low
- Very low

Limitations

The methodology used to calculate IROWC-N is based on many assumptions and approximations that enable reporting for large spatial scale units at a coarse temporal scale. The results, as portrayed in Figure 11–5 for 2011 farm management practices, are estimates only and should be interpreted accordingly. A lack of measured data precludes validation and makes the results suitable only for comparing different years and regions in Canada. They can, however, be used to identify areas that are at risk for potential N accumulation and loss of nitrate to the environment through leaching. The results should be confirmed by field testing, particularly in areas presenting a high level of risk.

Results and Interpretation

In 2011, the majority of farmland in Canada was at very low risk of water contamination by N, although some pockets of land in higher risk classes were observed in Central and Atlantic Canada (Figure 11–5, Table 11–4 – for 2011 values).

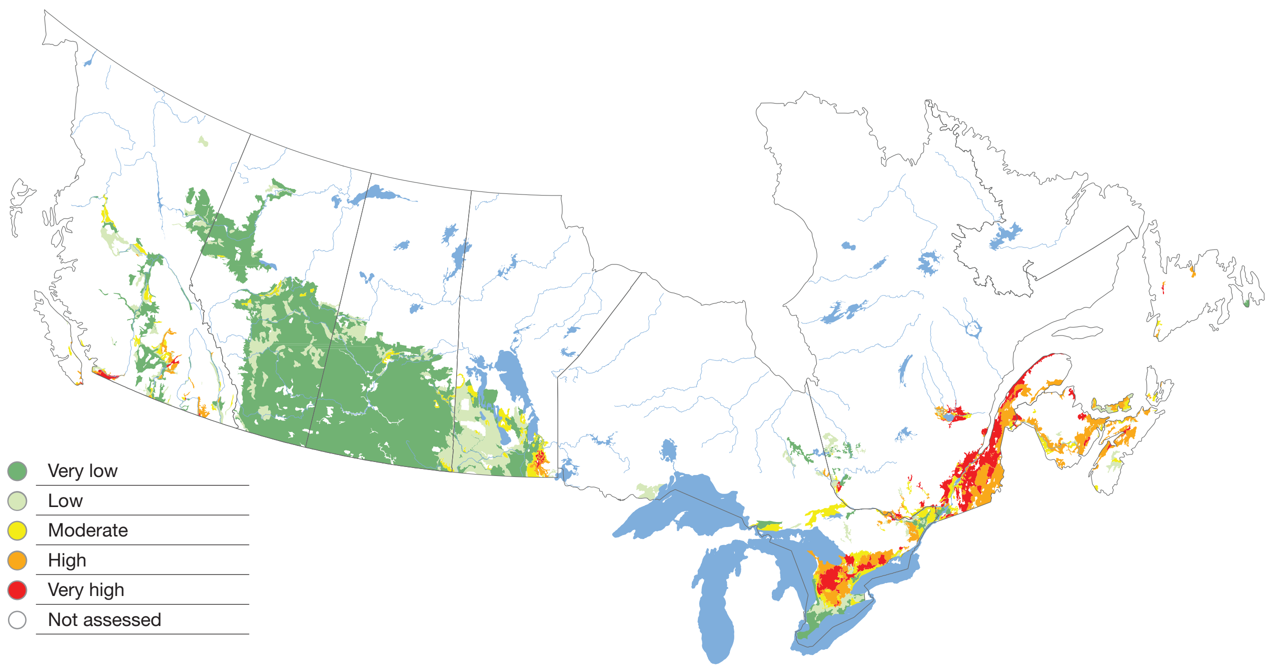


Figure 11–5: Risk of water contamination by nitrogen on farmland in Canada, 2011

Table 11–4: Percentage (%) of farmland in the various IROWC-N risk classes, 1981 to 2011[1]

Class	Very low							Low							Moderate							High							Very high						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	72	76	65	63	50	65	60	12	11	17	18	31	23	26	8	6	9	10	10	6	5	5	5	7	6	5	3	5	3	2	3	2	5	4	4
Alberta	100	99	99	95	92	86	86	0	0	1	5	8	13	13	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saskatchewan	100	100	100	98	98	96	94	0	0	0	2	2	4	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manitoba	100	98	70	49	39	37	31	0	2	30	50	55	59	61	0	0	0	1	6	3	8	0	0	0	0	1	1	1	0	0	0	0	0	0	0
Ontario	11	9	13	17	13	19	25	4	4	3	5	5	12	16	46	29	29	33	27	28	19	20	30	21	22	29	21	25	20	29	35	23	26	21	16
Quebec	14	6	6	9	2	5	5	13	7	6	4	6	5	4	29	27	24	28	11	19	16	31	30	29	29	20	24	28	13	29	34	31	62	48	47
New Brunswick	21	10	2	1	0	0	0	46	7	7	6	1	0	6	24	49	36	37	6	4	21	10	29	53	48	23	18	66	0	5	3	8	71	78	7
Nova Scotia	2	0	0	0	0	0	0	36	6	6	11	5	3	6	36	21	28	31	0	2	9	25	63	57	46	63	33	73	0	10	10	13	32	62	12
Prince Edward Island	35	23	0	0	0	0	0	65	31	36	12	0	0	31	0	46	25	41	3	0	25	0	1	40	47	81	14	45	0	0	0	0	17	86	0
Newfoundland and Labrador	75	0	0	0	0	42	24	8	71	66	40	0	0	0	17	20	16	51	41	5	20	0	0	10	10	51	28	34	0	9	7	0	8	26	22
Canada	**88**	**88**	**85**	**81**	**78**	**76**	**74**	**2**	**1**	**5**	**9**	**11**	**14**	**16**	**5**	**4**	**3**	**4**	**3**	**3**	**4**	**3**	**4**	**3**	**3**	**3**	**3**	**4**	**2**	**3**	**4**	**3**	**4**	**4**	**3**

1 This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding the numbers may not sum to exactly 100%

Figure 11–6 shows the change in the amount of land in the different classes between 1981 and 2011. The map shows that the risk of water contamination has remained fairly stable Canada-wide. During this 30-year period, the proportion of farmland in the *Very low* risk class decreased gradually from 88% to 74%, while the proportion in the *Low* risk class increased from 2% to 16%.

The national results are strongly influenced by the results for the Prairie Provinces, because this region accounts for a large proportion of the total farmland in Canada and has a lower amount of precipitation leading to a lower risk of drainage from agricultural soils, contributing to a lower risk of water contamination by nitrogen. Nevertheless, on a national scale, 14% of farmland moved from the *Very low risk* category to the *Low Risk* category between 1981 and 2011 (Table 11–4). Furthermore, there are pockets of land in Canada that now fall in higher risk categories. For example, in 1981 almost all of the land in the Prairie Provinces was in the *Very low risk* category (Table 11–4), but in 2011 some of the agricultural land in southeastern Manitoba was in the *Moderate*, *High* and *Very High* risk classes (Figure 11–5). Most of the agricultural land in central British Columbia was in the *Very low* and *Low* risk classes in 1981; however, by 2011 some areas in this region had moved to the *Moderate*, *High* and *Very High* classes. Central Canada (Ontario and Quebec) had various proportions of agricultural land in the *Moderate*, *High* and *Very High* risk classes in 1981 (Table 11–4). Most of the land in Ontario was in the same risk class in 2011 as in 1981 (Figure 11–6). Larger areas of higher risk were observed in 2011 in parts of the St. Lawrence Lowlands; however some pockets of land in southern Quebec and southwestern Ontario showed an improving trend with lower risk classes in 2011 than in 1981 (Figure 11–6). In 2011, higher crop yields (indicating significant plant uptake of N) were reported in southwestern Ontario, translating into favourable risk class results. The Atlantic Maritime region shows an increase in risk over the 30-year period, particularly in New Brunswick and Prince Edward Island.

In 1981, in general the annual N leaching loss was very low in the Prairie Provinces (0 to 0.5 kg N ha^{-1}), intermediate in the coastal provinces (British Columbia and Newfoundland, at 6.2 to 7.6 kg N ha^{-1}, respectively) and considerably higher in Central Canada and the rest of the Atlantic Provinces (11.5 to 22.2 kg N ha^{-1}). In British Columbia, Alberta, Saskatchewan and Ontario, N losses in water remained fairly constant across Census years from 1981 to 2011; however, substantial increases were observed in all other provinces (Table 11–5).

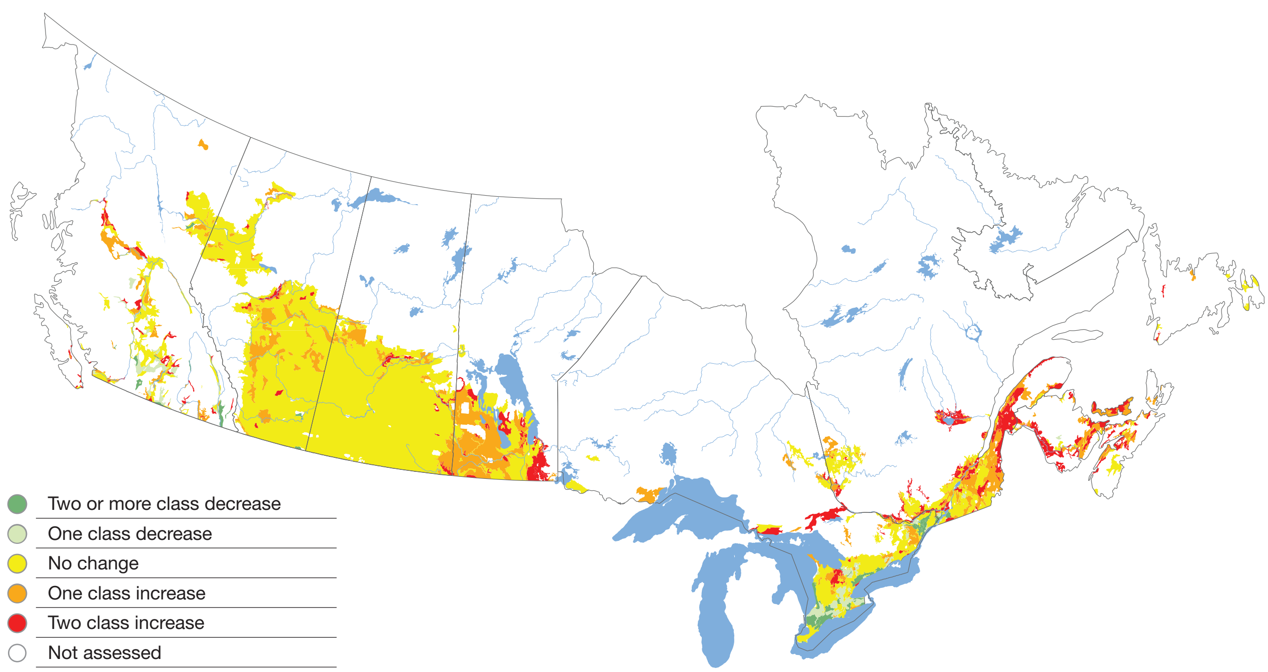


Figure 11–6: Change in the risk of water contamination by nitrogen on farmland in Canada, 1981 to 2011

Table 11–5: N loss (Nlost, kg N ha^{-1}) and N concentration (Nconc, mg N L^{-1}) in the non-growing season (NGS), the growing season (GS) and on an annual basis, 1981 to 2011

Class	Nlost-NGS							Nlost-GS							Nlost-Annual						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	4.6	4.8	4.9	6.1	6.4	6.3	5.2	1.6	1.6	2.2	2.1	2.1	1.8	2.1	6.2	6.4	7.0	8.2	8.5	8.1	7.3
Alberta	0.2	0.2	0.1	0.1	0.0	0.2	0.0	0.3	0.4	0.3	0.4	0.5	0.4	0.4	0.5	0.5	0.4	0.6	0.5	0.6	0.4
Saskatchewan	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.1	0.2	0.3	0.6	0.0	0.1	0.0	0.1	0.2	0.4	0.8
Manitoba	0.2	0.4	0.1	0.3	0.8	0.3	0.6	0.2	0.4	0.4	0.5	1.4	1.7	1.8	0.4	0.8	0.5	0.9	2.2	2.0	2.4
Ontario	14.3	17.1	16.6	14.0	13.6	14.4	12.1	2.1	2.9	2.7	2.6	2.5	1.8	2.0	16.4	20.1	19.3	16.6	16.2	16.2	14.1
Quebec	15.0	18.1	20.3	19.2	23.0	23.3	26.0	3.4	4.7	4.0	5.0	5.8	5.3	5.7	18.4	22.8	24.3	24.2	28.7	28.7	31.7
New Brunswick	13.0	13.9	19.3	18.8	23.4	31.5	21.8	2.8	3.7	3.3	3.9	5.7	6.0	4.8	15.8	17.6	22.6	22.7	29.1	37.5	26.6
Nova Scotia	18.9	20.3	26.4	24.7	35.3	37.3	30.6	3.3	5.6	4.0	4.6	6.7	7.5	6.1	22.2	25.8	30.4	29.3	42.0	44.8	36.6
Prince Edward Island	9.7	10.4	18.1	15.3	23.3	28.5	18.9	1.9	2.6	2.3	3.4	4.9	5.0	4.0	11.5	13.0	20.4	18.7	28.2	33.5	22.9
Newfoundland and Labrador	5.9	14.8	13.6	17.0	23.9	19.8	25.1	1.8	3.7	3.5	4.4	5.0	5.3	6.8	7.6	18.5	17.2	21.5	28.9	25.1	31.9
Canada	**2.0**	**2.2**	**2.2**	**2.1**	**2.3**	**2.4**	**2.3**	**0.5**	**0.6**	**0.6**	**0.7**	**0.9**	**0.9**	**1.0**	**2.5**	**2.9**	**2.7**	**2.8**	**3.1**	**3.3**	**3.4**

Class	Nconc-NGS							Nconc-GS							Nconc-Annual						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	5.3	4.9	6.1	6.3	7.8	6.7	7.2	6.2	5.2	7.1	7.7	9.1	7.5	8.4	5.6	5.0	6.6	6.7	8.2	6.8	7.7
Alberta	1.9	2.5	1.8	3.3	3.4	4.2	3.5	2.5	2.7	2.3	4.0	4.4	5.5	5.5	2.3	2.7	2.2	3.8	4.3	5.0	5.4
Saskatchewan	0.1	0.2	0.3	0.8	1.4	2.6	3.5	0.1	0.3	0.4	0.9	2.1	3.6	4.1	0.1	0.2	0.4	0.9	1.9	3.3	3.9
Manitoba	2.3	4.2	6.4	9.5	9.1	10.3	10.8	2.9	4.5	8.9	11.4	13.2	12.1	14.5	2.6	4.3	8.1	10.6	11.6	11.9	13.6
Ontario	8.5	9.0	9.3	8.1	9.7	7.9	7.8	9.2	9.5	10.7	8.8	11.4	9.5	9.5	8.6	9.1	9.4	8.2	10.0	8.0	8.0
Quebec	7.6	9.6	10.1	9.9	15.5	11.4	11.5	5.7	7.3	8.5	7.8	13.6	9.8	9.0	7.0	8.8	9.5	9.1	14.7	10.7	10.5
New Brunswick	4.9	7.4	7.0	8.1	12.0	12.6	8.0	3.3	5.4	5.2	7.0	10.0	10.2	5.6	4.4	6.7	6.6	7.8	11.4	11.8	7.2
Nova Scotia	5.0	7.7	6.6	7.0	10.2	12.2	8.5	3.0	4.6	4.4	4.8	7.0	8.0	4.9	4.5	6.8	6.1	6.4	9.4	11.0	7.5
Prince Edward Island	2.8	4.8	4.9	5.7	8.8	11.1	5.2	2.5	4.9	5.1	6.5	11.3	13.2	4.3	2.7	4.8	4.9	5.8	9.1	11.4	5.0
Newfoundland and Labrador	1.6	4.8	4.1	4.4	6.7	6.2	7.3	0.8	2.9	2.4	2.5	4.5	3.8	4.3	1.3	4.1	3.5	3.8	6.1	5.4	6.3
Canada	**2.1**	**2.6**	**2.7**	**3.7**	**4.2**	**4.8**	**5.1**	**2.3**	**2.6**	**3.2**	**4.2**	**5.4**	**6.0**	**6.5**	**2.2**	**2.6**	**3.0**	**4.0**	**5.1**	**5.6**	**6.2**

In 1981, the model estimated nitrate concentrations in drainage water at less than 5.0 mg N L^{-1} for all provinces except British Columbia, Ontario and Quebec, which had concentrations ranging from 5.6 to 8.6 mg N L^{-1} (Table 11–5). The nitrate concentration in drainage water increased over the 30-year period from 1981 to 2011 in all provinces except Ontario. In 2011, all provinces except Saskatchewan had nitrate concentrations higher than 5 mg N L^{-1}. Concentrations exceeding 10 mg N L^{-1} were observed in Manitoba (13.6 mg N L^{-1}) and Quebec (10.5 mg N L^{-1}).

A clearer picture of the timing of nitrate loss was obtained by dividing the data between the growing season and the non-growing season (Table 11–5). On a national scale, between 1981 and 2011, N leaching losses increased from 2.0 to 2.3 kg N ha^{-1} in the non-growing season (NGS) and from 0.5 kg N ha^{-1} to 1.0 kg N ha^{-1} in the growing season (GS). Nitrate concentrations increased over time in both the growing and non-growing seasons; however, in any given Census year fairly similar levels were recorded for the GS and the NGS. The nitrate concentrations increased between 1981 and 2011 as follows: from 2.1 mg N L^{-1} to 5.1 mg N L^{-1} in the NGS; and from 2.3 mg N L^{-1} to 6.5 mg N L^{-1} in the GS.

On a national basis, approximately 2.4 times more water was lost from agricultural land in the non-growing season (28 mm) compared to the growing season (12 mm) (Table 11–6). The Atlantic Provinces had the greatest drainage volumes (ranging from 207 to 617 mm), Central Canada had intermediate volumes (207 mm in Ontario and 278 mm in Quebec), and the Prairie Provinces had very small volumes (ranging from 8 to 13 mm). These patterns of drainage volumes correspond basically to differences in annual precipitation rates across Canada.

Table 11–6: Mean drainage volumes (mm) for all Census years 1981 to 2011

	Non-growing season drainage (mm)	Growing season drainage (mm)	Annual drainage (mm)	Ratio of drainage NGS/GS
British Columbia	89	37	125	2.4
Alberta	3	8	11	0.4
Saskatchewan	3	5	8	0.6
Manitoba	5	8	13	0.7
Ontario	180	27	207	6.6
Quebec	203	76	278	2.7
New Brunswick	252	87	339	2.9
Nova Scotia	360	128	488	2.8
Prince Edward Island	317	60	377	5.3
Newfoundland and Labrador	395	222	617	1.8
Canada	**28**	**12**	**40**	**2.4**

Response Options

This section discusses techniques and practices that producers consider when managing RSN and nitrogen contamination risk. The majority of these practices pertain to managing RSN levels, as high RSN levels are a major contributing factor in elevating water contamination risk, although methods to control the transport of leached nitrate are also considered. It is important to note that RSN tends to be more of an economic, rather than environmental concern for most of the Prairie Provinces as lower precipitation and runoff rates mean that soils tend not to get wet enough for denitrification to occur, and the rate of ground-water percolation of nitrates is far lower. Additionally, tile drainage is not a factor in Western Canada, save for isolated pockets in Manitoba where it is installed and therefore associated threats to surface water are also minimal.

Management techniques used to reduce RSN levels in Canadian soils are aimed at maximizing crop yield potential and controlling inputs. If the factor limiting yield is poor soil physical quality, management practices that enhance soil quality (i.e. practices that increase soil organic carbon levels and improve soil structure) can be implemented to increase the water holding capacity of the soil and allow excess water to drain from fields during high rainfall events. These include reduced tillage and no-till, the use of cover crops and higher residue crops in rotations and incorporation of manure.

In years marked by crop yield reductions and crop failures caused by drought conditions, excess rainfall and adverse climatic events (e.g. late frost at planting or early frost at end of growing season) or crop disease problems, N inputs can exceed N outputs, leading to a build-up of RSN. This is because N inputs are estimated on the basis of expected yields as opposed to actual crop yields and nutrient uptake. In years with lower crop yields, cover crops could be implemented to capture the unused inorganic N in the soil, which could help reduce N losses. In a field study in southwestern Ontario, cover crops captured some of the residual nitrate and reduced tile drainage nitrate concentration by 21% to 38% and nitrate loss by 14% to 16% as compared to no cover crop (Drury et al., 2014). Similarly, in Ames, Iowa, a rye cover crop reduced nitrate leaching from tile drainage by 59% and decreased N loads by 61% compared to a field without a cover crop (Kaspar et al., 2007). Non-leguminous cover crops may provide a solution as they can capture residual nitrogen from the soil, convert it to organic N in their tissues and then make N available to the next crop as their tissues decompose over the following spring and summer.

Drought conditions are more difficult to alleviate; however, irrigation or sub-irrigation may be a useful option. A recycling system may be the most efficient method whereby water and nutrients from surface runoff or tile drainage are stored in a pond or constructed **wetland** and pumped back onto the land during drought periods (Tan et al., 2007).

RSN levels can be reduced through improved nutrient management. Methods of using N inputs more efficiently include testing soil for inorganic N, using split application of fertilizer over the growing season to reduce losses, analyzing the nutrient content of manure prior to application, adjusting the manure or fertilizer application rate based on the results of soil and manure analyses, and measuring in-season crop N to determine if supplemental N is required (Zebarth et al., 2009). Side-banding is a practice used by many producers to ensure a slower release of nitrogen when the crop needs it. The timing of fertilizer and manure application is also critical. Applying fertilizer as close as possible to the period of rapid crop uptake will minimize losses of N from the field and will ensure adequate N availability to the crop during critical growth periods. Applying any input during or preceding heavy precipitation will significantly increase the risk of water contamination and lead to the loss of an expensive input. Wetter soils also increase the risk of N losses through denitrification.

In some cases, manure may have to be applied on farm fields located a considerable distance from where the manure originated, in order to more evenly distribute nutrients in agricultural soils. Since, on a national basis, an estimated 26% to 28% of the manure N that is produced is lost through ammonia **volatilization** and denitrification, improved management practices for manure application are required to increase manure N efficiency and possibly reduce the amount of fertilizer required. Ensuring that manure is stored properly in leak-proof containers and sited away from wells and water bodies is also very important. Using urease or nitrification inhibitors to slow fertilizer conversion to nitrate is an option that can reduce N losses and improve N uptake by crops, making it easier for producers to match N applications to crop requirements.

RSN problems cannot be solved by eliminating N fertilization and the addition of manure to crops. This was the conclusion of a long-term study implemented in southwestern Ontario in 1959 in which fertilized corn produced yields significantly higher than unfertilized corn (Drury and Tan, 1995). In another study, which was conducted in Western Canada, inadequate fertilization was found to limit crop growth along with nutrient and water uptake, and mineralized soil N was at greater risk of leaching through the soil profile (Campbell et al., 2006). Clearly, management practices should be aimed at achieving a better balance between N inputs from fertilizer and manure addition, and N outputs from crop uptake and harvested portions of crops.

The RSN management practices listed above are essential to consider when controlling nitrate contamination, as the build-up of RSN is the primary driver of contamination risk; however, a number of end-of-pipe solutions are available for producers to control or mitigate the surface water impacts of nitrate leaching from tile-drained fields. These include controlled tile drainage systems to manage the water table and retain the nitrate in the fields, where it can be used by growing crops; constructed or natural wetlands to trap nitrates and reactive biofilters to reduce the amount of nitrate in drainage before it gets to local surface waters. Some of these methods may enhance denitrification losses from soils, and could result in (as yet unquantified) pollution-swapping trade-offs (ex. N_2O emissions and/or P losses in surface runoff); and as well tend to have much higher installation and operating expenses, therefore reducing RSN levels through reducing inputs is the desired practice.

References

Campbell, C.A., F. Selles, R.P. Zentner, R. De Jong, R. Lemke and C. Hamel. 2006. *Nitrate leaching in the semiarid prairie: Effect of cropping frequency, crop type and fertilizer after 37 years*. Canadian Journal of Soil Science 86: 701-710.

Canadian Council of Ministers of the Environment. 1999. *Canadian environmental quality guidelines*. Ottawa, ON, Canada: Environment Canada.

Chambers P.A., M. Guy, E.S. Roberts, M.N. Charlton, R. Kent, C. Gagnon, G. Grove and N. Foster. 2001. *Nutrients and their impact on the Canadian environment*. Environment Canada. Ottawa, Ontario.

De Jong, R., C.F. Drury, J.Y. Yang, and C.A. Campbell, 2009. *Risk of water contamination by nitrogen in Canada as estimated by the IROWC-N model*. Journal of Environmental Management. 90: 3169-3181.

De Jong, R., J.Y. Yang, C.F. Drury, E.C. Huffman, V. Kirkwood, and X.M. Yang, 2007. *The indicator of risk of water contamination by nitrate-nitrogen*. Canadian Journal of Soil Science. 87:179-188.

De Jong, R., C.F. Drury, and J.Y. Yang. 2010. Indicator of risk of water contamination by nitrogen. In: Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds). Environmental sustainability of Canadian agriculture: Agri-Environmental indicator report series—Report # 3. Ottawa, ON, Canada: Agriculture and Agri-Food Canada; p. 80-86.

Drury, C.F. and C.S. Tan. 1995. *Long-term (35 years) effects of fertilization, rotation and weather on corn yields*. Can. J. Plant Sci. 75:355-362.

Drury, C.F., D.J. McKenney, W.I. Findlay and J.D. Gaynor. 1993. *Influence of tillage on nitrate loss in surface runoff and tile drainage*. Soil Sci. Soc. Am. J. 57:797-802.

Drury, C.F., C.S. Tan, J.D. Gaynor, T.O. Oloya and T.W. Welacky. 1996. *Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss*. J. Environ. Qual. 25:317-324.

Drury, C.F., C.S. Tan, T.W. Welacky, W.D. Reynolds, T.Q. Zhang, T.O. Oloya, N.B. McLaughlin, and J.D. Gaynor, 2014. *Reducing nitrate loss in tile drainage water with cover crops and water table management systems*. Journal of Environmental Quality. 43: 587-598.

Drury, C.F., J.Y. Yang, R. De Jong, T. Huffman, X.M. Yang, and K. Reid, 2010. *Residual Soil Nitrogen*. In: Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds). Environmental sustainability of Canadian agriculture: Agri-Environmental indicator report series—Report # 3. Ottawa, ON, Canada: Agriculture and Agri-Food Canada; p. 74-80.

Drury, C.F., J.Y. Yang, R. De Jong, X.M. Yang, E. Huffman, V. Kirkwood, and K. Reid, 2007. *Residual soil nitrogen indicator for Canada*. Canadian Journal of Soil Science. 87: 166-177.

Guy, M. 2008. *Ideal performance standards for the nitrate ion*. National Agri-Environmental Standards Initiative. Report No. 4–43. Environment Canada, Gatineau, Quebec, Canada.

Kaspar, T.C., T.B. Jaynes, and T.B. Moorman, 2007. *Rye cover crop and gamagrass strip effects on NO_3 concentration and load in tile drainage*. Journal of Environmental Quality. 36: 1503-1511.

Rochette, P., D.E. Worth, R.L. Lemke, B.G. McConkey, D.J. Pennock, C. Wagner-Riddle, and R.L. Desjardins, 2008. *Estimation of N_2O emissions from agricultural soils in Canada*. *I. Development of a country-specific methodology*. Canadian Journal of Soil Science. 88: 641-654

Sheppard, S.C., S. Bittman, and T.W. Bruulsema, 2010. *Monthly ammonia emissions from fertilizers in 12 Canadian Ecoregions*. Canadian Journal of Soil Science. 90: 113-127.

Soil Landscapes of Canada Working Group, 2005. Soil Landscapes of Canada v3.0. (digital map and database at 1:1 million scale). Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Tan, C.S., T.Q. Zhang, C.F. Drury, W.D. Reynolds, T. Oloya and J.D. Gaynor. 2007. *Water quality and crop production improvement using a wetland-reservoir and drainage/subsurface irrigation system*. Canadian Water Resource Journal. 32:129-136.

U.S. Department of Agriculture, 2013. *Nutrient uptake and removal*. Accessed Dec 2013 at: http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/nra/rca/?&cid=nrcs143_014150

Yang, J.Y., R. De Jong, C.F. Drury, E.C. Huffman, V. Kirkwood, and X.M. Yang, 2007a. *Development of a Canadian Agricultural Nitrogen Budget (CANB v2.0) model and the evaluation of various policy scenarios*. Canadian Journal of Soil Science. 87: 153-165.

Yang, J.Y., C.F. Drury, R. De Jong, E.C. Huffman, X.M. Yang, and K. Reid, 2013. *Sensitivity analysis for nitrogen inputs, nitrogen outputs, and changes in biofuel crop acreages for predicting residual soil nitrogen and nitrate leaching in Canadian agricultural soils*. Ecological Modelling. 267: 26-38.

Yang, J.Y., E.C. Huffman, R. De Jong, V. Kirkwood, K.B. MacDonald, and C.F. Drury, 2007b. *Residual soil nitrogen in soil landscapes of Canada as affected by land use practices and agricultural policy scenarios*. Land Use Policy. 24: 89-99.

Zebarth, B.J., C.F. Drury, N. Tremblay and A.N. Cambouris. 2009. *Opportunities for improved fertilizer nitrogen management in production of arable crops in Eastern Canada*. A review: Can. J. Soil Sci. 89:113-132.

12 Phosphorus

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Indicator Name:
Risk of Water Contamination by Phosphorus (IROWC-P)

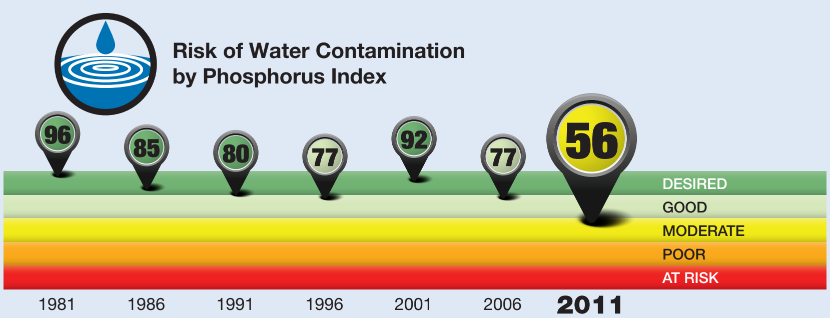
Status:
National Coverage, 1981 to 2011

Summary

Phosphorus (**P**)[1] is an important **nutrient** for plant and animal growth. However, applications of P contained in livestock manure and inorganic **fertilizer** in excess of crop removal may increase the risk of soil P saturation and consequent movement of P to water bodies. Excessive levels of P in surface waters contribute to **eutrophication** and **Cyanobacteria** blooms, and can lead to the deterioration of water quality and to restrictions on water use. The Risk of Water Contamination by Phosphorus (IROWC-P) Indicator was developed to

Risk of Water Contamination by Phosphorus Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of water quality from the standpoint of the risk of phosphorus contamination of surface water associated with farming activities in Canada was 'Moderate'. The index illustrates a deteriorating trend, representing an increased risk of contamination, between 1981 and 2011. Phosphorus contamination occurs when a P source intersects with high transport. The source component has increased somewhat due to the use of mineral fertilizers over the last 30 years and the intensification of livestock production in some regions. Abnormally high rates of spring runoff in several major watersheds, which increased phosphorus transport in 2011, played an even greater role in the decline in values observed between 2006 and 2011. The very high index value in 2001 is due to exceptionally low amounts of run-off in the Prairies that year, which reduced the risk of water contamination from phosphorus.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

assess the temporal trends in the risk of surface water contamination by P from Canadian agricultural land at the **watershed** scale.

The overall risk of water contamination by P is increasing in Canada. Intensification of livestock production and the use of mineral fertilizers contributed to regional P surpluses between 1981 and 2011. There is a wide range of soil types across Canada, which differ in their capacity to retain nutrients such as P and therefore pose different levels of risk of loss for the same P inputs. Surface **runoff**, subsurface drainage and water-induced soil erosion on agricultural land contribute significantly to the risk of P contamination of surface water in Eastern Canada. In Western Canada, surface runoff, particularly during the spring thaw, dominates P transport. Local implementation of nutrient management plans, regulations, conservation practices and **beneficial management practices** (**BMPs**) have brought about a considerable decrease in the annual P surplus in some areas. However, phosphorus is retained in the soil, so past surpluses continue to enrich soil P levels. Increased efforts to control both P sources and transport are required to reduce the risk of P loss to water and prevent surface water eutrophication and algal blooms.

In 2011, twenty-one of Canada's 280 agricultural[2] watersheds studied were classified as at *Very High* risk and thirty-five at *High* risk of water contamination by P. These *High* and *Very High* risk watersheds were located in both Eastern (Nova Scotia, Quebec, Ontario) and Western (Manitoba, Saskatchewan, Alberta and British Columbia) Canada. Between 1981 and 2011, 50% of the watersheds moved to higher risk classes. A notable shift to higher risk classes has occurred since 1991 in Alberta, Saskatchewan and Manitoba. The source component of this increased risk has been attributed to a positive annual P balance from increased livestock numbers and increased use of P fertilizers to maintain high crop yields. A much larger factor for this report was a significant increase in the transport component in 2011 due to higher-than-normal snowmelt runoff, which coincided with above-average spring rainfall, leading to record runoff levels and significant flooding.

The Issue and Why it Matters

Phosphorus is an essential nutrient for all plants and animals. It is applied to soils in the form of inorganic P fertilizers, manures and **biosolids** in order to maintain crop yields. Since the early 1950s, intensified cropping and animal production have increased soil nutrients in some regions to levels exceeding crop needs. Over time, cumulative P surpluses, which have resulted from inputs of P as fertilizer or manure exceeding the amount removed in harvested crops over several years, have enriched the soil and increased the risk of soil P transport from agricultural fields to surface water bodies. The loss of soil P is not only an environmental concern, it represents an economic loss to producers since this valuable nutrient is not available for crop production.

In natural freshwater systems, P occurs in very low concentrations which may vary significantly as a function of stream size and ecosystem characteristics. Excessive inputs of P contribute to eutrophication of water bodies and Cyanobacteria blooms, which can lead to the deterioration of water quality and to restrictions on the use of water bodies for drinking water and recreational activities such as swimming (Carpenter et al., 1998). This has been most evident in relatively shallow lakes with a large proportion of the watershed under agricultural or urban land uses, like Lake Winnipeg, Manitoba, Lake Erie, and Missisquoi Bay in Lake Champlain. While the source of the phosphorus is not only agricultural—municipal and industrial waste water as well as residential contributions from waste water or leaky septic systems also contribute—significant effort has been expended on reducing or mitigating agricultural contributions. Government programs and regulatory initiatives have been implemented to reduce agricultural P contamination associated with manure storage structures and manure application. Nutrient management plans including P have been developed specifically for farming operations in order to reduce the risk of nutrient contamination of adjacent surface water bodies in Quebec (1997), Ontario (2002) and Manitoba (2006).

2 For the purpose of this report an agricultural watershed is a watershed containing more than five percent of land in agricultural use.

The risk of P loss is dependent on the co-occurrence of two factors, P source and P transport, which may vary with local and regional conditions and with weather. Consequently, a given level of soil P may pose a high risk of loss in eastern Canada, while on the Prairies, the same level of P may pose a low risk due to the reduced risk of transport.

In light of the environmental and economic risks, along with regional risk disparities, it is critical to identify the highest risk areas and to tailor BMPs, programs and policies accordingly. This type of strategy will help to ensure that Canada maintains healthy water resources, productive soils, and sustainable food production.

The Indicator

The IROWC-P Indicator was developed to assess the status and trends over time for the risk of surface water contamination by P from Canadian agricultural land and is reported for agricultural watersheds. The information provided in this report builds directly on the IROWC-P results described in the previous indicator report (van Bochove et al., 2010a), and the authors gratefully acknowledge the work done by that team. IROWC-P first estimates the annual amount of dissolved P that may potentially be released from agricultural soils (P source). P source is estimated as a function of cumulative P additions and removals (P balance) over a 35-year period up to 2011 and the resulting degree of water extractable P (WEP). IROWC-P then integrates the P source through a transport hydrology function, which considers such processes as surface runoff, drainage and water erosion. This function was calibrated against P water-quality monitoring data collected in 88 agricultural watersheds in Canada from 1981 to 2001. IROWC-P also considers **hydrological connectivity**, based on a topographic index and estimates of intensity of tile drainage, surface drainage and **preferential flow**. The indicator uses information from the transport and hydrological functions to estimate the likelihood of P entering streams or water bodies.

The IROWC-P was calculated for all 280 watersheds (Natural Resources Canada, 2003) across Canada that contain more than 5% agricultural land. IROWC-P values were grouped separately for Western and Eastern Canada into five risk classes (*Very low, Low, Moderate, High and Very High*). The risk classes are relative rankings based on the distribution of risk classes in each Census year, as shown in Figure 12–1. In these two broad regions, 50% of watersheds were classified in the *Very low* risk class and the highest 5% of IROWC-P values fell into the *High* and *Very High* risk classes, in the 2006 Census year. To allow comparisons across years, the class cut-off values calculated for the 2006 Census year were used to classify risk in all other years. Further details on the development of the IROWC-P indicator can be found in van Bochove et al. (2010b).

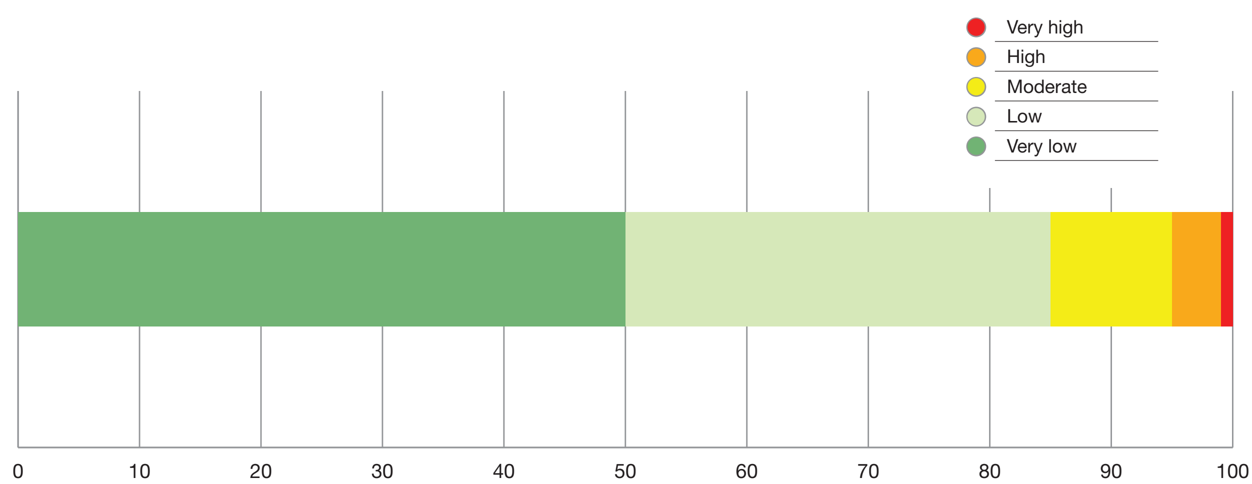


Figure 12–1: Derivation of IROWC-P Risk Categories based on percentile in which individual calculated risks fell. The categories were defined on the basis of the distribution of data in 2006, and were then used to classify risk in all years.

Limitations

IROWC-P assesses the risk associated with agricultural sources of phosphorus; non-agricultural sources are not considered. Calculations of cumulative P balance were performed using **Census of Agriculture** data for the period 1976 to 2011. Allocation of P applications to watersheds is subject to the limitations of the Census data and to any errors in the assumptions made in the allocation process. As soil test P and water extractable P data are not available across the country, these values were derived from the P-balance data, an approach that inevitably involves a measure of uncertainty. There were insufficient data to account for soil P enrichment before 1976 in Canada. The risk of direct losses of dissolved P from surface applications of manure or fertilizer is not included in IROWC-P because of insufficient data on nutrient application methods and timing.

Risk classes were defined separately for Eastern Canada and Western Canada to more accurately reflect the different conditions in different parts of the country, and are therefore not directly comparable.

Hydrological connectivity factors, which represent the pathways of P transfer to water bodies, were assumed to have equal weight in all agricultural areas across Canada. This component is influenced by the weather in each Census year, so changes in IROWC-P values can be due to differences in weather rather than in P management.

The calculation of IROWC-P accounts for most BMPs that lower P levels at the source (P application rates, crop removal) but accounts for few BMPs that reduce P movement in the landscape. This is because of a lack of comprehensive national BMP adoption data on practices such as P placement methods and timing as well as **riparian buffer** strips.

The transport hydrology function for this indicator was calibrated using the annual median P concentrations of 88 watersheds located across the country. In the case of these watersheds, the P may have come from a variety of sources, including urban wastewater and forests, but no effort was made to account for these non-agricultural sources. This may have influenced the IROWC-P calculations for agricultural areas, resulting in an over-estimation of risk.

IROWC-P could be further developed by incorporating information about new or existing BMPs that can have a significant effect on P source and P transport. For instance, P placement is not considered in the current model but it can have large impacts on P losses. Surface-applied P (fertilizer or manure) can release much higher concentrations of dissolved P into runoff water than into the soil, so differences in P concentration in runoff from changes in soil test P cannot be detected where the P has been left on the surface (Kleinman and Sharpley, 2003). Currently, there is a lack of national data on the extent to which BMPs are being applied and on the locations concerned, and particularly on where they would be most effective. This means that few BMPs associated with the transport component of the IROWC-P are adequately taken into account by the indicator algorithm. Infrastructure designed to reduce the impact of surface runoff could easily be included in the IROWC-P assessment. For example, as national data on buffer strips around surface water bodies become more widely available, their integration into the IROWC-P calculation will make it possible to determine the impact of buffer strips on P transport to surface waters.

Results and Interpretation

Changes in the IROWC-P Indicator are the result of changes in both the P source component (i.e. the amount of P that is available for export from agricultural land) and the transport hydrology component (i.e. runoff that can carry P from agricultural land to surface water). To understand the overall indicator results in 2011, it is useful to first consider the changes in each of the components (P source and transport hydrology) separately.

P SOURCE

P is bound tightly to soil particles, so only a fraction of P applied as fertilizer or manure is available to the crop in the year that it is applied. Furthermore, manure applied to meet the nitrogen requirements of crops will supply more P than those crops require. As a consequence, particularly in soils with low soil test P, the application rates often exceed the amount removed in the harvested portion of the crop. In other words, there is a positive P balance, and P accumulates in the soil over time. The amount of accumulation depends on the annual P balance and on how long there has been a positive P balance.

Figure 12–2 shows the annual P balance by province (combined for the Atlantic Provinces) from 1981 to 2011. The highest P-balance values have been recorded in the Atlantic Provinces (intensive livestock and potato production), followed by Quebec (intensive livestock production), British Columbia (intensive livestock and horticultural production) and Ontario. The trend in Eastern Canada has been towards a declining P balance, but the balance is still slightly positive in Ontario. Even though Ontario is the province that is closest to balancing P inputs and outputs, a small accumulation of P still occurs each year in the soil. In contrast, the Prairie Provinces had zero or negative P balances for the first few Census years, but this trend has been reversed with the intensification of production and consequent increases in fertilizer use. The greatest increase has been recorded in Manitoba.

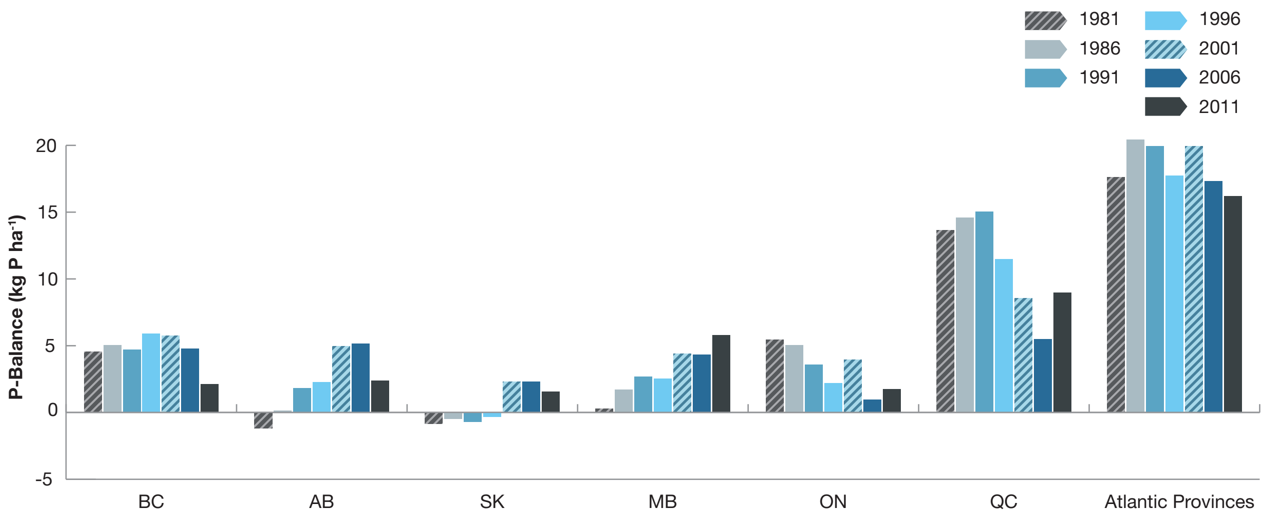


Figure 12–2: P balance (kg ha^{-1}) by province, 1981 to 2011

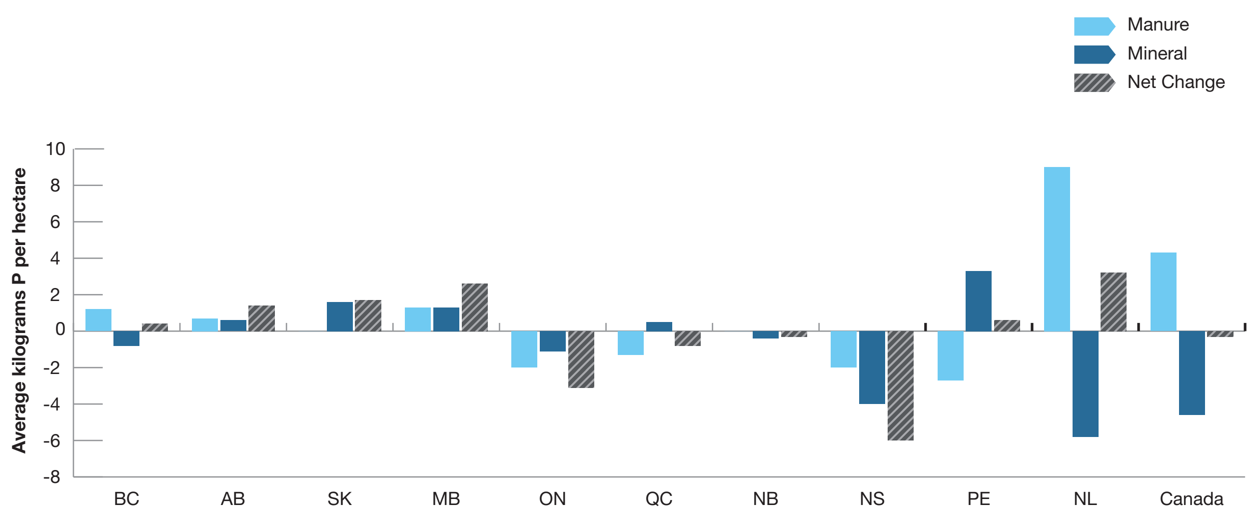


Figure 12–3: Change of P inputs, 1981–2011

Figure 12–3 shows the changes in P inputs—a key component of the P balance—from 1981 to 2011. Nationally, almost the same amount of manure P was applied to agricultural land in 2011 as in 1981, but there was a slight increase in the average mineral P application. The relative amounts vary from one area to another. Annual P application rates have increased in Alberta (manure and fertilizer), Saskatchewan (fertilizer), Manitoba (manure and fertilizer) and Newfoundland (more manure, less fertilizer), but all of the Prairie Provinces had very low P application rates to begin with. Less P is applied in Nova Scotia (manure and fertilizer), Quebec (less manure, more fertilizer) and Ontario (manure and fertilizer), all of which used relatively large amounts of fertilizer in 1981. The other provinces applied essentially the same amounts in 2011 as in 1981.

The net accumulation of P applied in excess of crop uptake (cumulative P balance) is combined with data on soil characteristics to calculate the P source components. There has generally been an increasing trend in P source levels in the surface layer of agricultural soils in Canada since 1976 as intensified agricultural practices have resulted in a positive annual P balance and have therefore increased soil P saturation (Figure 12–4). In 2011, very high concentrations of P (more than 4 mg of P kg^{-1}, or > 4 mg P kg^{-1} Water Extractable P) were at risk of being transported by storm events in regions where agricultural production was historically intensive and where soils had reached high P saturation values. These regions included Abbotsford, British Columbia; Lethbridge, Alberta; some areas in the Great Lakes basin in Ontario; the St. Lawrence Lowlands in Quebec; Grand Falls, New Brunswick; and Annapolis Valley, Nova Scotia (Figure 12–4, Table 12–1). *High* risk (3 to 4 mg P kg^{-1}) areas were also identified surrounding these regions, as well as in Manitoba and Prince Edward Island. Areas in the southern Prairies that showed high IROWC-P values actually had quite low P source ratings, but very high P transport risk because of the weather conditions in 2011.

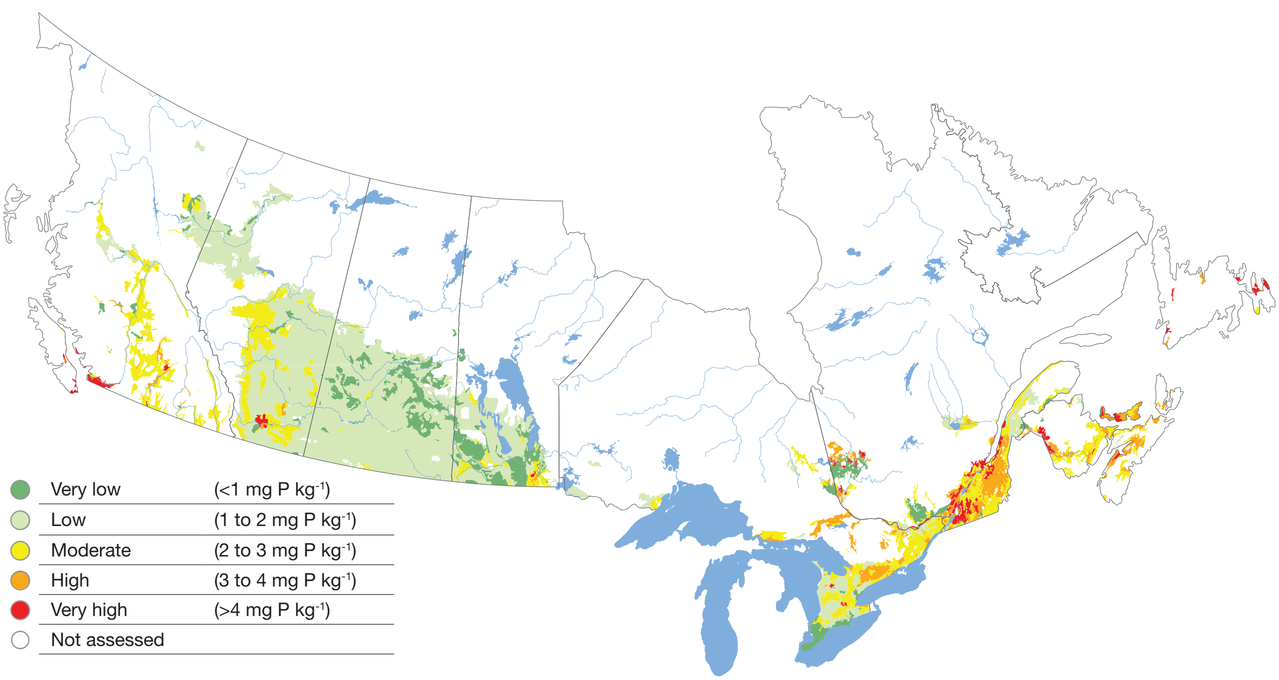


Figure 12–4: Soil P saturation (mg P kg^{-1} Water Extractable P) in agricultural land under 2011 management practices

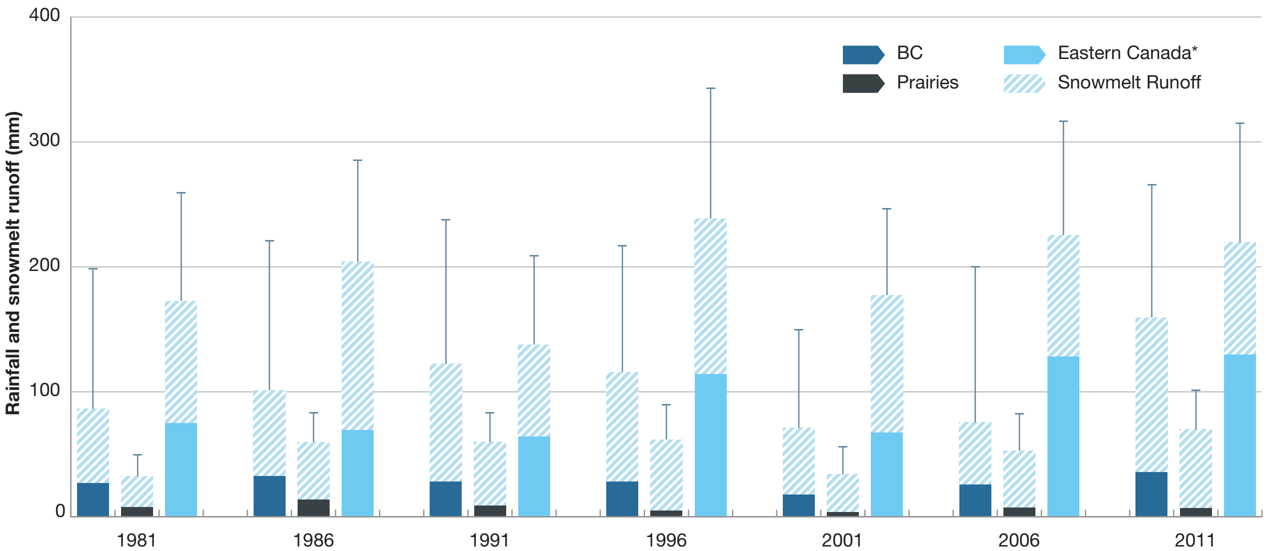
Table 12–1: Proportion[3] of farmland in P source risk classes, by Census year

Class	Very low							Low							Moderate							High							Very high						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	4	3	2	1	0	0	0	92	90	82	71	53	35	34	4	2	9	21	38	56	54	<1	2	1	1	2	3	4	0	2	4	4	5	4	6
Alberta	60	55	48	38	17	7	4	40	45	52	61	81	82	73	0	0	0	1	1	9	21	0	0	0	<1	<1	1	1	0	0	0	0	<1	1	1
Saskatchewan	69	63	65	63	53	39	33	30	36	34	36	46	60	66	0	0	0	0	0	0	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manitoba	100	99	92	86	72	59	38	0	<1	8	13	27	37	54	0	0	0	0	<1	3	7	0	0	0	0	0	<1	<1	0	0	0	0	0	0	<1
Ontario	42	30	19	19	18	16	17	56	58	61	57	46	40	38	2	12	19	23	31	35	34	0	0	<1	2	5	9	10	0	0	0	0	0	0	<1
Quebec	50	2	<1	<1	<1	0	0	50	71	57	30	16	13	10	0	27	26	39	46	44	35	0	<1	17	17	18	20	27	0	0	0	13	19	23	26
New Brunswick	70	3	0	0	2	2	2	28	82	59	40	11	2	3	2	12	29	44	50	55	43	0	2	10	14	25	26	23	0	<1	2	2	13	15	29
Nova Scotia	64	<1	0	0	0	0	0	36	95	61	14	6	6	5	0	5	37	79	76	54	26	0	0	2	6	14	35	54	0	0	0	<1	3	6	15
Prince Edward Island	67	1	0	0	0	0	0	33	99	76	37	1	0	0	0	0	24	63	70	55	23	0	0	0	0	29	45	52	0	0	0	0	0	0	24
Newfoundland and Labrador	45	9	0	0	0	0	0	46	64	36	16	4	24	0	5	18	48	47	21	13	8	0	9	11	0	41	4	22	4	0	5	37	32	57	70
Canada	**65**	**57**	**54**	**49**	**36**	**26**	**19**	**35**	**40**	**42**	**44**	**54**	**60**	**61**	**<1**	**2**	**3**	**5**	**7**	**10**	**14**	**0**	**1**	**1**	**1**	**2**	**2**	**3**	**0**	**0**	**<1**	**1**	**1**	**1**	**2**

3 Calculated as percentage of farmland classified for the whole watershed divided by the total amount of farmland in the province

TRANSPORT HYDROLOGY

IROWC-P values and trends are a function of transport processes which are highly dependent on regional climatic variations (Figure 12–5) that are beyond the control of producers and independent of agricultural intensity and its influence on P sources. IROWC-P values were very high in 2011 due to the amount of snowmelt in the Prairie Provinces, which was much greater than in 2006 and approximately double that of 2001. Conversely, the very low risk values in 2001 can be attributed to the exceptionally low amounts of runoff from both snowmelt and rainfall in the Prairies that year, which reduced the risk of water contamination from phosphorus. A more dramatic picture of the net impact of the unusually wet conditions in 2011 (particularly in the southern Prairie Provinces) is provided by the flows in the Assiniboine River at Headingley (Figure 12–6), which reflect the impacts of the snowmelt and spring rainfall from most of the watershed. In contrast, conditions in Eastern Canada were stable from 2006 to 2011.



* Eastern Canada includes Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador

Figure 12–5: Rainfall (blue) and snowmelt runoff (white). Error bars indicate standard deviation of total runoff.

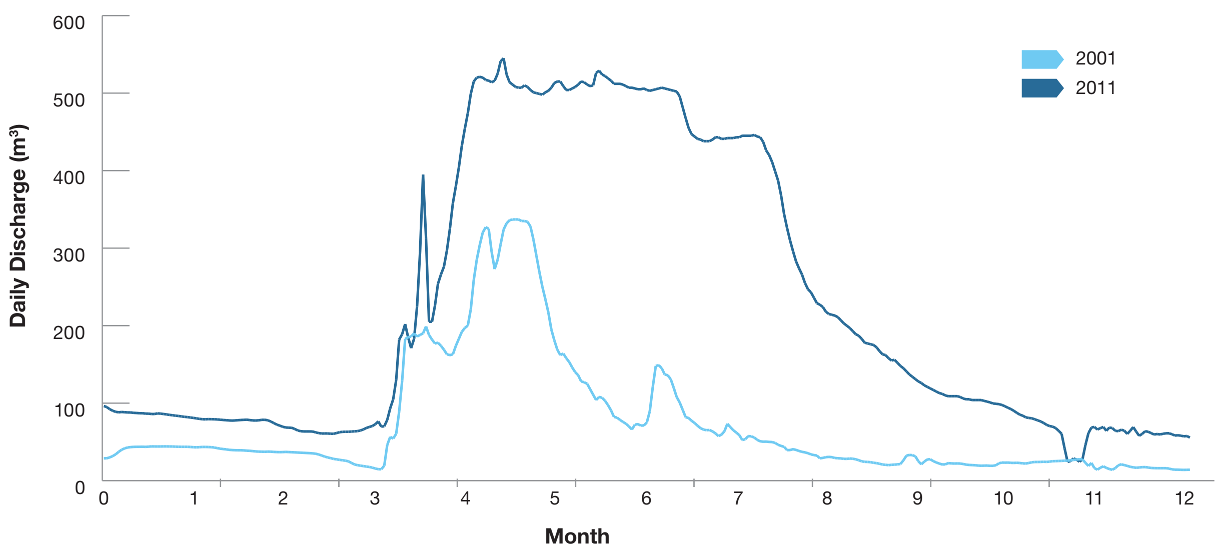


Figure 12–6: Comparison of flow rates at the Headingley, Manitoba gauge station on the Assiniboine River in 2001 and 2011 (Environment Canada Water Office, 2015)

IROWC-P RESULTS

In 2011, twenty-one watersheds were classified as at *Very High* risk and thirty-five as at *High* risk of water contamination by P. These *High* and *Very High* risk watersheds were located in both Eastern (Nova Scotia, Quebec, Ontario) and Western (Manitoba, Saskatchewan, Alberta and British Columbia) Canada, where farming intensity and P transport factors taken together pose a significant risk to water quality and mitigation measures are likely required (Figure 12–7). Sixty-nine watersheds were estimated to be at *Moderate* risk.

Between 1981 and 2011, 50% of the 280 watersheds moved to higher risk classes (Figures 12–8 and 12–9), indicating that greater implementation of P control measures is required to protect surface water at risk of becoming significantly degraded. The general analysis of trends over time across Canada (Table 12–2) shows that approximately 7% of the farmland located in British Columbia shifted from a *Low* risk of P water contamination in 1981 to a *Very High* risk in 2011. A shift to higher risk classes has occurred since 1991 in Alberta, Saskatchewan and Manitoba, which can be partly explained by the increasing cumulative P balance, although the rate of buildup has slowed in Alberta and Saskatchewan (Figure 12–2). A factor that had an even greater impact on the increased risk in 2011 in the southern Prairie Provinces is the higher-than-normal snowmelt runoff (Figure 12–5), which coincided with above-average spring rainfall, leading to record runoff levels and significant flooding (Manitoba Ministry of Infrastructure and Transportation, 2013).

Risk values are highly dependent on weather. In Table 12–2 it can be seen that the proportion of farmland in the IROWC-P *Moderate* to *Very High* risk class was higher in 2011 than in previous years; this is due to the high level of spring runoff, particularly in the Prairie Provinces (Figure 12–5). In Eastern Canada, the

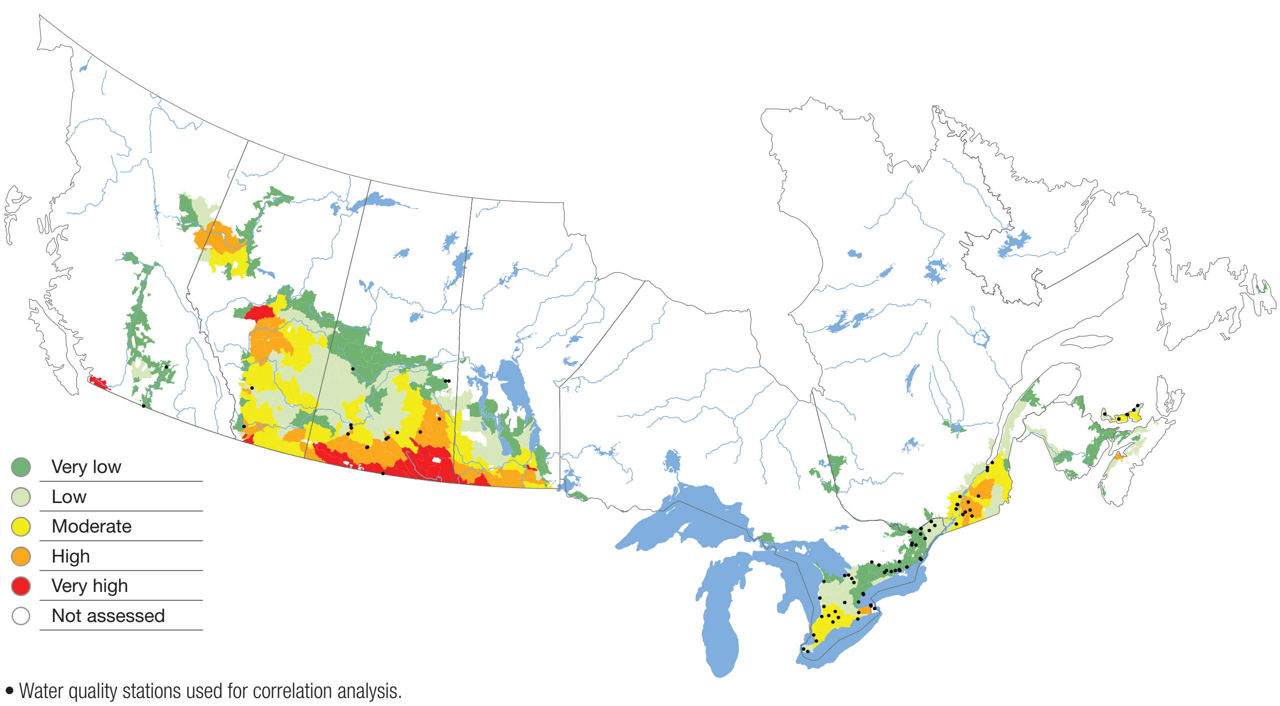


Figure 12–7: Risk of water contamination by phosphorus in agricultural watersheds under 2011 management practices

risk level in Ontario remained stable from 2006 to 2011, although a few watersheds in southwestern Ontario moved from the *Very low* risk category to the *Moderate* risk category over the 30 years from 1981 to 2011. Quebec, New Brunswick, Nova Scotia and Prince Edward Island have shown the same gradual shift to higher classes since 1991 that is observed in the Prairie Provinces (Table 12–2).

The overall trend in the risk of P loss has been a slowing of the buildup of soil P, particularly in Eastern Canada. However, this trend was offset in 2011 by the unusually high P transport caused by the weather conditions. Further improvements in P management will be needed, particularly where high P levels have built up in the soil, to reduce the risk of P loss; however, the legacy of past P applications will persist in these soils for several decades.

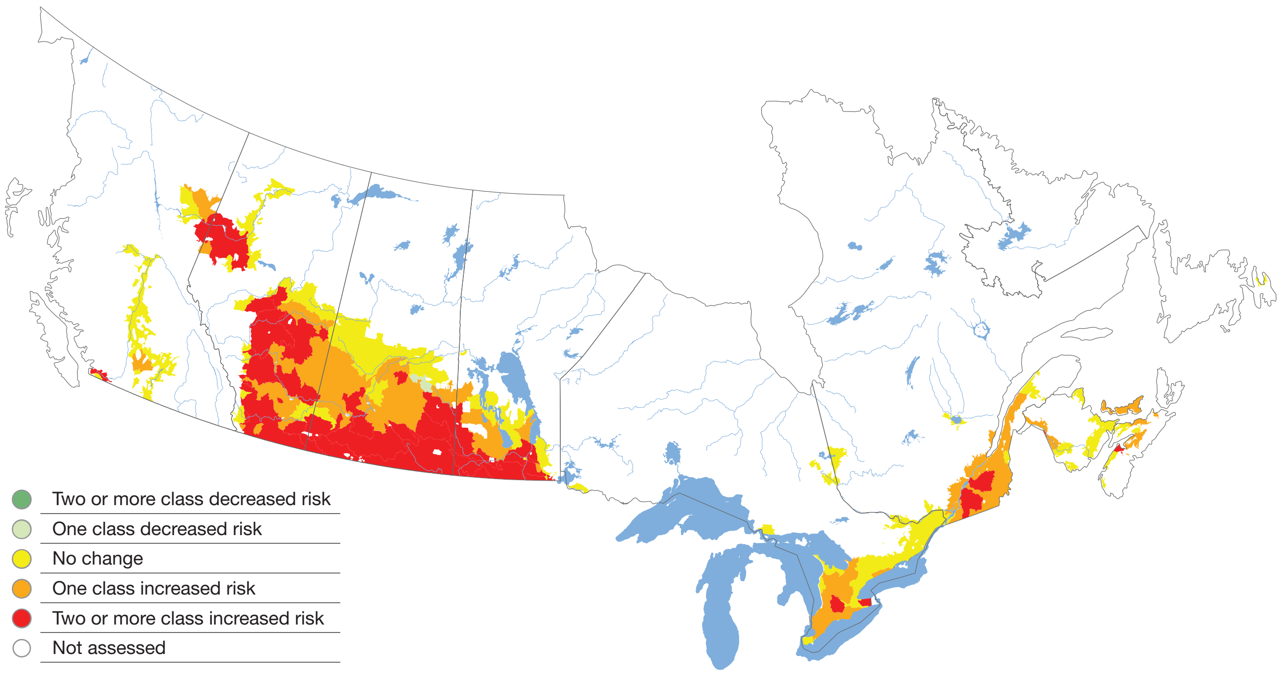


Figure 12–8: IROWC-P risk class change, 1981 to 2011

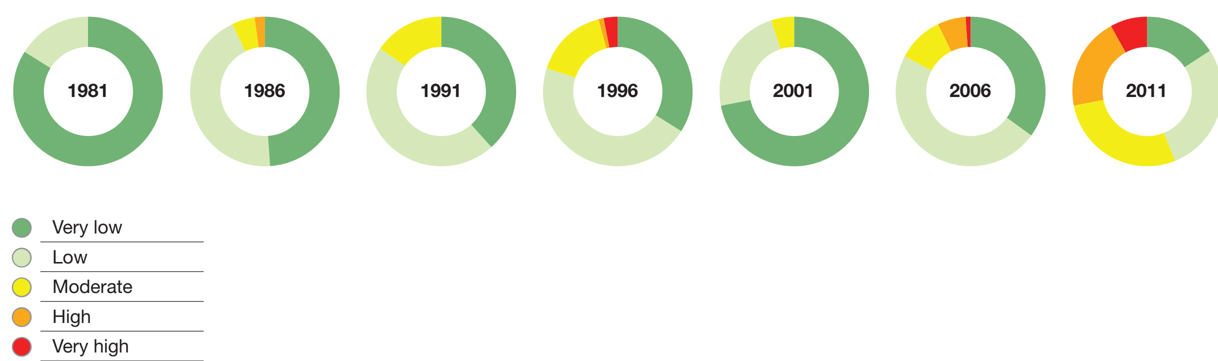


Figure 12–9: Percentage area of farmland in risk classes, by Census year

Table 12–2: Proportion[4] of farmland in various IROWC-P classes, 1981 to 2011

Class	Very low							Low							Moderate							High							Very high						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	93	93	93	93	93	93	64	5	0	0	0	0	0	29	0	5	5	5	0	0	0	0	0	0	0	5	0	0	2	2	2	2	2	7	7
Alberta	89	52	44	25	96	40	12	10	44	39	48	4	44	25	0	3	16	18	0	12	39	0	2	0	1	0	4	22	0	0	1	9	0	0	2
Saskatchewan	85	42	20	41	69	30	16	15	43	55	42	23	50	31	0	11	25	17	7	8	16	0	4	0	0	0	10	19	0	0	0	0	0	3	18
Manitoba	100	51	55	38	46	35	8	0	49	41	45	38	62	24	0	0	4	13	16	3	28	0	0	0	4	0	0	28	0	0	0	0	0	0	11
Ontario	62	60	56	35	46	28	33	38	37	44	56	54	53	36	0	3	0	9	0	16	29	0	0	0	0	0	3	3	0	0	0	0	0	0	0
Quebec	28	27	12	8	22	10	8	72	73	81	56	78	33	34	0	0	7	35	0	33	31	0	0	0	0	0	24	28	0	0	0	0	0	0	0
New Brunswick	100	100	99	85	100	85	60	0	0	1	15	0	15	38	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nova Scotia	58	58	58	30	58	51	20	42	42	42	48	42	27	57	0	0	0	22	0	22	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0
Prince Edward Island	26	70	26	0	26	0	0	74	30	74	100	74	100	26	0	0	0	0	0	0	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Newfoundland and Labrador	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Canada	**84**	**49**	**38**	**34**	**72**	**35**	**16**	**16**	**44**	**46**	**46**	**23**	**48**	**28**	**0**	**5**	**15**	**16**	**5**	**10**	**28**	**0**	**2**	**0**	**1**	**0**	**6**	**20**	**0**	**0**	**0**	**3**	**0**	**1**	**8**

4 Calculated as percentage of farmland classified for the whole watershed divided by the total amount of farmland in the province

Response Options

Any BMPs that can bring the P level into line with crop needs or that can reduce the transport of P to surface water will decrease the risk of water contamination by P. For example, appropriate use of the enzyme phytase in monogastric animal feed may allow producers to reduce P supplementation and, consequently, reduce the P concentration in manures (Gueguen, 2005). As the proportion of animals fed rations containing phytase increases nationally, the quantities of P in manure will decrease. An opposite trend consists of the increased use dried distiller's grains and solubles (DDGS), a by-product of ethanol production, which increases the P concentration of livestock diets and therefore of manure. Another BMP that can potentially reduce the P source component is the introduction of crops with high P uptake (like **forages**) into crop rotations on P-enriched soils. These crops take up large amounts of P, which is subsequently removed at harvest. Regular soil nutrient testing and manure nutrient testing can help producers get a better idea of the level of nutrients already present in the soil and of how much is potentially being added, thus generating economic benefits and supporting soil P management. In the long run, such crop management measures can progressively reduce the amount of soil P available for transport to surface waters and return agro-ecosystems to lower risk classes.

BMPs capable of impeding the movement of P into the drainage network can reduce the risk of P contamination of surface waters. For example, buffer strips established around surface water bodies help to trap and filter particulate P from surface runoff. However, buffer strips can also impede agricultural activities. To make this BMP more economically acceptable to producers, the use of plant species offering potential economic returns to producers should be considered. Other BMPs that may be appropriate in some circumstances include subsurface placement of P fertilizers to prevent P transport in runoff, soil structure improvements to encourage better water infiltration, and management of tile drains through controlled drainage.

IROWC-P enables the identification of areas that are at high risk of water contamination by P from agricultural sources. A more detailed examination of agricultural practices in these regions could reveal which regional characteristics contribute to the risk of water contamination by P. This information could be used to guide mitigation practices and research efforts.

References

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howath, A.N. Sharpley, and V.H. Smith, 1998. *Non-point pollution of surface waters with phosphorus and nitrogen*. Journal of Applied Ecology. 8: 559-568.

Environment Canada Water Office, 2015. *Daily discharge graph for Assiniboine River at Headingly (05MJ001)*. Retrieved April 29, 2015 from https://wateroffice.ec.gc.ca/report/ stn=05MJ001&mode=Graph&type=h2oArc&dataType=Daily&parameterType=Flow&-year=2011&y1Max=1&y1Min=1)

Gueguen, L., 2005. *La petite histoire du phosphore en alimentation animale: les grandes* étapes *du demi-siècle*. INRA Productions Animales. 18: 149-151.

Kleinman, P.J.A., and A.N. Sharpley, 2003. *Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events*. Journal of Environmental Quality. 32:1072-1081.

Manitoba Ministry of Infrastructure and Transportation, 2013. Manitoba 2011 Flood Review Task Force Report. Winnipeg, Manitoba, Canada. Retrieved January 22, 2015 from http://www.google.ca/url?sa=t&rct= t&rct=-j&q=&esrc=s&frm=1&source==web&cd=1&cad=rja&uact=8&ved=0CB0QFjAA&url=http%3A%2F%2Fwww.gov.mb.ca%2Fasset_library%2Fen%2F2011flood%2F-flood_review_task_force_report.pdf&ei=pU_BVKibO872yQSbqoHIDA&usg=AFQjCNH17ulzCHgrA8-0qBIhRwnlpLwoUQ&sig2=IUggy9cJ-jtN2Vg3TbycIQ)

Natural Resources Canada, 2003. Atlas of Canada 1,000,000 National frameworks data, hydrology – Fundamental drainage areas (version 6.0). Ottawa, ON, Canada. Retrieved June 30, 2014 from http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/bd90f757-58d0-5226-848f-2122d505eefc.html)

van Bochove, E., G. Thériault, and J.-T. Denault, 2010a. Indicator of risk of water contamination by phosphorus (IROWC_P). A handbook for presenting the IROWC_P algorithms. Canada: Agriculture and Agri-Food Canada.

Van Bochove, E., G. Thériault, J.-T. Denault, F. Dechmi, A.N. Rousseau, and S.E. Allaire, 2010b. Risk of water contamination by phosphorus (IROWC-P). In: W. Eilers, R. MacKay, L. Graham, A. Lefebvre (eds.). Environmental sustainability of Canadian agriculture: Agri-Environmental indicator report series, Report #3. Ottawa, Canada: Agriculture and Agri-Food Canada.

13 Coliforms

Authors:
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Indicator Name:
Indicator of the Risk of Water Contamination by Coliforms

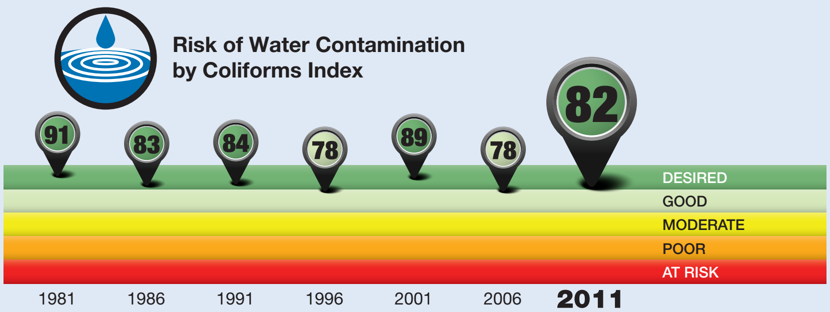
Status:
National Coverage, 1981 to 2011

Summary

Animal manure can be used as a valuable organic **fertilizer**[1] for agricultural soils. However, animal manure may also be a potential source of **pathogens** including viruses, bacteria and protozoa. Inappropriate use of manure as a fertilizer, or inappropriate management of grazing livestock, can heighten the risk of pathogen contamination of surface water. Canadian citizens have become increasingly concerned about the quality of the water they consume or use for everyday activities. Water quality is often assessed using **coliform** bacteria levels as an indicator of fecal contamination.

Coliforms Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of the environment from the standpoint of risk of water contamination by agricultural coliforms in Canada was 'Desired'. The index levels improved from 2006 but are still below the 1981 baseline. It is important to note that risk is driven by runoff and is therefore much higher in wetter years.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

The risk that pathogen contamination from manure poses to **watersheds** varies widely across Canada. In both Eastern and Western Canada, high densities of grazed livestock represent the largest source of coliform bacteria, although the timing of losses from agricultural sources varies with the climate conditions. In the Prairies, **runoff** from pastures during the spring thaw period accounts for almost 90% of the risk to water. In Eastern Canada, runoff occurs over a much larger portion of the year, and a greater proportion of bacteria come from land spreading of manure from confined livestock operations. The risk of coliform contamination is highly sensitive to weather conditions during the spreading and grazing periods and therefore can vary from one year to the next.

The Indicator of the Risk of Water Contamination by Coliforms (IROWC-Coliform) was created to assess the risk of water contamination by **enteric micro-organisms** from agricultural sources. The IROWC-Coliform Indicator has two major components: one quantifies the source of fecal material and the associated coliform bacteria, and the other describes transport processes and connectivity between agricultural land and water bodies.

In 2011, for the majority of Canada's 280 agricultural[2] watersheds, the risk of water contamination by coliforms was considered to be *Very low*. A few watersheds at *High* and *Very High* risk of water contamination by coliforms were found in British Columbia, Alberta, Ontario, Quebec and Nova Scotia. All other watersheds in Canada were either at *Very low* or *Low* risk.

The Issue and Why it Matters

Canadians are more conscious about agriculture and its environmental effects, including contamination of water by fecal material. The potential for this type of contamination is assessed by the presence of fecal coliforms—thermotolerant bacteria universally found in animal feces. The consequences of water contamination by coliforms include increased cost for water treatment, loss of use of recreational waters, and the potential for human health effects. This can lead to the adoption of more stringent regulations that place constraints on the expansion and operation of the livestock industry. In mixed watersheds, sources of surface water contamination are often numerous and can include municipal wastewater discharges, leaking septic systems, wildlife and livestock operations.

Livestock manure is commonly used in agriculture as a valuable source of **nutrients** for crop growth. Bacteria are an important component of all types of manure, but the microbial composition of manure varies widely with the type of livestock (e.g. poultry, swine and cattle) and herd health. As a consequence, the use of animal manure as crop fertilizer may pose some risks to environmental and human health if bacteria from the manure end up in nearby surface water or shallow **ground water**. The risk of contamination of surface water by coliforms is likely highest in areas with high manure production, dense water drainage networks and high susceptibility to surface runoff, **preferential flow** and soil erosion.

In Canada, there has been a notable intensification of dairy, beef, swine and poultry production and concentration of these operations on fewer but larger farms (Figure 13–1). This trend of concentrating livestock on a smaller land base has continued between 2006 and 2011 despite the significant decreases in swine and cattle numbers at the national level. There has also been an increase in larger confined animal production facilities such as cattle feedlots, hog barns and poultry production facilities. The number of broiler and layer chickens has increased, while the number of farms raising these animals has decreased. Similarly, the average number of pigs per farm increased by 31.5% between 2006 and 2011 (Statistics Canada, 2013) and the number of dairy cows per farm has risen by about 13% since 2005 (Canadian Dairy Commission, 2012). One of the potential consequences of consolidation and intensification is that on-farm manure volumes may grow to exceed the capacity of the surrounding land to receive it, resulting in manure being applied at higher rates on the same or a smaller land base. Appropriate manure management can ensure the protection of valuable surface water and groundwater resources, as well as food safety and human health. Awareness of at-risk agricultural lands and waters and an understanding of land-use practices that can mitigate potentially negative impacts will help ensure that Canada continues to maintain sustainable agricultural landscapes while producing safe, high-quality livestock products.

2 For the purpose of this report an agricultural watershed is a watershed containing more than five percent of land in agricultural use.

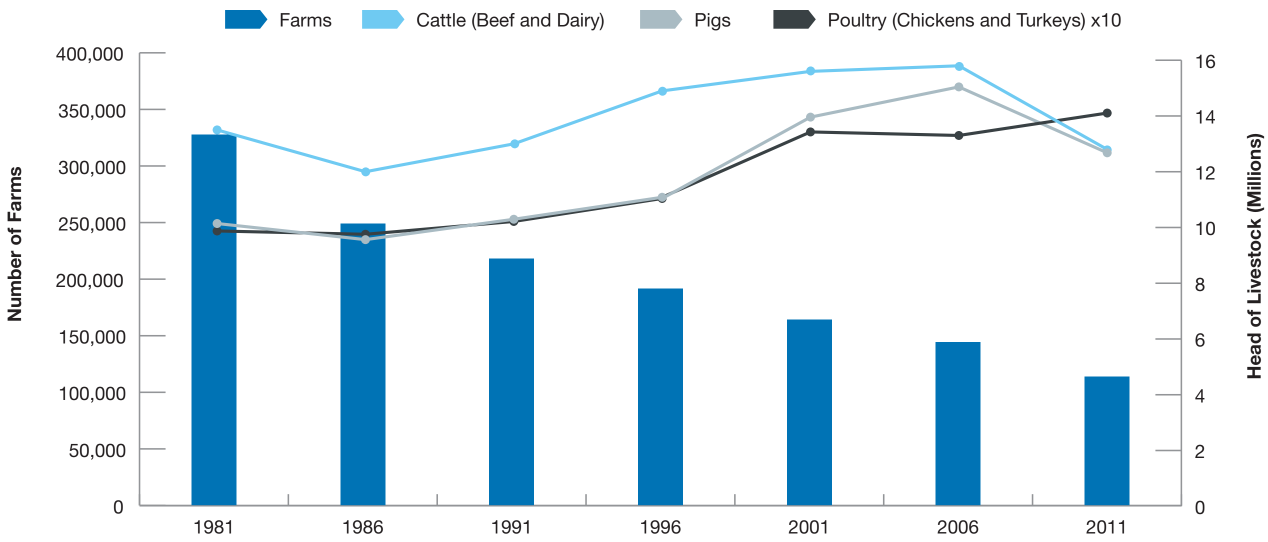


Figure 13–1: Concentration of livestock production in Canada from 1981 to 2011. Lines represent animal populations and bars represent number of livestock farms.

The Indicator

IROWC-Coliform assesses the relative risk of contamination of surface water bodies by fecal material from agricultural sources using thermotolerant coliforms as a marker. It also evaluates how this risk is changing over time. It provides a tool to predict and evaluate which farm practices can be managed differently to minimize the level of risk. This version of the indicator builds on the previous work described in van Bochove et al. (2010a).

IROWC-Coliform is determined by considering both an estimate of potential numbers of coliforms of agricultural origin (coliform source) and an estimate of the likelihood of their movement to surface waters (transport). Coliform contamination from municipal wastewater discharges, leaking septic systems and wildlife was not considered within the scope of this indicator. Risk is ranked in one of five classes (*Very low*, *Low*, *Moderate*, *High* and *Very High*). The risk classes are relative rankings such that 50% of water-sheds are classified in the *Very low* risk class and the highest 5% of IROWC-Coliform values fall into the *High* and *Very High* risk classes.

The coliform source component considers the manures of the four main livestock types (cattle, swine, sheep and poultry) that make up more than 80% of Canadian livestock production. The average populations of coliforms from pastured animals and from confined animals are estimated on a daily basis using manure production coefficients, fecal coliform coefficients (American Society of Agricultural Engineers [ASAE], 2003.) and a daily decay rate (Himathongkham et al., 1999). Coliforms from pasturing- animal manure are considered to be available for transport the very day they are produced, while those from confined-animal manure are assumed to be available for transport only after the manure has been spread on fields. For each province, it is assumed that there are four spreading periods per year based on the first and the last day of soil freezing, and harvest dates.

The transport component was adapted from IROWC-Phosphorus (van Bochove et al., 2010b) (see Chapter 12 “Phosphorus”) and integrates three transport processes (surface runoff, deep drainage and soil water erosion) as well as factors accounting for connectivity between coliform sources and water bodies (a topographic index, tile drainage, surface drainage and preferential flow). The impact of different manure management strategies (e.g. soil incorporation, surface spreading and composting) on the availability of coliform bacteria for transport by surface runoff was also included in the calculations.

Limitations

For the purposes of the model, it was assumed that grazing livestock have no direct access to surface water bodies. Manure-spreading periods and climatic data were respectively available at provincial and **ecodistrict** levels and uniformly applied to **polygons** within the province or the ecodistrict. Thermotolerant coliform concentrations in the fresh manure of animal categories for which data were unavailable were extrapolated from closely related animal categories.

The IROWC-Coliform values reflect the timing of surface runoff from storm events in relation to the active population of coliforms present on agricultural land when such events occur. Days when surface runoff occurs are random because such events are triggered by particular climatic conditions which vary from year to year. The variation in IROWC-Coliform values is attributable partly to variation in annual weather conditions during the Census years, and partly to changes in the source of coliforms.

This indicator assesses the risk of bacteria contaminating surface water, using coliforms as an indicator. Coliforms are not necessarily harmful; however they indicate the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. This indicator does not attempt to assess the relative risk to human health associated with pathogenic bacteria, only the risk of such organisms reaching surface water.

Results and Interpretation

In 2011, two watersheds were identified as being at *Very High* risk of water contamination by coliforms, both of them located in the Manitoulin-Lake Simcoe **ecoregion** of southwestern Ontario; and six watersheds were identified as being at *High* risk; these were located in, Alberta, Ontario and Quebec (Figure 13–2). In these regions, agricultural intensity and coliform transport factors may pose a significant risk to water quality if targeted mitigation measures are not in place. Nationally, these high-risk watersheds represented 5% of total farmland (Figure 13–3). Twenty-six watersheds, comprising 11% of total farmland, were estimated to be at *Moderate* risk. All other watersheds in Canada were either at *Very low* or *Low* risk. IROWC-Coliform values varied from one year to the next between 1981 and 2011 (Figure 13–2); however, there was a generally increasing risk as the area of farmland in the *Very low* risk class decreased while the *Low* and *Moderate* risk classes increased over this 30-year time period (Table 13–1, Figure 13–4). There is some indication of a reversal of this trend in 2011, as there was an increase in the area of farmland in the *Very low* risk class (Figure 13–3).

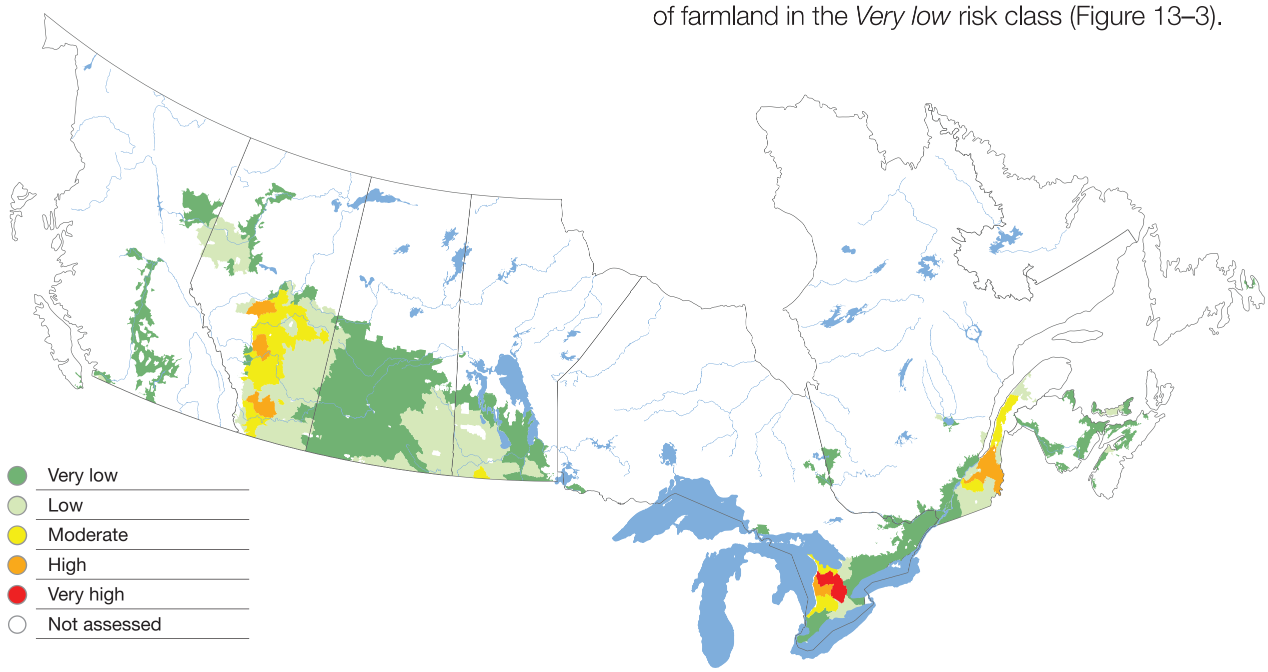


Figure 13–2: Risk[3] of water contamination by coliforms in agricultural watersheds under 2011 management practices

3 The map in Figure 13-2 considers both source and transport factors.

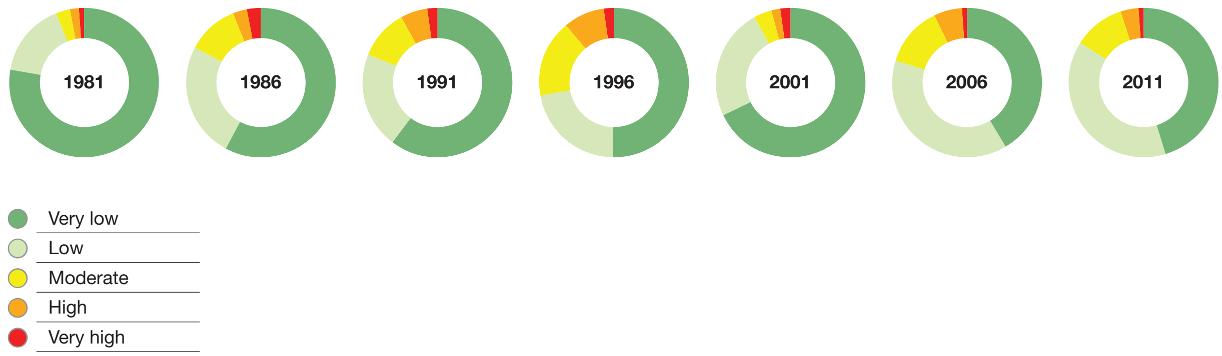


Figure 13–3: Percentage area of farmland in IROWC-Coliform risk classes, 1981 to 2011

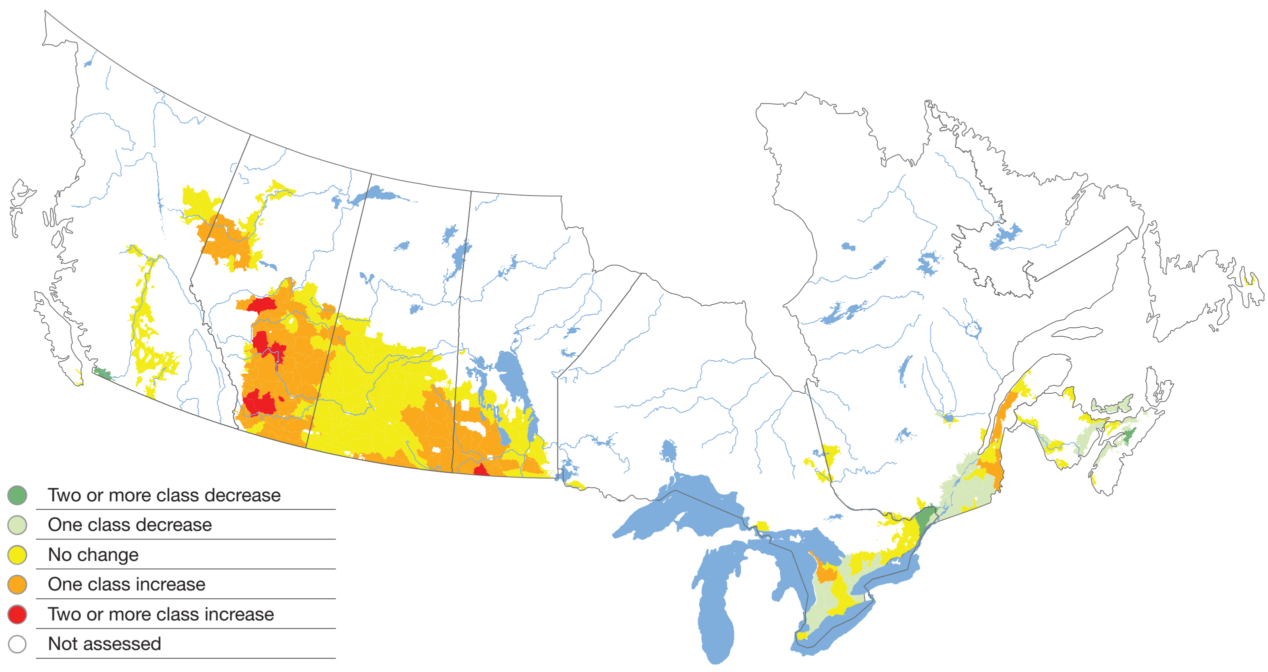


Figure 13–4: Change in risk of water contamination by coliforms in agricultural watersheds, 1981 to 2011

Table 13–1: Proportion[4] of farmland in various IROWC-Coliform classes, 1981 to 2011

	Proportion (%) of Farmland in Different Risk Classes																																		
Class	Very low							Low							Moderate							High							Very high						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	93	93	93	93	93	93	98	0	0	4	4	4	4	2	4	4	0	0	0	2	0	0	0	0	2	2	0	0	2	2	2	0	0	0	0
Alberta	69	16	19	14	43	19	15	30	57	45	29	52	39	55	0	24	22	36	5	29	24	0	2	12	18	0	11	7	0	0	2	2	0	3	0
Saskatchewan	100	100	100	87	98	62	81	0	0	0	13	2	38	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manitoba	100	100	100	80	100	58	28	0	0	0	20	0	42	70	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ontario	23	15	35	23	29	31	52	40	30	35	31	31	38	14	8	14	5	21	6	9	15	16	6	13	14	15	22	6	13	34	11	10	19	0	13
Quebec	4	3	7	4	7	4	43	39	35	36	34	31	32	30	43	27	46	42	40	44	14	14	34	11	20	11	10	13	0	0	0	0	10	10	0
New Brunswick	43	43	58	60	74	100	100	57	33	16	40	26	0	0	0	24	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nova Scotia	16	13	16	13	21	36	78	51	33	62	33	57	41	22	34	31	22	31	22	22	0	0	22	0	22	0	0	0	0	0	0	0	0	0	0
Prince Edward Island	0	0	11	0	26	26	43	43	43	62	43	74	74	57	57	0	27	30	0	0	0	0	57	0	27	0	0	0	0	0	0	0	0	0	0
Newfoundland and Labrador	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Canada	**77**	**58**	**61**	**51**	**68**	**41**	**46**	**16**	**25**	**21**	**22**	**24**	**38**	**39**	**3**	**11**	**11**	**17**	**4**	**13**	**11**	**2**	**3**	**6**	**9**	**2**	**6**	**4**	**1**	**3**	**2**	**2**	**2**	**1**	**1**

4 Calculated as percentage of farmland classified for the whole watershed divided by the total amount of farmland in the province

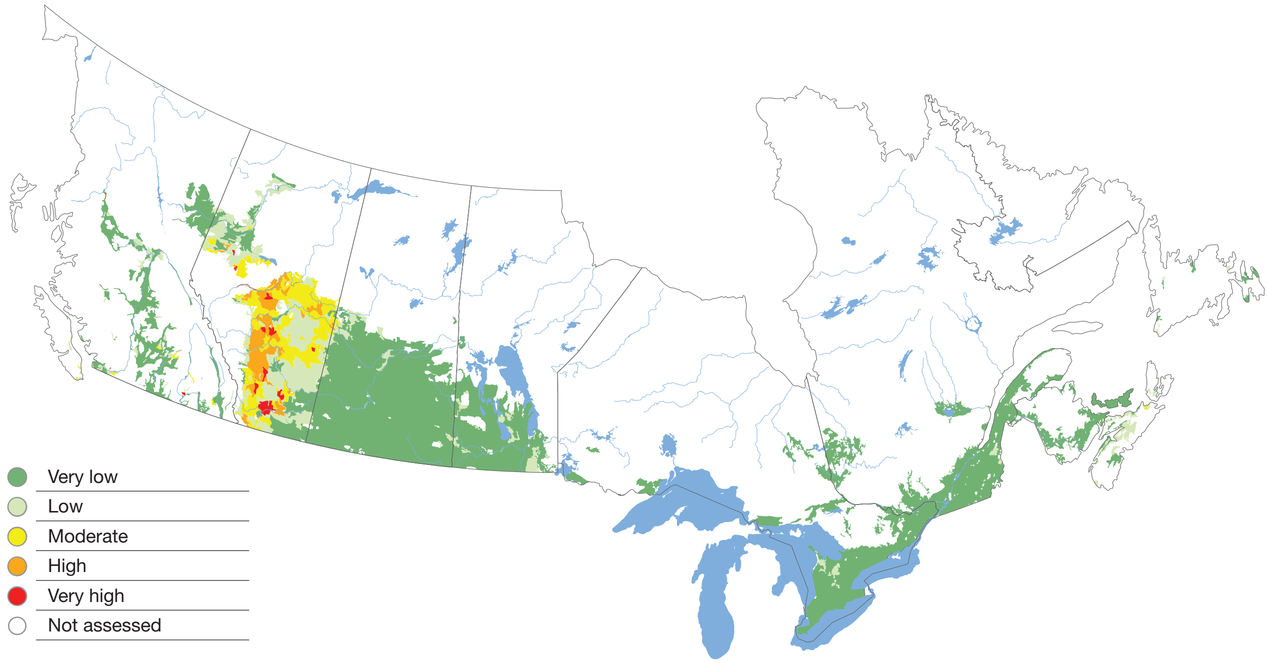


Figure 13–5: Coliform source classes on pasture lands under 2011 land management practices

Watersheds at *Moderate* to *High* risk generally correspond to areas with intensive animal production. These areas have high volumes of manure and, consequently, high rates of coliform inputs. High concentrations of manure on pasture can result in a source of coliforms that are readily available for transport by runoff. The highest concentration of manure on pasture occurred in western Alberta (Figure 13–5).

Various regions showed a high incidence of coliforms resulting from manure applied to agricultural lands (Figure 13–6), including pockets in the Lower Mainland region of British Columbia, the Lake Nipigon Ecoregion of western Ontario, and the Abitibi Plains region of eastern Ontario and western Quebec. However, the highest risk areas are concentrated in the Manitoulin-Lake Simcoe ecoregion of Ontario and the St. Lawrence Lowlands of Quebec, where livestock production and associated land application of manure are generally more intense. However, coliform source decreased in the intensive agricultural regions of Ontario, mainly due to declines in the cattle and swine sectors (Figure 13–7). Other regions such as parts of New Brunswick and Nova Scotia, and the central portion of British Columbia, also showed a reduction in coliform source because of reductions in the cattle and swine populations.

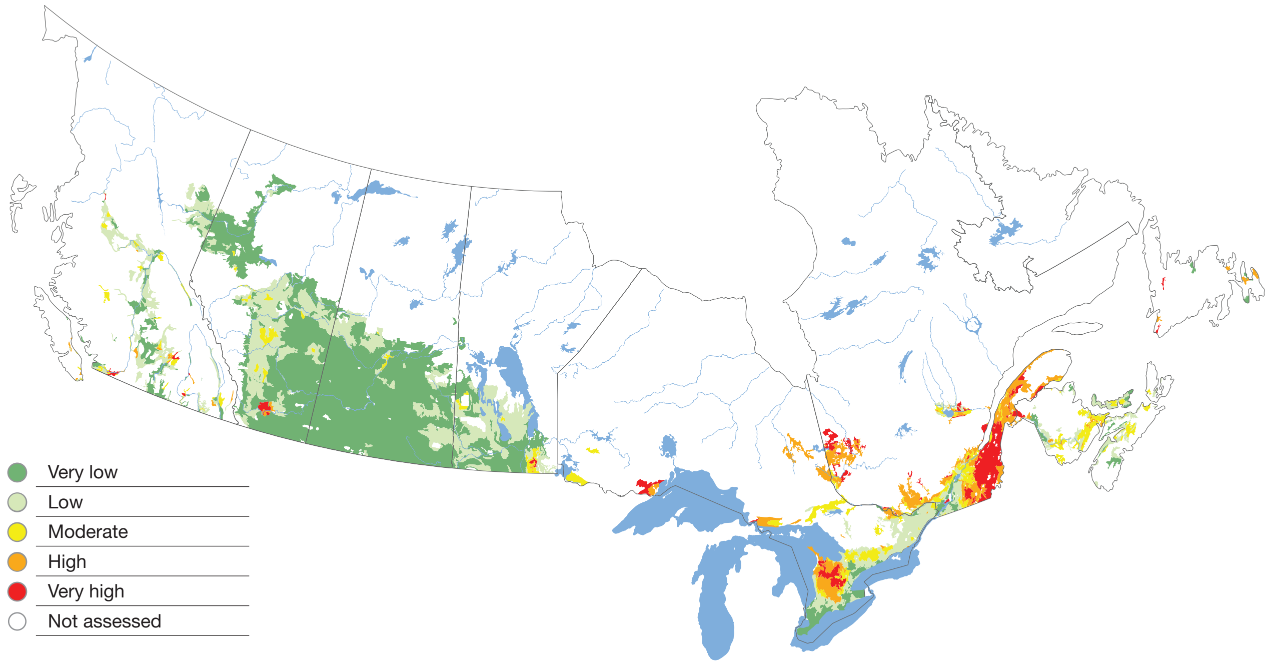


Figure 13–6: **Coliform source spread on agricultural land under 2011 management practices**

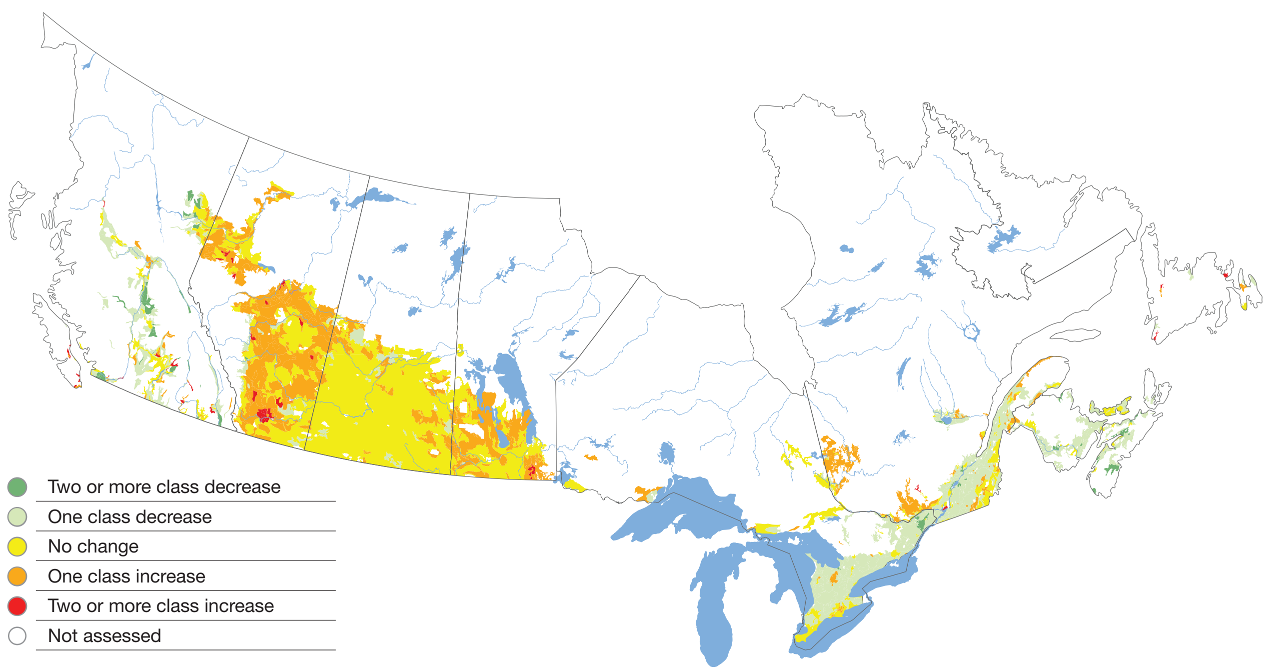


Figure 13–7: **Coliform source risk class change, 1981 to 2011**

Weather conditions have a significant impact on the risk of water contamination by coliforms in any particular year. In 2011, the amount of snowmelt runoff was greater in BC and the Prairie Provinces than in any Census year since 1981, while Eastern Canada had the highest levels of rainfall runoff (See Figure 12–5 in the "Phosphorus" chapter). A high level of runoff increases the risk of coliform runoff relative to a drier year such as 2001. The timing of runoff events in relation to the availability of coliform source also plays a critical role in determining risk. In the western provinces, some animals remain outside during winter, keeping the amount of coliforms available for transport at a high level throughout the year (Figure 13–8). On the Prairies, spring snowmelt runoff represents almost the entire annual runoff, and this Prairie pasture runoff accounts for almost 90% of the risk value.

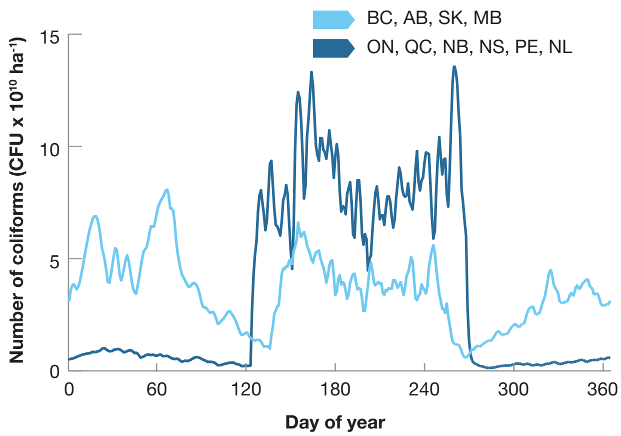


Figure 13–8: Daily mean coliform population intensity on pasture, 2011

In Eastern Canada, the risk is more variable across the seasons. Most animals are confined during winter months and the manure is stored for spreading during the warmer season. The largest volume of stored manure is spread in the spring before planting (March to April). Other major applications occur in June following **forage** harvest, as well as in the fall (Figure 13–9). The timing between the period of spreading and the weather conditions during or following these periods has a critical impact on the risk value.

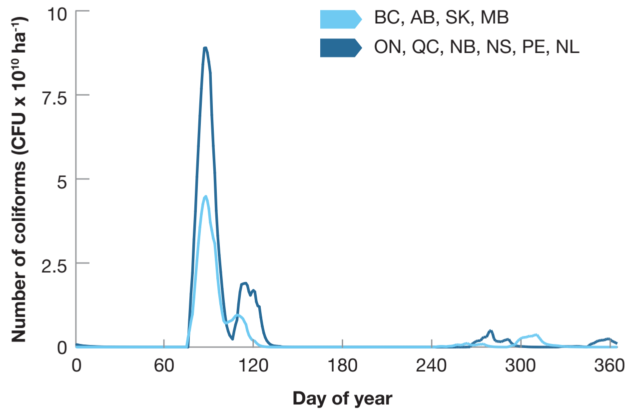


Figure 13–9: Daily mean coliform population intensity on cropland, 2011

Response Options

At the national scale, manure excreted by pastured animals was the largest source of coliforms potentially available for transport to surface water. Independent of storm events, direct access of animals to surface water bodies, while not currently reflected in the indicator model, presents a risk of coliform contamination of water. Implementation of good practices such as fencing along surface water bodies to prevent access by pastured animals, as well as discouraging access to streams through the provision of off-site watering facilities, will reduce this risk. Reducing livestock density on pastureland could also be considered where feasible. For manure spreading, any practice that incorporates manure into the soil immediately or shortly after application will substantially reduce the risk of coliform transport to streams. Strict nutrient management will help to ensure that the minimum amount of manure necessary (i.e. the amount that can be used by the growing crop) is spread onto the receiving fields. Transport risks associated with manure applied to agricultural land can be managed by establishing suitable spreading setback distances from water bodies or streams, establishing buffer strips around water bodies, and avoiding application to sloping land, particularly when the soil is wet and rain is expected soon after application.

Efforts to minimize soil water erosion on lands receiving manure will also reduce transport of coliforms to adjacent surface water. Practices that reduce the amount of manure per animal production unit, such as improved feeding strategies and manure handling practices that stabilize stored manure (e.g. composting) will reduce the coliform population and thus the risk of water contamination by coliforms from livestock production. Retention ponds can be constructed directly downstream from feedlots or manure storage areas to capture and neutralize coliforms (through the effect of ultraviolet light from sunlight) before the water is used on-farm as irrigation water. Artificial **wetland** areas on farms can perform this function. In cases where manure must be stored prior to spreading, storage facilities must be designed and maintained so as to prevent overflow and leakage.

Over the years, there has been an intensification of animal production operations, both with respect to the size of individual farms and the density of operations within a given region. Under these conditions, where the nearby land base is too small to sustainably spread the manure and where longer distance transport is not economically viable, strategies to reduce the microbial loads in manure become more important. For example, the increasing costs of energy and **inorganic** fertilizer could result in increased adoption of advanced manure management techniques such as biogas digesters and slurry fractionation that stabilize manures and capture nutrients.

IROWC-Coliform identifies the regions where the risk of water contamination by fecal material is high. A detailed analysis of the IROWC-Coliform components and the agricultural activities of these high-risk regions could reveal regional characteristics responsible for the high risk. Depending on the recurrence of such regional characteristics, research or intervention priorities can be put in place to mitigate the risk.

A sensitivity analysis of the IROWC-Coliform results could potentially identify which component has the greatest impact on the indicator's final risk value. Various beneficial management practices (BMPs) could then be suggested as potential ways to mitigate the situation. However, some BMP options involve a high cost in terms of the loss of cultivated land or increased labour and other farm expenses. Research should focus on ways to make BMPs more acceptable at the farm level by providing an economic benefit to offset the cost of implementation. For example, the establishment of **riparian buffer strips**, while costly, might be offset by using plant species that have a market value, such as switchgrass, shrubs and trees.

References

American Society of Agricultural Engineers (ASAE), 2003. *Manure production and characteristics.* ASAE D384.1 FEB03.

Canadian Dairy Commission, 2012. *Production*. Retrieved from the Canadian Dairy Commission website http://www.cdc-ccl.gc.ca/CDC/index-eng.php?id=3801

Himathongkham, S., S. Gahari, H. Riemann, and D. Cliver, 1999. *Survival of escherichia coli O157 :H7 and salmonella typhimurium in cow manure and cow manure slurry.* FEMS Microbiology Letters. 178: 251-257.

Statistics Canada, 2013. Snapshot of Canadian Agriculture in: *2011 Farm and Farm Operator Data*. Retrieved from the Statistics Canada website http://www.statcan.gc.ca/pub/95-640-x/2011001/p1/p1-03-eng.htm#VII

van Bochove, E., E. Topp, G. Thériault, J.-T. Denault, F. Dechmi, A.N. Rousseau, and S.E. Allaire, 2010a. Coliforms. In: Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds.). *Environmental sustainability of Canadian agriculture: Agri-Environmental indicator report series, Report #3*. Ottawa, ON, Canada: Agriculture and Agri-Food Canada; p. 94 -100.

van Bochove, E., G. Thériault, J.-T. Denault, F. Dechmi, A.N. Rousseau, and S.E. Allaire, 2010b. Phosphorus. In: Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds.). *Environmental sustainability of Canadian agriculture: Agri-Environmental indicator report series, Report #3.* Ottawa, ON, Canada: Agriculture and Agri-Food Canada; p. 87-93

14 Pesticides

Authors:
P. Gagnon, C. Sheedy, A. Farenhorst, A.J. Cessna, N. Newlands and D.A.R. McQueen

Indicator Name:
Indicator of the Risk of Water Contamination by Pesticides

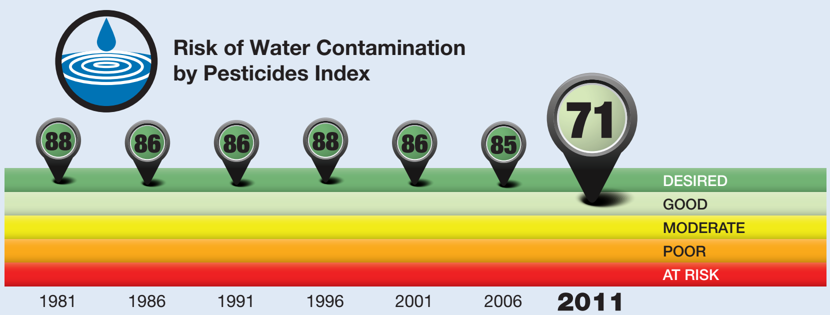
Status:
National Coverage, 1981 to 2011

Summary

Pesticides[1] are applied to crops to prevent damage and yield losses caused by weeds, insects and diseases. However, pesticides may move from agricultural land to the broader environment and adversely affect aquatic **ecosystems** and drinking water quality. The Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest) has been developed to evaluate the relative risk of water contamination across agricultural areas in Canada. It can be used to assess the inputs of pesticides to **crop**

Risk of Water Contamination by Pesticides Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign single values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of the environment from the standpoint of the risk of water contamination by pesticides on farmland in Canada was ‘Good’. The index illustrates a downward trend, representing increased risk to water quality. From 1981 to 2001, the overall risk remained stable, with about 90% of Canadian cropland in the *Low* or *Very low* risk category. By 2011, however, the level of risk had increased (as shown by a steep decline in the index values), with several areas moving into higher risk classes. From 1981 to 2011, the level of risk increased on 50% of agricultural land, primarily due to an increase in the area treated with pesticides. Much of this increase took place between 2006 and 2011, owing to a shift to cropping systems requiring greater use of pesticides such as reduced tillage systems and, to a lesser extent, to wet weather in the Prairies and the Maritimes in 2010.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section. More information on how performance indices are calculated can be found in Chapter 2 “Assessing the Environmental Sustainability of the Agri-Food Sector.”

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

land and the amounts of pesticide transported to surface waters and **ground water**, based on pesticide physical-chemical properties, soil and landscape characteristics, and climate. It is also used to assess the broad-scale *state* and *trend* of the risk of water contamination by pesticides within the Canadian agricultural landscape.

In 2011, 71% of total cropland was considered to be at *Low* or *Very low* risk. Risk is considered to be low in the Prairies; while this region has the highest percentage of agricultural land treated with herbicides and fungicides, the normally dry Prairie climate means that there are fewer days with **runoff** and fewer pesticide applications per year. From 1981 to 2011, the risk of water contamination by pesticides increased for 50% of cropland across the country. The risk remained stable for 46% of cropland and decreased for only 4%. The increase in risk observed between 2006 and 2011 was caused by an increase in the area treated with pesticides, compounded by wetter-than-usual weather in the Maritimes and the Prairies. The highest risk increase from 2006 to 2011 occurred in the Prairies, largely due to a doubling of the area treated by fungicides (from 3.7 to 7.5%) during that period. The area treated with herbicides and insecticides also increased in the Prairies over this time period, with an increase of 7% for herbicides (from 33 to 35.1%) and 47% for insecticides (from 2.6 to 3.7%). This is likely related to increased use of **reduced tillage** systems on the Prairies, which are more prone to fungal disease as well as insect and plant pests. The prospect of improved crop quality and yields, as well as increased commodity prices, may have also contributed to the rise in pesticide usage.

The Issue and Why it Matters

Pesticides help agricultural producers reduce losses caused by weeds, insects and plant diseases, enabling a greater diversity of crops to be grown on existing farmland. Pesticide usage has been increasing in Canada. According to Health Canada's Pest Management Regulatory Agency (PMRA), pesticide sales (based on weight of active ingredients) increased by 13.9% between 2008 and 2010 (Health Canada, 2008; Health Canada, 2010).

Pesticides are generally classified by target organism, with some of the best-known categories being fungicides, herbicides and insecticides. While most pesticides are formulated to target a specific pest organism, the active ingredients found in some products may also cause unintentional harm to non-target species, which can become exposed when pesticides move from on-farm application sites into the surrounding environment and contaminate surface waters and ground water. Pesticide residues have been detected in surface waters and ground water in monitoring studies conducted in various regions of Canada (e.g. Cessna et al., 2005) raising concerns for potential adverse effects on aquatic and terrestrial species as well as on drinking water quality.

Canada has a rigorous pesticide approvals process, managed by Health Canada's PMRA, which registers and re-evaluates the use of products in agriculture and for other purposes. Canada has put in place water quality guidelines to protect aquatic life and ensure the safety of drinking water and water used for recreation. However, maximum acceptable concentrations for drinking water have been established for only a few agricultural pesticides, as these limits are only developed following detection of the chemical at multiple water quality monitoring locations across Canada and not as part of the registration process. There are approximately 400 different pesticide active ingredients and approximately 7,600 pesticide products (trade names) registered for use in Canada (BC Agriculture, 2014). Because of the number of active ingredients currently in use, there is wide range of **toxicity** among pesticide products, and this toxicity is determined not only by the specific chemistry of the ingredients, but also by the level, duration, and frequency of exposure to such products, either individually or in combination.

How easily pesticides move into the broader environment also depends on various factors, including the method of application and climatic variables. For example, during application a portion of the pesticide may be lost to the atmosphere due to application drift, and while it has been estimated that pesticide drift from ground application can account for 1% to 5% of the amount applied, losses from aerial application can be significantly larger (Felsot et al., 2010). Several physical, chemical and biological processes are involved in determining the extent of pesticide transport by wind or water from the application site to other parts of the

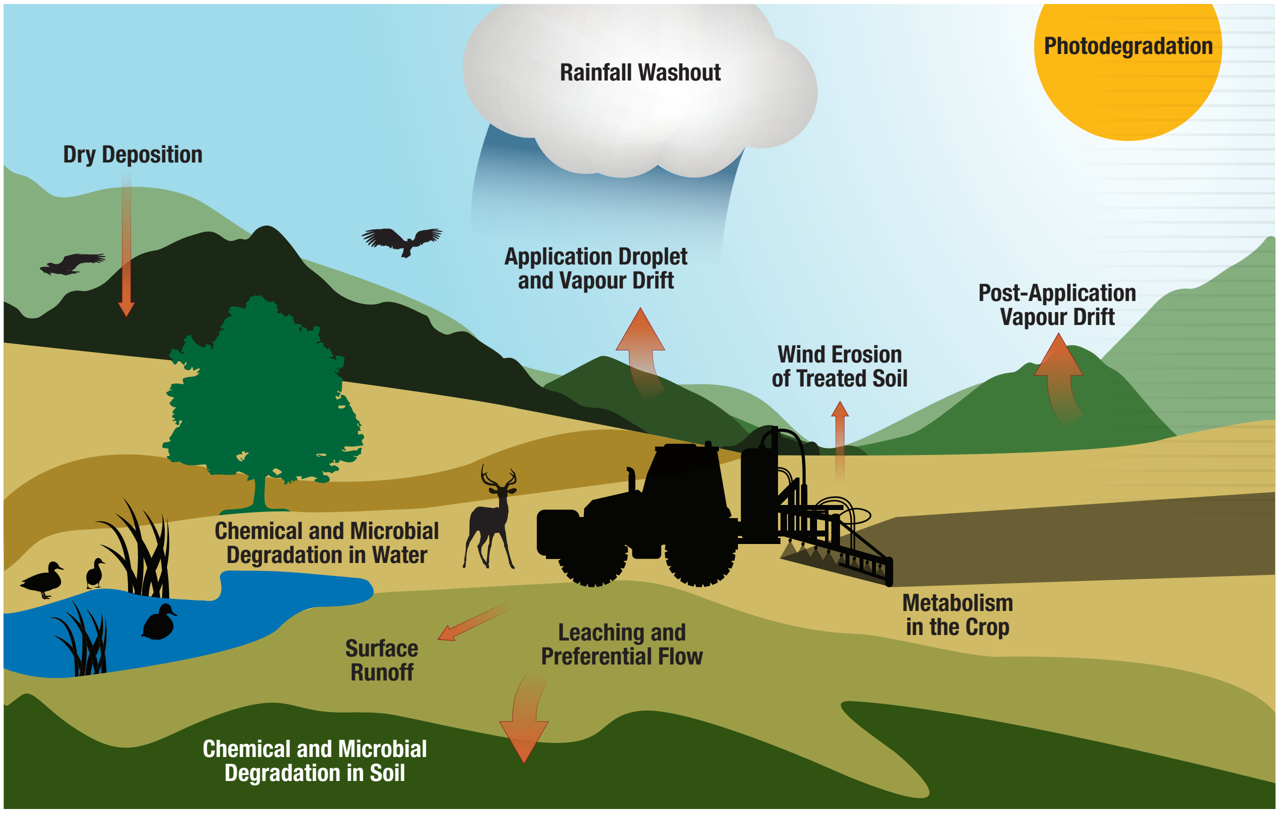


Figure 14–1: Processes involved in the movement of pesticides from the application site (Cessna et al., 2005)

ecosystem (Figure 14–1). In addition to the potential environmental impacts, whenever pesticides are lost to the environment, there is an economic impact for producers. First, the "lost" pesticide is not serving the intended purpose of protecting crops from weeds, insect pests and diseases, resulting in increased crop losses due to pests. Second, the cost associated with purchasing and applying the pesticide that is lost represents a direct economic loss to producers.

In addition to the increase in pesticide use areas, it is likely that in some instances, and for certain crops, larger quantities of pesticides (in kilograms of active ingredient) are being applied. For example, the introduction of **genetically modified** crops with herbicide resistance has resulted in more extensive use of the herbicide glyphosate. Sales of glyphosate, in kilograms of active ingredient, have increased year over year in Canada since Health Canada released its first report on pesticide product sales in 2008. Between 2008 and 2011, glyphosate sales increased by 24% (Health Canada, 2014). This increase has been offset by a decrease in the use of those herbicides that were previously applied to similar crops that did not have the glyphosate-resistant trait. The uses of some **systemic pesticides** have also been debated. While systemic pesticides provide increased protection because the pesticide can move from the site of application to untreated plant parts, this could result in increased risks to pollinators and non-target organisms of the food chain, particularly since some pesticides are persistent and have long **residence times**.

Producers in Canada and worldwide are exploring **integrated pest management** (**IPM**) systems (see text box "What is Integrated Pest Management (IPM)?" in the Response Option section of this chapter) and alternatives to pesticides that include biological and mechanical control methods and **beneficial management practices** (**BMPs**). These and other approaches aim to make pesticide use and application methods more efficient, reducing pesticide use per unit of crop production. Other options for agricultural pest control are discussed in the response options section at the end of this chapter.

The Indicator

The Indicator of the Risk of Water Contamination by Pesticides (IROWC-Pest) assesses the relative risk of water contamination by agricultural pesticides in Canada. It is responsive to changes in management practices that affect pesticide use and to pesticide transport in surface runoff and water infiltrating into the soil. The indicator uses the Pesticide Root Zone Model (PRZM) (Suarez, 2005) to estimate the amount of pesticides moving in water into the surrounding environment. Input data from several sources are used in the model: agricultural practices (e.g. crops grown, area treated by pesticides, tillage practices, irrigation) from the Statistics Canada **Census of Agriculture**; pesticides applied to each crop and national averages estimated from a commercially available database of national pesticide use (© Kynetec Limited, United Kingdom); pesticide chemical properties, from the Pesticide Properties Database (PPDB, 2013); soil-landscape properties (e.g. organic **carbon** content, field capacity, **hydraulic conductivity**) from the Soil Landscapes of Canada Working Group (2010); and daily weather data interpolated on a 10-km grid.

Simulations are conducted at the **Soil Landscape of Canada** (**SLC**) **polygon** scale (Soil Landscapes of Canada Working Group, 2010). In order to improve on the previous model (Cessna et al., 2010), a separate model was developed to generate the PRZM input parameters from several scenarios of probable pesticide application and management (Gagnon et al., 2014). The refinements entailed the generation of 100 different scenarios for each SLC polygon and for each Census year, providing a more reliable and accurate range of outcomes. This has reduced the impact of the uncertainty in the input data, and consequently made the model more robust. As a result of these improvements, risk of water contamination by pesticides for all previous Census years has been recalculated. In the event of a discrepancy between the findings in this report and the previous Agri-Environmental Indicator Report (Eilers et al., 2010), this latest report should be used.

For each simulated scenario, the annual mass and concentration of pesticides are calculated for both surface runoff and water infiltrating into the soil to a depth of one metre. The pesticides in surface runoff are in both the dissolved and particulate phases, whereas pesticides moving through the soil to the ground water are only in the dissolved phase. Because more than one pesticide may be applied on a given site, the masses and concentrations that are calculated are the sum of all pesticides applied. (Differences in pesticide toxicity are not considered in the calculations.) The median values for each SLC polygon and each year are taken from the 100 scenarios that are run.

Five classes of risk are defined on the basis of both the annual pesticide concentration and the annual mass of pesticide transported in water (Table 14–1). Because Canada has not established a water quality guideline value for pesticide mixtures, the maximum acceptable concentration of 0.5 µg/L established by the European Union for pesticide mixtures in drinking water was used (European Union, 1998). Both concentration and mass transported are grouped in classes, as shown in Table 14–1, and the highest calculated risk ranking between surface runoff and ground water is assigned to each SLC polygon. Only SLC polygons containing at least 5% cropland were considered in any given Census year.

Table 14–1: IROWC-Pest risk classes, based on the mean concentration of pesticides in water and the total amount of pesticides transported

	Pesticide Transported (g/ha)				
Concentration (µg/L)	< 0.5	0.5 – 1.0	1.0 – 2.0	2.0 – 4.0	> 4.0
< 0.5	Very Low	Very Low	Low	Moderate	High
0.5 – 1.0	Very Low	Low	Moderate	High	Very High
> 1.0	Low	Moderate	High	Very High	Very High

IROWC-Pest risk classes

- Very High
- High
- Moderate
- Low
- Very Low

Limitations

The PRZM is a one-dimensional model, which means that the simulation only considers the vertical movement of chemicals in the soil layer. The estimates of pesticide concentration and the mass of pesticide transported in surface runoff are edge-of-field values and therefore not representative of the corresponding levels in the surrounding environment. The estimated concentrations are significantly higher than the actual concentrations found in streams, given that significant dilution occurs when runoff enters surface waters. As a result, the estimated concentrations cannot be directly compared with the values reported in monitoring studies. IROWC-Pest should be used as a relative indicator to estimate the spatial distribution of risk of water contamination by pesticides and the change in this risk over time, not as a predictive estimate of the concentration expected in the environment.

Most of the input data are only available from field measurements at a coarser scale than SLC polygons; some input data required for the model were estimated based on expert advice. While the areas treated with pesticides in each SLC polygon are identified in the Census of Agriculture, data on the pesticide products used and the amounts involved are not available at this scale. For this reason, a **stochastic modelling** approach was used.

Pesticide transport processes such as **preferential flow** (which affects water and pesticide movement in the soil), spray drift and direct **atmospheric deposition** to surface water require data at a finer spatial scale than that of the SLC polygon. Consequently, these potentially important processes are not considered in the current version of the indicator.

The pesticide-use data that were employed in calculating the indicator value for 2011 were from the recent past (2002–2009), and it was assumed that crop-specific use was consistent from 1981 to 2011, although pesticide chemistry and application practices likely changed during that period. The chemical properties of pesticides significantly influence their transport and degradation in the environment. Therefore, IROWC-Pest estimates for the earlier Census years, for which no pesticide product and rate data were available, must be considered highly uncertain. Furthermore, because differences in pesticide toxicity are not considered in the IROWC-Pest model, no direct interpretations can be made concerning toxicity risk or the impact of changing pesticide chemistry on temporal trends in toxicity risk.

Results and Interpretation

For more than 99% of the SLC polygons across Canada, the risk of ground water contamination, evaluated on the basis of the mass and concentration of pesticides in infiltrating water at a depth of one metre, was *Very low* for the entire 30-year period under study. The risk of ground water contamination was lower in infiltrating water at a depth of one metre than in edge-of-field runoff. Thus, the overall IROWC-Pest value assigned to each SLC polygon almost always represented the risk calculated for edge-of-field surface runoff.

In 2011, 71% of total cropland was considered to be at *Low* or *Very low* risk (Figure 14–2). Small areas at *Very High* risk, representing 7% of cropland, were located on Prince Edward Island and in the Mixedwood Plains regions of Ontario and Quebec, the Red River region of Manitoba, the Parkland region of Alberta, and the Lower Fraser River Valley region of British Columbia. It should be noted that none of the SLC polygons for Newfoundland and Labrador had more than 5% cropland; hence, the level of risk was not calculated for this province.[2]

2 Similarly, no data for Newfoundland and Labrador were considered in Figure 14–3: Area treated with herbicides, insecticides and fungicides, or Figure 14–4: Average number of days with surface runoff. For both these graphics, the Maritimes refers to the provinces of New Brunswick, Nova Scotia and Prince Edward Island.

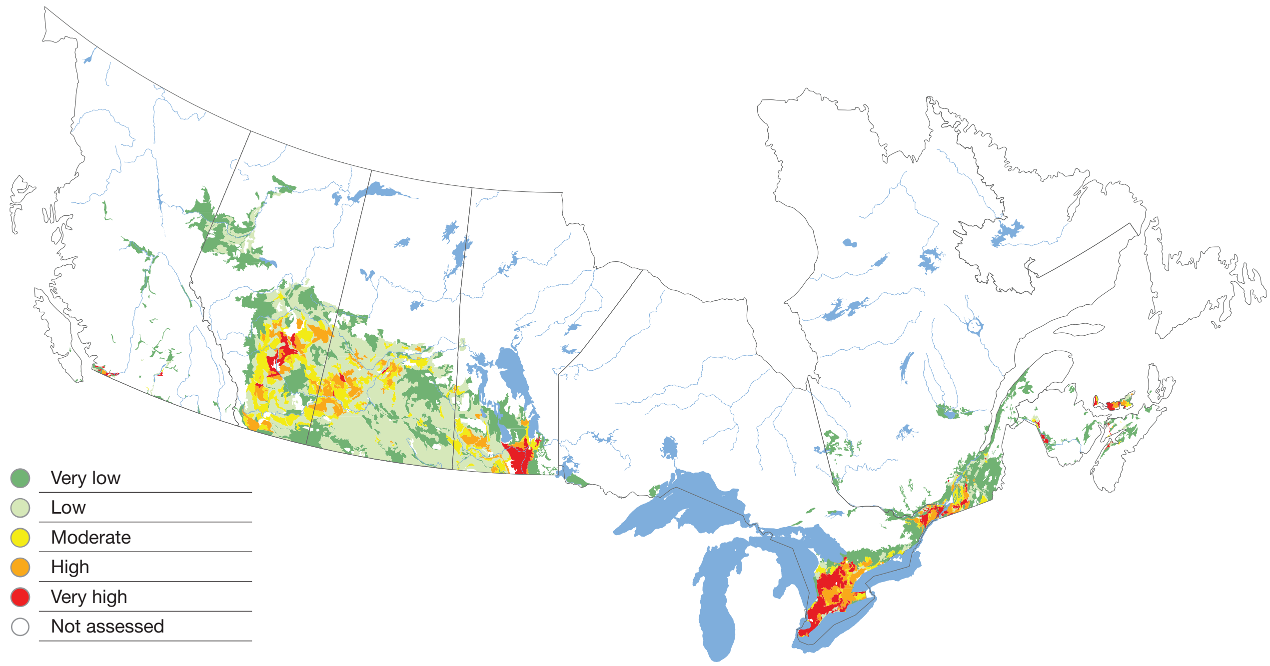
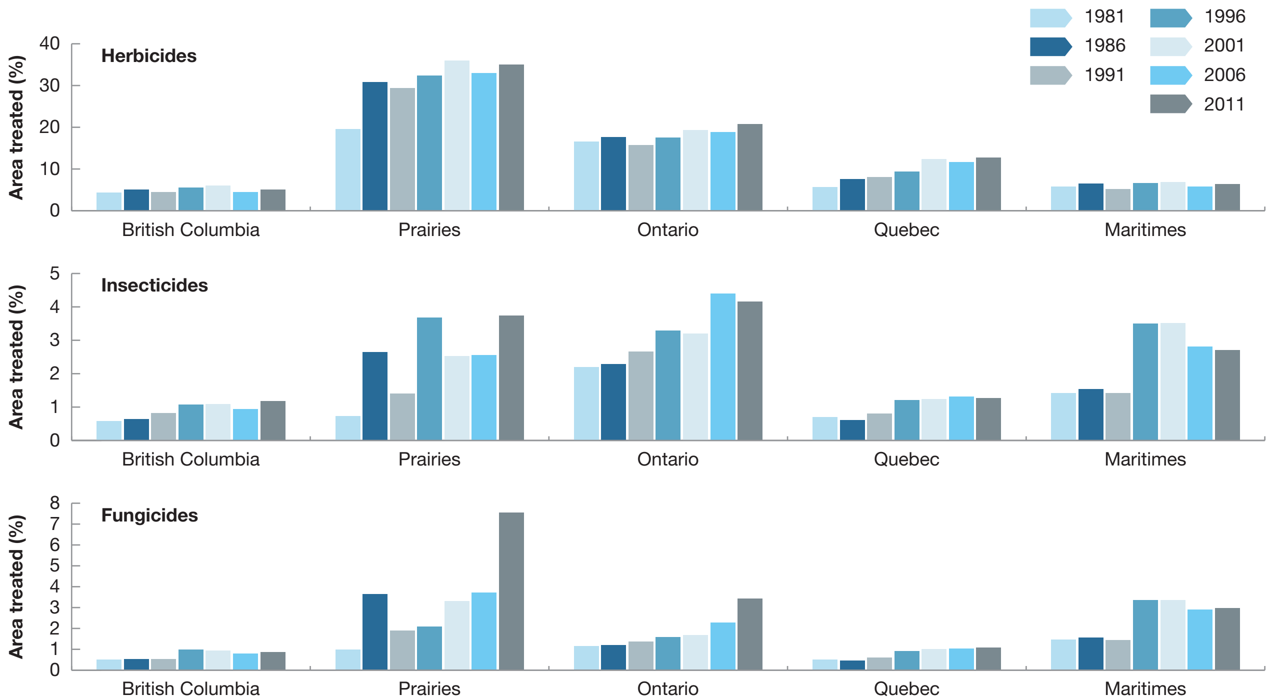


Figure 14–2: Relative risk of pesticide contamination of water on cropland under management practices in 2011

The risk of water contamination by pesticides is likely to be high if both a large amount of pesticides is available to be transported and there is an effective means of transport. The amount of pesticides available depends in part on the size of the area treated with pesticides. Figure 14–3 shows the percentage of agricultural land area treated with pesticides for all Census years since 1981, by region for the Prairies (Alberta, Saskatchewan, and Manitoba) and the Maritimes (New Brunswick, Nova Scotia, and Prince Edward Island), which have been grouped based on similarities of climate and agricultural activities, or by province (British Columbia, Ontario, and Quebec). The Prairie region has the highest percentage of agricultural land treated with herbicides and fungicides, and Ontario, the Prairies and the Maritimes have the highest percentage of agricultural land treated with insecticides.

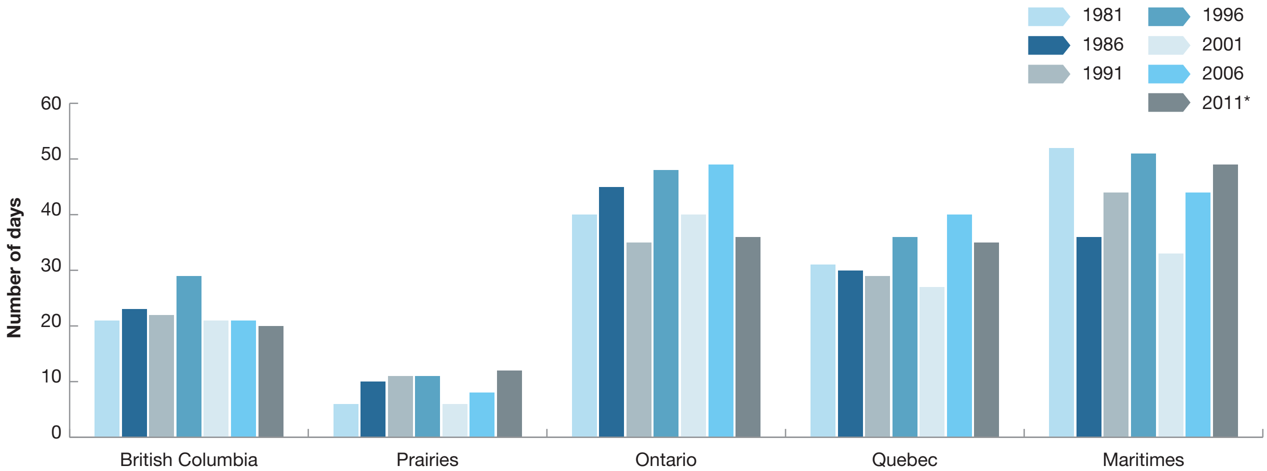
Figure 14–3 shows the percentage of agricultural land (percentage of agricultural SLC polygons) treated with different types of pesticides. It does not, however, provide information on the number of pesticide applications made each year, which depends partly on crop type and climatic conditions and hence can vary among regions across Canada. For example, because fruits are so vulnerable to insect infestations, fruit production usually requires more frequent insecticide applications than field crop production. In addition, more fungicide applications are generally required in wetter climates to control a given crop disease (Bloomfield et al., 2006). British Columbia is characterized by two distinctly different agricultural regions, with high pesticide application rates in the Lower Fraser River Valley region, where the climate is wetter and fruit production is predominant, and very low rates in the drier northern agricultural regions, which are dominated by field crop production systems and pasture land.



* The large increase in area treated by insecticides and fungicides in the Maritimes between 1991 and 1996 is likely an artifact from different data sources between these years.

Figure 14–3: Area treated with herbicides, insecticides and fungicides (% of agricultural SLC polygons)

Surface runoff is an important means of transport for pesticides. Surface runoff occurrence and intensity depend mainly on the amount of precipitation and the soil moisture content when precipitation occurs. Soil moisture content is influenced by precipitation frequency, duration and intensity, by soil texture, and by farm management practices such as the type of crop grown and tillage practices. As shown in Figure 14–4, the average number of days with surface runoff in a given year, as estimated by the PRZM model, is highest for the Maritimes (annual average of 44 days) and Ontario (42 days), followed by Quebec (32 days), British Columbia (22 days) and the Prairies (9 days).



* Weather data from 2010 are used for 2011 simulations.

Figure 14–4: Average number of days with surface runoff

The dry climate characterizing the Prairies, leading to a low number of days with runoff and fewer pesticide applications per year (Bloomfield et al., 2006), explains why much of the Prairies cropland was at *Low* or *Very low* risk, despite the fact that a large area of land is treated with pesticides (Figure 14–3). *High* and *Very high* risk areas are present in some wetter regions, such as the Red River Valley region of Manitoba, where water infiltration into soils is slow and surface runoff is a primary transport mechanism for herbicides in eroded sediments; and the Parkland region of Alberta, where crops requiring greater pesticide use are common. Regions of *High* to *Very high* risk are found in every province, in areas characterized by wetter climatic conditions and production systems requiring significant pesticide use. This is the case on Prince Edward Island and in the Mixedwood Plains regions of Ontario and Quebec.

From 1981 to 2011, the risk of water contamination by pesticides increased for 50% of cropland across the country (Figure 14–5). The risk remained stable for 46% of cropland and decreased for only 4%.

The change in relative risk from 1981 to 2011 is detailed for each province in Table 14–2. Because of the improvements in the IROWC-Pest methodology described above, the values and trends shown here for past Census years differ significantly from those reported in the last Agri-Environmental Indicator Report (Eilers et al., 2010).

At the national scale, the risk of water contamination by pesticides was relatively stable from 1981 to 2001. From 2001 to 2006, there was a shift of about 10% of cropland from the *Very low* risk class to the *Low* risk class, whereas the other classes remained stable. The largest changes occurred between 2006 and 2011. During that period, the cropland area in the *Very low* risk class decreased from 55% to 35%, while the cropland area in the three highest risk classes increased as follows:

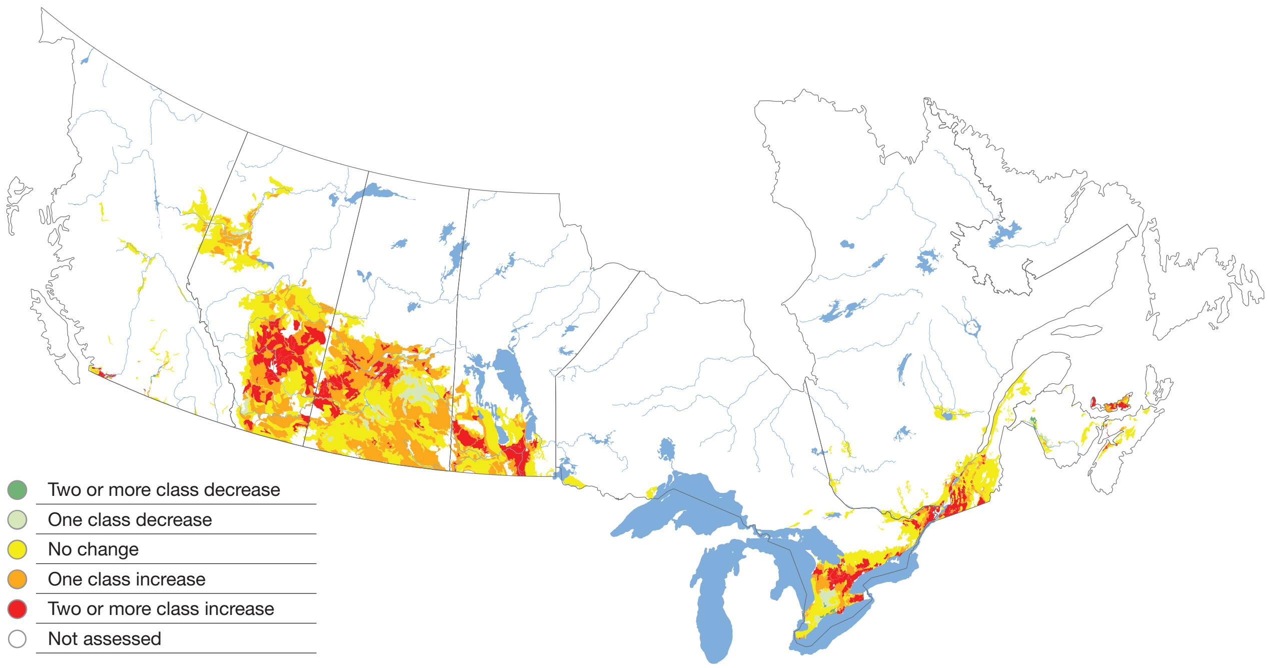


Figure 14–5: Change in IROWC-Pest risk class from 1981 to 2011

cropland area in the *Moderate* risk class rose from 4% in 2006 to 12% in 2011; cropland area in the *High* risk class rose from 3% to 10%; and cropland area in the *Very high* risk class rose from 3% to 7% (Table 14–2).

In general, the increases in risk observed in 2006 and 2011 were caused by an increase in the area treated with pesticides (Figure 14–3), compounded by variations in seasonal weather (Figure 14–4). On the Prairies, the increase in the use of fungicides (from 3.7% to 7.5% of the land area) can be attributed to wetter-than-usual weather in 2010 and the shift to reduced tillage systems, both of which increase the risk of fungal diseases such as fusarium blight. When compared to **conventional tillage**, reduced tillage also entails increased herbicide use for weed control and a higher reliance on insecticide use to combat insects and pests (for example slugs or wireworms which can overwinter in the crop residue). The area treated with herbicides and insecticides increased in the Prairies over this time period, with an increase of 7% for herbicides (from 33 to 35.1% of the land area) and 47% for insecticides (from 2.6 to 3.7% of the land area). Another factor that may have contributed to the increase in pesticide use per unit cropland in recent years is the expansion of land devoted to glyphosate-tolerant canola, soybeans and corn and the mass of glyphosate applied in these systems.

Table 14–2: Percentage of farmland in each risk class of water contamination by pesticides[3], 1981 to 2011

Class	Very low							Low							Moderate							High							Very high						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	90	87	70	85	75	83	79	6	8	19	3	13	6	10	2	3	8	3	7	2	1	1	1	0	9	2	5	2	1	1	3	1	4	5	7
Alberta	73	79	72	76	62	46	34	25	19	25	21	38	50	33	3	3	3	2	0	4	19	0	0	0	0	0	1	10	0	0	0	0	0	0	4
Saskatchewan	63	56	54	67	73	47	23	37	44	44	31	27	50	61	0	1	2	2	0	2	9	0	0	0	0	0	0	7	0	0	0	0	0	0	0
Manitoba	53	59	28	54	26	80	31	32	27	31	28	34	19	33	14	12	18	15	15	1	13	2	2	15	4	8	0	11	0	0	8	0	18	0	12
Ontario	57	49	68	49	59	54	38	7	10	5	10	9	12	9	7	6	10	8	9	3	12	12	10	12	10	10	14	18	16	25	5	22	13	17	24
Quebec	96	86	97	92	88	77	75	2	6	2	2	7	7	10	2	3	1	3	1	9	7	1	2	0	2	2	4	5	0	2	0	1	1	3	3
New Brunswick	38	66	37	37	71	71	64	28	5	29	7	0	4	1	0	0	0	28	0	0	10	9	14	5	0	22	24	0	26	15	29	29	7	0	24
Nova Scotia	93	82	86	82	88	85	78	4	8	5	0	0	3	9	2	4	1	5	6	5	1	0	0	1	0	5	4	0	1	6	7	13	2	3	11
Prince Edward Island	70	65	51	47	81	35	35	8	0	13	4	10	0	13	7	13	12	20	8	17	10	15	21	18	1	1	27	14	1	1	6	28	0	21	28
Newfoundland and Labrador	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Canada	**67**	**65**	**62**	**68**	**64**	**55**	**35**	**25**	**25**	**27**	**22**	**26**	**36**	**36**	**4**	**4**	**5**	**5**	**3**	**4**	**12**	**2**	**2**	**4**	**2**	**3**	**3**	**10**	**3**	**4**	**2**	**4**	**4**	**3**	**7**

3 This table includes only SLC polygons that had at least 5% of cropland area in each Census year from 1981 to 2011. Due to rounding, numbers may not sum to exactly 100%.

Response Options

Strategies for reducing the risk of water contamination by pesticides include reducing the risk of pesticide transport to surface water or ground water, decreasing the amount of pesticide used and reducing the persistence or mobility of the active ingredients.

Because surface runoff and spray drift are important pesticide transport mechanisms, it is critical that pesticides only be applied in suitable weather conditions with the recommended application techniques. Local spray advisory forecasts provide helpful guidance for producers in this regard. **Beneficial management practices** (**BMPs**) that reduce runoff or soil erosion, or increase **soil organic matter** content, help to reduce pesticide transport. These include **riparian buffers**, **contour farming**, **strip cropping**, and reduced tillage or **zero tillage** systems. It should be noted, however, that herbicide use and in many cases, insecticide and fungicide use, typically increases with reduced tillage and zero tillage, which may offset the pesticide-related benefits of the reduction in runoff associated with this practice. Other practices that can help reduce pest pressure include crop rotation and the planting of resistant crop varieties. According to Statistics Canada's Farm Environmental Management Survey (FEMS), in 2011, 59% of producers used crop rotations to control pests (Statistics Canada, 2013). An integrated approach to environmental risk management is required in order to assess all the environmental benefits and risks associated with a given practice.

In addition, an integrated pest management approach (see text box "What is Integrated Pest Management (IPM)?"), which combines the use of cultural, biological and chemical control measures, can reduce the need for chemical pesticides.

Canada is a large country with a broad range of climatic and physiographic conditions, and a wide range of agricultural production systems and practices. This diversity of practices, together with uncertainties stemming from complex, location-specific natural processes, makes it challenging to evaluate the risk of water contamination by pesticides. Since agricultural production is constantly evolving, it is important to periodically evaluate the risk of water contamination by pesticides. New pesticide products are continually being developed, a situation that can lead to changes in the active ingredients used and levels of toxicity. In light of these compounding factors, a robust methodology based on an **agro-ecosystem** perspective is required to reliably assess changes in risk across space and time. Ongoing research aimed at developing pesticide-specific BMPs, pest-resistant crops and pesticides with active ingredients that are environmentally less persistent and less mobile will help advance efforts to reduce the risk of water contamination by pesticides.

What is Integrated Pest Management (IPM)?

By Leslie Cass, Pesticide Risk Reduction Program, AAFC

IPM involves the deliberate application of a combination of approaches or techniques to avoid, mitigate, or manage pests while minimizing non-target impacts. A comprehensive IPM program may involve the use of the following:

- cultural techniques and sanitation practices (such as washing soil off equipment when moving from a nematode-infested field to one that isn't infested, or plowing under infected plant residues) to prevent the development of or suppress harmful organisms;
- resistant cultivars or certified disease-free seed;
- practices to protect and enhance natural enemies and other beneficial organisms;
- scouting and monitoring of crops for the presence of harmful organisms;
- forecasting systems to inform pest management decisions;
- mechanical methods or biological control measures (e.g. **biopesticides**, natural enemies) when pest pressure reaches the threshold for action; and
- chemical pesticides, which are employed as a last resort, taking into account resistance management concerns and strategies to mitigate impacts on non-target organisms and habitat.

The goal of an IPM program is not the eradication of pests; rather the aim is to produce healthy crops by using environmentally sound approaches to keep pest damage at an economically acceptable level.

Like their counterparts in other countries, Canadian growers must deal with various challenges, including the deregistration of pest control products, resistance development in pest populations, incursions of **invasive alien species**, and concerns about pollinator species. Growers are increasingly turning to IPM to address these issues. For example, the Kootenay area of British Columbia has achieved international recognition for its approach to the management of apple codling moth, a major insect pest of apples throughout North America and Europe. Under a sterile insect release program, all area farmers and urban residents participate in a mating disruption strategy (biological control measure) which, together with other IPM methods, has kept codling moth damage below economically significant thresholds for more than 10 years. This approach helped to reduce organophosphate insecticide use by as much as 93% between 1991 and 2008.

References

Bloomfield, J.P., R.J. Williams, D.C. Gooddy, J.N. Cape, and P. Guha, 2006. *Impacts of climate change on the fate and behaviour of pesticides in surface and groundwater—A UK perspective*. Science of the Total Environment. 369: 163-177.

British Columbia Ministry of Agriculture (BC Agriculture), 2014. *About Pesticides*. Retrieved on July 9, 2014 from http://www.agf.gov.bc.ca/pesticides/a_3.htm

Cessna, A.J., C. Sheedy, A. Farenhorst, and D.A.R. McQueen. 2010. *Chapter 15, Pesticides.* Pages 101–107 in Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds.), 2010. Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series - Report #3. Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

Cessna, A.J., T.M. Wolf, G.R. Stephenson, and R.B. Brown, 2005. *Pesticide movement to field margins: Routes, impacts and mitigation*. In: Field boundary habitats: Implications for weed, insect and disease management. A.G. Thomas (ed.), 69-112. Sainte-Anne-de-Bellevue, QU, Canada: Canadian Weed Society/Société canadienne de malherbologie.

Eilers, W., R. MacKay, L. Graham, and A. Lefebvre (eds.), 2010. *Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series — Report #3.* Ottawa, ON, Canada: Agriculture and Agri-Food Canada.

European Union, 1998. Council Directive 98/83/EC on the quality of water intended for human consumption. *OJ L* 330**:** 5.12.1998, 32-54.

European Union, 1998. Drinking Water Directive 98/83/EC, Official Journal L 330, 05/12/1998 32-54

Felsot, A.S., J.B. Unsworth, J.B. Linders, G. Roberts, D. Rautman, C. Harris, and E. Carazo. 2010. *Agrochemical spray drift; assessment and mitigation—A review.* Journal of Environmental Science and Health Part B: Pesticides, Food Contaminants, and Agricultural Wastes. 46(1): 1-23.

Gagnon, P., C. Sheedy, A. Farenhorst, D.A. McQueen, A.J. Cessna, and N.K. Newlands, 2014. *A coupled stochastic/deterministic model to estimate the evolution of the risk of water contamination by pesticides across Canada*. Integrated Environmental Assessment and Management. 10(3): 429-436.

Health Canada, 2008. *Pest control products sales report for 2007 and 2008*. Ottawa, ON, Canada. Pest Management Regulatory Agency of Health Canada.

Health Canada, 2010. *Pest control products sales report for 2010*. Ottawa, ON, Canada. Pest Management Regulatory Agency of Health Canada.

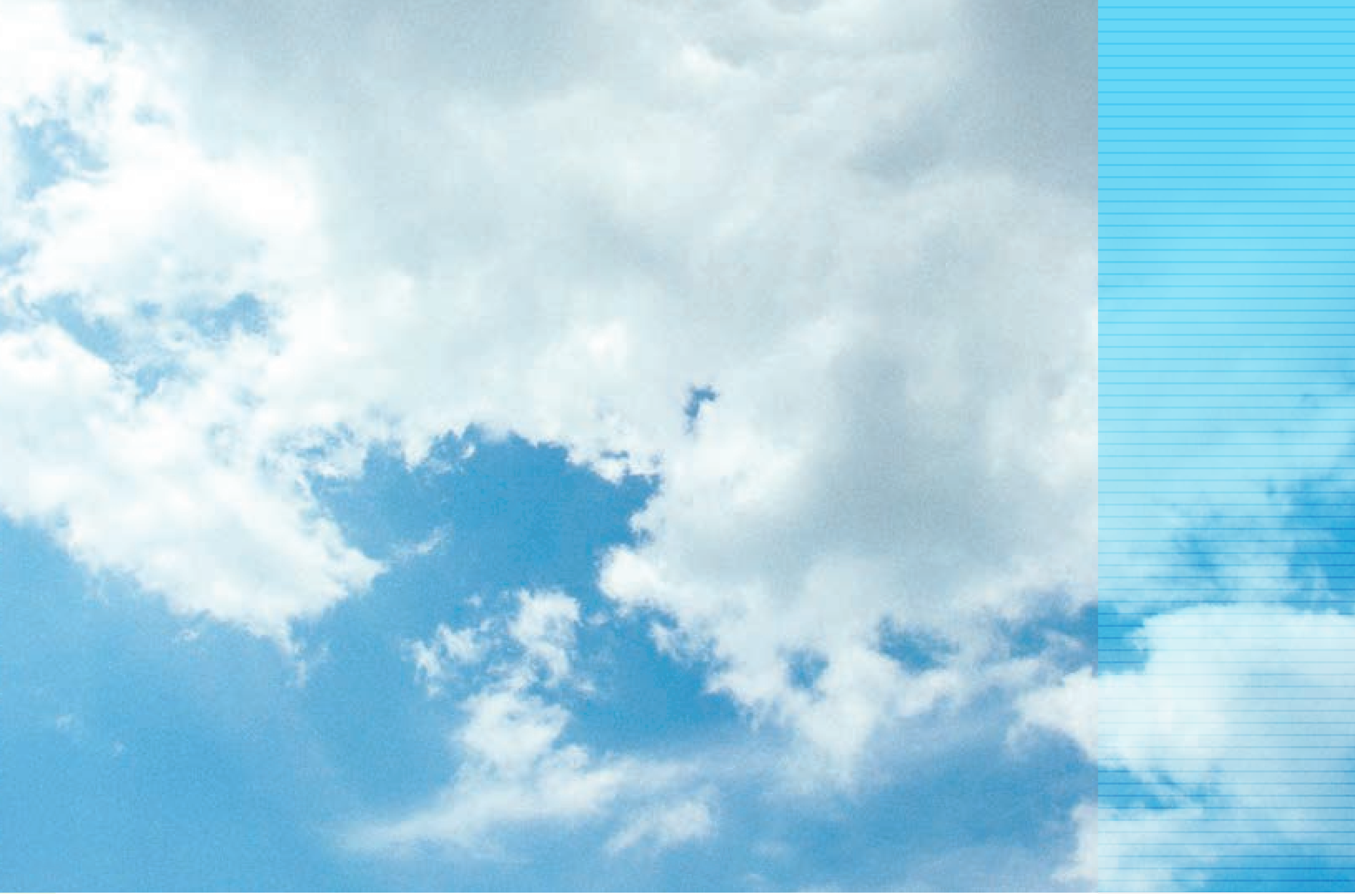
Health Canada, 2014, *Request for glyphosate information*. Email message to author, received October 7, 2014.

PPDB, 2013. The Pesticide Properties DataBase (PPDB), developed by the Agriculture & Environment Research Unit (AERU), University of Hertfordshire, funded by UK national sources and through EU-funded projects, 2006-2013.

Soil Landscapes of Canada Working Group, 2010. Soil Landscapes of Canada version 3.2. Agriculture and Agri-Food Canada. (digital map and database at 1:1 million scale) Retrieved in April 2012 from http://sis.agr.gc.ca/cansis/nsdb/slc/v3.2/index.html

Statistics Canada, 2013. *Farm environmental management s*urvey 2011. Available at http://www.statcan.gc.ca/pub/21-023-x/21-023-x2013001-eng.htm.

Suarez, L.A., 2005. *PRZM-3: A model for predicting pesticide and nitrogen fate in the crop root and unsaturated soil zones: User's manual for release 3.12.2*. EPA/600/R-05/111. Athens, GA, United States: U.S. Environmental Protection Agency, National Exposure Research Laboratory, Ecosystems Research Division. Retrieved in April 2012 from http://www.epa.gov/athens/publications/reports/Suarez600R05111PRZM3.pdf



Air Quality and Greenhouse Gas Emissions

Summary

Atmospheric emissions of **greenhouse gases**,[1] **ammonia** and **particulate matter** from agricultural activities can affect air quality and contribute to climate change.

Greenhouse gases (GHGs) perform an essential role in the atmosphere, trapping radiant energy and maintaining the earth at a temperature that can support life. However, the emission of GHGs from human activities, including agriculture, has resulted in global atmospheric concentrations that are greater than at any point in the last 800,000 years and that are likely to bring about unpredictable climatic variation (IPCC, 2013). The main GHGs emitted from agricultural activities are **nitrous oxide** (**N_2O**) and **methane** (**CH_4**). **Carbon dioxide** (**CO_2**) can be either emitted from soils or absorbed by soils and **sequestered** as soil **carbon**.

Ammonia (NH_3), a natural waste product of animal and microbial metabolism, is a colourless gas that in excessive amounts can be harmful to animals and plants. It is present in natural and managed landscapes, with agriculture contributing about 85% of all human-caused emissions to the atmosphere. It can react with other pollutants to generate secondary particles contributing to **smog** and can contribute to **eutrophication** of sensitive aquatic ecosystems. NH_3 emissions from agriculture have been increasing due to increases in **nitrogen fertilizer** use.

Suspended particulate matter (PM) decreases visibility and can affect the climate by reducing the amount of solar energy reaching the earth. It can contribute to stratospheric **ozone** depletion, acid rain, and smog formation. Inhalation of PM, particularly fine PM, is associated with adverse health effects. PM emitted from agriculture includes dust from soil and plant or animal material, bacteria and droplets or particles from agro-chemicals.

In an effort to help quantify these emissions and to assess their status and trends in relation to changes in agricultural management practices over time, three agri-environmental indicators have been developed:

1. The Agricultural Greenhouse Gas Budget Indicator (Chapter 15) provides an estimate of net on-farm emissions of nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2).
2. The Ammonia Emissions from Agriculture Indicator (Chapter 16) estimates agricultural NH_3 emissions.
3. The Agricultural Particulate Matter Emissions Indicator (Chapter 17) estimates the contribution of agricultural operations to airborne primary PM.

These indicators show mixed results with respect to the extent to which agriculture has affected air quality issues.

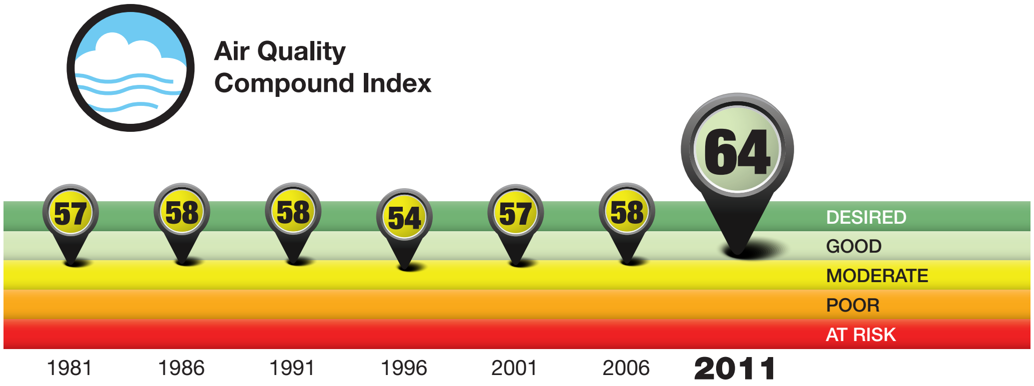
- **Agricultural Greenhouse Gases.** Between 1981 and 2011, net (emissions minus removals by soil) agricultural GHG emissions declined (by about 10%). The decline in net GHG emissions over this period is attributable mainly to the change in CO_2 emissions from agricultural soils, which went from being a small carbon source in 1981 to a **sink** by 2011. The CO_2 sink role played by agricultural soils is particularly evident in the Prairie Provinces of Canada, owing to the widespread adoption of **beneficial management practices** (**BMPs**) such as **reduced tillage** intensity, decreased **summerfallow** and, to a lesser extent, conversion from annual crops to perennial cropping systems. Emissions of N_2O and CH_4 increased by 31% and 2%, respectively, over the same period. Agricultural CH_4 emissions increased primarily as a result of growth in livestock populations up until 2006 and then declined slightly. Agricultural N_2O emissions increased primarily because of a doubling of nitrogen fertilizer use and an increase in livestock populations up until 2006. Although manure-related N_2O emissions have decreased since that time, the increase in synthetic fertilizer use has more than offset this decline, leading to an overall increase in N_2O emissions since 2006. These increases in N_2O and CH_4 were more than offset by carbon sequestration, however, with the result that this indicator has improved over time.

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each Chapter or section.

- **Ammonia.** The Ammonia Indicator has shown an improvement, with emissions falling to 1996 levels. NH_3 emissions from livestock accounted for 81% of total agricultural NH_3 emissions in 1981 and for about 74% from 1986 to 2006 before decreasing markedly in 2011 to a low of 65%. Throughout this period, emissions from fertilizer steadily increased as a result of increases in N fertilizer use. Livestock emissions decreased by 22% from 2006 to 2011 as a direct result of the decline in the beef cattle population over this period.
- **Particulate Matter.** Since 1981, there has been a dramatic improvement in particulate matter emissions Canada-wide, with a decrease of 63% for total suspended PM. This national-scale improvement came about primarily as a result of the widespread adoption of reduced tillage and **no-till**, as well as decreases in the use of summerfallow in Manitoba, Saskatchewan and Alberta.

Air Quality Compound Index

The overall trend from 1981 to 2011 for air quality is an improvement across Canada, as illustrated by the compound air quality index below.



This compound performance index is a weighted average of the performance indices reported for each of the air quality indicators discussed in the following three chapters. [2] As such, it provides a highly generalized statistical snapshot of all the results obtained for the Greenhouse Gases, Ammonia and Particulate Matter Indicators, both in terms of current state and changes over time. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector.

2 All national "core" indicators, which include Agricultural Greenhouse Gases, Ammonia and Particulate Matter, have a weighted value of 1.

15 Agricultural Greenhouse Gases

Authors:
D.E. Worth, R.L. Desjardins, D. MacDonald, D. Cerkowniak, B.G. McConkey, J.A. Dyer and X.P.C Vergé

Indicator Name:
Agricultural Greenhouse Gas Budget Indicator

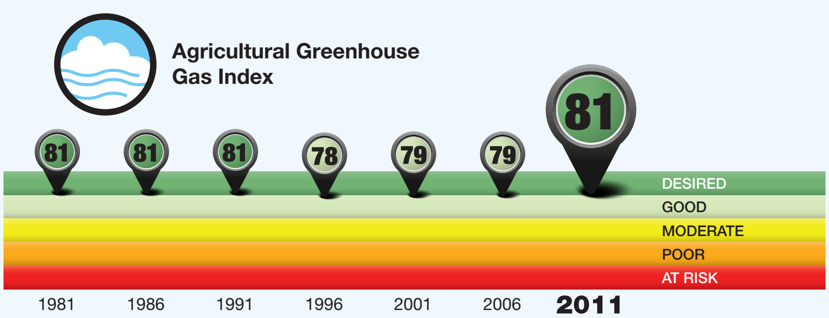
Status:
National Coverage, 1981 to 2011

Summary

Anthropogenic greenhouse gas (**GHG**)[1] emissions and the accumulation of GHGs in the atmosphere have been conclusively linked to global warming and climate change. Between 1880 and 2012, earth's mean surface temperature warmed by 0.85°C, primarily due to the increase in atmospheric GHG concentrations

Agricultural Greenhouse Gas Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign single values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of the environment from the standpoint of greenhouse gas emissions resulting from farming activities in Canada was 'Desired'. The index illustrates a relatively constant trend since 1981, with emissions associated with increased production largely countered by improvements in production efficiency and by enhanced carbon storage in soils due to tillage reductions. More recently (since 2006), the decline in beef production has led to a decrease in methane (CH_4) emissions, resulting in a slight index value increase, from 79 back to the 1981 value of 81.

The index tends to aggregate and generalize trends. In particular, it does not capture significant emission reductions that have occurred within the lowest and highest emissions classes, which have resulted in a decline in annual greenhouse gas emissions of nearly 5 Mt CO_2e, or about 10 % since 1981. These more detailed findings, as well as regional variations and interpretations, are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector".

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

(IPCC 2013). Agriculture plays a dual role in climate change, since it is both a source of and a **sink** for GHG emissions. While agricultural activities inevitably generate GHG emissions, which contribute to climate warming, agricultural soils have the capacity to sequester, or store, **carbon**, offsetting the sector's overall contribution. Furthermore, agriculture is dependent upon a stable climate in order to realize predictable crop yields and profitability. The Agricultural Greenhouse Gas Budget Indicator (also referred to as the Greenhouse Gas Indicator) assesses the state and trend of greenhouse gas emissions resulting from Canadian agricultural activities.

The main GHGs emitted from agriculture are **nitrous oxide** (**N_2O**) and **methane** (**CH_4**), while **carbon dioxide** (**CO_2**) can be either emitted or removed (**sequestered**) by agricultural activities. The Greenhouse Gas Indicator has been used to track the combined N_2O, CH_4 and CO_2 emissions generated by agricultural activities in Canada between 1981 and 2011. Since N_2O, CH_4 and CO_2 have different **global warming potentials** per molecule, the accepted practice is to report their combined effects in terms of **carbon dioxide equivalents** (CO_2e).

In 2011, the net GHG emissions (emissions minus removals) from Canadian agricultural activities, excluding **fossil fuel** use, amounted to 42.0 million tonnes of CO_2 equivalents (Mt CO_2e), which is equal to about 6% of Canada's overall GHG emissions.[2] Although net agricultural GHG emissions declined between 1981 and 2011 (by about 10%), emissions of N_2O and CH_4 increased by 31% and 2%, respectively. The decline in net GHG emissions over this period is attributable mainly to the change in CO_2 emissions from agricultural soils, which went from being a small carbon source of about 1.2 Mt CO_2e in 1981 to a sink (indicating removal by sequestration) of about -11.9 Mt CO_2e in 2011.[3] Agricultural soils are now a significant sink for CO_2, particularly in the Prairie Provinces of Canada, owing to the widespread adoption of **beneficial management practices** (BMPs) such as reduced tillage intensity, decreased **summerfallow** and, to a lesser extent, conversion from annual crops to perennial cropping systems.

Between 1981 and 2011, agricultural N_2O emissions increased primarily because of a doubling of **nitrogen fertilizer** use and an increase in livestock populations, whereas agricultural CH_4 emissions increased primarily as a result of growth in livestock populations. Emissions of CH_4 peaked in 2006 and have been declining since then. Challenging economic conditions for Canadian livestock producers in recent years have led to a decline in population for many animal types and an associated decrease in agricultural CH_4 emissions since 2006. Although manure-related N_2O emissions decreased during the same period, the increase in synthetic fertilizer use has more than offset this decline, leading to an overall increase in N_2O emissions since 2006.

The Issue and Why it Matters

Greenhouse gases perform an essential role in the atmosphere, trapping radiant energy and maintaining the earth at a temperature that can support life. Although these gases are essential for the planet, the ongoing addition of GHGs is undesirable, as the resulting increases are likely to bring about major changes in climate. Anthropogenic emissions of carbon dioxide, methane and nitrous oxide have resulted in global atmospheric concentrations that are greater than at any point in the past 800,000 years (IPCC, 2013).

Agricultural activities influence net GHG emissions from a variety of agricultural sources and sinks (Figure 15–1). Direct N_2O emissions originate from field-applied organic and **inorganic** fertilizers, **crop residue decomposition**, manure storage and cultivation of organic soils. Indirect N_2O emissions occur when nitrogen (N) is transported off-site through processes such as **volatilization** (loss of N to the air as a gas) and the subsequent deposition of **ammonia**, as well as N **leaching** and **runoff** (N dissolved in water). Methane is emitted through **enteric fermentation**, the process of feed digestion in ruminant animals, as well as through the **anaerobic** decomposition of stored manure. When feed is consumed by livestock, particularly ruminants, microbes that are naturally present in the digestive system decompose the cellulosic material. During this

2 This net figure includes soil CO_2 exchange, the process whereby CO_2 is removed by agricultural soils, thus offsetting total emissions. When soil CO_2 exchange is reported separately, as it is in Canada's National Inventory Report 1990-2012 (Environment Canada, 2014), the agricultural sector accounts for 8% of national GHG emissions. Small differences in GHG emissions estimates exist between Canada's National Inventory Report 1990-2012 and this report, owing to ongoing updates in methodology and input data, as well as error detection and correction.

3 The sink of -11.9 Mt CO_2 in 2011 is strictly the amount of carbon sequestered in soil. This figure does not include changes in carbon stocks (losses) associated with changes in living biomass and dead organic matter resulting from the conversion of forestland to cropland. When these other changes are included, and including N_2O and CH_4 emissions, the net sink for 2011 is approximately -5 Mt CO_2e (Environment Canada, 2014)

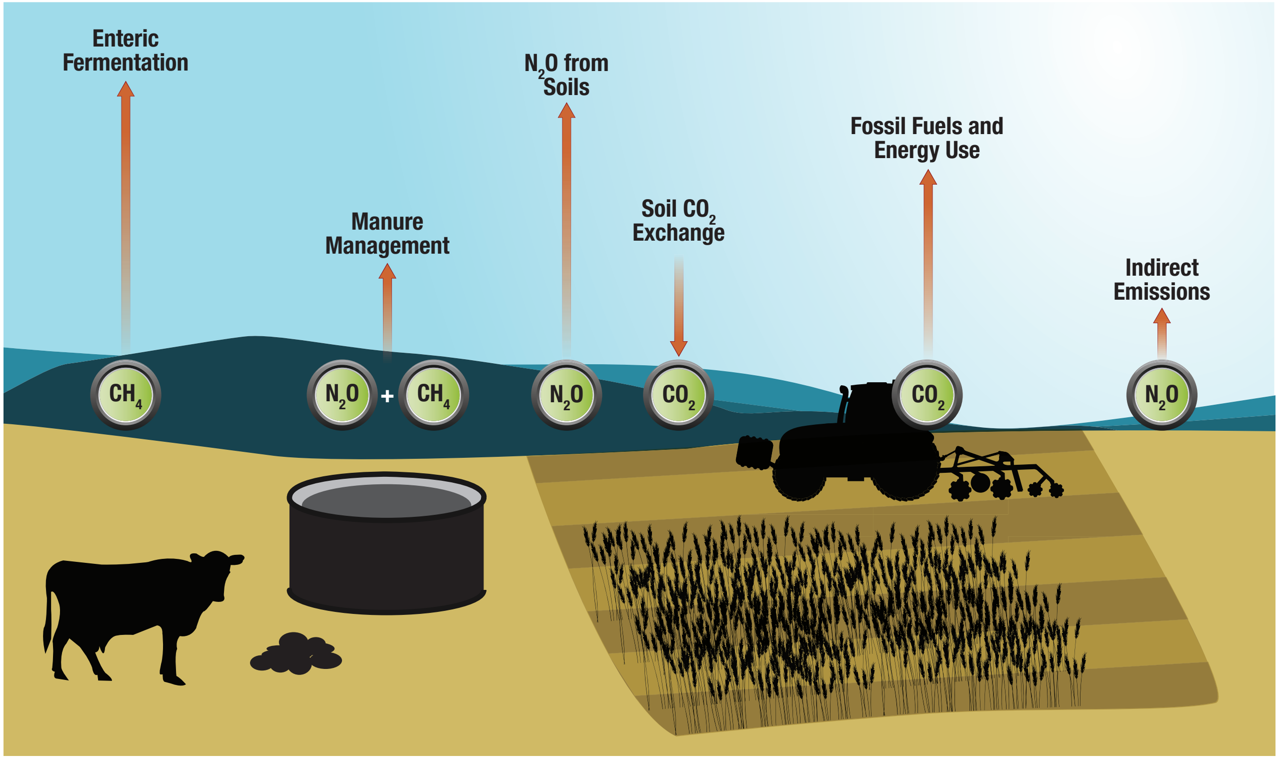


Figure 15–1: Agricultural GHG emissions in Canada in 2011. Arrow length is proportional to the magnitude of the emissions; arrow direction upwards indicates a source and downwards indicates a sink.

process, some of the feed is converted to CH_4, which is released into the atmosphere when the animals eructate. Similarly, microbial decomposition of manure under anaerobic conditions results in CH_4 emissions. Burning of agricultural residues to manage excessive straw accumulation, which is now a rare practice in Canada, produces N_2O and CH_4 emissions. Carbon dioxide emissions are also associated with burning, but are not included in the estimate because they represent a return to the atmosphere of carbon that was recently extracted by **photosynthesis**, and therefore do not represent a net addition.

Agricultural soils can be a net source or sink of CO_2. The net effect is the difference between CO_2 removal from the atmosphere by growing crops (and subsequent storage in the soil in the form of crop residues and **soil organic matter**) and its emission to the atmosphere through the decomposition of crop residues and soil organic matter. Management practices that promote the sequestration of carbon in soils tend to minimize soil disturbance and slow the rate of decomposition. These practices include decreasing tillage intensity, reducing the frequency of summerfallow and converting annual crops to perennial crops. For a more detailed explanation of the soil carbon exchange process, refer to Chapter 9 “Soil Organic Matter”.

Carbon dioxide is emitted during fossil fuel combustion by farm machinery and during the manufacture of agricultural fertilizers and machinery. Because these emissions of CO_2 are typically reported by the transportation and manufacturing sectors, they are not included in the Greenhouse Gas Indicator calculations. However, since the emissions are directly associated with decisions that are made on-farm, it is important to assess their magnitude and their evolution over time in response to management practices. For this reason, these emissions have been estimated, but are excluded from the net estimate of agricultural GHG emissions. (See the text box on GHG emissions from fossil fuel and energy use.)

CO_2 emissions from energy use and fossil fuel consumption in agriculture

Agricultural GHG emissions typically exclude CO_2 emissions associated with fossil fuel combustion and energy use. In keeping with international reporting standards, these emissions are normally reported by the energy and transportation sectors of the economy, rather than by the agriculture sector. However, since the emissions are directly related to agricultural management decisions made at the farm level, they are presented here to provide additional context.

Agricultural GHG emissions associated with various fossil fuel and energy use activities were estimated using input data from the Canadian **Census of Agriculture** in a farm energy model. There are six major sources of emissions from fuel and energy use in agriculture:

- Field operations (ploughing, planting, spraying, harvesting)
- Farm transport
- Heating
- Electricity
- Machinery manufacturing
- Agrochemical production (e.g. the manufacturing of fertilizers)

Emissions associated with fossil fuel combustion and energy supply to the Canadian agricultural sector are shown in Figure 15–2. These emissions are dominated by three sources: chemical production, field operations and machinery manufacturing, which respectively accounted for 37%, 26% and 18% of the total. Since 1981, there has been a 22% increase (from 15.9 to 19.4 Mt CO_2) in CO_2 emissions from fossil fuel and energy use; however, this increase has been associated exclusively with the production of chemical inputs. While other sources of fossil fuel energy emissions have changed by only a few percent, emissions associated with agrochemical production have increased by more than 100% since 1981. This is due to the significant increase in the use of nitrogen fertilizers manufactured using a variation of the Haber-Bosch process which operates at high temperature and high pressure and consumes natural gas as a feedstock, producing CO_2 as a by-product.

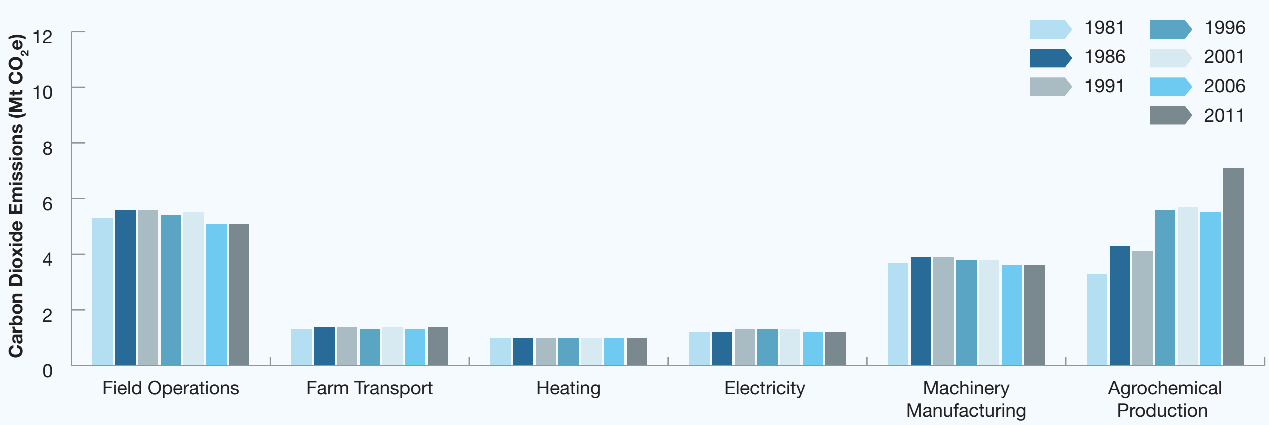


Figure 15–2: Canadian agricultural fossil fuel and energy use CO_2 emissions, 1981 to 2011

There are several reasons why developing a national methodology for reporting agricultural GHG emissions is an important area of focus for Canada and for Canadians. The first reason relates to the connection between GHG emissions and climate. Anthropogenic GHG emissions have been conclusively linked to global climate change, and continued emissions may exacerbate this problem for future generations. Therefore, efforts to decrease net emissions will help mitigate the impacts of climate change. The agriculture sector has the potential to work towards this goal by reducing the emissions intensity of agricultural products, by sequestering carbon in agricultural soils, and by producing bioenergy from agricultural by-products.

Second, greenhouse gas emissions can be an indication of **nutrient** losses from the agricultural system, and can therefore be considered a measure of inefficiency and, consequently, an economic loss to the producer. For example, N_2O emissions from fertilizer applications do not contribute to crop growth, and feed that is converted into CH_4 represents an energy loss for the animal. On-farm management practices that improve productivity and nutrient-use efficiency can also reduce GHG emissions intensity and improve profitability. However, the full cost of implementing such practices should be taken into account, as the reduction in GHG emissions and associated savings to the producer may only partially offset the investment.

The third reason for concern regarding agricultural GHG emissions relates to marketing and trade. There is a growing interest in sustainable sourcing among retailers and agricultural supply chains, which may include reporting on, or meeting GHG emissions standards. Some nations and multinational corporations have identified the reduction of GHG emissions as a desirable goal, and are developing policies favouring products and services that reduce emissions per unit of production. For example, in 2012 Canada exported roughly 30,000 tonnes of canola oil (valued at over $34 million) to the European Union, which was destined for the production of **biofuel** for use in transportation. Data and information derived from the Greenhouse Gas Indicator were used to demonstrate that the Canadian canola exceeded the GHG threshold for feed stock under the European Union's Renewable Energy Directive, enabling access to the European market by Canadian canola producers. This concept is explored in greater detail in Chapter 18 "Greenhouse Gas Emission Intensities of Agricultural Products".

The Indicator

The Greenhouse Gas Indicator estimates the net emissions (emissions minus removals) of the three primary GHGs associated with agriculture, specifically CO_2, CH_4 and N_2O. International standards, developed by the Intergovernmental Panel on Climate Change (IPCC), require that emissions be reported in carbon dioxide equivalents (CO_2e) using the global warming potential (GWP) of each gas. The GWP accounts for the unique ability of each gas to absorb radiation and for its residence time in the atmosphere. The GWP values used in the IPCC's Second Assessment Report (1996) are as follows: 1 kilogram of N_2O has 310 times the warming impact of 1 kilogram of CO_2, while 1 kilogram of CH_4 has 21 times the impact of 1 kilogram of CO_2. The calculation of CO_2e involves multiplying the mass of N_2O, CH_4 and CO_2 by the factors 310, 21 and 1, respectively[4].

Agricultural N_2O and CH_4 emissions are estimated using a globally recognized approach recommended by the IPCC. A Canada-specific IPCC Tier II methodology has been developed by adapting the IPCC framework methodology to account for Canadian conditions, such as climate characteristics, crop management practices and animal husbandry techniques that are unique to our country (Rochette et al., 2008). There are three main steps in the implementation of the Canadian IPCC Tier II methodology, as follows:

1. Collection of basic input data on climate, farming and farming systems in Canada, including the ratio of precipitation to potential **evapotranspiration**, the area of major crop types, the rate of nitrogen fertilizer application for each crop type, the population of each animal type and feed intake by animal type;

2. Estimation of interim variables such as the amount of nitrogen in crop residues and the gross energy intake of cattle, and calculation of the annual **emission factor** for one kilogram of nitrogen (for N_2O emissions) or one animal (for CH_4 emissions). The emission factors are sensitive to management practices that change over time, so a new set of emission factors is required for each year that emissions are calculated, in order to reflect current management practices and

4 These values have since been revised in the IPCC Fourth Assessment Report (2007), but the Agricultural Greenhouse Gas indicator is calculated using the values established in the second assessment report for inventory reporting under the United Nations Framework Convention on Climate Change (UNFCCC), and consequently, the second assessment report values are used in Canada's National Inventory Report, produced by Environment Canada. It is likely that future calculations will use the new values which may change the magnitude of the emissions reported, but not the trend of the emissions.

knowledge. A total of 449 unique emission factors are estimated each year for N_2O emissions associated with specific regions of the country. Individual emission factors for CH_4 emissions from enteric fermentation and manure management have been developed for 52 animal categories;

3. Calculation of GHG emissions by multiplying the amount of nitrogen (for N_2O emissions) and the animal population (for CH_4 emissions) by the appropriate emission factor, and then summing the resulting emissions to obtain values at the provincial and national scales.

While the methodology for estimating CO_2 emissions from **cropland** employs the same three basic steps as the method for N_2O and CH_4 emissions, it differs in that complex computer models are used to develop the emission factors (Smith et al., 2001; Smith et al., 2012). These models estimate the rate of change in soil carbon as a function of local climate, soil type and soil properties and taking into account land management practices that can cause a change in soil carbon levels. These include the frequency of summerfallow and tillage intensity as well as shifts from annual crops to perennial cropping. Rates of change are estimated for more than 3,000 geographical regions in Canada. For more information on the calculation of soil carbon change, see Chapter 9 "Soil Organic Matter".

Limitations

Agricultural activities in Canada are carried out on more than 60 million hectares (ha) of land and give rise to many crop and animal products. These products originate from farms ranging in size from a few hectares to several thousand hectares, each with its own unique combination of management practices. Furthermore, soil and climatic conditions vary substantially depending on location. Because of the wide range of crops and animal products, the diversity of management practices, and the variability in soil and climatic conditions, it would be difficult to estimate the Canada-wide agricultural GHG emissions without making certain generalizations to simplify the calculations. For example, when using information at the **Soil Landscapes of Canada** (**SLC**) **polygon** scale as model inputs, the soil type, soil characteristics and climatic conditions were assumed to be uniform within each parcel, and all animals in a specific animal category for a given province were assumed to have the same diet, weight and growth characteristics. These and many other assumptions used in the calculations are sources of uncertainty which affect the estimation of emissions.

Another source of uncertainty relates to the field measurements that are required in order to derive Canada-specific emission factors. Field measurements are usually limited to a very specific time and place; however, in calculating the Greenhouse Gas Indicator, these were generally applied to a much broader geographic area and to a much longer time frame. Occasionally, it is necessary to use coefficients or emission factors that are not based on Canadian field measurements, but are instead obtained from international research. These add uncertainty to the estimates due to the unknown nature of their applicability to Canada.

It should also be noted that while the models used are robust, due to limitations in the understanding of processes that control GHG emissions, it is not possible to account for all factors that affect emissions in the calculations.

Results and Interpretation

Net Canadian agricultural emissions declined by about 5 Mt CO_2e, or about 10 %, between 1981 and 2011 (Table 15–1, Table 15–2). The decline in net agricultural GHG emissions is primarily attributable to the change in soil carbon during this period, which went from being a small source (1.1 Mt CO_2e) in 1981 to a sink of about -11.9 Mt CO_2e. This reduction in annual emissions more than offset the 31% increase in agricultural N_2O emissions (from 25.8 to 33.7 Mt CO_2e) and the 2% increase in agricultural CH_4 emissions (from 19.8 to 20.2 Mt CO_2e). These findings are particularly apparent in the Prairie Provinces. Figure 16–3 shows the trend for N_2O, CH_4 and soil CO_2 individually as well as collectively in terms of net GHG emissions in the Prairie Provinces (Alberta, Manitoba and Saskatchewan) between 1981 and 2011 (data for this graph can be referenced in Table 15–1).

The trends in the emissions of the three agricultural greenhouse gases are due to different factors. For instance, the 31% increase in agricultural N_2O emissions is primarily attributable to increases in nitrogen fertilizer application. National nitrogen fertilizer use, which stood at about 0.94 million tonnes of nitrogen in 1981, has more than doubled, reaching 2.0 million tonnes in 2011 (Figure 15–4). The increase in nitrogen fertilizer use is not evenly distributed across the country, as use in Western Canada increased by more than 150%, whereas use in Eastern Canada increased by only 22%. While the dramatic increase in nitrogen fertilizer use has boosted crop yields in Canada, N_2O emissions to the atmosphere have increased as well. Two other factors have also contributed to the upward trend in agricultural N_2O emissions since 1981, albeit to a lesser extent: the increase in manure nitrogen excretion associated with the expanded overall livestock population and the general increase in animal size.

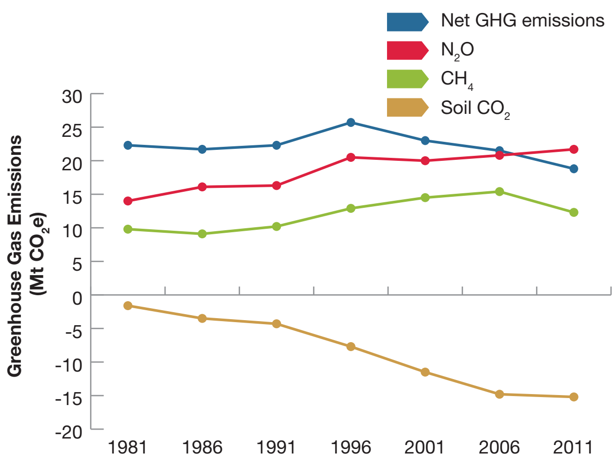


Figure 15–3: Agricultural greenhouse gas emissions in the Canadian Prairies (Alberta, Manitoba and Saskatchewan, collectively) (Mt CO_2 equivalents), 1981 to 2011

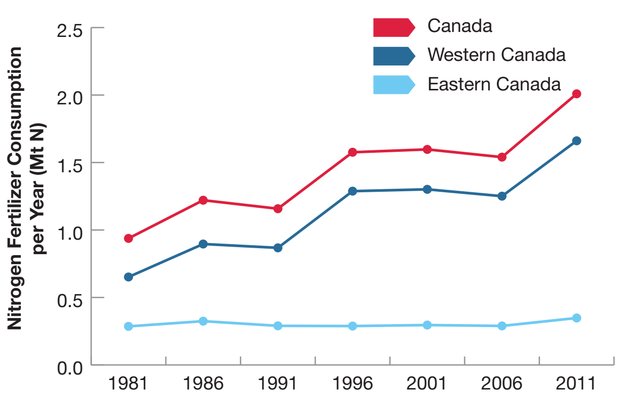


Figure 15–4: Nitrogen fertilizer use in Eastern and Western Canada, 1981 to 2011

In contrast, agricultural CH_4 emissions in Canada increased by only 2% between 1981 and 2011. And during the 2006 and 2011 period, there was a significant decrease in CH_4 emissions in Canada. This change in emissions over time is primarily attributable to fluctuations in the total livestock population, with cattle (beef and dairy) accounting for 88% of total agricultural CH_4 emissions (the remainder is attributable to manure management). Between 1981 and 2011, Canada's dairy cow population experienced a steady decline from about 1.8 million to 1.0 million head (Figure 15–5), which came about because of the productivity gains achieved in terms of milk production per dairy cow. These productivity gains have allowed total milk production in Canada to remain relatively constant while permitting a reduction in the overall dairy cow population.

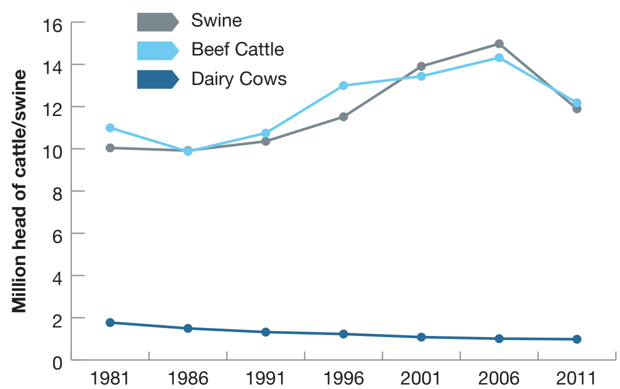


Figure 15–5: Cattle and swine population in Canada, 1981 to 2011

The beef cattle population in Canada followed a different trend, increasing between 1986 and 2006, then decreasing between 2006 and 2011. The recent decline in the beef cattle population has a variety of causes, including holdover effects from the **bovine spongiform encephalopathy** (**BSE**) crisis in 2003-2004; a high Canadian dollar which has made exports to the United States more expensive; higher feed costs; lower per-capita consumption of beef; and country-of-origin labelling which could discourage consumers in other nations from consuming Canadian beef. These factors, among others, have combined to create a challenging economic environment for Canadian cattle producers and have resulted in a decline of about 2 million head (about 14%) in the beef population. Primarily as a result of declining cattle numbers, Canada's agricultural CH_4 emissions decreased between 2006 and 2011, and are now only 2% higher than they were in 1981. However, cattle emissions per head have increased over time, as the animals now tend to consume more feed and they are larger than their counterparts in 1981. The trend toward larger animal size has partially offset the recent decline in the cattle population.

Swine are not as important a direct source of CH_4 emissions as cattle because they do not produce significant CH_4 emissions from enteric fermentation. However, liquid manure management systems predominate in the swine industry, and they are a major source of CH_4 emissions due to the anaerobic decomposition of the organic material in the stored liquid manure. The swine population has increased by 18% since 1981, but a recent decline in the population has reduced CH_4 emissions from swine.

Changes in agricultural land management practices have been the primary factor behind the decrease in carbon dioxide emissions. Crop management practices that minimize soil disturbance, such as reducing summerfallow and tillage intensity and increasing perennial cropping, can enhance carbon sequestration in the soil. Between 1981 and 2011, there was a significant increase in the land area on which these beneficial crop management practices were carried out. For instance, although the total farm area in Canada has stayed constant at around 60 million ha, the area devoted to summerfallow has declined from 8.7 million ha to 2.0 million ha; the area dedicated to **perennial forage** crops has increased from 5.7 million ha to 6.4 million ha; and the area under no-tillage has increased from 0.6 million ha to 15.2 million ha. Conversion to perennial forage as well as **minimum till** and **no-till** practices limits soil disturbance by reducing the need to use machinery to turn the soil. As a result, decomposition of organic material slows, and more carbon is stored in the soil.

The net agricultural GHG emissions per hectare of farmland area at the scale of SLC polygons for 2011 are generally lower per hectare in Western Canada than in Eastern Canada (Figure 15–6). Data for this map can be referenced in Table 15–2. There are many reasons for this difference. For instance, in the Prairie Provinces, soil and climatic conditions are favourable for the adoption of land management practices that can enhance carbon sequestration in the soil. As a result, net GHG emissions tend to be much lower per hectare there. Wetter conditions in Eastern Canada are favourable for formation of N_2O; the rate of N_2O emissions is often twice as high as in Western Canada. Since water is less of a limiting factor for crop growth in Eastern Canada, high yielding crops such as corn, which require greater inputs of nitrogen fertilizer, are widely grown there. Furthermore, in Eastern Canada there is less land area for agriculture, a situation that has resulted in a concentration of farming activities and an increase in GHG emissions per hectare. Despite this, there are some areas of Western Canada where emissions per hectare can be as high as in Eastern Canada. These areas tend to have large concentrations of either beef cattle or swine.

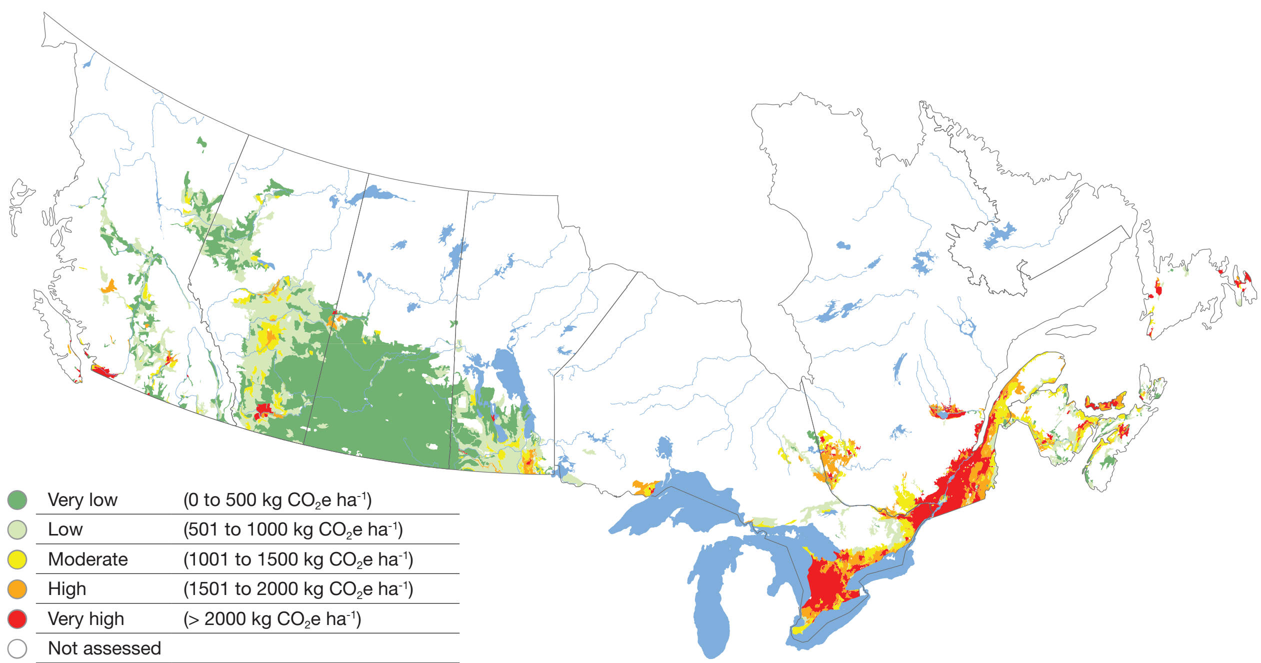


Figure 15–6: Net agricultural GHG emissions per hectare of land, 2011 (kg CO_2e ha^{-1})

Table 15–1: Canadian agricultural GHG emissions (Mt CO_2e)[5], 1981 to 2011[6]

	N_2O							CH_4							Soil CO_2							Total						
Province	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
BC	0.9	1.0	0.9	1.0	1.1	1.0	1.0	1.2	1.1	1.2	1.3	1.4	1.4	1.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	2.3	2.2	2.1	2.4	2.5	2.3	2.0
AB	6.4	6.7	7.2	8.5	8.7	8.8	9.5	5.5	5.3	6.1	7.6	8.7	8.5	6.9	-0.7	-0.8	-1.2	-2.1	-3.3	-4.0	-4.2	11.3	11.1	12.1	13.9	14.1	13.3	12.3
SK	4.7	5.9	5.4	7.6	7.0	7.5	8.1	2.7	2.3	2.5	3.3	3.6	4.3	3.4	0.1	-1.6	-1.9	-4.4	-6.9	-9.2	-9.6	7.5	6.6	6.1	6.6	3.7	2.7	1.8
MB	2.9	3.5	3.7	4.4	4.3	4.5	4.1	1.6	1.5	1.6	2.0	2.2	2.6	2.0	-1.0	-1.1	-1.2	-1.2	-1.3	-1.6	-1.4	3.5	4.0	4.1	5.2	5.2	5.5	4.7
ON	6.4	6.3	5.7	5.7	5.5	6.5	6.3	4.7	4.2	4.0	4.2	4.0	3.9	3.3	2.0	1.8	1.7	1.6	1.7	1.5	1.7	13.0	12.3	11.4	11.5	11.1	11.9	11.3
QC	3.8	4.0	3.8	3.9	4.0	3.9	4.2	3.4	3.2	3.0	3.2	3.2	3.2	3.0	0.6	0.6	0.8	1.0	1.3	1.3	1.4	7.8	7.8	7.6	8.2	8.5	8.4	8.5
NB	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.4	0.5	0.5	0.5	0.5	0.5	0.5
NS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.4
PE	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.6	0.5	0.6	0.5
NL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Canada	**25.8**	**28.1**	**27.4**	**32.0**	**31.5**	**33.2**	**33.7**	**19.8**	**18.2**	**19.0**	**22.3**	**23.6**	**24.5**	**20.2**	**1.2**	**-0.9**	**-1.5**	**-4.9**	**-8.4**	**-11.8**	**-11.9**	**46.7**	**45.4**	**45.0**	**49.4**	**46.7**	**45.9**	**42.0**

Table 15–2: Percentage of agricultural farmland in each GHG emission category[7], 1981 to 2011

Class	Very low (<500 kg CO_2e ha^{-1})							Low (501 to 1000 kg CO_2e ha^{-1})							Moderate (1001 to 1500 kg CO_2e ha^{-1})							High (1501 to 2000 kg CO_2e ha^{-1})							Very high (>2000 kg CO_2e ha^{-1})						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	46	48	44	38	33	36	54	41	37	46	48	52	54	35	6	8	3	6	8	3	4	2	2	2	2	3	1	2	5	5	5	5	5	5	5
Alberta	43	53	47	41	41	43	47	51	41	42	40	40	43	42	6	5	10	17	15	11	9	0	0	1	2	3	2	1	0	0	0	1	1	1	1
Saskatchewan	98	96	98	95	98	98	99	2	4	2	4	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manitoba	52	52	48	25	32	21	48	47	47	50	65	58	68	43	0	1	2	10	9	8	6	0	0	0	0	1	2	2	0	0	0	0	0	0	0
Ontario	0	0	0	0	1	0	1	6	7	8	12	13	8	10	12	12	14	10	15	13	17	17	18	22	23	20	25	23	65	63	55	56	51	54	49
Quebec	1	1	1	1	0	0	0	5	5	5	5	4	4	4	14	14	16	16	14	14	14	22	24	23	22	25	18	23	58	56	54	57	57	65	59
New Brunswick	6	6	6	6	6	2	8	36	29	31	27	18	21	28	47	51	46	36	31	32	49	9	12	13	30	41	43	10	2	1	4	2	4	3	6
Nova Scotia	18	16	11	17	13	17	26	26	25	30	22	26	29	29	18	22	21	23	23	19	28	26	26	25	21	22	29	7	11	10	13	18	15	6	10
Prince Edward Island	0	0	0	0	0	0	0	0	1	0	0	0	0	0	20	7	8	1	5	0	19	35	39	33	22	28	22	50	46	53	59	77	67	78	31
Newfoundland and Labrador	27	30	18	17	19	7	14	41	19	29	21	22	22	20	14	18	7	18	21	13	17	3	16	15	16	7	13	9	16	18	32	27	30	45	40
Canada	**59**	**62**	**60**	**54**	**56**	**55**	**61**	**25**	**22**	**23**	**25**	**24**	**25**	**21**	**4**	**4**	**6**	**9**	**8**	**7**	**6**	**3**	**3**	**4**	**4**	**5**	**4**	**4**	**9**	**8**	**8**	**8**	**8**	**8**	**8**

5 Numbers may not add to the totals because of rounding. Negative values represent soil sinks or removal of CO_2 from the atmosphere.

6 Note that soil CO_2 values, along with the total (combined N_2O, CH_4 and soil CO_2) emissions values, are based on the carbon sink (in CO_2e) in soils. These figures do not account for changes in carbon stocks (losses) associated with changes in living **biomass** and dead organic matter, which are mainly attributable to deforestation events and conversion of forestland to cropland. Soil carbon is discussed in greater detail in Chapter 9 "*Soil Organic Matter*".

7 Numbers may not add to the totals because of rounding.

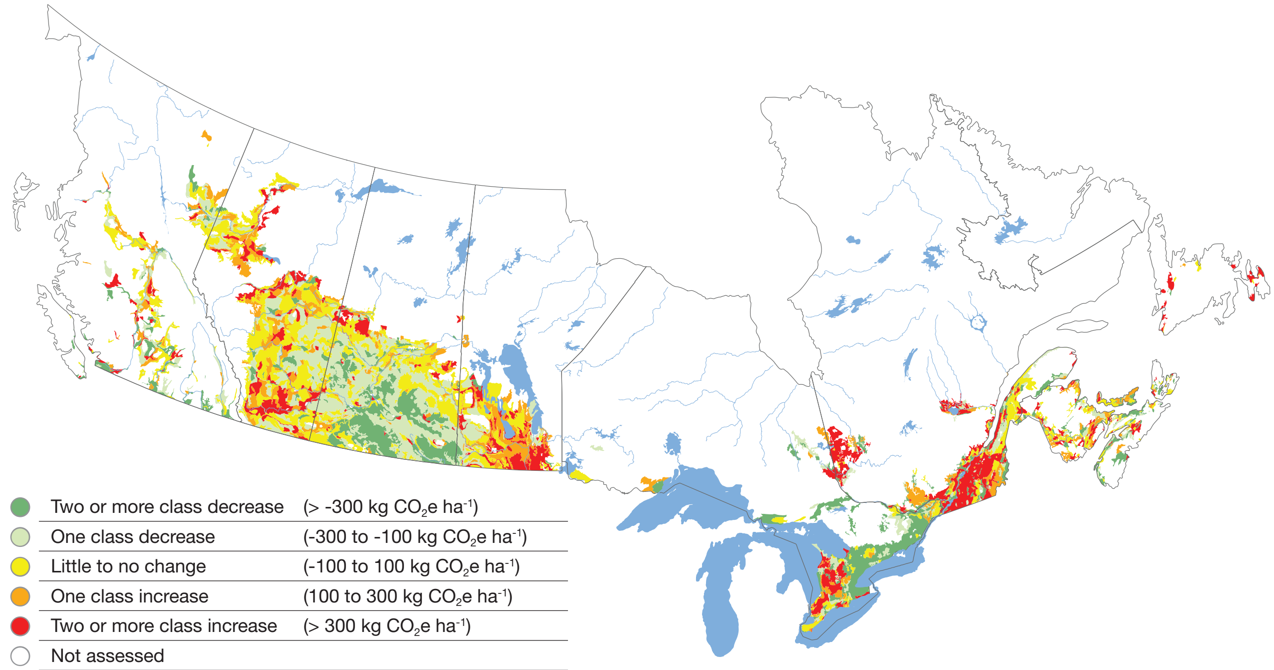


Figure 15–7: Change in net agricultural GHG emissions, 1981 to 2011 (kg CO_2e ha^{-1})

Figure 15–7 shows the change in net agricultural GHG emissions between 1981 and 2011 in kilograms per hectare of farm area at the SLC scale (data for this map can be referenced in Table 15–2). Negative values indicate that net emissions have declined over this time period, whereas positive values indicate that net emissions have increased. Large areas of the Prairie Provinces saw either no change or a decline in net GHG emissions, primarily as the result of soil carbon sequestration. However, certain areas of Alberta and Manitoba experienced an increase in net agricultural GHG emissions, mainly due to the expansion of the animal population between 1981 and 2006, as well as an increase in nitrogen fertilizer use between 1981 and 2011. In Eastern Canada, large areas in southwestern Ontario, the St. Lawrence River Valley and the St. John River Valley have posted a net increase in agricultural GHG emissions as a result of an expansion in annual cropping and an increase in land area dedicated to crops with a high N-demand, such as corn. Declining dairy herds in these regions have led to a decreased need for perennial forage crops and a consequent conversion to annual crops, resulting in higher soil CO_2 emissions.

Response Options

The goal of the Canadian agricultural sector is to provide a sustainable source of safe and nutritious food while maintaining profitability for the producer. As the Canadian population and the global population expand, and as global affluence increases along with the trend towards higher protein diets, the demand for Canadian agricultural products is likely to increase. A certain level of N_2O and CH_4 emissions will always be associated with farming activities. Therefore, if agricultural production continues to grow in the future, there is a strong likelihood that N_2O and CH_4 emissions from Canada's agriculture sector will also increase. There are several options for the mitigation of agricultural GHG emissions, including the following:

- Ruminant diet supplementation with edible oils to reduce CH_4 emissions from enteric fermentation;
- Improved manure management to reduce direct emissions and to produce bioenergy;
- Adoption of precision farming techniques to reduce or optimize nitrogen fertilizer use;

- Increased production of pulses and other legumes, which require less nitrogen fertilizer due to their ability to fix nitrogen;
- Production of biofuels from agricultural by-products to replace fossil fuels;
- Adoption of management practices such as decreased use of summerfallow, reduced tillage intensity and increased perennial cropping to increase carbon storage in agricultural soils.

However, the wider adoption of many of these practices is hindered to some extent by current economic, regulatory, cultural, technological and/or physical factors. Here are some examples.

- Feeding of edible oils is rarely justified for strictly economic reasons;
- Production of green energy from manure management is often limited owing to technological and regulatory constraints;
- The level of pulse and legume production is dictated by demand, which is partly dependent upon cultural and dietary preferences;
- Soils have a finite capacity to store carbon and, over time, will approach their maximum sequestration capacity.

The need for increased food production to satisfy growing global demand and the limitations of existing mitigation measures for agricultural GHG emissions mean that achieving sizeable reductions in net agricultural GHG emissions will likely become a significant challenge in the future. An important related benchmark for the agricultural sector is **emission intensity** change over time (refer to Chapter 18 “Greenhouse Gas Emission Intensities of Agricultural Products”). Emission intensity is a measure of the amount of greenhouse gas emitted per unit of agricultural commodity produced, such as a litre of milk or a kilogram of beef. Opportunities exist for producers to continue reducing emission intensity through the adoption of increasingly more efficient management strategies; however, total emissions may nonetheless increase due to an overall increase in production.

References

Environment Canada, 2014. *National Inventory Report 1990-2012: Greenhouse gas sources and sinks in Canada*. Submission to the United Nations Framework Convention on Climate Change. Available at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8108.php

IPCC (2013). *Summary for policy makers*. In: Climate change 2013: *The physical science basis. Working Group I contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* T.F. Stocker, D. Qin, G.-K. Plattner et al. (eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC (2007), *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., et al. (eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC (1996), Climate Change 1995: *Second Assessment Report of the Intergovernmental Panel on Climate Change*. J.T Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A Kattenburg et al. (eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press

Rochette, P., D. Worth, R.L. Lemke, B.G. McConkey, D.J. Pennock, C. Wagner-Riddle, and R.L. Desjardins (2008). *Estimation of N2O emissions from agricultural soils in Canada. I - Development of a country specific methodology*. Canadian Journal of Soil Science. 88: 641-654.

Smith, W.N., R.L. Desjardins, and B.B. Grant (2001). *Estimated changes in soil carbon associated with agricultural practices in Canada*. Canadian Journal of Soil Science. 81: 221-227.

Smith, W.N., B.B. Grant, C.A. Campbell, B.G. McConkey, R.L. Desjardins, R. Kroebel, and S.S. Malhi (2012). *Crop residue removal effects on soil carbon: Measured and inter-model comparisons*. Agriculture, Ecosystems and Environment. 161: 27-38.

16 Ammonia

Authors:
S. Sheppard and S. Bittman

Indicator Name:
Ammonia Emissions from Agriculture Indicator

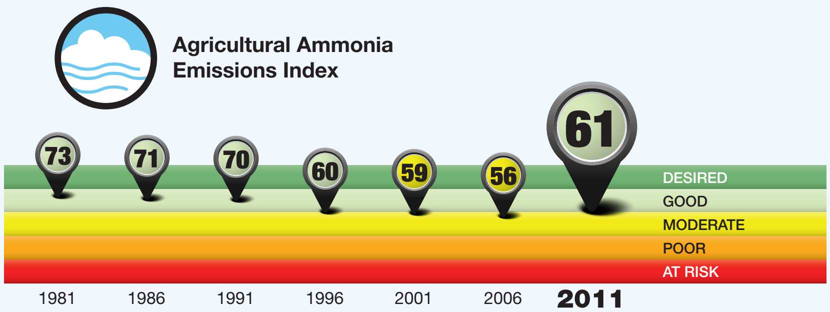
Status:
National Coverage, 1981 to 2011

Summary

Ammonia[1] (NH_3) is a basic, reactive and toxic gas composed of **nitrogen** (**N**) and **hydrogen** (**H**) that can have negative impacts on the environment and human health. In Canada, agriculture contributes about 85% of the total **anthropogenic** NH_3 gas emissions to the atmosphere (Ayres et al., 2010). Very high NH_3 emissions to the atmosphere occur in regions with concentrated livestock production, especially in the southern parts of Quebec, Ontario and Manitoba, parts of Alberta and the lower Fraser Valley of British Columbia. Ammonia is released mainly through naturally occurring processes, such as the breakdown of excreted urea (cattle and pigs) or uric acid (poultry). Ammonia emissions also come from N **fertilizers** containing ammonium or urea. When present at high concentrations in enclosed spaces, agricultural NH_3 emissions can be toxic to humans and animals.

Agricultural Ammonia Emissions Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the graph, in 2011 the state of NH_3 emissions from farming activities in Canada was 'Good'. The index illustrates a downward trend between 1981 and 2006, representing an increase in emissions over this time frame. Emissions have declined since 2006, as evidenced by an upturn in the index values, reaching a level above 1996 values, partly because of the decrease in beef cattle numbers over this period.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector."

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter

The Ammonia Emissions from Agriculture Indicator has been developed to estimate Canadian agricultural NH_3 emissions based on information about agricultural production, management practices and **emission factors** associated with agricultural practices. The Indicator assesses the broad-scale *state* and *trend* of the NH_3 emission levels nationally and across the Canadian agricultural landscape.

In 2011, national ammonia emissions from livestock accounted for 65% of total agricultural NH_3 emissions and emissions from fertilizers accounted for 35% of the total. This is in contrast to 1981 when livestock emissions accounted for 81% and fertilizers accounted for 19% of the total. Since 1981, emissions from fertilizer have doubled (from a reported 63,000 kilotonnes (kt) N in 1981, up to 130,000 kt N in 2011) as a result of increases in N fertilizer use, whereas livestock emissions have been decreasing, particularly since 2006. The emissions reflect an overall trend towards fewer livestock and increased area under crops, necessitating greater fertilizer use.

The Issue and Why it Matters

Ammonia is both a plant **nutrient** and a toxic by-product of protein digestion, especially protein consumed in excess of an animal's requirements, which is then excreted from livestock in the form of urea in mammalian urine and uric acid in avian manure. It is also released from the breakdown of organic N compounds in manure and from fertilizer containing urea and ammonium-N. Ammonia emissions are inherent to all plant and animal life and occur in natural, as well as managed, landscapes.

Ammonia is water soluble and readily reacts with acid gases in the atmosphere, generating ammonium (NH_4^+) compounds in the form of fine respirable particulate less than 2.5 micrometres in diameter ($PM_{2.5}$) which can contribute to smog and be detrimental to human health (Deutsch et al., 2008). While not all respirable $PM_{2.5}$ can be attributed to agricultural NH_3 emissions, the agricultural sector in Canada contributes the majority (85%) of the total anthropogenic NH_3 gas emissions and hence secondary NH_4 based particles, especially in areas near large urban centres where livestock production and extensive fertilizer use occurs. Much of the haze that forms in southern Ontario and in the Lower Fraser Valley of British Columbia can be attributed to NH_3-induced particles. Barthelmie and Pryor (1998) attributed the extensive "grey **smog**" events that occur in late summer in the Lower Fraser Valley to livestock-related NH_3 emissions reacting with acid gases from vehicles (Figure 16–1). These events reduce visibility and likely have a negative impact on tourism revenue (McNeill and Roberge, 2000).

Atmospheric NH_3 may be deposited onto soil and vegetation within a few hundred metres of a source, whereas NH_4^+ that is chemically bound to particles or aerosols may travel up to hundreds of kilometres downwind, crossing political boundaries. In the soil, NH_3 is mostly in the ammonium form NH_4^+ and is transformed into several environmentally important reactive forms of nitrogen, such as the **greenhouse gas nitrous oxide** (**N_2O**) and the water contaminant **nitrate** (**NO_3^-**). Reactive N is eventually converted back into relatively inert nitrogen gas (N_2) which makes up almost 80% of the atmosphere. The sequence of transformations that reactive forms of N undergo in the environment, referred to as the **nitrogen cascade** (Galloway et al., 2003), is depicted in Figure 16–2, which illustrates how all forms of reactive N resulting from ammonia emissions can have an impact on the environment.

In natural ecosystems, **atmospheric deposition** can be an important source of N for **nitrophilic** plants such as crops. However, in sensitive ecosystems (such as bogs and alpine meadows) this deposition will reduce the competitiveness of adapted **oligotrophic** plants and cause a decrease in biodiversity. Atmospheric deposition of nitrogen may also contribute to **eutrophication** of surface waters, to soil acidification, and to the secondary release of N_2O as well as nitrogen oxides (NOx), which contribute to ground-level **ozone**. Also, both NH_3 and NH_4^+ can be directly toxic to sensitive vegetation. There is modelling evidence that ammonia emitted in the U.S. Midwest affects air quality in southern Ontario, and NH_3 emitted in southern Ontario affects ecosystems located downwind in other parts of Ontario and in Quebec (Maker et al., 2009).

As an air pollutant, NH_3 falls under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) and the associated Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol). Canada has not ratified the revised protocol which was adopted in 2012, but has committed to annually report emissions from all agricultural and non-agricultural sources.

Figure 16–1: Mountains in British Columbia's Lower Fraser Valley shrouded in a haze caused by secondary PM during the late summer, August 12, 2012 (left photo) and the same vista on a clear day, February 2, 2013 (right photo). The haze-inducing particulate matter, composed primarily of ammonium nitrate, results from chemical reactions between ammonia emitted mainly from agricultural sources (such as poultry housing like that visible at bottom of left photo) and nitrogen oxides emitted by vehicles. (From Bittman and Sheppard, 2014)

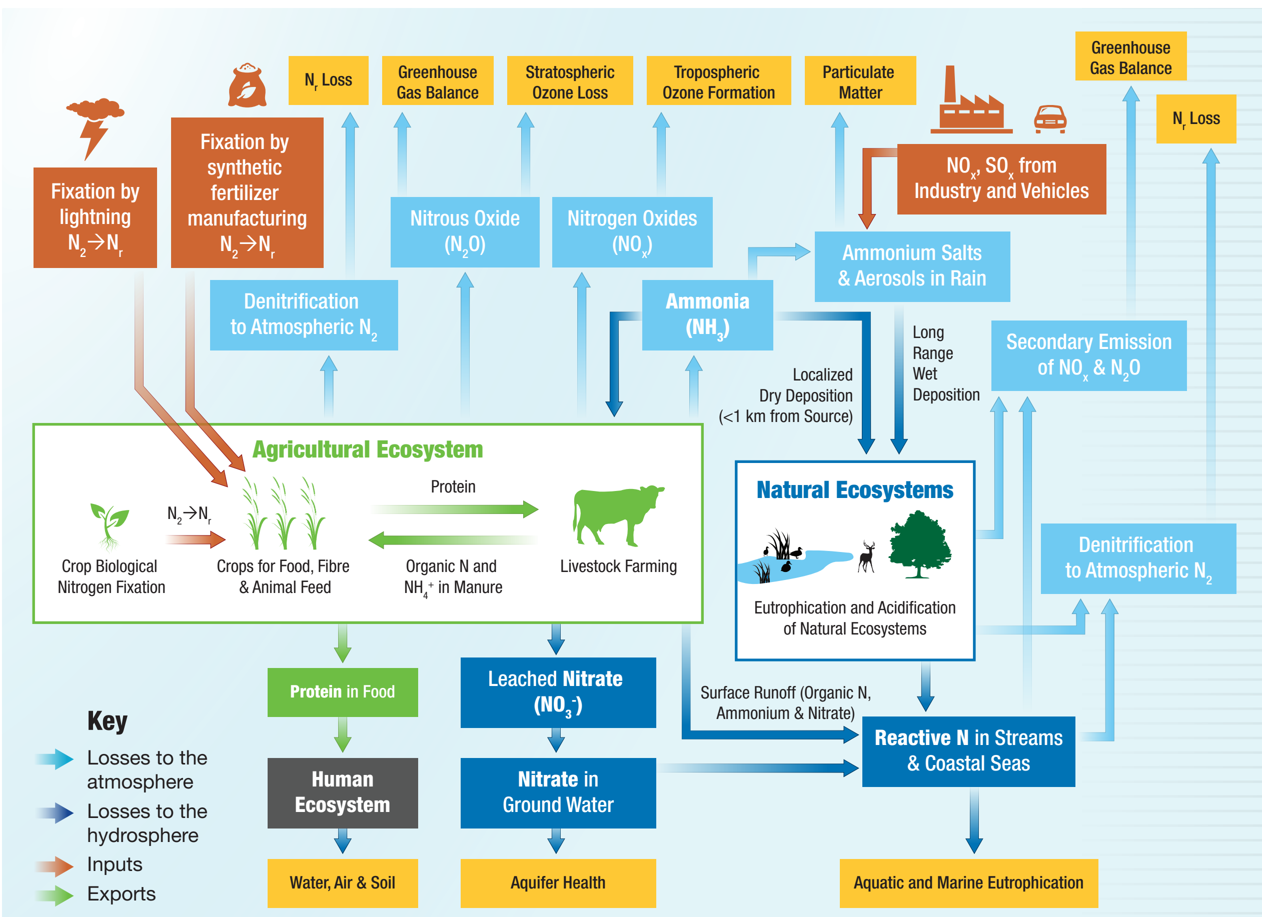


Figure 16–2: Simplified nitrogen cascade (Galloway et al., 2003), showing the fate of reactive N used in agriculture (adapted from Sutton et al., 2011)

The two most pertinent consequences of NH_3 emissions in Canada relate to the exposure of people living in population centres downwind of agricultural land and the direct loss of N, an essential and expensive crop nutrient, from agricultural operations. For farmers, the loss of NH_3 from agriculture represents the loss of a critical nutrient which must be replaced by expensive inputs. Canada-wide, the loss of 371,000 tonnes (t) of NH_3 (306,000 t of N) from farms in 2011 is equivalent to approximately 15% of all the fertilizer N shipped to farms that year, which translates into an economic cost of around $400 million (Temple Scott Associates, Inc., 2013). Replacement of lost NH_3-N not only has a monetary cost for the producer, it has broader economic and environmental implications because the production of N fertilizer uses large amounts of natural gas and is therefore a major indirect component of agricultural energy consumption in Canada.

The Indicator

The Ammonia Emissions from Agriculture Indicator estimates the annual emissions of NH_3 to the atmosphere from livestock production and fertilizer applications, per hectare of farmland, in each agricultural **Soil Landscapes of Canada** (**SLC**) **polygon.** This approach allows the NH_3 indicator to be compatible with other nitrogen indicators. The indicator also computes emissions on a monthly basis since these data are needed to interpret the fate and impact of NH_3 and to propose abatement measures.

The indicator is generated with a series of computational models that use data from several sources: farm practices in 12 **ecoregions** from farm surveys focusing on ammonia emissions; Census of Agriculture data on livestock numbers and industry data on fertilizer use; and ammonia emission factors adapted to Canadian farm practices and conditions. Specialized models are used for broilers, layers, turkeys, swine, dairy cattle, beef cattle and fertilizers and to accommodate their particular attributes. Sub-models are used for subsectors such as, in the case of the dairy sector, calves, heifers, dry cows and lactating cows. The livestock models have several common attributes:

- They are based on **total ammoniacal nitrogen** (**TAN**) in excreted manure, including urine and uric acid, estimated from feeding practices.
- The amount of N excreted is assumed to be equal to the amount of protein-N consumed by the animal, minus the protein-N retained in animal tissues or products (eggs and milk). TAN is a proportion of excreted N.
- For housed animals, the models track the transfer of excreted TAN and the loss of NH_3 from successive stages of housing, storage and land spreading. Losses from grazing animals are considered to result from a single stage.
- Canadian feeding and production practices for all sectors are analyzed using several NH_3-focused farmer surveys conducted by Statistics Canada and other entities.
- Wherever possible, mathematical functions from the literature that relate emissions to farm practices and environmental factors are used to calculate emission fractions for each of 12 ecoregions, because these mathematical functions typically summarize a large amount of data and they allow interpolation to specific conditions. Canadian emission rates are adjusted based on regional monthly average temperatures and the probability of precipitation immediately following land spreading of manure.
- Animal numbers are taken from the Census of Agriculture.

The fertilizer emission model (Sheppard et al., 2010) computes the NH_3 emissions per area of land for 37 crop types. Emissions from fertilizer use are estimated as the amount of fertilizer N forms applied per hectare multiplied by the fractions of applied N that are emitted as NH_3, based on fertilizer properties, application practices and conditions.

Limitations

The indicator has been calculated for the Census years from 1981 to 2011, based on detailed information about livestock feeding, housing and manure management and fertilizer application practices compiled in 2006. It has been necessary to assume 2006 farm practices for this 30-year period, due to the lack of alternative data, and therefore changes in farm practices that affect emissions (such as injection of liquid manure and winter grazing of beef cattle) cannot be quantified for that time frame. Going forward, with a strong database of practices from 2006 and with periodic updates, for example, the beef farm survey conducted in 2012 (Sheppard et al., 2015), it will be possible to link changes in emissions to changes in farming practices.

The indicator utilizes data that are inherently uncertain in some respects. Where Canadian emission factors were not available, the most suitable emission factor data from Europe and the United States were used and adjusted to reflect Canadian conditions to the extent possible. However, the overall estimates are influenced most strongly by livestock and fertilizer statistics (Sheppard et al., 2007), which are very reliable in Canada, and by excretion rates, which are fairly well understood for most types of livestock, and therefore our model adjusted excretion rates for protein in feeds reported by farmers. Farm practice information is less certain, although the input data are based on the detailed results of farm activity surveys focusing on ammonia. While the emission fractions are relatively uncertain given gaps in Canada-specific emission data, the large number of independent computations in the model suggests statistically diminishing error for the total emissions estimate. In Canada, emissions factors for beef cattle farms are subject to the highest level of uncertainty, and more research is needed on these operations. As in other national inventories, local deposition is not removed from the emission calculations due to lack of data. Note that an uncertainty level of 20% was estimated for the United Kingdom's inventory of NH_3 emissions from agriculture (Webb et al., 2006).

This indicator requires careful interpretation because the atmospheric transport of and reactions involving NH_3 are affected by the weather, and emission rates vary markedly throughout the year (Makar et al., 2009; Philip et al., 2014; Vet et al., 2010). Furthermore, emission rates may have a much greater impact in some regions than the same rates in other regions, and the impact may be felt a considerable distance from the source depending on the prevailing winds. Averaging emissions over time is a limitation with respect to the role of NH_3 emissions in the formation of smog. Smog events can last hours or days, depending on whether other atmospheric pollutants able to react with NH_4^+ are present and depending on weather conditions, notably wind, temperature and sunlight (Chu, 2004). Although monthly averaging of NH_3 emissions is not ideal for modelling these processes, monthly averages are a significant improvement over annual averages, given the large monthly variations in emissions.

Results and Interpretation

Ammonia emissions from livestock accounted for 81% of total agricultural NH_3 emissions in 1981 and for about 74% from 1986 to 2006, before decreasing markedly in 2011 to a low of 65% (Figure 16–3). Throughout this period, emissions from fertilizer steadily increased as a result of increases in N fertilizer use. Livestock emissions decreased by 22% from 2006 to 2011 as a direct result of the decline in the beef cattle population over this period, with the largest declines occurring in Alberta, Saskatchewan and Manitoba (Figure 16–4). In 2011, the beef sector accounted for 35% of emissions (Figure 16–5), which represents a notable decline from 46% in 2006. Emissions from fertilizers accounted for 35% of the total, an increase from 22% in 2006. This reflects an overall trend towards increased area under crops and fewer livestock, a trend that can also be seen in Figure 16–3.

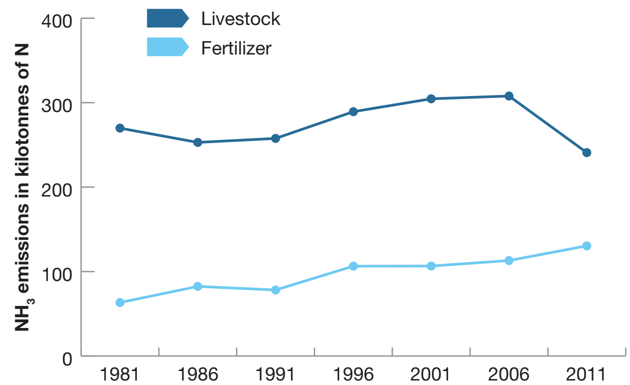


Figure 16–3: Total NH_3 emissions from livestock and fertilizer in Canada for each Census year, 1981 to 2011

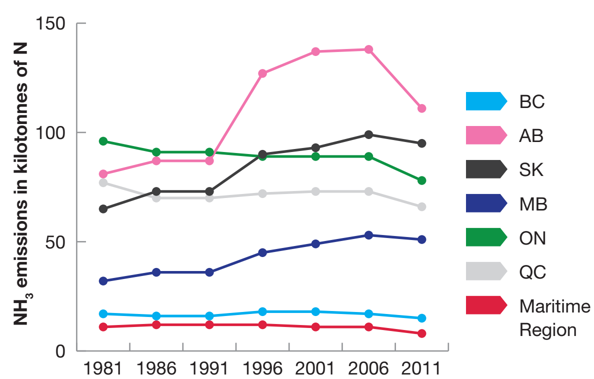


Figure 16–4: Total NH_3 emissions from both livestock and fertilizer by province or region (Maritime Region includes NL, NS, NB and PE) for each Census year, 1981 to 2011

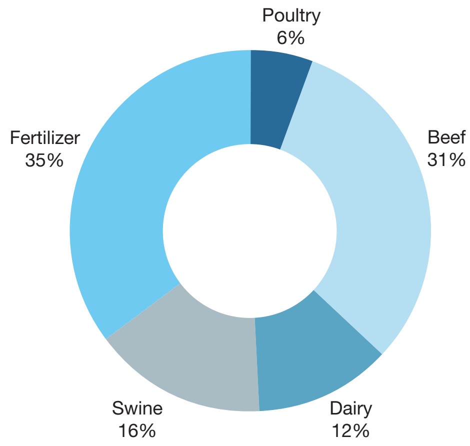


Figure 16–5: Sector percentage contribution of NH_3 emissions in 2011

Figure 16–6 shows the total NH_3 emissions per hectare across Canada in 2011, resolved by SLC units,[2] and Figures 16–7 and 16–8 similarly map emissions from fertilizers and beef cattle, respectively. Table 16–1 shows the proportion of farmland in each province in each emission intensity category for five-year intervals from 1981 to 2001. Some of the highest emissions per hectare (relating to both livestock and fertilizer emissions) occur in the Mixedwood Plains Region of southern Ontario and Quebec. The high population density in these regions increases the potential for human health implications. Other areas of relatively high emissions include the Aspen Parkland, Moist Mixed Grassland and Lake Manitoba Plain regions of the Prairies. The Lower Fraser Valley region is a small area surrounded by mountains that also has relatively high emissions per land area.

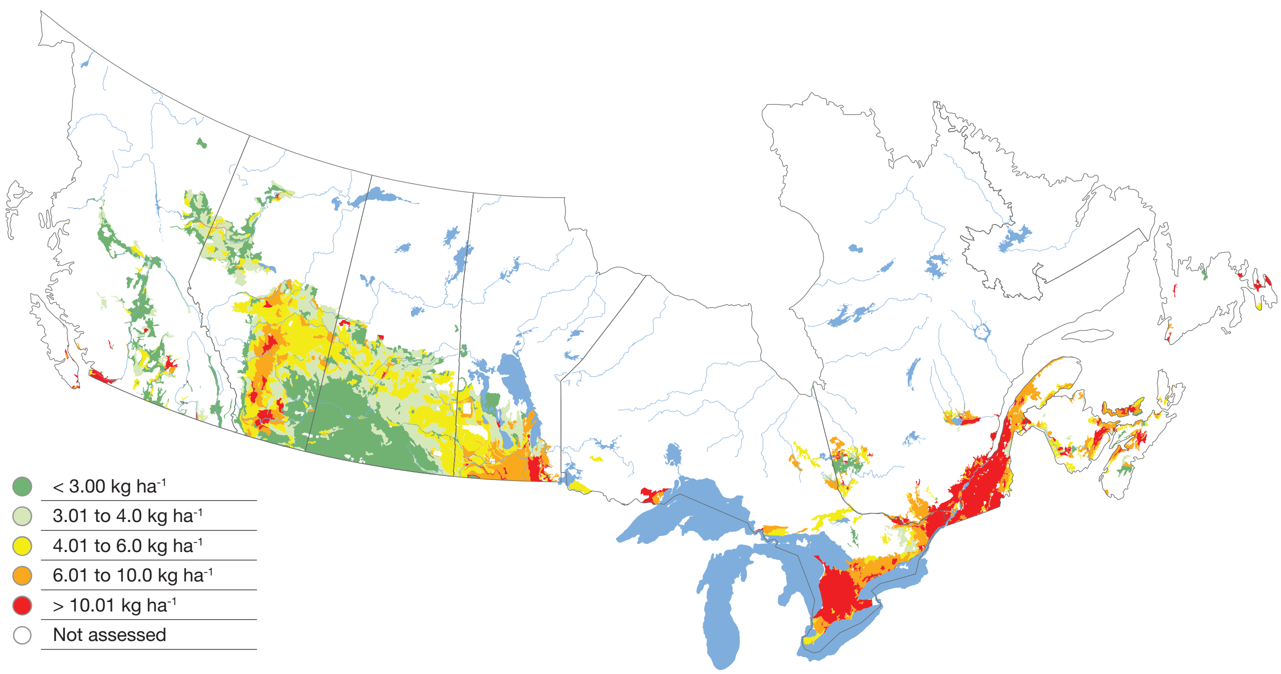


Figure 16–6: Total NH_3 emissions from livestock production and fertilizer application per hectare of agricultural land in 2011

2 It is important to note that when reporting at the scale of SLC polygons, it is necessary to assume that all areas within a given polygon are uniform. Consequently, polygons containing small pockets of very concentrated livestock production that are surrounded by lower concentrations tend to report a more favourable average emission intensity than is the actual case.

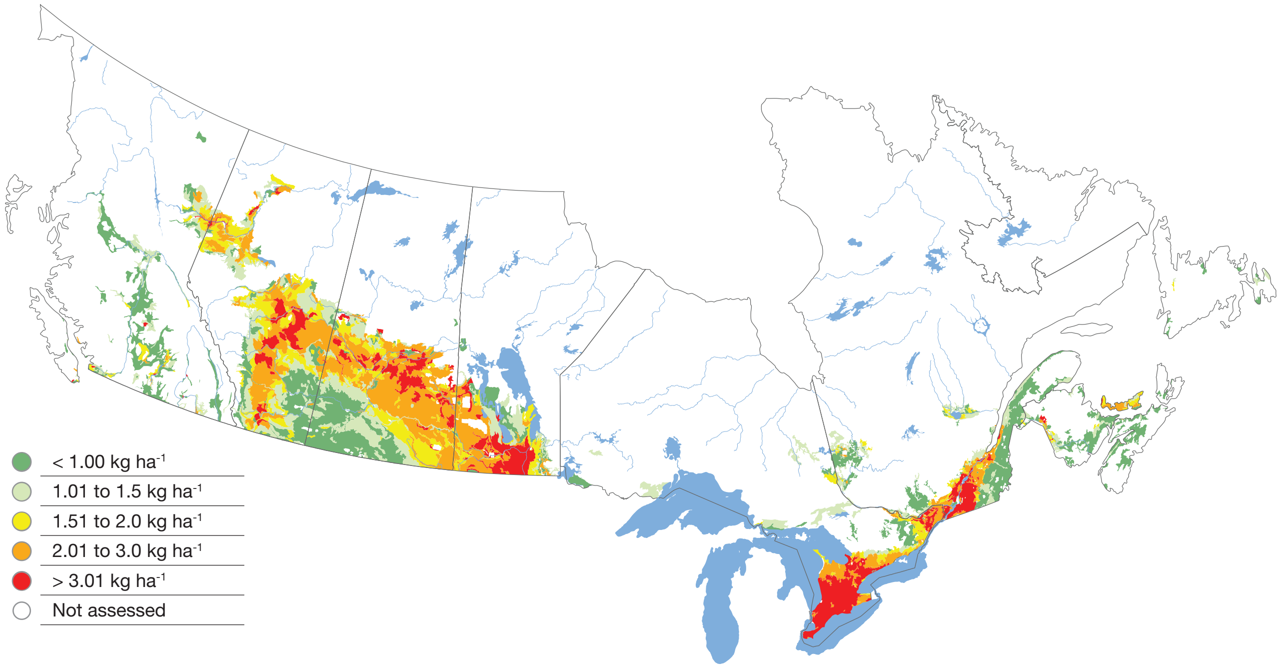


Figure 16–7: Ammonia emissions from fertilizer application per hectare of agricultural land in 2011

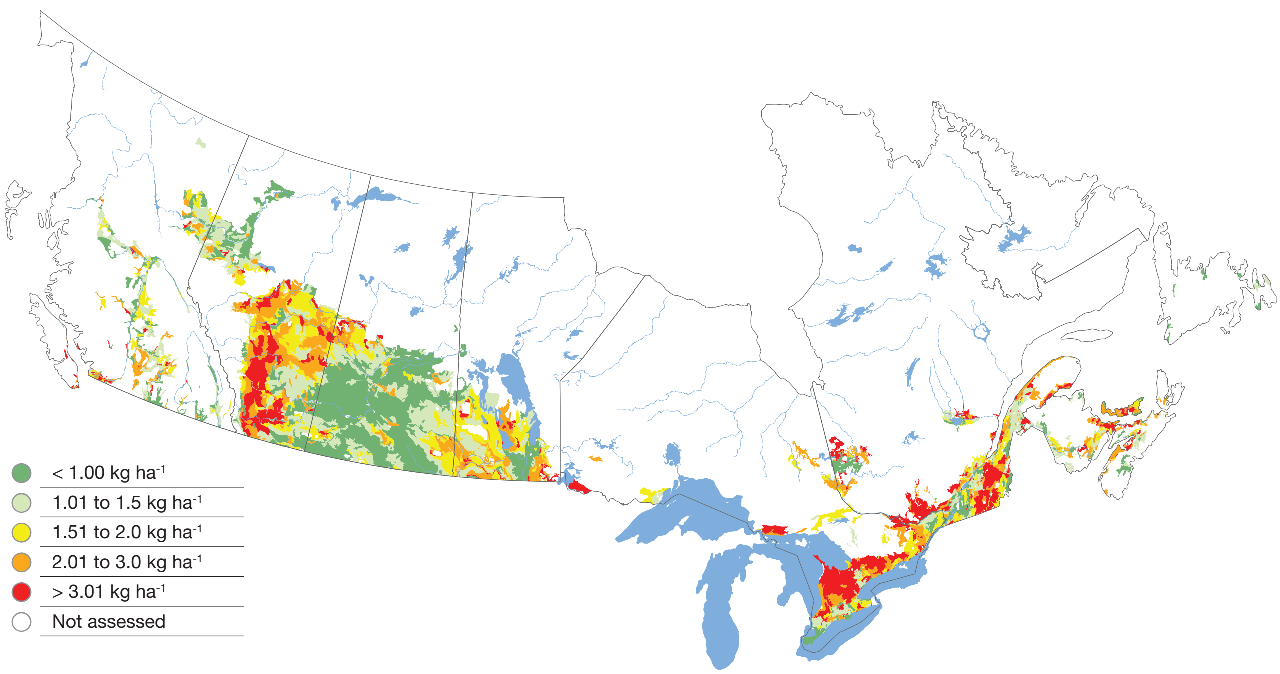


Figure 16–8: Ammonia emissions from beef cattle production per hectare of agricultural land in 2011

Table 16–1: Percentage of total farmland in each province in each of the five NH3 emission intensity classes[3], 1981 to 2011

Class	<3 kg NH_3 ha^{-1}						
Year	1981	1986	1991	1996	2001	2006	2011
British Columbia	65	74	70	51	52	52	64
Alberta	45	41	38	18	16	12	21
Saskatchewan	90	83	82	52	51	44	47
Manitoba	27	14	25	4	5	3	4
Ontario	0	0	0	0	0	0	1
Quebec	0	0	1	0	0	0	1
New Brunswick	0	0	0	0	0	1	1
Nova Scotia	6	5	4	7	9	9	17
Prince Edward Island	0	0	0	0	0	0	2
Newfoundland and Labrador	16	0	16	16	18	16	9
Canada	**55**	**50**	**50**	**29**	**28**	**24**	**28**

Class	3–4 kg NH_3 ha^{-1}						
Year	1981	1986	1991	1996	2001	2006	2011
British Columbia	17	13	15	27	29	30	20
Alberta	22	20	15	19	17	19	22
Saskatchewan	8	14	14	35	35	33	28
Manitoba	33	38	27	23	17	8	18
Ontario	0	0	0	0	0	0	2
Quebec	0	0	0	0	0	1	1
New Brunswick	4	0	2	1	1	1	17
Nova Scotia	7	7	8	6	5	9	6
Prince Edward Island	0	0	0	0	0	0	0
Newfoundland and Labrador	0	16	11	0	0	0	0
Canada	**14**	**16**	**14**	**24**	**22**	**21**	**21**

Class	4–6 kg NH_3 ha^{-1}						
Year	1981	1986	1991	1996	2001	2006	2011
British Columbia	6	4	5	11	8	9	8
Alberta	19	24	27	29	32	34	36
Saskatchewan	1	3	3	11	10	21	23
Manitoba	35	40	39	44	46	46	36
Ontario	6	8	9	8	8	7	11
Quebec	1	2	4	4	5	4	7
New Brunswick	16	19	20	15	17	17	36
Nova Scotia	2	8	3	8	8	7	17
Prince Edward Island	5	5	6	5	6	6	24
Newfoundland and Labrador	4	0	0	3	16	19	16
Canada	**11**	**14**	**15**	**19**	**20**	**25**	**26**

Class	6–10 kg NH_3 ha^{-1}						
Year	1981	1986	1991	1996	2001	2006	2011
British Columbia	3	2	4	3	2	1	1
Alberta	13	13	18	27	26	25	16
Saskatchewan	1	1	1	1	2	2	1
Manitoba	5	8	7	24	29	38	37
Ontario	10	11	13	14	21	20	31
Quebec	16	20	21	21	20	18	23
New Brunswick	49	44	46	51	48	43	25
Nova Scotia	24	24	29	18	29	31	38
Prince Edward Island	19	22	21	17	31	19	45
Newfoundland and Labrador	39	28	16	24	24	23	14
Canada	**7**	**7**	**9**	**14**	**15**	**16**	**14**

Class	>10 kg NH_3 ha^{-1}						
Year	1981	1986	1991	1996	2001	2006	2011
British Columbia	8	7	7	8	8	7	6
Alberta	1	2	2	7	9	9	5
Saskatchewan	0	0	0	0	1	0	0
Manitoba	0	1	2	5	4	5	5
Ontario	83	81	78	78	71	72	55
Quebec	82	77	74	75	74	76	68
New Brunswick	30	37	32	33	34	37	21
Nova Scotia	61	56	56	62	50	44	22
Prince Edward Island	77	73	73	78	63	76	29
Newfoundland and Labrador	41	56	57	58	42	42	61
Canada	**12**	**12**	**12**	**14**	**14**	**14**	**11**

3 Only Soil Landscapes of Canada (SLC) polygons with >5% farmland area were included in these calculations. Due to rounding, the numbers may not sum exactly to 100%.

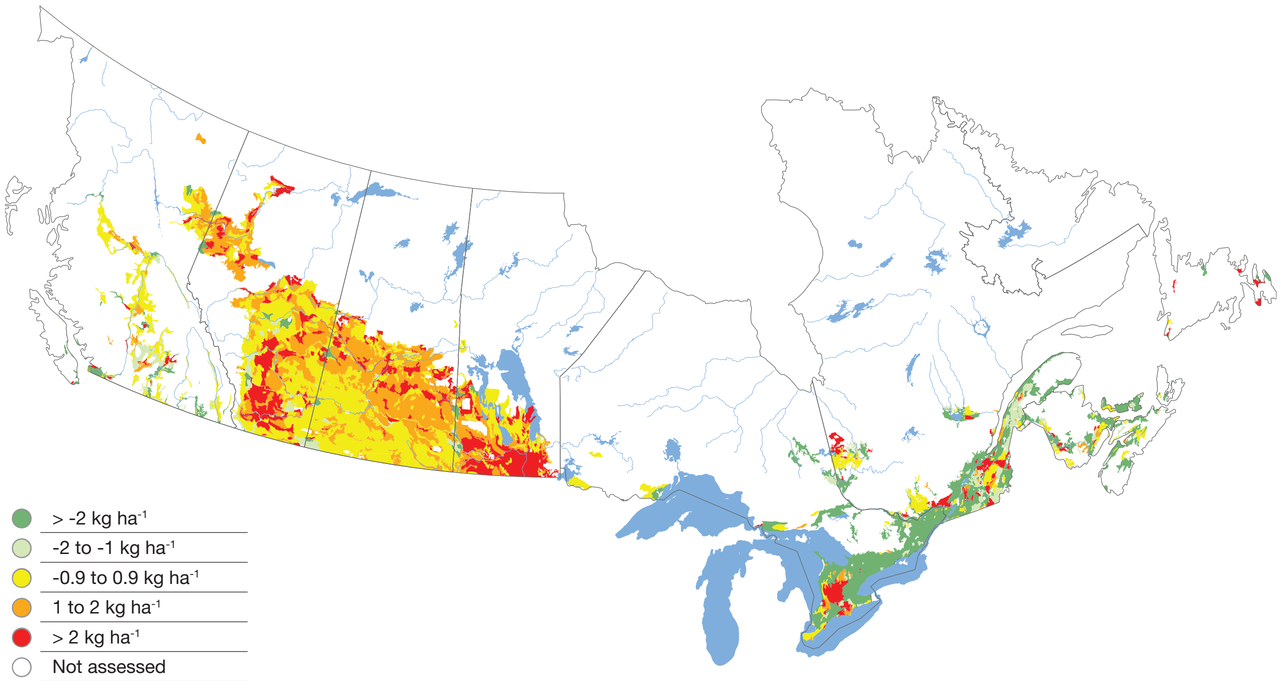


Figure 16–9: Change in total NH_3 emissions per hectare between 1981 and 2011 (negative values indicate decreased emissions with time)

While the 2011 maps show areas of high emissions, it should be noted that the percentage of farmland in each of the five emission classes changed markedly from 1981 to 2011 (Table 16–1). On the Prairies, less land was in the lowest emission class in 2011 than in 1981 (decline from 54% in 1981 to 24% in 2011), and there was a concomitant increase in the amount of land in the *No change* category. By contrast, in Ontario and Quebec, most of the land (over 82%) was in the highest emission class in 1981. Some of this land (about 14%) had dropped to the next lower class by 2011. Thus, emission intensity on an SLC basis is generally declining in the Mixedwood Plains Region, but rising slightly on the Prairies. This trend can be partly attributed to a reduction in beef production in the Mixedwood Plains Region, and an increase in fertilizer use in the Prairies. These regional trends can be viewed more clearly in Figure 16–9, which uses a smaller scale (~ 1 kilogram increments) to illustrate the more subtle changes in this indicator between 1981 and 2011.

The sources of emissions from livestock vary among the provinces (Table 16–2). Most emissions of NH_3 from livestock (across all sectors) can be linked to housing, feedlots and grazing (53%), along with land application of manure (39%). The use of fertilizer results in a widespread but relatively low NH_3 emission rate per land area, particularly in Western Canada, owing to the extensive areas of cropland with low application rates and good application techniques. Because of more widespread application of fertilizer by injection, emissions of NH_3 from fertilizer applied to cropland accounted for only 7% of applied N in Saskatchewan compared to about 13% in Ontario and Quebec, where injection is less common due to different cropping systems (more N applied to winter wheat and **forages** where injection of N is not practical.[4])

4 Fertilizer injection is a suitable technique for grain crops planted in spring using a large seeder. Injection technology is less suited to winter crops, corn and forages, which are more common in the East.

Table 16–2: NH_3 emissions from livestock sectors and fertilizer use, by province, in 2011, and total provincial emissions for 1981, 2006 and 2011

Province	Poultry	Beef	Dairy	Swine	Fertilizer	Provincial share of national emissions (%)		
	Sector percentage contribution to 2011 NH_3 emissions					1981	2006	2011
BC	21.9	27.3	28.4	3.4	19.0	4.5	3.6	3.6
AB	2.2	50.4	3.6	6.2	37.6	21.4	28.6	26.2
SK	1.2	32.3	1.4	5.6	59.4	17.1	20.7	22.4
MB	3.7	24.9	4.0	26.8	40.6	8.5	11.1	12.0
ON	10.7	22.9	21.7	22.2	22.5	25.3	18.6	18.3
QC	8.4	14.2	30.4	34.1	12.9	20.3	15.2	15.5
NB	13.8	24.0	35.2	10.7	16.3	0.8	0.7	0.6
NS	26.9	24.7	36.1	3.6	8.7	1.1	0.8	0.7
PE	3.5	29.4	30.2	13.3	23.5	0.9	0.7	0.6
NL	37.7	3.3	54.2	0.5	4.3	0.1	0.1	0.1
Canada	**5.7**	**31.3**	**12.2**	**15.7**	**35.1**	**100**	**100**	**100**
	Total national emissions (tonnes of NH_3 per year)					**333,136**	**420,866**	**371,258**

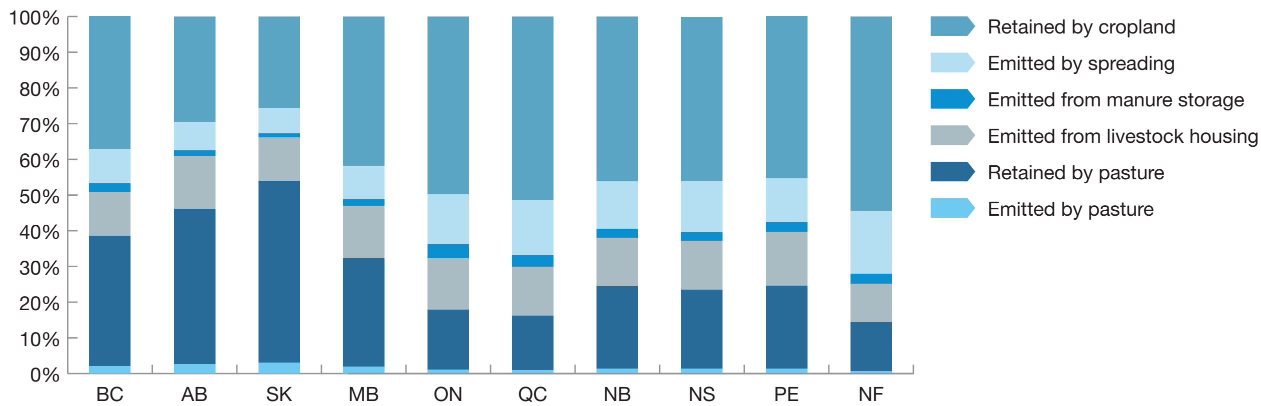


Figure 16–10: Relative fate of N excreted by livestock in each province in 2011, including the fractions emitted to the atmosphere as NH_3 and the fractions transferred to and retained in soils

Only about 2% of the total N excreted by livestock is emitted as NH_3 from pasture (Figure 16–10). However, the fraction of all N excreted over the year that is retained (as **inorganic** and organic N) in pasture soils varies between 15% in Ontario and 51% in Saskatchewan owing to differences in the amount of grazing time.

Because emissions from manure storage make up only about 2% of excreted N, manure-storage **beneficial management practices** (**BMPs**) only address a very small component of NH_3 emissions in Canada. Overall, emissions from livestock housing vary little among the provinces, ranging from 11% to 15% of total excreted N, but they vary across livestock sectors and for housing types within some sectors. Emissions from land spreading of manure vary considerably from region to region, ranging from a low of 7% of excreted N in Saskatchewan to levels as high as 16% in Quebec and 18% in Newfoundland. This is largely attributable to the greater use of manure injection by pig farmers and to fall application of manure on the Prairies as well as to the greater losses of NH_3 from cattle housing in Western Canadian feedlots. Manure injection is a more practical method on the Prairies because of relatively stone-free soils, level terrain and larger farms and tractors and probably greater reliance on manure application contractors who have specialized applicators. Application in the fall is generally environmentally acceptable on the Prairies because of the cold dry winters.

Emissions from livestock production and from fertilizer use across Canada are highest in May, because of manure and fertilizer applications prior to planting, and lowest during the winter, when manure is in storage and the temperatures in storage facilities and most cattle housing are relatively low.

In most provinces, 26% to 54% of excreted N is spread on and retained in arable cropland soils (Figure 16–10). However, the mineral vs. organic composition of this N varies. The organic fraction of land-applied manure N ranges from 56% in the Prairie Provinces to 62% in Ontario and 65% in Quebec and in several Atlantic Provinces. It should be noted that in the East, more of the non-organic N is emitted as NH_3. Feedlots in the West are an exception, given that the manure taken from feedlots is nearly all organic. The rest of the land-applied manure N is inorganic and consists largely of ammoniacal N, which is converted quickly to nitrate, thus becoming rapidly available to crops and susceptible to **leaching** and emission of N_2O. In contrast, the organic N is slowly converted to ammonia and nitrate over a number of years. Note that although a larger fraction of the land-applied manure N consists of ammoniacal N on the Prairies, the dry climate there limits the risk of leaching and **denitrification** of nitrate N.

Response Options

Beneficial management practices (BMPs) for reducing NH_3 losses from the livestock sector are complex. Since ammonia has a high propensity to escape into the atmosphere, it is important to ensure that nitrogen applied to the soil in the form of manure or fertilizer is rapidly adsorbed and eventually taken up by crops. Care must be taken to ensure that the BMP chosen to mitigate NH_3 does not have an adverse effect on some other aspect of farm operations. For example, manure injection may lead to higher emissions of N_2O and leaching of nitrate than manure broadcasting under some conditions.

Sheppard and Bittman (2013) explored the benefits and costs of the key BMPs for abating NH_3 emissions using internationally accepted cost factors (Bittman et al., 2014), They estimated the cost of reducing NH_3 emission to the atmosphere to be $0.80 per kg, which is very similar to the cost of fertilizer N per kg. When applied individually, most of these BMPs decreased emissions from the livestock sectors concerned by only 10% or less. The more effective BMPs focused on increased grazing of cattle (as opposed to confined feeding), avoiding oversupply of feed protein (by closely matching the amount of protein in the diet to animal requirements), and on low emission application methods for manure and fertilizer such as injection or rapid incorporation. When considered collectively and applied to all livestock sectors, low-cost BMPs for the reduction of NH_3 emissions have the potential to decrease overall livestock emissions by as much as 26%. Some of these BMPs require minimal and low-cost changes in existing practices, whereas others require specialized equipment or newly built facilities, such as livestock barns. When *all* emissions (i.e. also including fertilizers) are considered, low-cost mitigation measures such as reducing the N content of the diet, more efficient covering of manure stores and more timely incorporation of manure into soil could decrease total NH_3 emissions by 10%.

It should be noted that many Canadian farmers are already employing BMPs that abate NH_3 emissions. Examples include the widespread use of staged, or phased, feeding of protein to pigs and chickens. In recent years, there has been an increase in the use of low-emission application of liquid manure (especially injection of liquid pig manure into cropland), and increased winter feeding of cattle on pastureland rather than in wintering feedlots (Sheppard et al., 2013). Furthermore, in the dairy sector, higher milk production per cow has reduced overall herd size, and in the poultry sector, increased growth rates in meat (broiler) chickens have reduced the time it takes for these animals to reach maturity. Emissions have been reduced as a result of these improvements in efficiency.

Subsurface injection at seeding (referred to as side-banding) of urea and of NH_4 based fertilizer has come into widespread use in Western Canada. This development has offset the emissions that would otherwise have occurred because of the industry's switch from ammonium nitrate to urea based fertilizers, which are much more prone to volatilization. At the same time, other trends are leading to higher emissions, including, in the case of the dairy industry, the increased use of unventilated, loose (free-stall) housing, reduced grazing time, and increased use of dry distiller grains with very high concentrations of crude protein. There is also a concern that an increase in composting may contribute to higher emissions, although the extent of this activity is not well documented.

Decreasing feed protein inputs is an especially effective BMP for reducing livestock NH_3 emissions because feed N is the source of all subsequent NH_3 emissions from livestock. However, precisely managing feed protein is more easily done in the poultry and swine sectors than in the cattle sectors because of the complexities of ruminant digestion and grazing and the extensive use of home-grown forages of varying and untested quality. Although using animal residues in poultry feeds reduces waste, this practice can lead to overfeeding of protein. This is also true for the increased use of residues from the grain distillation industry.

Canadian emissions from manure storage are lower than those reported by other countries because of the very cold storage conditions and the formation of crusts associated with ample bedding and dry winter weather. Losses from housing can be reduced by adding chemicals to bedding (e.g. acidifying agents) and using barn designs that segregate faeces from urine and that allow floating covers for in-barn slurry tanks as well as absorbent filters on barn vents. In Europe, there is growing interest in acidification of slurry before land application but this approach has not been tested in Canada. There is a special need for research into the effectiveness of BMPs for abating NH_3 from beef production in confinement and on pasture.

The regional and local impacts of NH_3 emissions need to be investigated in relation to temporal factors (Bittman et al., 2015). The peak emissions from agriculture, which result from manure spreading and fertilizer application, occur too early in the year to have a direct effect on smog, which is mainly a summer phenomenon. Summertime emissions do occur, however, especially from barns or manure and from fertilizer application to forages and after the winter wheat harvest. Recent studies have shown, paradoxically, that the greatest benefits from abatement of atmospheric particulate formation occur when NH_3 emission levels are low, since little NH_3 is available for the formation of atmospheric particulates (Vet et al., 2010). When NH_3 emission levels are high, acid gases are a limiting factor. Environmentally, early spring emissions likely lead to ecological effects associated with excess N, because high ammonia levels in the atmosphere may be deleterious to new tissue in sensitive plant species and because invasive plants, such as grasses that respond strongly to N, undergo rapid growth in the spring. Early spring emissions are likely to increase secondary emissions of N_2O following deposition in relatively moist and warm soils. Further research on impacts is needed in Canada.

The production and use of urea fertilizers is increasing relative to nitrate N sources because of the lower cost and concern about the safety of ammonium nitrate, in particular. There is a very high potential for loss of NH_3 from urea, especially when the fertilizer is broadcast and/or banded on the soil surface. In the cropping sector, there is an economic incentive for adopting BMPs since this can reduce losses. Effective application methods such as injection (side-banding and side-dressing) are increasingly being used to improve the efficiency of urea-containing fertilizers, but these methods are not available for established crops such as forages or winter wheat. Precision farming techniques that improve N efficiency can also help to reduce emissions.

Preventing NH_3 losses can have direct and indirect beneficial effects on water, air and soil. Mitigation of NH_3 emissions requires a thorough understanding of the full range of impacts associated with these losses. Care must be taken to ensure that abatement of ammonia does not have unintended consequences like increased leaching of nitrate in emissions of N_2O (referred to as pollution swapping). There are many ways for producers to increase the efficiency of their practices; however, BMPs for mitigating NH_3 emissions must be part of a suite of effective practices for managing all nitrogen species and other nutrients on farms.

Primary References

Barthelmie, R.J., and S.C. Pryor, 1998. *Implications of ammonia emissions for fine aerosol formation and visibility impairment: A case study of the Lower Fraser Valley, British Columbia*. Atmospheric Environment. 32:345-352.

Bittman, S., M. Dedina, C.M. Howard, O. Oenema , and S. Sutton, 2014. *Options for ammonia mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen*. Edinburgh, United Kingdom: Centre for Ecology & Hydrology.

Bittman, S., K. Jones, R. Vingarzan, D.E. Hunt, S.C. Sheppard, J. Tait, R. So, J. Zhao, 2015. *Weekly agricultural emissions and ambient concentrations of ammonia: Validation of an emission inventory*. Atmopheric Environment (in press).

Bittman S., and S.C. Sheppard, 2014. Ammonia emissions in Canada. In: Van der Hoek, K.W., and N.P. Kozlova (eds.). Ammonia workshop 2012 Saint Petersburg. Abating ammonia emissions in the UNECE and EECCA region; p. 29-46. Семинар по аммиаку 2012, Санкт Петербург.Снижение выбросов аммиака в регионах ЕЭК ООН и ВЕКЦА.RIVM Report 680181001/SZNIIMESH Report. Bilthoven, The Netherlands. ISBN: 978-90-6960-271-4.

Chu, S-H., 2004. *$PM_{2.5}$ episodes as observed in the speciation trends network*. Atmospheric Environment. 38: 5237-5246.

Deutsch, F., J. Vankerkom, L. Janssen, S. Janssen, L. Bencs, R. Van Grieken, F. Fierens, G. Dumont, and C. Mensink, 2008. *Modelling concentrations of airborne primary and secondary PM_{10} and $PM_{2.5}$ with the BelEUROS-model in Belgium*. Ecological Modelling. 217: 230-239.

Galloway, J.N., J.D. Aber, J.W. Erisman, S.P. Seitzinger, R.W. Howarth, E.B. Cowling, and B.J. Cosby, 2003. *The nitrogen cascade*. Bioscience. 53(4): 341-356.

Makar, P.A., M.D. Moran, Q. Zheng, S. Cousineau, M. Sassi, A. Duhamel, M. Besner et al., 2009. *Modelling the impacts of ammonia emissions reductions on North American air quality*. Atmospheric Chemistry and Physics. 9(18): 7183-7212

McNeill, R., and A. Roberge, 2000. *The impact of visual air quality on tourism revenues in Greater Vancouver and the Lower Fraser Valley*. GBEI report number EC/GB-00-028. www.clearairbc.ca/visibility/Documents/VisibiltyTourism-McNeill.pdf (retrieved April 4, 2013).

Philip, S., R. Martin, A. van Donkelaar, J. Wai-Ho Lo, Y. Wang , D. Chen, L. Zhang et al., 2014. *Global chemical composition of ambient fine particulate matter for exposure assessment*. Environmental Science & Technology. 48(22): 13060-13068.

Sheppard, S.C., and S. Bittman, 2013. *Estimated net application of ammoniacal and organic N from manure, and potential for mitigating losses of ammonia in Canada*. Agriculture, Ecosystems & Environment. 171: 90-102.

Sheppard, S.C., S. Bittman, and T.W. Bruulsema, 2010. *Monthly ammonia emissions from fertilizers in 12 Canadian Ecoregions*. Canadian Journal of Soil Science. 90: 113-127.

Sheppard, S.C., S. Bittman, G. Donohoe, D. Flaten, K.M. Wittenberg, J.A. Small, R. Berthiaume et al., 2015[a]. *Beef cattle husbandry practices across ecoregions in Canada in 2011*. Canadian Journal of Animal Science. (in press)

Sheppard, S.C., S. Bittman, J. Tait, S.G. Sommer, J. Webb, 2007. *Sensitivity analysis of alternative model structures for an indicator of ammonia emissions from agriculture.* Canadian Journal of Soil Science. 87: 129-139

Sutton, M.A., C.M. Howard, J.W. Erisman, G. Billen, A. Bleeker, P. Grennfelt, H. Van Grinsven, and B. Grizzetti (eds), 2011. *The European nitrogen assessment: Sources, effects and policy perspectives*. Cambridge, UK: Cambridge University Press.

Temple Scott Associates, Inc. 2013. *Fertilizer report for the Canadian fertilizer industry*. http://www.cfi.ca/_documents/Fertilizer%20Industry%20Report-%20FINAL.pdf

Vet, R., S-M. Li, G. Beaney, W. Belzer, E. Chan, T. Dann, K. Friesen et al., 2010. *Characterization of ambient ammonia, PM and regional deposition across Canada*. In: Lillyman, C. and K. Buset (eds.). The 2008 Canadian atmospheric assessment of agricultural ammonia. National agri-environmental standards technical series report No. 4-1. Gatineau, QC, Canada: Environment Canada; p. 129-217.

Further Resources

The following manuscripts and book chapters have been developed using the indicator work explained in this Chapter and are primary sources. Some of these, but not all, have been referenced within this chapter.

MANUSCRIPTS

Chai, L., R. Kröbel, H.H. Janzen, K. A. Beauchemin, S.M. McGinn, S. Bittman, A. Atia, I. Edeogu et al., 2014*. A regional mass balance model based on total ammoniacal nitrogen for estimating ammonia emissions from beef cattle in Alberta, Canada.* Atmospheric Environment. 92: 292-302.

Clair, T.A., N. Pelletier, S. Bittman, A. Leip, A.P. Arp, M.D. Moran, I. Dennis et al., 2014. *Interactions between reactive nitrogen and the Canadian landscape: a budget approach.* Global Geochemical Cycles. 28 (11):1343-1357.

Makar, P.A., M.D. Moran, Q. Zheng, S. Cousineau, M. Sassi, A. Duhamel, M. Besner, D. Davignon, L-P. Crevier, and V.S. Bouchet, 2009. *Modelling the impacts of ammonia emissions reductions on North American air quality*. Atmospheric Chemistry and Physics. 9(18): 7183-7212.

Philip, S., R. Martin, A. van Donkelaar, J. Wai-Ho Lo, Y. Wang , D. Chen, L. Zhang et al., 2014. *Global chemical composition of ambient fine particulate matter for exposure assessment*. Environmental Science & Technology. 48(22):13060-13068.

Sheppard, S.C., and S. Bittman, 2011. *Farm survey used to guide estimates of nitrogen intake and ammonia emissions for beef cattle, including early season grazing and piosphere effects*. Feed Science and Technology. 166-167: 688-698.

Sheppard, S.C., and S. Bittman, 2012. *Farm practices as they affect NH_3 emissions from beef cattle*. Canadian Journal of Animal Science. 92: 525-543.

Sheppard, S.C., and S. Bittman, 2013. *Estimated net application of ammoniacal and organic N from manure, and potential for mitigating losses of ammonia in Canada*. Agriculture, Ecosystems and Environment. 171: 90-102.

Sheppard, S.C., and S. Bittman. 2015. *Linkage of food consumption and export to ammonia emissions in Canada and the overriding implications for mitigation.* Atmospheric Environment (in press).

Sheppard, S.C., S. Bittman, M. Beaulieu, and M.I. Sheppard, 2009. *Ecoregion and farm size differences in feed and manure nitrogen management: 1) Survey methods and results for poultry*. Canadian Journal of Animal Science. 89: 1-19.

Sheppard, S.C, S. Bittman, and T.W. Bruulsema, 2010. *Monthly ammonia emissions from fertilizers in 12 Canadian Ecoregions*. Canadian Journal of Soil Science. 90: 113-127.

Sheppard, S.C., S. Bittman, G. Donohoe, D. Flaten, K.M. Wittenberg, J.A. Small, R. Berthiaume et al., 2015. *Beef cattle husbandry practices across ecoregions in Canada in 2011*. Canadian Journal of Animal Science. (in press).

Sheppard, S.C., S. Bittman, M.L. Swift, M. Beaulieu, and M.I. Sheppard, 2011. *Ecoregion and farm size differences in dairy feed and manure nitrogen management: A survey*. Canadian Journal of Animal Science. 91: 459-473.

Sheppard, S.C., S. Bittman, M.L. Swift, and J. Tait, 2010. *Farm practices survey and modelling to estimate monthly NH_3 emissions from swine production in 12 Ecoregions of Canada*. Canadian Journal of Animal Science. 90: 145-158.

Sheppard, S.C., S. Bittman, M.L. Swift, and J. Tait, 2011. *Modelling monthly NH_3 emissions from dairy in 12 Ecoregions of Canada*. Canadian Journal of Animal Science. 91: 1-13.

Sheppard, S.C., S. Bittman, and J. Tait, 2009. *Monthly NH_3 emissions from poultry in 12 Ecoregions of Canada.* Canadian Journal of Animal Science. 89: 21-35.

Sheppard, S.C., S. Bittman, J. Tait, S.G. Sommer, and J. Webb, 2007. *Sensitivity analysis of alternative model structures for an indicator of ammonia emissions from agriculture.* Canadian Journal of Soil Science. 87: 129-139.

Sheppard, S.C., R. De Jong, M.I. Sheppard, S. Bittman, and M.S. Beaulieu, 2007. *Estimation of ammonia emission episodes for a national inventory using a farmer survey and probable number of field working days*. Canadian Journal of Soil Science. 87: 301-313.

BOOK CHAPTERS

Ayres, J., S. Bittman, S. Girdhar, S. Sheppard, D. Niemi, D. Ratte, and P. Smith, 2010. Chapter 5: *Sources of Ammonia Emissions*. In: Lillyman, C. and K. Buset (eds.). The 2008 Canadian atmospheric assessment of agricultural ammonia. National Agri-Environmental Standards Initiative technical series report No. 4-1. Gatineau, QC: Environment Canada; p. 57-75.

Bittman, S., J. Ayres, S. Sheppard, and S. Girdhar, 2010. Chapter 4: *Emission inventory development*. In: Lillyman, C. and K. Buset (eds.). The 2008 Canadian atmospheric assessment of agricultural ammonia. National Agri-Environmental Standards Initiative technical series report No. 4-1. Gatineau, QC: Environment Canada; p. 77-91.

Bittman, S., D. Masse, E. Pattey, M. Cournoyer, G. Qiu, G., A. Narjoux, S.C. Sheppard, and A.C. VanderZaag, 2013. Chapter 11. *Effects of agriculture on air quality in Canada*. In: Taylor, E. and A. McMillan (eds.) Air quality management: Canadian perspectives on a global issue. Springer; p. 237-259.

Bittman S., and S.C. Sheppard, 2014. Ammonia emissions in Canada. In: Van der Hoek, K.W. and N.P. Kozlova, (eds.). Ammonia workshop 2012 Saint Petersburg. Abating ammonia emissions in the UNECE and EECCA region; p. 29-46. *Семинар по аммиаку* 2012*, Санкт Петербург.Снижение выбросов аммиака в регионах ЕЭК* ООН *и ВЕКЦА*.RIVM Report 680181001/SZNIIMESH Report. Bilthoven, The Netherlands. ISBN: 978-90-6960-271-4

Bittman, S., J. Brook, A. Bleeker, and T. Bruulsema, 2013. Chapter 12. *Air quality, health effects and management of ammonia emissions from fertilizers*. In: Taylor, E. and A. McMillan (eds.). Air quality management: Canadian perspectives on a global issue. Springer; p. 261-277

17 Particulate Matter

Authors:
E. Pattey, G. Qiu, S. Fiset, E. Ho, D. MacDonald and L. Chang

Indicator Name:
Agricultural Particulate Matter Emissions Indicator

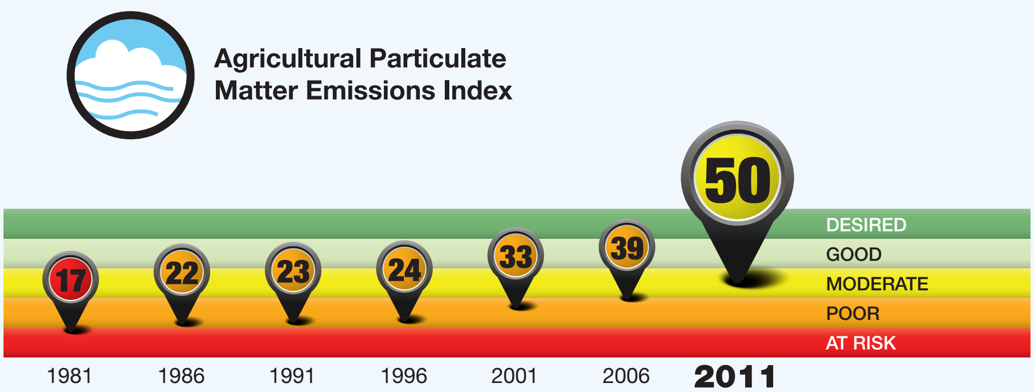
Status:
National Coverage, 1981 to 2011

Summary

Particulate matter (**PM**)[1] is considered a type of air pollution due to its adverse effects on human health and the environment. PM decreases visibility and has climatic effects since it alters the amount of solar energy reaching the earth's surface and the amount of energy radiating back into space. It contributes to stratospheric **ozone** depletion, acid rain and **smog**. The emission of PM from agricultural operations is an emerging air quality issue with important implications for the health of agricultural workers and animals. The Agricultural Particulate Matter Emissions Indicator (APMEI) has been developed to estimate the PM emissions from agriculture and to assess emission-reduction measures. The APMEI estimates emissions of primary PM from wind erosion, land

Particulate Matter Index – *T. Hoppe, T. Martin and R.L. Clearwater*

A performance index is a statistical snapshot of a set of variables used to show the current state and to track changes over time. Agriculture and Agri-Food Canada has developed performance indices that assign single values to the indicator results. By statistically converting the indicator map to a single value from 0 to 100 for each year, we can assess whether the indicator has improved or declined over time.



State and Trend

As illustrated by the performance index, in 2011 the state of particulate matter emissions resulting from farming activities in Canada was 'Moderate'. The index illustrates an improving trend, representing a reduction in PM emissions between 1981 and 2011. This reduction is primarily attributed to the widespread adoption of reduced tillage and no-till, as well as decreases in the use of summerfallow in Manitoba, Saskatchewan and Alberta.

The index tends to aggregate and generalize trends. Specific findings, regional variations and interpretations are more explicitly discussed in the Results and Interpretation section of this chapter. More information on how performance indices are calculated can be found in Chapter 2 "Assessing the Environmental Sustainability of the Agri-Food Sector".

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

preparation, crop harvesting, **fertilizer** and chemical application, **crop residue** burning, grain handling, pollen, animal feeding operations and animal carcass burning for the Census years 1981 to 2011. The Particulate Matter Indicator assesses both the *state* and the *trend* of emissions of **primary PM** resulting from Canadian agricultural activities.

Total PM emissions from agricultural sources in Canada decreased from 1981 to 2011, with a decline of 63% for total suspended particulate (TSP), 58% for PM^{10} and 61% for $PM_{2.5}$ (refer to Figure 17–2 in the text box "Particulate Matter Explained" for an explanation of PM size classes). In 2011, emissions were 3,066 kilotonnes (kt) for TSP, 1,190 kt for PM_{10} and 276 kt for $PM_{2.5}$. The greatest improvements have occurred in the Prairie Provinces, and can mainly be attributed to a reduction in **summerfallow**, along with a shift to **reduced tillage** and **no-till** practices in this region, which has reduced the quantity of particulates produced during land preparation and harvesting.

The Issue and Why it Matters

Particulate matter is a mixture of solid particles and liquid droplets of varying size and chemical composition that are suspended in the air. It is classified as either primary particles emitted directly into the air or as secondary particles formed in the air by chemical or physical processes. Epidemiological studies show that increases in PM concentrations, especially the concentrations of **fine particulate matter** ($PM_{2.5}$), are associated with adverse health effects such as increased incidence of respiratory diseases and premature death (Donham and Thelin, 2006; Samet and Krewski, 2007; U.S. EPA, 2004). Additionally, PM is recognized as an air pollutant that decreases visibility, contributes to stratospheric ozone depletion, acid rain and smog, and influences climate by altering both the amount of solar energy reaching the earth's surface and the amount of energy radiating back into space.

Agriculture has long been recognized as a significant contributor of atmospheric PM emissions (Saxton, 1996). The main agricultural sources of primary PM include dust from soil and biological material, droplets and particles from agrochemicals, and bacteria that affect both indoor and outdoor air quality. **Ammonia** emissions are the main agricultural source of **secondary PM** (i.e. those particles that are formed in the air – see Figure 17–1). Little is known about outdoor air quality in rural environments since monitoring stations are sparse.

Agricultural PM emissions show temporal and spatial variations. For example, emissions from land preparation and crop harvesting tend to be seasonal, and emissions from livestock operations vary by type of livestock and by type of building. Estimates of PM emissions from various agricultural sources can be improved by taking into account these temporal and spatial variations and the impact of mitigation measures such as changes in land use and management practices. It is important to be able to demonstrate how agricultural practices can mitigate PM emissions in various regions and production systems, and the response to these practices over time. For instance, changes and improvements in land management have led to a steady decline in agricultural contributions to PM emissions since 1981.



From left to right: Primary particulate matter resulting from wind erosion, land preparation (tillage) and harvest.

Particulate Matter Explained

WHAT IS THE DIFFERENCE BETWEEN PRIMARY AND SECONDARY PARTICULATE MATTER?

Primary PM refers to particles that are released intact into the air. Primary PM results from processes such as wind erosion and tillage (soil dust), burning (soot), crop harvesting and grain handling (grain dust). Secondary PM refers to particles that are formed in the air. For example, ammonia, biogenic volatile organic compounds (VOCs) emitted from plants and nitric oxide from soils can all react with other airborne pollutants to form particles that contribute to smog (Figure 17–1).

WHAT ARE THE MAIN AGRICULTURAL SOURCES OF PRIMARY PARTICULATE MATTER?

Inorganic PM is a complex mixture of minerals composed chiefly of dust particles generated from the soil matrix which consist primarily of quartz and other silicates. Inorganic dusts, especially quartz, have been identified as a contributing factor to lung fibrosis (Canadian Centre for Occupational Health and Safety, 2012).

Biological PM consists of a broad range of material from organic sources, including animal dander, dust from manure, urine droplets, grain dust, mould spores, bacteria and pollen. This material may include infectious pathogens. Health risks may include allergic reactions, and general respiratory infections.

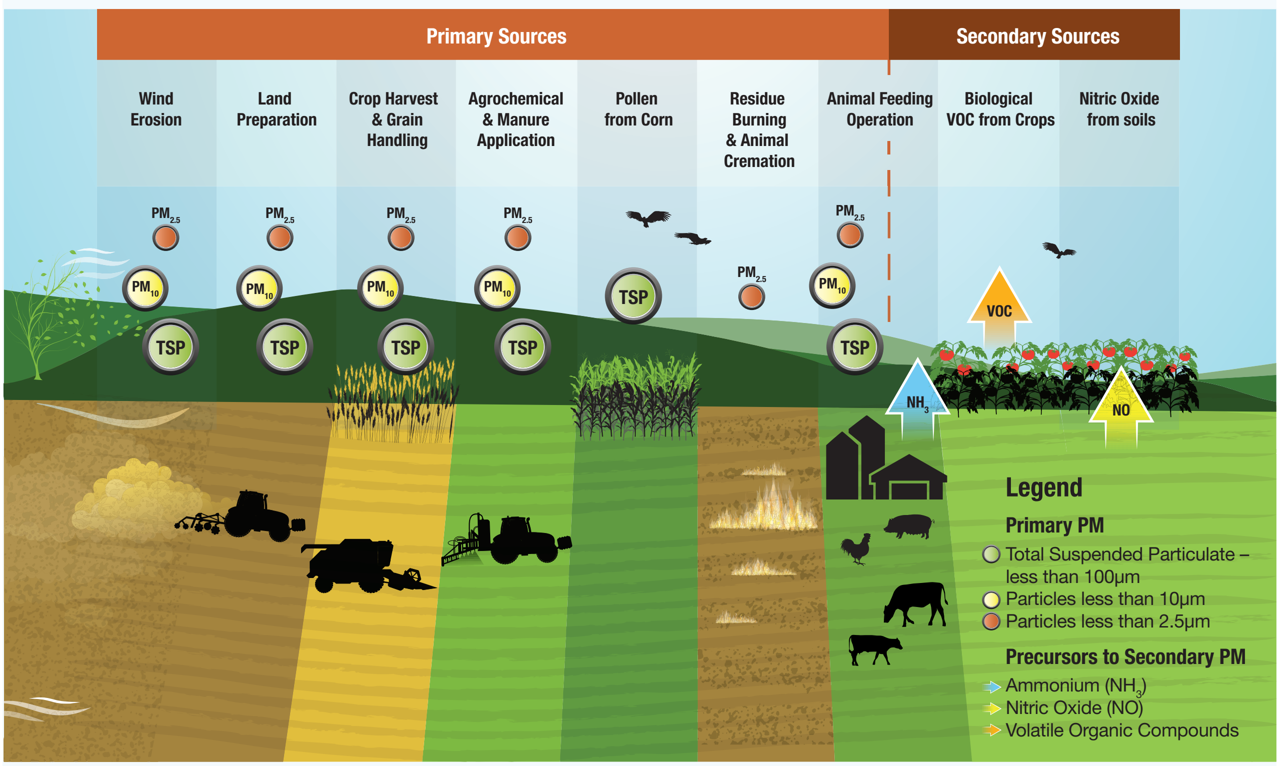


Figure 17–1: Main activities and factors contributing to primary and secondary PM emissions in agriculture

Continued on next page

Particulate Matter Explained

WHAT DO THE DIFFERENT SIZE CLASSES OF PARTICULATE MATTER REPRESENT?

Particulate matter is comprised of millions of different chemical compounds, dust and biological material, including feather fibres, dander and bacteria. These particles are classified according to their **aerodynamic diameter** and illustrated in Figure 17–2. They are defined as follows:

$PM_{2.5}$ Particles with an aerodynamic diameter of less than 2.5 micrometres. These particles are easily inhaled into the lower airways (the gas-exchange regions of the lungs) and deposited in the lungs, causing adverse health effects.

PM_{10} Particles with an aerodynamic diameter of less than 10 micrometres, including $PM_{2.5}$. These particles can be inhaled into and settle in the bronchi and lungs, leading to health problems.

TSP Total suspended particulates consist of all PM suspended in the atmosphere with an aerodynamic diameter of less than 100 micrometres.

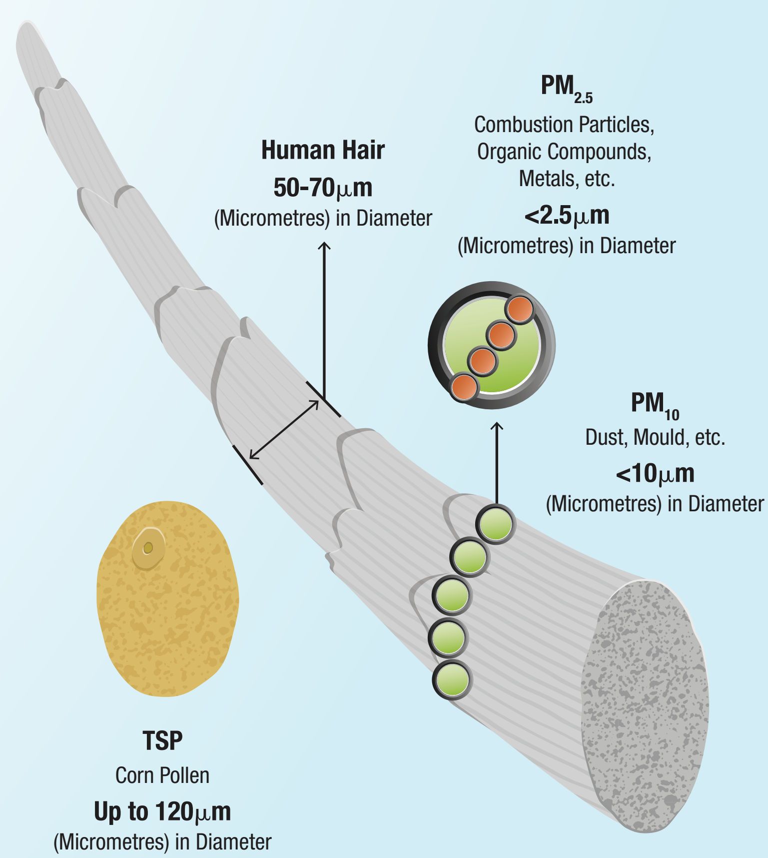


Figure 17–2: **Particle matter size classes – adapted from the United States Environmental Protection Agency (2004)**

The Indicator

The APMEI model has been modified, and new data, including data from the 2011 **Census of Agriculture**, have been incorporated into the analysis since the previous Agri-Environmental Indicator report (Eilers et al., 2010). The values for all previous Census years have been recalculated, resulting in differences in reported values. In the event of a discrepancy between the findings in the two reports, this report should be used.

The APMEI was developed to estimate emissions of primary PM from agricultural operations and to assess the effect of practices adopted to mitigate these emissions. The indicator estimates annual agricultural emissions for three classes of PM (TSP, PM_{10} and $PM_{2.5}$ in kt per year). Agricultural sources of PM include wind erosion, land preparation, crop harvesting, crop residue burning, grain handling, pollen emission, fertilizer and chemical application, animal feeding operations and carcass burning (Figure 17–1).

To calculate the APMEI, activity data are collected for each agricultural source and a corresponding **emission factor** is applied in order to estimate the total PM emissions. For example, emissions of primary PM from crop harvesting are calculated by multiplying the area of the crop concerned by an emission factor (kg of PM per ha of crop type per year). Most of the activity data stem from the Census of Agriculture and the Farm Environmental Management Survey (FEMS). PM emission calculations were completed for each Census year at the **Soil Landscape of Canada** (**SLC**) **polygon** level, and then the PM emissions for each SLC polygon were summed to estimate emissions at the provincial and national scales. The range of emissions was divided into five relative risk classes, ranging from very low to very high risk, to highlight both the changes within an individual SLC polygon over the time period of interest (1981 to 2011) and the differences between SLC polygons on an annual basis. The classes obtained from each agricultural SLC polygon provide an indication of the size of the contributions of PM, but are not directly related to regional air quality. Local and regional air quality is influenced by numerous environmental factors that ultimately control the dispersion and distribution of PM from the original source. Additionally, since the temporal variation in PM emissions from most agricultural sources is not discernible when results are presented on an annual basis, monthly PM emissions are presented for wind erosion, tillage and harvesting.

Limitations

To provide a comprehensive estimate of emissions of primary PM, the APMEI takes into account the widest possible range of agricultural activities that are likely to generate emissions. There are, however, some limitations, which are mainly related to the quality of the activity data and the corresponding emission factors. Where possible, missing activity data were estimated based on expert opinion (e.g. data for some aspects of grain handling) or obtained from other government agencies (e.g. data on chemical **pesticide** applications). Since few emission factors have been derived to date for Canadian agricultural systems, it is necessary to use factors from studies conducted in the United States where conditions may not match those in Canada.

Although the indicator focuses on primary PM from agricultural operations, secondary PM is also an important component of agricultural PM emissions. To get a complete picture of PM emissions in the agriculture sector, emissions of secondary PM need to be incorporated into this indicator in the future.

Further research on agricultural PM emissions and emission factors relevant to Canadian conditions could enhance the Agricultural Particulate Matter Emissions Indicator (APMEI) and contribute to better modelling of PM emissions. This could include integrating secondary PM into the APMEI—a step that will require collaboration with atmospheric modelling experts.

Results And Interpretation

In 2011, agricultural PM emissions stood at 3,066 kt for TSP, 1,190 kt for PM_{10} and 276 kt for $PM_{2.5}$ (Table 17–1). Figures 17–3, 17–4 and 17–5 show the net PM emissions per hectare of farmland, at the scale of SLC polygons, for TSP, PM_{10} and $PM_{2.5}$ respectively, for 2011. For all PM classes, there are areas of *High* or *Very High* emissions in the Moist Mixed Grassland, Mixed Grassland, Aspen Parkland and Manitoba Plains regions of the Prairies, and in the Manitoulin-Lake Simcoe, Lake Erie Lowlands and St. Lawrence Lowlands of the Mixedwood Plains Region.

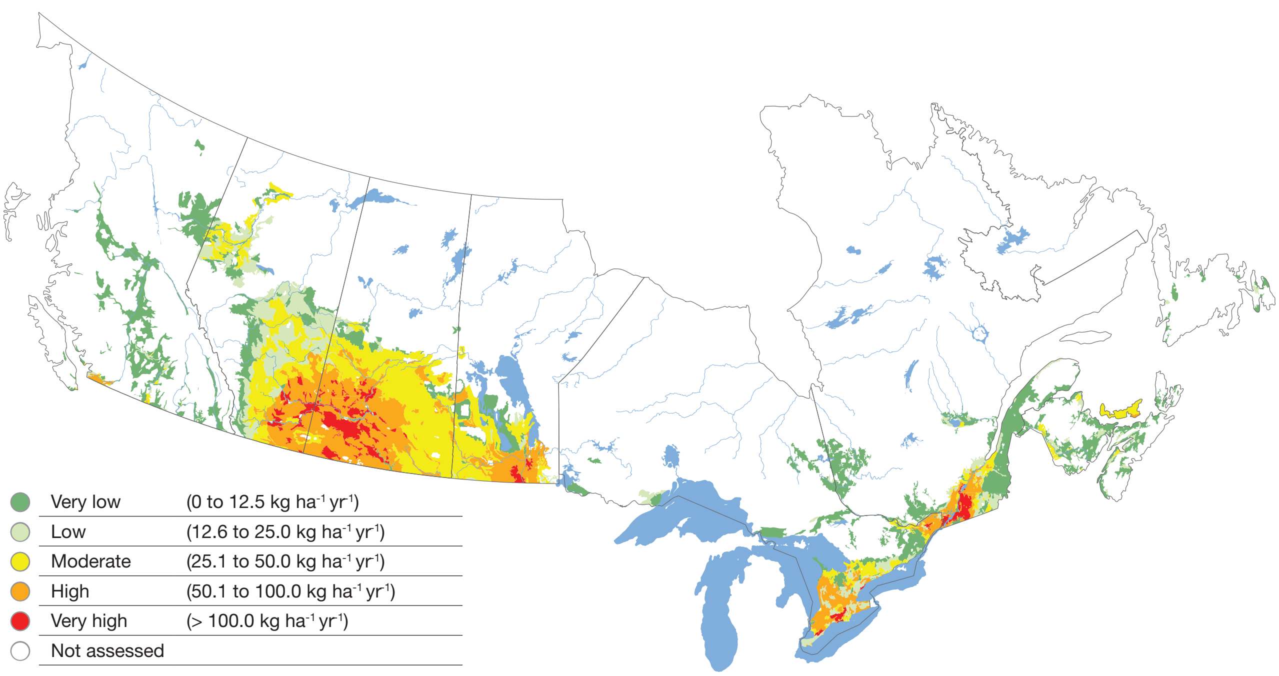


Figure 17–3: TSP emissions (kg ha^{-1} yr^{-1}) in 2011

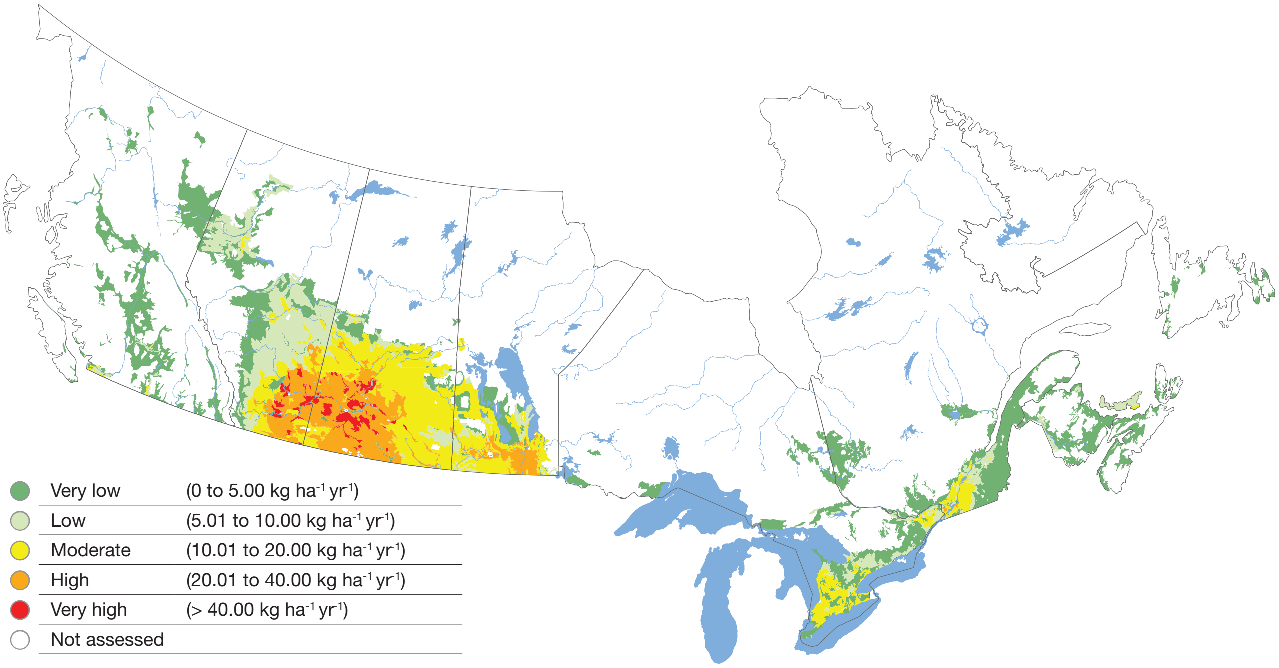


Figure 17–4: PM_{10} emissions (kg ha^{-1} yr^{-1}) in 2011

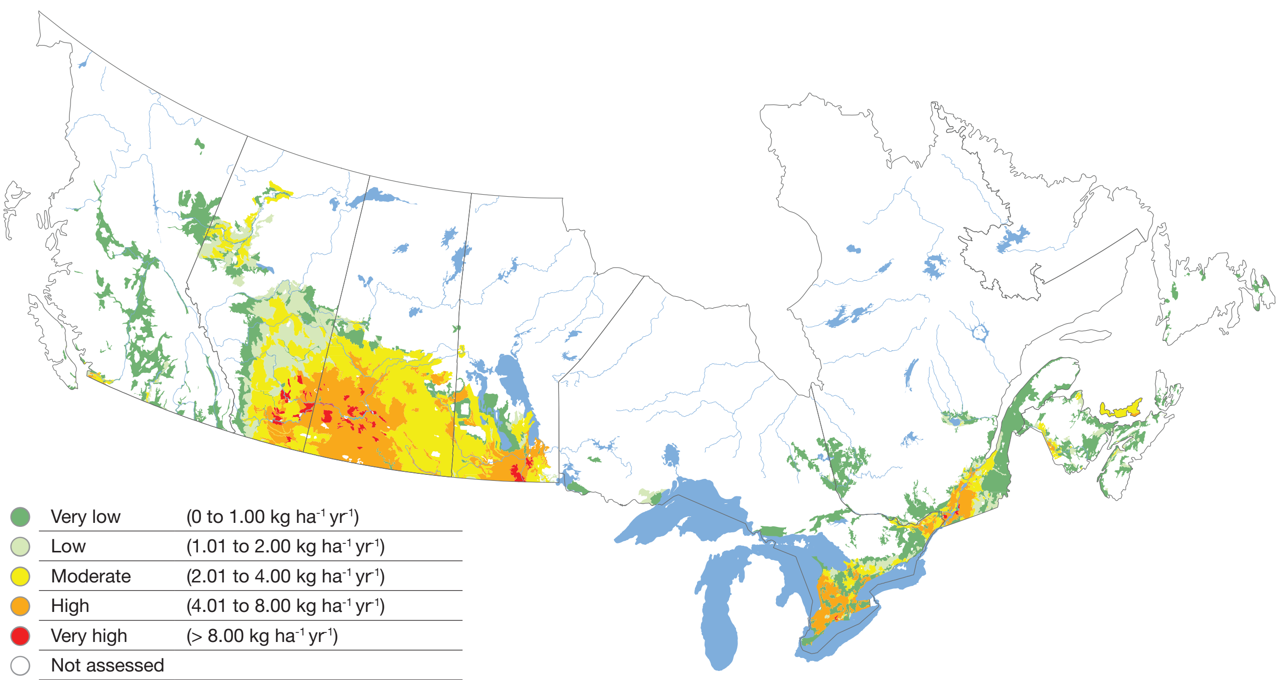


Figure 17–5: $PM_{2.5}$ emissions (kg ha^{-1} yr^{-1}) in 2011

Total PM emissions from agricultural sources in Canada show a decreasing trend from 1981 to 2011 (Tables 17–1 and 17–2), with a decline of 63% for TSP, 58% for PM_{10} and 61% for $PM_{2.5}$. Between 2006 and 2011, the decrease for all three PM classes was about 22%, demonstrating significant recent improvements in this indicator. Figure 17–6 illustrates the change in TSP emissions between 1981 and 2011 (results are similar for TSP, PM_{10} and $PM_{2.5}$; therefore, only the TSP map is presented here). Improvements are apparent across the country in all regions, with the Prairie region showing the greatest improvements. This can be attributed directly to the implementation of soil management BMPs such as reduced tillage and to the reduction in summerfallow, which have reduced PM emissions resulting from wind erosion in this region.

Table 17–1: Particulate matter emissions (in kilotonnes) from Canadian agricultural operations, 1981 to 2011

	TSP Emissions (kt yr^{-1})							PM_{10} Emissions (kt yr^{-1})							$PM_{2.5}$ Emissions (kt yr^{-1})						
Province	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
BC	29	28	27	25	24	23	19	8	8	8	8	6	7	5	2	2	2	2	2	2	1
AB	2,053	1,962	1,779	1,527	1,253	1,027	777	712	688	632	588	474	412	325	184	176	159	144	110	90	68
SK	4,672	4,148	3,676	3,137	2,775	2,079	1,518	1,707	1,529	1,357	1,248	1,107	883	647	409	364	322	286	243	184	139
MB	772	675	611	542	497	418	368	255	230	210	202	173	152	131	67	61	54	52	50	43	37
ON	643	565	542	488	490	255	232	89	84	81	71	61	57	49	32	31	30	26	23	21	18
QC	161	171	179	193	243	129	130	25	24	24	26	27	26	26	9	9	9	9	11	10	10
Atlantic Provinces*	29	26	25	26	27	23	21	7	7	7	7	6	6	5	3	2	2	2	2	2	2
Canada	**8,360**	**7,575**	**6,840**	**5,938**	**5,308**	**3,954**	**3,066**	**2,803**	**2,571**	**2,319**	**2,150**	**1,856**	**1,543**	**1,190**	**707**	**644**	**578**	**522**	**441**	**353**	**276**

* Atlantic Provinces include New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador.

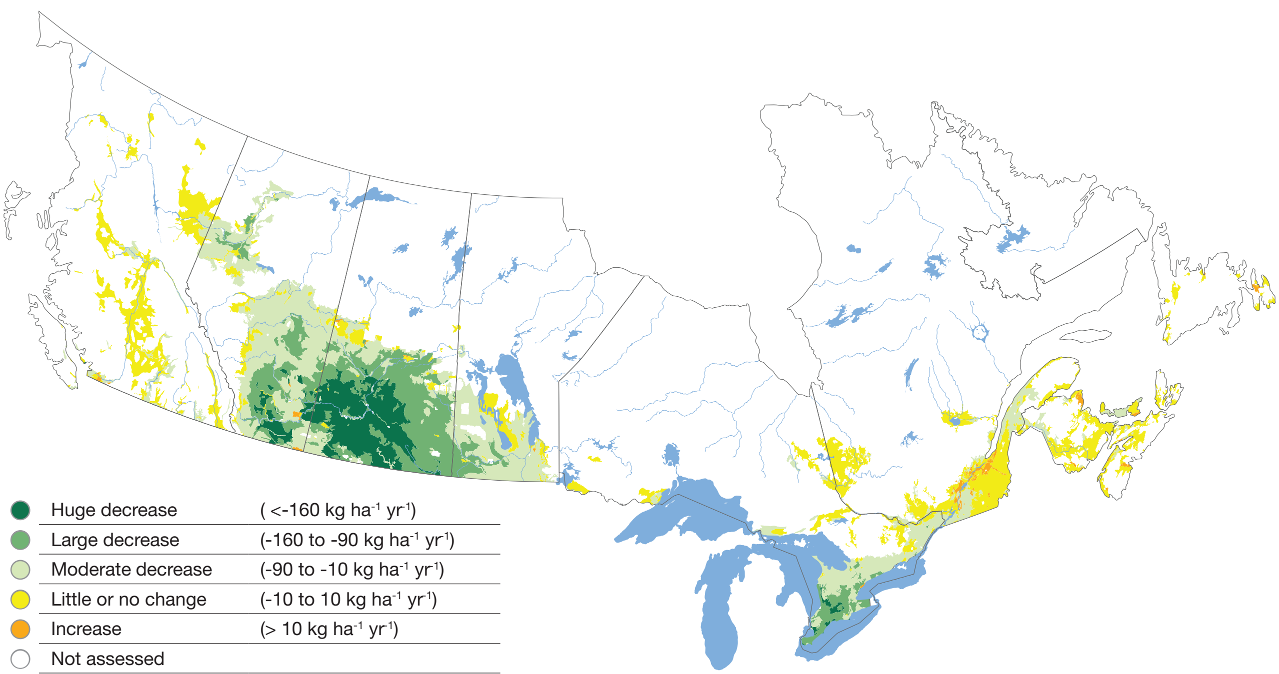


Figure 17–6: Change in TSP emissions (kg ha^{-1} yr^{-1}) between 1981 and 2011 (negative values indicate decreased emissions with time)

Table 17–2: Percentage of farmland in each TSP emission intensity class, 1981 to 2011

Class	Very low							Low							Moderate							High							Very high						
Year	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
British Columbia	69	82	85	81	88	89	89	18	8	7	11	6	4	5	7	7	6	4	5	4	2	5	2	2	3	2	3	3	1	0	0	1	0	0	0
Alberta	3	4	4	5	7	7	12	4	5	5	5	11	11	29	7	9	11	14	29	45	37	24	30	41	46	38	26	18	62	52	39	29	16	10	4
Saskatchewan	1	2	2	2	3	2	2	1	1	0	1	0	1	1	0	0	0	1	2	17	45	3	7	10	20	44	45	41	95	90	87	77	51	35	10
Manitoba	7	10	10	8	10	11	11	3	2	1	3	1	1	2	2	3	3	5	7	29	47	13	29	44	47	64	54	36	75	56	42	37	18	5	4
Ontario	10	12	12	12	15	13	21	5	10	12	3	15	14	21	9	25	25	15	29	21	17	23	48	46	23	41	51	37	53	5	5	46	0	1	4
Quebec	25	39	39	27	32	30	41	25	26	22	17	21	20	15	22	19	20	21	25	18	12	13	16	19	12	22	29	19	15	0	0	23	0	3	13
New Brunswick	39	59	47	30	55	49	61	33	14	26	40	17	24	18	20	19	20	15	23	21	21	9	8	7	15	5	6	0	0	0	0	0	0	0	0
Nova Scotia	52	71	73	41	70	65	72	36	19	19	44	24	28	20	6	9	8	14	6	6	5	5	0	0	1	0	2	3	0	0	0	0	0	0	0
Prince Edward Island	0	0	0	0	0	0	0	0	0	0	0	0	0	1	51	69	76	47	83	100	97	49	31	24	53	17	0	2	0	0	0	0	0	0	0
Newfoundland and Labrador	94	100	100	95	100	99	91	6	0	0	2	0	1	9	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Canada	**7**	**10**	**10**	**9**	**11**	**11**	**14**	**5**	**5**	**5**	**4**	**6**	**6**	**13**	**5**	**7**	**8**	**8**	**15**	**27**	**37**	**13**	**20**	**26**	**31**	**41**	**37**	**30**	**70**	**58**	**52**	**48**	**27**	**18**	**7**

* This table includes only SLC polygons composed of at least 5% cropland in each Census year from 1981 to 2011.

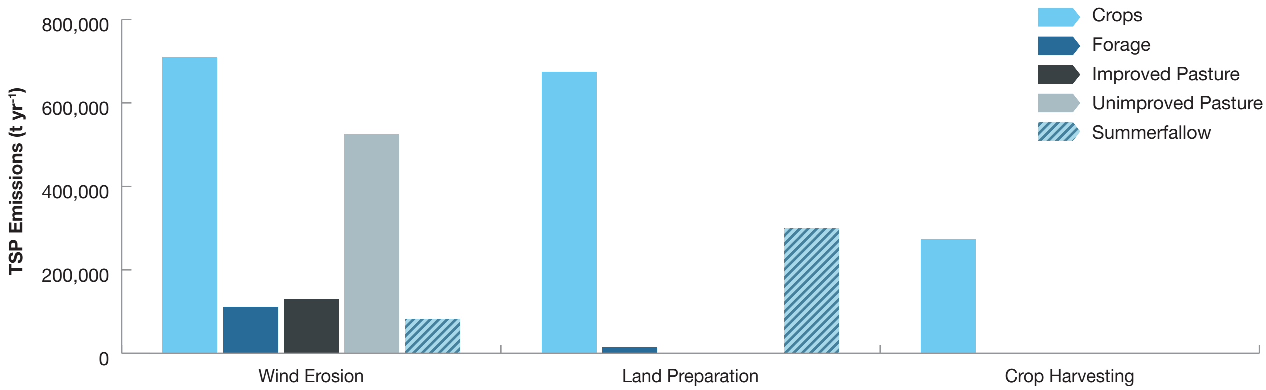


Figure 17–7: Contribution of land cover to PM emissions associated with wind erosion, land preparation and crop harvesting

Wind erosion, land preparation and crop harvesting are the principal sources of particulate emissions from cultivated **cropland** (Figure 17–7). Over 75% of all PM emissions from agricultural activities in Canada stem from land preparation and wind erosion. Wind erosion alone generates about half of the total PM emissions in Canada. Land preparation is the second largest source of agricultural PM emissions, accounting for 17% to 36% of the total, and crop harvesting contributes 10% of the total PM emissions.

Other activities account for the remaining approximately 10% of total PM emissions from agriculture. A significant portion of TSP comes from **unimproved pasture** that is exposed to wind erosion. Summerfallow generates a significant portion of the PM emissions associated with land preparation. PM emissions vary with the seasonal changes in land management (refer to text box "Monthly Changes in PM Emissions").

Monthly Changes in PM Emissions

Since there is a seasonal pattern to the dominant sources of PM emissions, the monthly emissions from the three main agricultural sources were quantified for 2011. The results for land preparation and crop harvesting were calculated using crop harvest and tillage dates. The amount of residue on the ground was used for the calculation related to wind erosion.

WIND EROSION

During the winter months (November to March), snow cover greatly reduces the emission of total suspended particulates (Figure 17–8). After the soil thaws in the spring, an upward trend in emissions can be seen that begins in April and continues until the soil surface is protected from wind erosion by vegetation cover. TSP emissions then follow a declining trend until August, when some early-maturing crops are harvested. After the harvest, the field surface is either partly or fully exposed, depending on whether residues have been left on the soil surface and when tillage, if any, takes place. The land is then subject to wind erosion until the onset of snow cover.

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Monthly Changes in PM Emissions

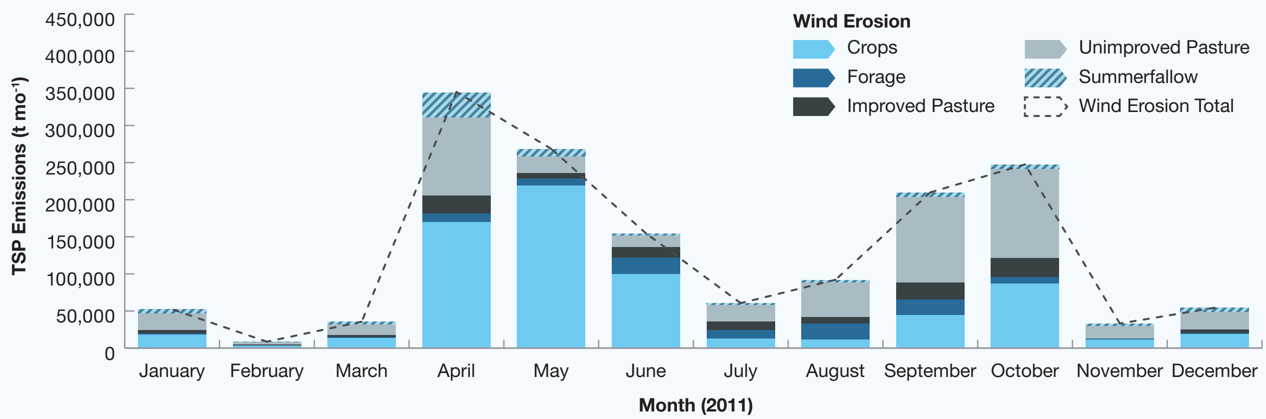


Figure 17–8: Canadian monthly TSP emissions from different types of land cover associated with wind erosion, based on 2011 Census data

Two peaks of TSP emissions which are associated with the main tillage periods are observed for cultivated field crops and summerfallow fields (Figure 17-9). TSP emissions from crop harvesting are much lower than those from wind erosion and land preparation, and occur only during the period August to October.

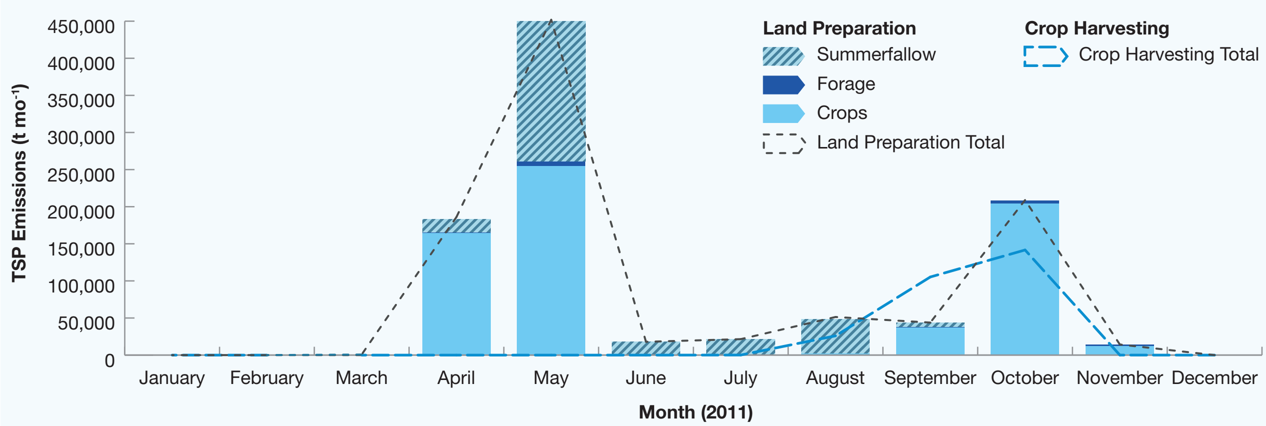


Figure 17–9: Canadian monthly TSP emissions from different types of land cover associated with land preparation and crop harvesting, based on 2011 Census data

The decrease in PM emissions that occurred between 1981 and 2011 strongly reflects changes in land use and management practices. Although wind erosion, land preparation and crop harvesting are the main contributors to PM emissions (Figure 17–8, Figure 17–9), the overall decrease in PM emissions is mainly attributable to the adoption of reduced tillage and no-till practices and the reduction in summerfallow. These changes more than offset the emissions associated with increases in animal populations, fertilizer application and cropland area. Figure 17–10 shows the specific contributions of agriculture-related sources to PM emissions in 2011.

Because the Prairie Provinces contain the largest proportion of agricultural land in Canada, they also account for the bulk of TSP, PM_{10} and $PM_{2.5}$ emissions, with the highest contributions coming from Saskatchewan (around half the national emissions) and Alberta (about a quarter of all national emissions). A few key areas devoted to field crop production in Ontario and Quebec also generate significant PM emissions. Due to the small size of the agriculture sector and associated data shortages, the estimates for Newfoundland and Labrador likely do not provide an accurate picture of the province's PM emissions. Figure 17–11 illustrates the decline in TSP emissions observed for all provinces between 1981 and 2011.

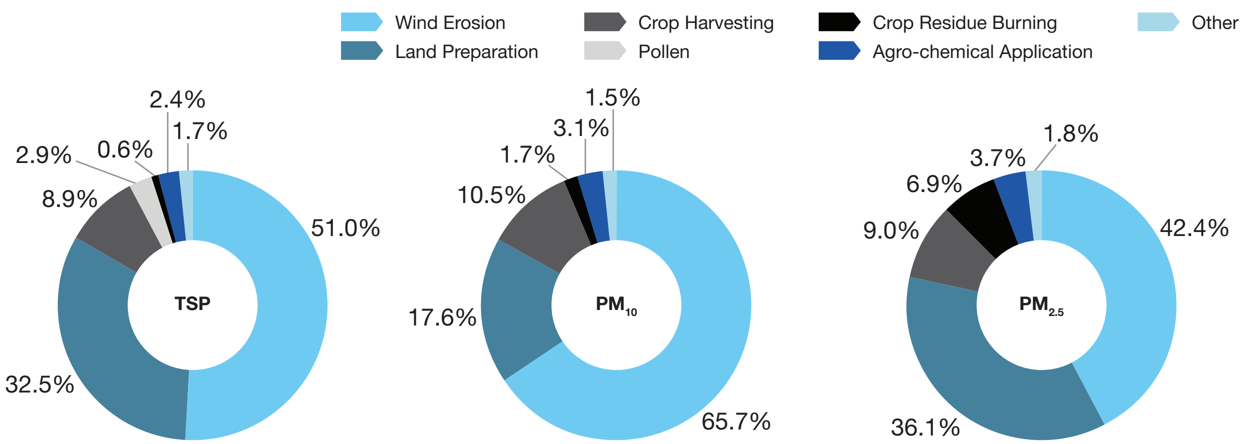
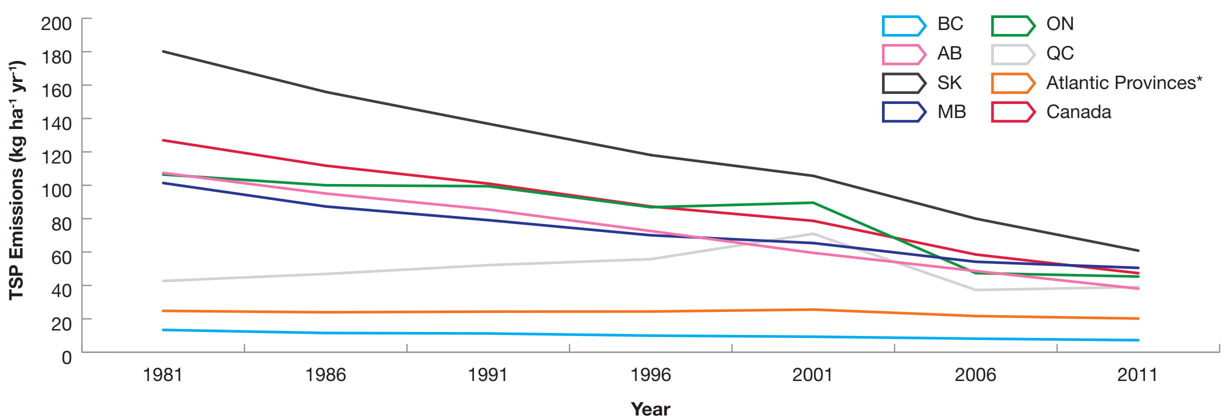


Figure 17–10: Contribution of agriculture-related sources to TSP, PM_{10} and $PM_{2.5}$ emissions in 2011



* Atlantic Provinces include New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador.

Figure 17–11: Change in PM emissions per hectare of agricultural land between 1981 and 2011

Response Options

There are many land-use practices that can be modified in order to mitigate agricultural PM emissions. The specific mitigation measures that are useful depend on the agricultural operation concerned. Practices that are effective in reducing PM emissions include increasing soil cover on cropland and decreasing the area of summerfallow.

Primary PM from animal feeding operations is attributable to livestock activities in barns or on feedlots. PM emissions can be reduced by changing the production environment in the following ways: decreasing animals' confinement time (or increasing the grazing period), collecting litter and manure more frequently, installing dust extraction or filtered ventilation systems, and sprinkling water mist or oil onto the floor or ground surface to reduce dust.

Increasing the amount of soil cover can bring about a significant decrease in PM emissions caused by wind erosion. The key practices that can be used to increase soil cover include using reduced tillage and no-till, decreasing the amount of land under summerfallow, increasing the area of permanent grassland, using **forages** in rotations, growing **winter cover crops**, and using strip cropping, **contour cultivation** and windbreaks.

Airborne soil PM emissions are generated during tillage by the mechanical operations used to prepare the soil. PM emissions from agricultural tillage are proportional to the area tilled, the type of tillage implement used (e.g. disking vs. ploughing) and the number of tillage operations performed in a year. Reducing tillage frequency or using no-till reduces PM emissions. In addition, using chemical weed control on summerfallow land can reduce PM emissions by decreasing the number of tillage operations required in a year.

PM emissions associated with crop harvesting are generated when combines and other types of farm machinery are operated in fields. These emissions vary with the type of crop. There are few specific practices that can reduce PM emissions from crop harvesting. Crop harvesting under conditions of high relative humidity and low wind speed can mitigate PM emissions. Some practices used for wind erosion control, such as the use of terraces, contouring and strip-cropping, decrease the transport of harvested crop fragments by the wind. Using reduced tillage or no-till practices and managing crop residues decreases PM emissions from farm machinery operated in fields.

PM emissions can occur when fertilizer applications are made in windy conditions or when land preparation operations disturb the soil. Optimum nutrient management is the best way to reduce PM emissions associated with the application of fertilizer. This includes optimizing the timing of fertilizer application and fertilizer placement and matching applications to the **nutrient** needs of crops.

The application of agrochemicals to cropland is a widely used management practice in Canadian agricultural systems. This practice greatly improves productivity, but chemical drift from such applications may contribute to TSP emissions. Although the estimated emissions from this source are currently very low, at the estimated scale, chemical drift may have significant negative local impacts compared to other agricultural sources. The risk of chemical drift and associated TSP emissions can be reduced by restricting applications to cool days with calm conditions, selecting the appropriate nozzle, reducing sprayer travel speed and lowering sprayer boom height.

Continued research and development will help to expand the existing knowledge base and increase confidence in reported values and the effectiveness of mitigation solutions. Research will also strengthen our predictive capacity, for instance, our ability to predict the effects of climate change and the associated changes in the agricultural landscape, which can affect future PM emissions. The knowledge that is acquired will allow the agricultural sector to continue to respond effectively and efficiently as markets, production systems and climates change.

References

Canadian Centre for Occupational Health and Safety, 2012. http://www.ccohs.ca/oshanswers/chemicals/lungs_dust.html (last visited February 2, 2015)

Donham, K.J., and A. Thelin, 2006. *Agricultural medicine: Rural occupational and environmental health for the health professions*. Victoria, Australia: Blackwell Publishing.

Samet, J., and D. Krewski, 2007. *Health effects associated with exposure to ambient air pollution*. Journal of Toxicology and Environmental Health. 70: 227-242.

Saxton, K.E., 1996. *Agricultural wind erosion and air quality impacts: A comprehensive research program*. American Journal of Alternative Agriculture. 11: 64-70.

United States Environmental Protection Agency (U.S. EPA), 2004. *Air quality criteria for particulate matter*. EPA Report 600/P-99/002aF-bF. Washington, DC: Environmental Protection Agency.

Applications and Future Directions

Summary

The **agri-environmental indicators** (**AEIs**)[1] presented in this report provide a snapshot of the current state and trend for Canada's agri-environmental performance. They typically fall into one of two categories:

1. *Risk indicators* are an estimate of the likelihood of a potential environmental impact.

2. *State indicators* estimate the actual presence and degree of an impact.

Increasing attention is being given to a third type of indicator; the intensity indicator, which can estimate resource-use efficiency, typically by comparing inputs and outputs of a given resource, such as water or fuel. Agri-food product consumers are increasingly requiring retailers – and therefore commodity groups and producers – to demonstrate that products are produced in an environmentally sustainable manner. This has created a demand for commodity specific indicators which identify environmental impacts or risks on the basis of a unit of production, for example per litre of milk, kilogram of beef, or tonne of grain.

1. Chapter 18, on Greenhouse Gas Emission Intensity of Agricultural Products, presents calculations of the total greenhouse gas (GHG) emissions that occur during the production of one unit of a given agricultural product in different regions of Canada. Findings for major field crops, dairy products and beef are included. Ongoing sustainability metrics work at AAFC is focused on delivering the science-based data and calculation methods required for these and other environmental footprint or intensity calculations.

To be viable, environmentally sustainable production systems must also be economically sustainable. AAFC is developing tools and approaches for linking agri-environmental sustainability indicators to economic models as a means of providing guidance for policy and program evaluation and development, and to answer commodity-specific questions on the economic sustainability of alternative land use or management practices that have been identified as environmentally beneficial.

2. The Integrated Modelling Chapter (Chapter 19) provides information on how the indicators can be combined with economic models to inform policy and program development and evaluation. It provides examples of how the AEIs have been used recently, in providing Environment Canada with GHG emissions estimates for the agriculture sector and in conducting environmental assessments of business risk management programs.

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter or section.

18 Greenhouse Gas Emission Intensities of Agricultural Products

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Summary

The **Greenhouse Gas** (**GHG**)[1] **Emission Intensity** Indicator for Canadian agricultural products is an estimate of the net amount of GHG emissions (emissions minus removals) associated with the per-unit production of agricultural products, such as a tonne of a given crop, or a kilogram (kg) of milk. It considers all GHG emissions associated with on-farm production as well as those that occur up to the exit gate of the processing plant. The sum of GHG emissions and removals associated with a given product that occur from the farm to the processing plant gate can also be referred to as a partial **carbon footprint** (Figure 18–1).

Emission intensity refers to the amount of greenhouse gases, measured in **carbon dioxide equivalents** (**CO_2e**)[2], emitted per hectare (ha) or per unit weight of product. For ease of comparison, this chapter uses kilograms as the unit weight, recognizing that most grain crops are more commonly reported in tonnes, and that fluid products such as milk are more commonly reported in litres. The magnitude of the GHG emission intensity of an agricultural product depends on factors such as climate, agricultural management practices, crop yield and animal productivity and can vary over time and between regions. For example, the average emission intensity for beef production at the farm gate in Canada decreased from 14.9 kg to 9.5 kg of CO_2e per kg of **live weight** between 1991 and 2006 (Desjardins et al., 2012). There were also differences in the emission intensities for beef production between Eastern and Western Canada primarily due to differences in the emission intensities of the crops used to feed the cattle.

Estimates of emission intensities of agricultural crops, at the provincial scale, ranged from 130 kg of CO_2e per ha to 3,380 kg of CO_2e per ha, while the emission intensities of Canadian milk products ranged from 1.0 kg of CO_2e per kg of fluid milk to a high of 10.1 kg of CO_2e per kg of milk powder. Based on an **economic allocation**, whereby emissions are attributed based on the relative price of the product (refer to text box "Allocation of Emissions"), the GHG emission intensities for beef and beef co-products ranged from 19 kg of CO_2e per kg of **primal cuts** of meat to about 2 kg of CO_2e per kg of **rendering** products.

1 Words included in the glossary (at the end of this publication) are bolded the first instance they appear in each chapter.

2 A detailed explanation of carbon dioxide equivalents is provided in Chapter 15 "Agricultural Greenhouse Gases" as well as in the glossary.

The Issue and Why it Matters

Agricultural activities such as land use and farm management have the potential to affect GHG emissions. While significant progress has been achieved in the last 30 years in increasing agricultural productivity, a concurrent increase in **methane** (**CH_4**) and **nitrous oxide** (**N_2O**) emissions has also occurred since 1981. Due to the expected growth in the population and the rising demand for food, reducing total agricultural GHG emissions may be unrealistic in the short term. However, producers could improve their resource-use efficiency and reduce their GHG emissions per unit of production with appropriate management practices. As an example, Figure 18–1 shows the complete production cycle of fluid milk, and the associated sources of GHGs. For the purposes of the Greenhouse Gas Emission Intensity Indicator, all GHG emissions from crop production to processing are included. All processes from packaging onwards are excluded from the calculations.

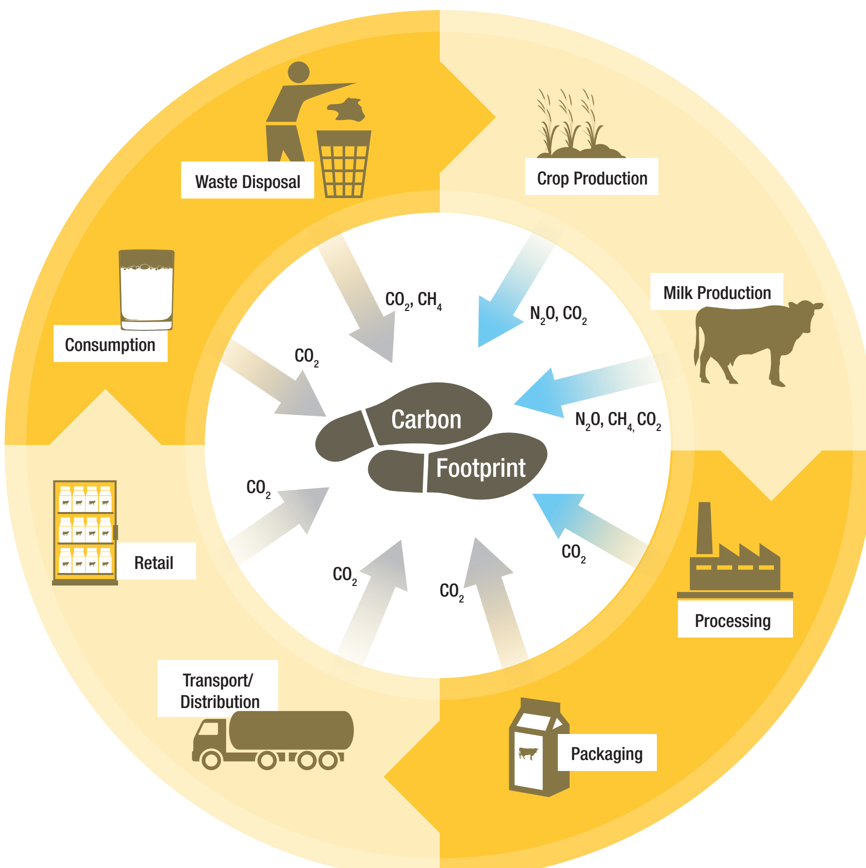

Figure 18–1: Sources of GHGs throughout the Canadian milk production cycle. All emissions from crop and milk production to processing are included. These represent more than 80% of the total GHG emissions associated with milk products. The steps from packaging through to waste disposal (as indicated by the light grey arrows) are excluded from the calculations for this indicator.

As referred to in Chapter 3 “Driving Forces”, key capital market players are increasingly aware of the connection between environmental issues and companies’ financial value, which is resulting a continuing growth in sustainability reporting by corporations as more and more corporations commit to using sustainably produced agricultural products—including Walmart, General Mills, Unilever and others. In addition to sustainability reporting, there can also be cases where it is necessary to demonstrate that Canadian agricultural products meet prescribed GHG emission targets imposed by trading partners to gain access to lucrative foreign markets. For example, Canadian canola producers had to demonstrate that canola results in a 35% reduction in GHG emissions relative to fossil fuel use, to be able to sell Canadian canola as feedstock for biodiesel production in the European Union. Sustainability reporting and foreign market demands are making it increasingly important to report on and demonstrate that the emission intensities of Canada’s agricultural products are among the lowest in the world. Some retailers could also use GHG emissions reporting to help advertise their products to consumers, for example through a carbon footprint, often referred to as ’green labelling’. Accurate GHG emission intensity estimates of Canadian food products not only helps to provide consumers and retailers with information, but also provides policy makers with data to assess options for reducing GHG emissions from the agriculture sector.

The Indicator

The agricultural GHG Emission Intensity Indicator represents the total GHG emissions that occur during the production of one unit of a given agricultural product. Depending on the product in question, one unit may represent a litre of milk, a kilogram of beef, or a tonne of canola (Shrestha et al., 2014). For ease of comparison, all products have been calculated on a per-kilogram basis, including grain products which are typically reported in tonnes, and milk, which would typically be reported in litres.

Many factors affect the magnitude of the Emission Intensity Indicator such as crop yields, animal production characteristics (e.g. rate of weight gain per unit of feed), environmental conditions, and agricultural management practices. In order to evaluate the complex link between these factors and GHG emissions, two spreadsheet-based calculators were developed (Vergé et al., 2012; Vergé et al., 2013) to estimate the emission intensities of a wide range of agricultural products.

The on-farm GHG emissions were estimated using the Unified Livestock Industry and Crop Emissions Estimation System (ULICEES) calculator, which considers all GHG emissions associated with livestock production up to the farm gate. The off-farm GHG emissions were estimated using the Canadian Food Carbon Footprint (Cafoo)[2] calculator, which considers all GHG emissions from the farm gate to the exit gate of the processing plant.

Limitations

Data gaps affect the accuracy of the estimation of the GHG emission intensities of agricultural products. For instance, animal diet is of critical importance in estimating GHG emission intensities. There are only two national surveys (1990 and 2001) available to determine animal diet. However, livestock diets have changed since 2001, and now canola meal, soy meal and dried distiller’s grains with solubles are a much more important part of the livestock diet than when these surveys were conducted. Similarly, a limited number of quantitative surveys are available that provide information on the fraction of manure stored, by animal type. As a result, changes in animal diet and manure management are not always accurately represented in the calculations.

Additional data gaps exist with respect to energy use by the animal sector, as information is only available for 2001 (Dyer and Desjardins, 2009; Dyer et al., 2011). Furthermore, because the data in the red meat sector are all combined, it is not possible to differentiate between the energy use for pork and beef production. Lastly, because of a lack of energy data specific to Canada, data from the United States are used and it is assumed that, because of the integrated nature of both agricultural sectors, the U.S. data apply to Canadian conditions (Desjardins et al., 2012).

Results and Interpretation

As a first step in the determination of GHG emissions associated with animal products, it is necessary to estimate the emission intensities of the crops that are used to feed the animals, as well as all major field crops including grains, **oilseeds**, pulses, roots and fodder. The average Canadian emission intensities associated with these crops are presented in Figure 18–2 on a per-hectare basis and on a dry-matter (DM) basis. The results vary considerably depending on the units used. On a per-hectare basis, corn (both silage and grain) and potatoes emit more GHGs than the other 18 crops studied. Durum wheat had the lowest emission intensity on an area basis among the **cereals**, while emission intensities for the other cereal crops were quite similar, ranging from 60% to 70% of the intensity for grain corn. Sugar beets had the second highest emission intensity among the pulse and root crops. Among the oilseeds, canola had the highest emission intensity value and soybeans the lowest value. The lowest emission intensity among all crops was for alfalfa.

However, expressing the results per hectare does not incorporate the relative yields of each crop. For example, the high yield of corn (both silage and grain) and potatoes compensates for the high GHG emissions associated with the inputs (e.g. **fertilizers**) needed to grow these crops, reducing their rank as GHG emitters on a dry matter basis. Oilseeds, which are lower yielding than corn, but which require significant inputs, tend to have higher emissions when expressed on a dry matter basis.

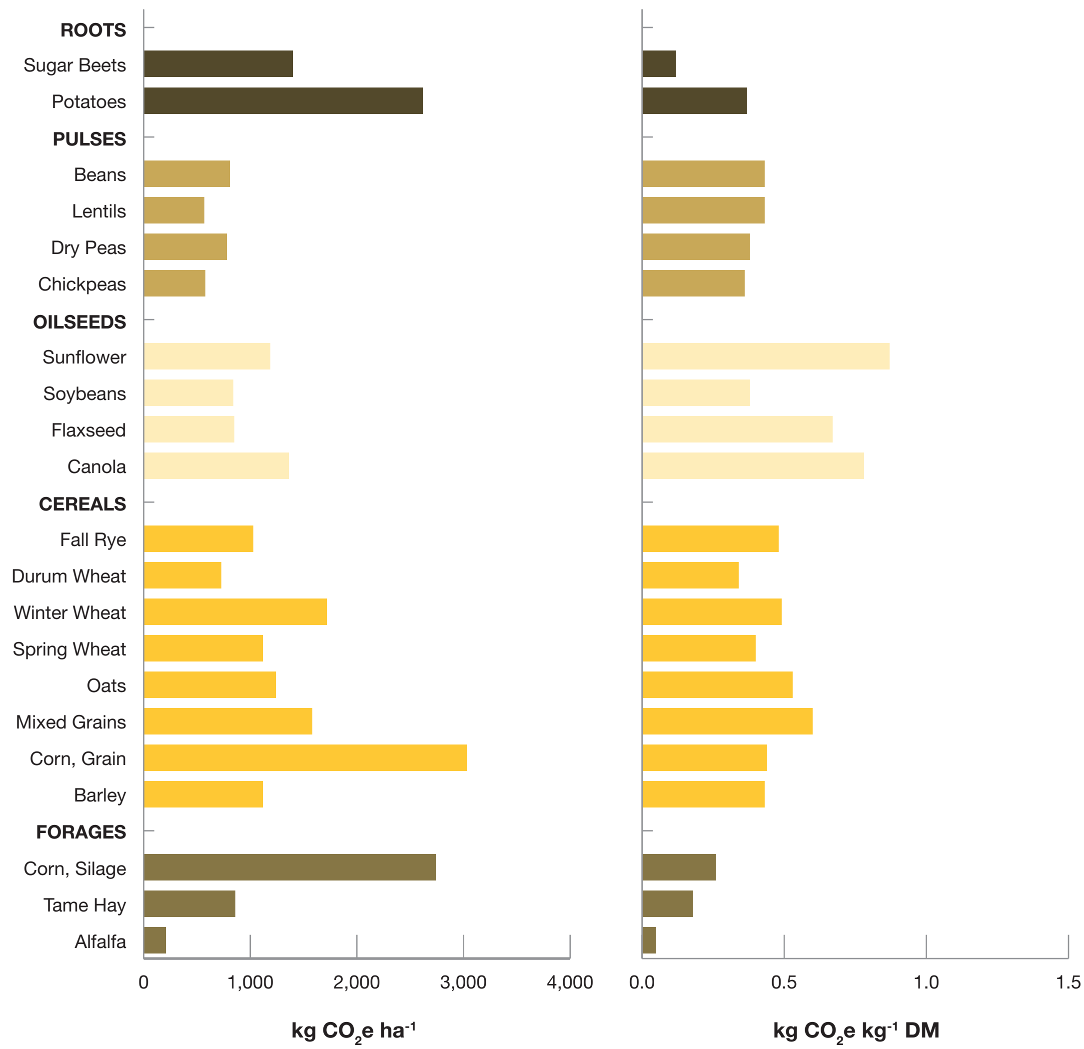

Figure 18–2: GHG emissions (excluding emissions related to soil carbon) per unit area and per unit of dry matter for the 21 most important field crops in Canada during 2011

The emission intensity of individual crops also differs by region in Canada. The provincial GHG emission intensities for 21 crops are shown in Table 18–1 on a per hectare basis, and in Table 18–2 on a per kilogram of dry matter (DM) basis. Both these tables exclude emissions and absorption of carbon dioxide by soils. Generally speaking, for crops that are grown nation-wide (e.g. small grain cereals such as barley and wheat) even though the yields are generally larger in Eastern Canada than in the Prairie Provinces, the emission intensity is also higher because the wetter climate in Eastern Canada tends to result in greater nitrous oxide (N_2O) emissions.

Table 18–1: Greenhouse gas emission intensities by province on a crop area basis for 21 Canadian field crops, 2011

Province	kg CO_2e ha^{-1}								
	Group Averages					Oilseeds			
	Oilseeds	Pulses	Roots	Forages	Cereals	Canola	Flaxseed	Soybeans	Sunflower
BC	1,680		2,480	1,290	1,270	1,680			
AB	1,180	830	1,630	870	1,060	1,300	1,070		
SK	910	600	1,210	330	670	1,040	780		
MB	950	620	1,780	930	1,280	1,280	930	420	1,190
ON	1,690	1,070	2,600	1,480	2,040	2,450		930	
QC	1,720		3.280	1,530	2,420	2,450		990	
Atlantic Provinces	780		3.220	1,360	1,950			780	
Canada	**1,060**	**680**	**2,010**	**1,270**	**1,450**	**1,360**	**850**	**840**	**1,190**

	Pulses				Roots		Forages		
	Chickpeas	Dry Peas	Beans	Lentils	Potatoes	Sugar Beets	Alfalfa	Tame Hay	Corn Silage
BC					2,480		240	950	2,700
AB	720	990	760		1,850	1,400	160	680	1,770
SK	530	690		570	1,210		130	540	
MB		740	510		1,780		160	790	1,830
ON			1,070		2,600		310	1,020	3,100
QC					3,280		330	990	3,280
Atlantic Provinces					3,220		300	1,240	2,530
Canada	**580**	**780**	**790**	**570**	**2,620**	**1,400**	**210**	**860**	**2,740**

	Cereals							
	Barley	Grain Corn	Mixed Grains	Oats	Spring Wheat	Winter Wheat	Durum Wheat	Fall Rye
BC	1,240			1,280	1,310			
AB	980	1,720	1,040	980	980	930	920	890
SK	690			710	680	670	650	640
MB	1,110	1,830		1,180	1,170	1,230		1,160
ON	1,640	3,190	1,650	1,950	1,810	2,160		1,910
QC	2,000	3,380	2,020	2,340	2,360	2,450		
Atlantic Provinces	1,570	2,700	1,570	1,880	1,940	2,050		
Canada	**1,120**	**3,030**	**1,580**	**1,240**	**1,120**	**1,720**	**730**	**1,030**

Atlantic Provinces include New Brunswick, Nova Scotia, Price Edward Island and Newfoundland and Labrador.

Table 18–2: Greenhouse gas emission intensities by province on a per-kilogram basis for 21 Canadian field crops, 2011

Province	kg CO_2e kg DM^{-1}								
	Group Averages					Oilseeds			
	Oilseeds	Pulses	Roots	Forages	Cereals	Canola	Flaxseed	Soybeans	Sunflower
BC	1.16		0.32	0.15	0.45	1.16			
AB	0.61	0.39	0.16	0.12	0.33	0.65	0.58		
SK	0.64	0.38	0.15	0.1	0.28	0.63	0.65		
MB	0.73	0.36	0.25	0.14	0.47	0.88	0.92	0.27	0.87
ON	0.82	0.56	0.53	0.17	0.62	1.28		0.36	
QC	0.83		0.43	0.19	0.87	1.22		0.43	
Atlantic Provinces	0.39		0.51	0.2	0.67			0.39	
Canada	**0.68**	**0.39**	**0.25**	**0.16**	**0.46**	**0.78**	**0.67**	**0.38**	**0.87**

	Pulses				Roots		Forages		
	Chickpeas	Dry Peas	Beans	Lentils	Potatoes	Sugar Beets	Alfalfa	Tame Hay	Corn Silage
BC					0.32		0.05	0.2	0.21
AB	0.42	0.44	0.31		0.2	0.12	0.04	0.17	0.15
SK	0.34	0.36		0.44	0.15		0.04	0.15	
MB		0.41	0.31		0.25		0.04	0.19	0.2
ON			0.56		0.53		0.06	0.18	0.26
QC					0.43		0.06	0.19	0.31
Atlantic Provinces					0.51		0.06	0.25	0.28
Canada	**0.36**	**0.38**	**0.4**	**0.43**	**0.37**	**0.12**	**0.05**	**0.18**	**0.26**

	Cereals							
	Barley	Grain Corn	Mixed Grains	Oats	Spring Wheat	Winter Wheat	Durum Wheat	Fall Rye
BC	0.49			0.47	0.39			
AB	0.31	0.34	0.3	0.36	0.34	0.29	0.36	0.37
SK	0.26			0.26	0.3	0.27	0.29	0.33
MB	0.52	0.36		0.54	0.53	0.36		0.49
ON	0.56	0.38	0.65	0.82	0.59	0.48		0.83
QC	0.81	0.46	0.92	1.15	0.99	0.87		
Atlantic Provinces	0.67	0.49	0.71	0.95	0.62	0.56		
Canada	**0.43**	**0.44**	**0.6**	**0.53**	**0.4**	**0.49**	**0.34**	**0.48**

Atlantic Provinces include New Brunswick, Nova Scotia, Price Edward Island and Newfoundland and Labrador.

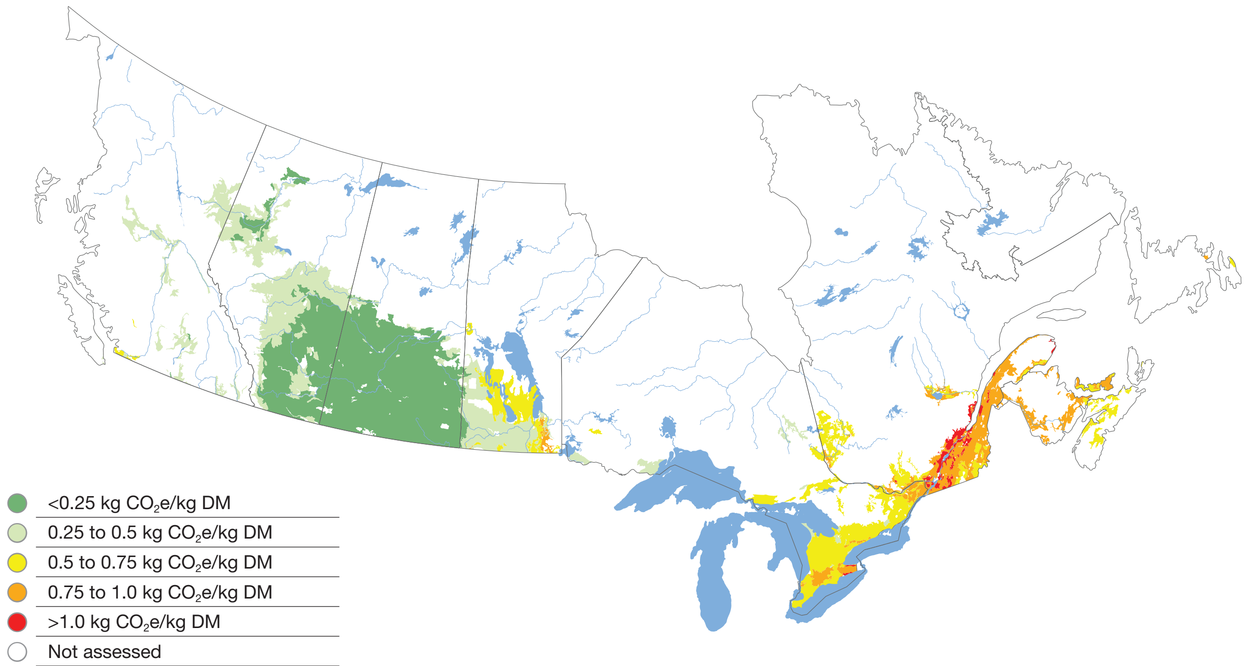

Figure 18–3: GHG emissions per kg of dry matter (kg DM) for barley at the SLC scale, 2011

As an example of the range in GHG emission intensities, Figure 18–3 shows the GHG emission intensities for barley crops in terms of kg CO_2e per kg of dry matter at the SLC scale for all of Canada for 2011. Illustrated is the fact that the GHG emissions per kg of grain DM vary dramatically across the country. The Prairie Provinces have experienced high adoption rates of BMPs, such as conservation tillage and no-till, that favour the retention of soil carbon; and the reduction in **summerfallow**, which has resulted in the establishment of soil carbon sinks. This is combined with a climate that leads to lower N_2O emissions, and large field sizes that permit more efficient use of fossil fuels. In Western Canada therefore, emission intensities are generally small, often less than 0.25 kg of CO_2e per kg of DM. However, in Eastern Canada, the wetter climate tends to increase N_2O emissions and the smaller field sizes lead to greater fossil fuel inefficiencies. Additionally, in Eastern Canada there has been a net loss of soil carbon, primarily associated with an increase in the area of annual crops, such as corn and soybean, at the expense of **perennial forage** crops. These factors tend to contribute to greater emission intensities, generally above 0.50 kg of CO_2e per kg of DM.

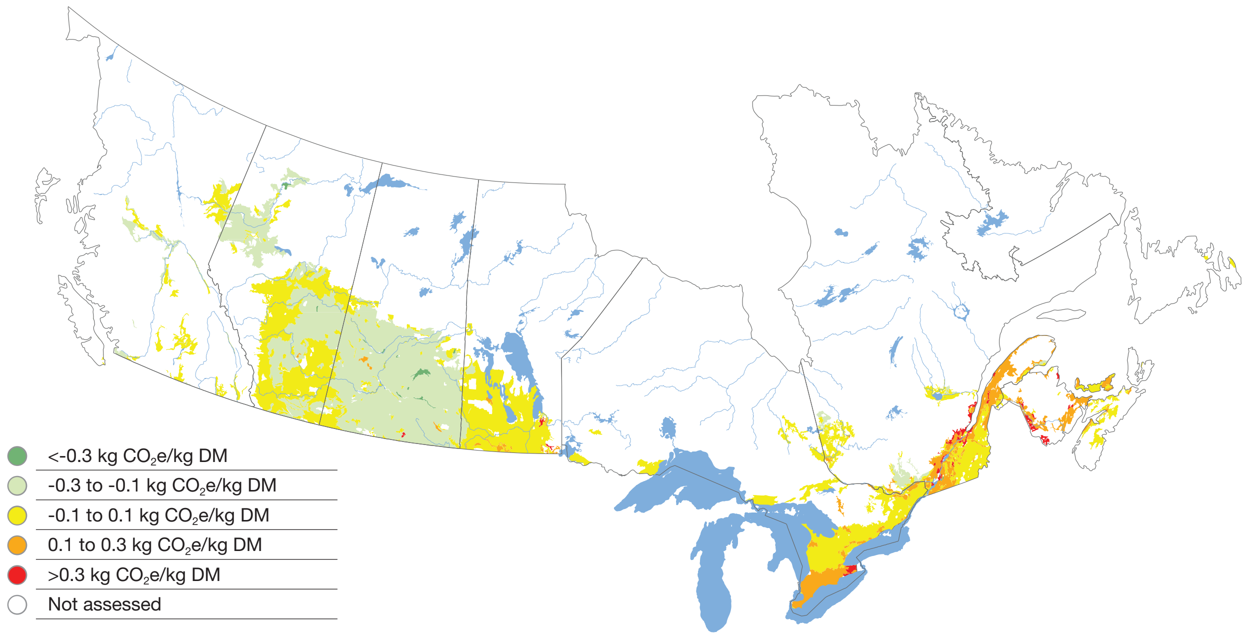

Figure 18–4: Change in GHG emission intensities on a dry matter basis for barley at the SLC scale between 1981 and 2011. Negative numbers indicate a reduction in the GHG emission intensities; positive numbers indicate an increase in the GHG emission intensities.

Figure 18–4 illustrates the change in emission intensities for barley at the SLC level from 1981 to 2011. This shows that for Western Canada, the level of GHG emissions per kg of DM remained fairly constant, or declined between 1981 and 2011. This is the result of increases in crop yields, combined with the adoption of BMPs that both increase soil carbon and decrease fossil fuel consumption. In contrast, for Eastern Canada the emissions per kg of DM remained fairly constant, or increased between 1981 and 2011. Although Eastern Canada has experienced gains in crop yield, soil and climatic conditions are not as favourable for the widespread adoption of management practices that sequester carbon. As a result, increases in the rate of **nitrogen** fertilizer application and losses in soil carbon associated with the conversion of perennial crops to annual crops have generally resulted in an increase in the intensity of GHG emissions.

Using the emission intensity of individual crops, it is possible to evaluate more complex agricultural products, such as milk and milk products, as well as beef meat and beef products. Canada produces a variety of milk products, and the emission intensities have been determined at the provincial scale for a total of 11 products. The results show that the GHG emission intensity associated with fluid milk production in Canada range from 0.9 kg CO_2e per kg of milk in British Columbia to 1.2 kg of CO_2e per kg milk in the Atlantic Provinces, whereas the GHG emission intensities associated with milk products such as cheese, cream, sour cream, yogurt, buttermilk, frozen dairy products, powder milk and butter range from a low of 1.1 kg of CO_2e per kg for buttermilk, to a high of 10.1 kg of CO_2e per kg for milk powder (Table 18–3). Differences in the emission intensity between products are primarily related to the amount of milk that is required to produce each product. Products that require more milk tend to have greater emission intensities. Results also differ by region in Canada and the differences are related to the different crops used in animal diets, and to the different provincial sources of electrical energy production (e.g. hydroelectric vs. coal).

Similar emission intensity estimates were obtained for beef meat and beef-based products (Desjardins et al., 2012) such as raw hide, offal and rendering products. On a mass basis (see “Allocation of Emissions” text box for a discussion of mass allocation and economic allocation), the national emission intensity of all beef and beef-based products was equal to 12.9 kg of CO_2e per kg product. However, based on an economic allocation, the emission intensity of each product differs significantly and ranges from nearly 20 kg of CO_2e per kg of primal cuts of meat to 2 kg of CO_2e per kg of rendering products. Economic allocation allows the emission intensities to better reflect the

Table 18–3: Emission intensities by region for several unpacked dairy products in 2006 (Vergé et al., 2013)

	GHG – Dairy Products										
	kg CO_2e/kg product										
	BC	AB	SK	MB	Prairies	WEST	ON	QC	Atlantic	EAST	**Canada**
Cheese*	4.2	4.9	4.8	5.1	4.9	4.7	5.5	5.4	5.7	5.4	**5.3**
Cottage Cheese	1.4	1.6	1.6	1.7	1.6	1.6	1.8	1.8	1.9	1.8	**1.8**
Creams	1.7	1.9	1.9	2	2	1.9	2.2	2.2	2.3	2.2	**2.1**
Sour Cream	2	2.3	2.3	2.5	2.3	2.2	2.6	2.6	2.7	2.6	**2.5**
Yogurt	1.2	1.8	1.7	1.4	1.7	1.5	1.6	1.5	1.8	1.5	**1.5**
Fluid Milk	0.8	0.9	0.9	0.9	0.9	0.9	1	1	1.1	1	**1**
Buttermilk	0.9	1.1	1	1.1	1.1	1	1.2	1.1	1.2	1.2	**1.1**
Frozen Dairy Products	1.5	2.8	2.5	1.8	2.5	2.1	2.2	1.9	2.6	2.1	**2.1**
Powders	8.3	9.6	9.4	9.7	9.6	9.1	10.4	10.2	10.8	10.3	**10.1**
Concentrated Milk	2.6	3.1	3.1	3	3.1	2.9	3.2	3.1	3.4	3.2	**3.1**
Butter	5.9	6.6	6.5	7.1	6.7	6.4	7.6	7.5	7.8	7.3	**7.3**

* The generic 'cheese' category includes a combination of cheddar, mozzarella, specialty cheeses and processed cheese, but excludes cottage cheese, which has its own category.

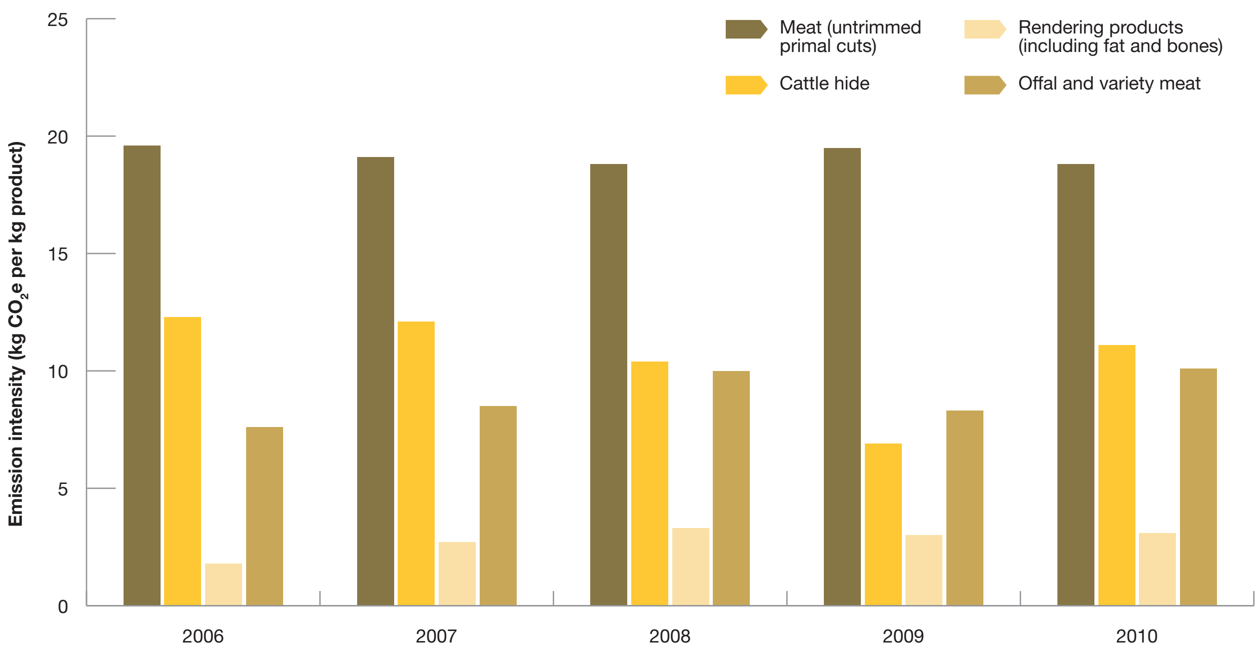

Figure 18–5: Emission intensities of beef products from 2006 to 2010 based on an economic allocation (Desjardins et al., 2012)

market drivers of beef production; however, this adds complications in terms of comparing the footprint over time. For instance, in 2006, the emission intensity of hides was estimated at 12.3 kg of CO_2e per kg of hide (Figure 18–5). However, between 2006 and 2009, the price of hide decreased by half while the price of meat remained relatively constant. For this reason, the economic approach makes comparison over time difficult.

In addition to changes in the emission intensities over time, there are regional differences within Canada. As shown in Table 18–4, the emission intensities per kg of live weight (LW) of cattle from Eastern and Western Canada exhibit differences, primarily due to the larger N_2O emissions associated with feed production in Eastern Canada and the increasing importance of agricultural soils as a carbon sink in Western Canada due to the reduced frequency of summerfallowing and the widespread adoption of **no-till**. The emission intensities associated with beef production have declined markedly in all regions of Canada. There are several reasons for this decline, including an increase in the average carcass weight of beef from 265 kg in 1991 to 355 kg in 2006, a decrease in the GHG emissions associated with crop production and an improved animal diet.

Table 18–4: Cradle-to-farm gate emission intensities associated with beef production in Eastern and Western Canada from 1991 to 2006, including the GHG emissions associated with all GHG sources except land-use change (Desjardins et al., 2012)

	Eastern Canada	Western Canada	Canada
	kg CO_2e per kg LW		
1991	18.6	13.8	14.9
1996	18.0	11.6	12.8
2001	16.0	9.2	10.2
2006	15.3	8.4	9.5

Allocation Of Emissions

A central issue in determining the GHG emission intensity of an agricultural product with multiple outputs is the allocation (the division and assignment) of the GHG emissions to the various outputs. For instance, beef cattle production results in the primary product—beef—but also results in other valuable products such as leather (from cow hides), rendering products (from processed fats and bone) and offal (from the organ meat). During the growth of cattle, it is not possible to explicitly determine the GHG emissions associated with each of these products; hence, GHG emissions must be allocated, depending on the relative mass, economic value or energy content or some other parameter that enables the assignment of the total GHG emissions, to the various outputs. Figure 18–6 illustrates a range of different allocation scenarios, based on varying factors.

The choice of allocation method can have a major impact on the GHG emissions associated with a given product. For instance, in the example below, if we allocate GHG emissions based on economic value, beef meat accounts for 83% of the total GHG emissions. However, if we allocate GHG emissions based on the mass of each product, beef meat only accounts for 48% of the total GHG emissions, as rendering products make up a significant fraction of the total mass. There are strengths and weaknesses to each of these approaches. For instance, in the economic approach, the fundamental driver behind the production of a given product is recognized, but this can result in variations in emission intensities over over time due to factors beyond the producer's control, such as global supply and demand.

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Allocation Of Emissions

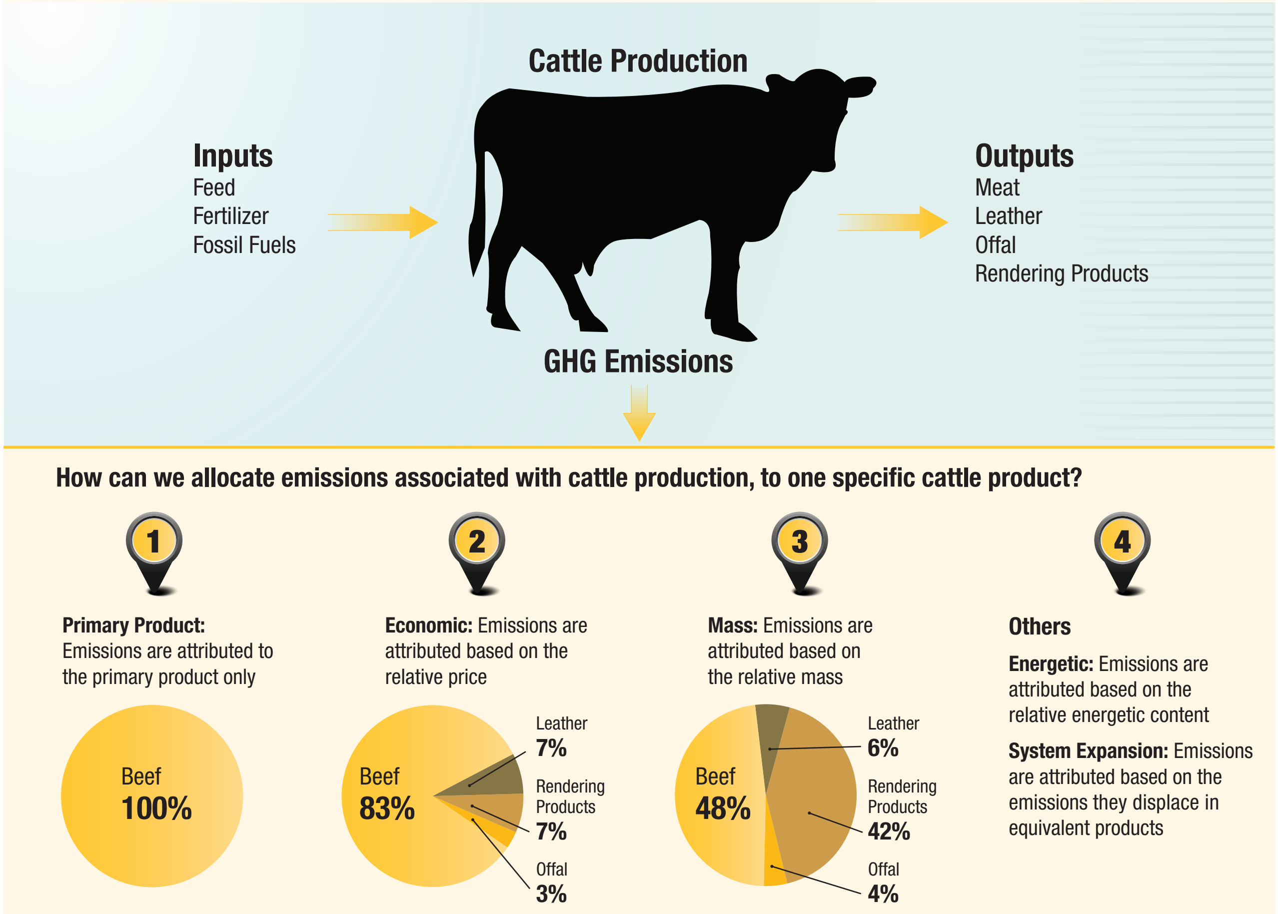

Figure 18–6: Allocation of greenhouse gas emissions in a multi-output system, such as beef production

Response Options

In light of growing populations and demand for food, reducing GHG emissions by decreasing agricultural production is not an option, in the absence of transformative technology. To meet consumer demands and maintain a sustainable supply chain, agricultural producers will be under greater pressure to improve resource-use efficiency.

Further research into Canadian-specific emission intensity values, as well as research into on-farm practices that can lower these values, could give Canadian farmers and agri-food industries a competitive advantage. Efforts need to focus on increased livestock productivity and crop yields, efficient feeding strategies to minimize methane production in cattle, and the development and implementation of land management practices that increase soil carbon and decrease fossil fuel consumption. Not only can these practices reduce GHG emissions and decrease environmental impacts, they can help to increase profitability, through a decrease in inputs (such as fuel) and greater returns (i.e. higher yields and increased market value).

Tools such as the Unified Livestock Industry and Crop Emissions Estimation System (ULICEES) calculator and the Canadian Food Carbon Footprint calculator (Cafoo)[2] can be used to provide a greater understanding of the emission intensities of a variety of food products, and to encourage the production of agricultural products with lower GHG emission intensities. Such tools transfer knowledge to the market regarding the carbon footprint of agricultural products. They could also help policy makers identify scenarios and assess options related to net GHG emissions at the national scale. In their simplest application, ULICEES and Cafoo[2] can be used to estimate the GHG emission intensity associated with the production of most Canadian agricultural products. These tools have the potential to allow policy makers to study indicator trends at a broad level such as at the **Soil Landscape of Canada polygon** scale, or provincial or national scales.

A competitive advantage can be achieved if it can be demonstrated to the international community that the emission intensities of Canadian agricultural products are among the lowest in the world. This advantage can be particularly valuable and profitable for producers wanting to sell their products on the international market.

References

Desjardins, R.L., D.E. Worth, X.P.C. Vergé, D. Maxime, J.A. Dyer, and D. Cerkowniak, 2012. *The carbon footprint of beef cattle*. Sustainability. 4: 3279-3301.

Dyer, J.A. and R.L. Desjardins, 2009. *A review and evaluation of fossil energy and carbon dioxide emissions in Canadian agriculture*. Journal of Sustainable Agriculture. 33(2): 210-228.

Dyer, J.A., S.N. Kulshreshtha, B.G. McConkey, and R.L. Desjardins, 2011. *An assessment of fossil fuel energy use and CO_2 emissions from farm field operations using a regional level crop and land use database for Canada*. Energy. 35: 2261-2269.

Janzen, H., R.L. Desjardins, P. Rochette, M. Boehm., and D. Worth (eds.), 2008. *Better farming, Better Air: A scientific analysis of farming practice and greenhouse gases in Canada*. Agriculture and Agri-Food Canada: Ottawa, ON, Canada. 143 p.

Shrestha, B.M., R.L. Desjardins, B.G. McConkey, D.E. Worth, J.A. Dyer, and D. Cerkowniak, 2014. *Change in carbon footprint of canola production in the Canadian Prairies from 1986 to 2006*. Renewable Energy. 63: 634-641.

Vergé, X.P.C., J.A. Dyer, D.E. Worth, W.N. Smith, R.L. Desjardins, and B.G. McConkey, 2012. *A greenhouse gas and soil carbon model for estimating the carbon footprint of livestock production in Canada*. Animals. 2: 437-454.

Vergé, X.P.C., D. Maxime, J.A. Dyer, R.L. Desjardins, Y. Arcand, and A.C. VanderZaag, 2013. *Carbon footprint of Canadian dairy products. Calculations and issues*. Journal of Dairy Science. 96: 6091-6104.

19 Integrated Economic and Environmental Modelling – Linking Science to Policy

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Summary

Understanding how changes to agricultural policies and programs will impact economic and environmental outcomes is critical to policy evaluation and development in Canada. Linking science-based models to economic models can help provide some insight. Agriculture and Agri-Food Canada (AAFC) has developed integrated modelling capacity by linking the Canadian Regional Agriculture Model (CRAM), an economic model, to the biophysical models used to calculate its **agri-environmental indicators** (**AEIs**).[1] This capacity provides a way to estimate environmental impacts that result from changes in resource use in the agriculture sector.

In recent years, this integrated modelling approach has provided valuable input for agricultural policy analysis within AAFC, for example, to evaluate various **greenhouse gas** (**GHG**) mitigation strategies or to conduct environmental assessments of business risk management (BRM) programs. While demand for this type of analysis is increasing, many methodological issues still remain.

CRAM-AEI Integrated Modelling Framework

CRAM is a regional economic model of the agriculture sector which has the ability to estimate changes in resource use due to changes in market conditions, growing conditions, government programs or policies and changes in technology. CRAM, a non-linear optimization model, maximizes a modified welfare function (consumer plus producer surplus, less processing and transportation costs) subject to a set of linear constraints affecting various sectors of the Canadian agricultural economy. CRAM covers all major agricultural commodities derived from crops and livestock and some processing activities.[2] Government policies are incorporated through direct payments, and indirectly through policies such as supply management, subsidized input costs, and transport rates.

AAFC has developed a set of science-based agri-environmental indicators that integrate information on soils, climate and topography with statistics on land use and crop and livestock management practices. The indicators provide valuable information on the overall

1 Words included in the glossary (at the end of this publication) are bolded in the first instance they appear in each chapter.

2 For more information, refer to Agriculture and Agri-Food Canada, 2014. Canadian Regional Agriculture Model: Description, Structure and Applications.

environmental risks and conditions in agriculture and how these change over time. They are also designed to be sensitive to the considerable differences in conditions and in the commodity mix across Canada, which are reflected in significant variations in environmental performance between regions.

Using the CRAM-AEI integrated modelling framework for analysis involves two stages. The first stage involves using CRAM to estimate changes in resource use due to changes in the economic viability of the agriculture sector. In the second stage, the resource use patterns from CRAM are used as input to the AEI models, which then provide estimates of environmental impacts due to these changes. The AEI models operate at a finer resolution than CRAM, providing the ability to highlight "hot spots" of concern. The AEIs that are presently linked to CRAM are greenhouse gas emissions, residual soil **nitrogen** and the risk of water contamination from nitrogen, the soil erosion indicators, and the wildlife habitat capacity indicator (Figure 19–1).

Recent Applications of Integrated Modelling for Policy Analysis

CLIMATE CHANGE AND GREENHOUSE GAS EMISSIONS

AAFC has used its integrated modelling framework to develop estimates of greenhouse gas (GHG) emissions from the agriculture sector. To achieve this, CRAM has been linked with a GHG emissions module[3] to estimate changes in emissions from primary agriculture, and to the CanAg-MARS model to estimate changes in emissions from land use and land use change. By aligning CRAM with the estimated future production patterns in the Canadian Agricultural Outlook, it is possible to provide an estimate of future resource use in the agriculture sector at a regional level. The GHG emissions module and CanAg-MARS can then be used to estimate the GHG emissions associated with these future production patterns.

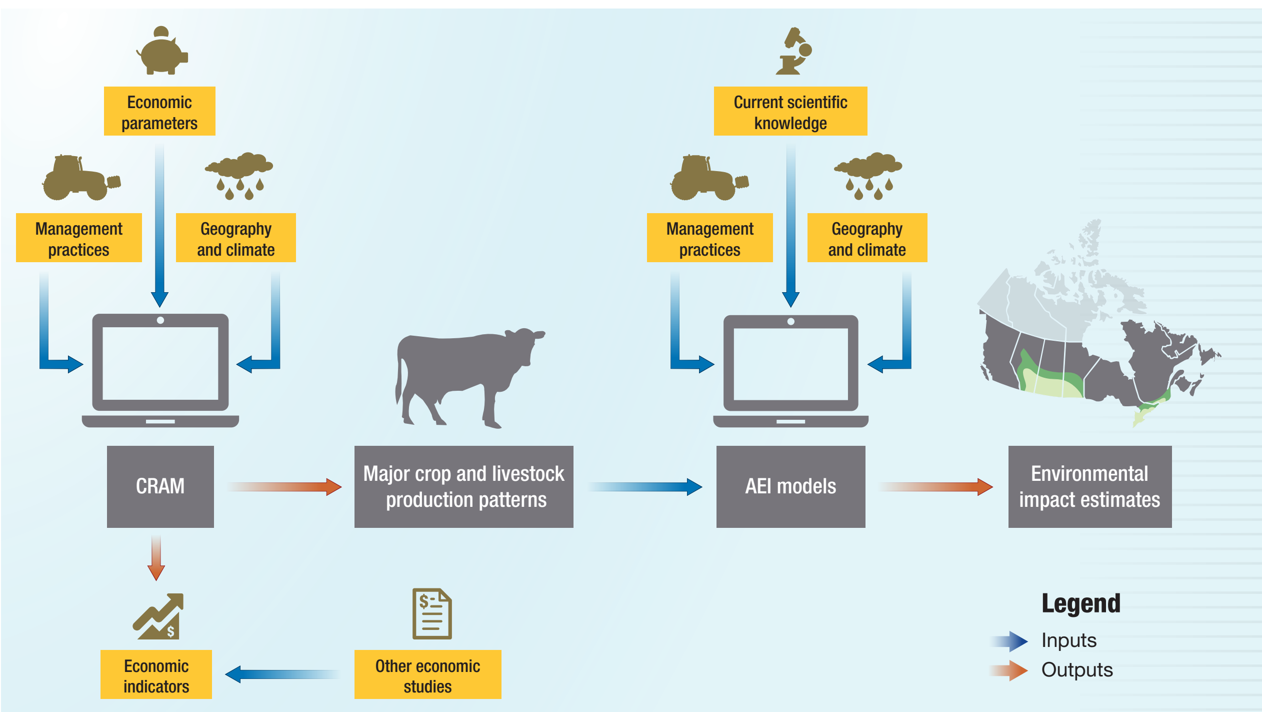


Figure 19–1: Integrated economic and environmental modelling: CRAM is a policy model that is interfaced with AEI models

3 The GHG emissions module is built to replicate the methodology used in estimating agricultural emissions for the National Inventory Report that is submitted to the UNFCCC.

Figure 19–2 summarizes recent estimates for future GHG emissions from agriculture. These estimates have been used to inform the agricultural component of Canada's Emissions Trends Report (Environment Canada, 2014), and to meet Canada's reporting requirements under the United Nations Framework Convention on Climate Change (UNFCCC). Based on the results of the analyses, the combined GHG emissions, measured in carbon dioxide equivalents (CO_2e),[4] from crops, livestock and fuel use are expected to stay fairly constant over time, increasing from 69 Mt in 2012 to 70 Mt in 2020 and 72 Mt in 2030. The rate of soil **carbon sequestration** in cropland is expected to decline from 10 Mt in 2012 to 8 Mt in 2020. This is due to the soil carbon **sink** approaching equilibrium and the limited scope for further adoption of carbon sequestration practices such as **no-till**.

All estimates of GHG emissions are based on net changes in total GHG emissions. For example, if a change in management practices reduces GHG emissions from one component of the agriculture sector but increases them in another, the model will report the net impact. It is also recognized that many GHG mitigation practices have other environmental co-benefits such as improved soil and water quality as well as enhanced biodiversity protection. These co-benefits are not reported here but could be estimated by the use of other AEIs.

ENVIRONMENTAL ASSESSMENT OF BUSINESS RISK MANAGEMENT PROGRAMS

Business risk management (BRM) programs were implemented under **Growing Forward 2**, **Growing Forward** and similar programs to help farmers protect their income and manage risks such as drought, flooding, low prices, and increased input costs. AgriStability and AgriInsurance are the primary BRM programs which provide protection for different types of losses. AgriStability is a margin-based disaster program that provides support when farmers experience large income losses; it is applicable when a producer's current year net income (referred to as a program margin) falls below 70% of the average income from previous years (referred to as a reference margin). AgriInsurance provides insurance against production losses for specified perils (such as weather, pests and disease) and covers a wide range of crops.

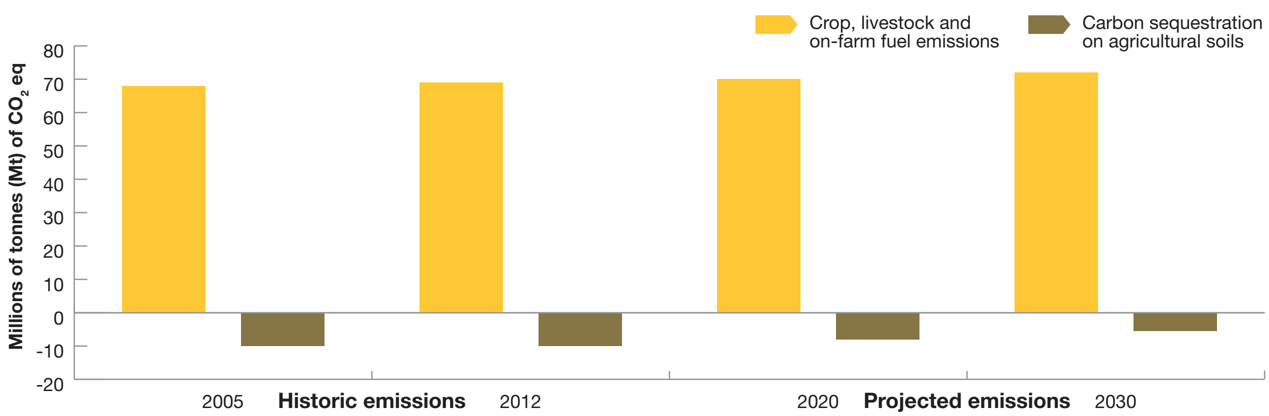


Figure 19–2: Canada's agricultural greenhouse gas emissions projections (Environment Canada, 2014)

4 For an explanation of carbon dioxide equivalents, refer to Chapter 15 "Agricultural Greenhouse Gases".

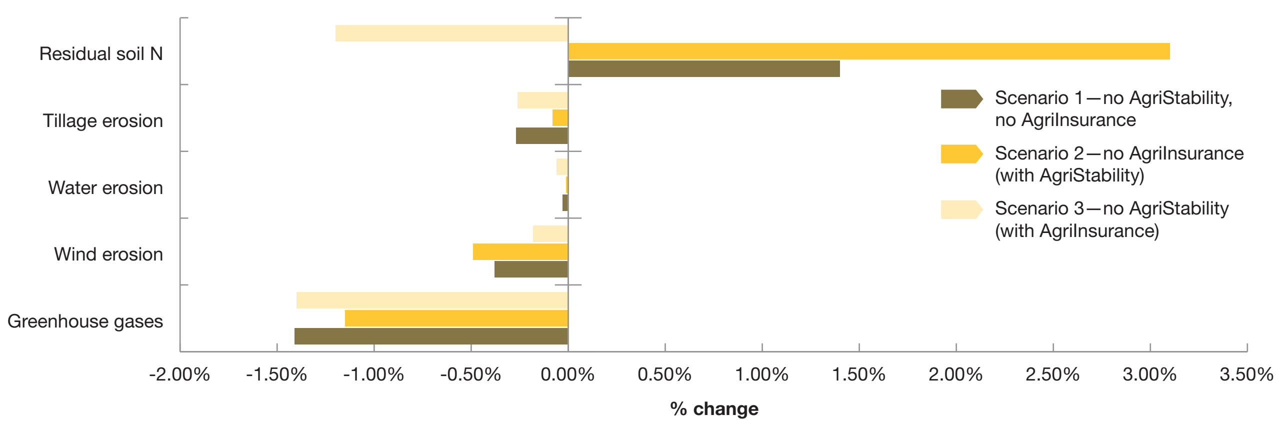
In 2013, AAFC used integrated modelling to assess the environmental impacts of BRM payments through the AgriStability and AgriInsurance programs under Growing Forward, based on three different scenarios. CRAM was linked to key agri-environmental indicators for this purpose. Changes in production, production practices and resource use all have an impact on the environmental indicators. The analysis was based on 2011 conditions. For the 2011 baseline, the model was calibrated to replicate 2011 **Census of Agriculture** land-use levels, based on the expected level of profit and its variance from AgriStability and AgriInsurance program payments. Solutions for three alternative scenarios were obtained for comparison with the baseline:

- Scenario 1: Removal of both AgriStability and AgriInsurance
- Scenario 2: Removal of AgriInsurance only
- Scenario 3: Removal of AgriStability only

The simulated economic impacts in these scenarios indicated that about 3.3% of cropland area would shift toward less intensive uses (for example, pasture) as a result of removing both programs (Scenario 1).

The estimated impact of removing AgriInsurance (Scenario 2) was very small (about 0.2% change in land use) because the yield losses were still covered to some extent through a different channel (income coverage by AgriStability). Moreover, the estimated livestock-related impacts of removing programs are very small (ranging from 0% to -0.6% under different scenarios) because market prices are a major source of risk for livestock producers, whereas this is not the case for crops. With respect to environmental impacts, the analysis indicated that removing both programs (Scenario 1) would reduce production, resulting in a 1.4% decrease in GHG emissions and a 1.4% increase in residual soil nitrogen. Tillage, water and wind erosion were not expected to undergo any noticeable changes, with the model estimating decreases of less than 0.5% (Figure 19–3).

The findings were used for the mandated environmental assessment of the BRM programs under Growing Forward. This assessment using the integrated modelling approach helped demonstrate that the BRM programs do not have a significant impact, positive or negative, on the environmental performance of primary agriculture in Canada.



Source: AAFC calculation using CRAM, 2013

Figure 19–3: Environmental effects of BRM program payments under different scenarios

Limitations

There are a number of limitations associated with the integrated modelling framework that AAFC used, including the following:

- While CRAM includes some regional disaggregation, environmental issues are inherently local, and the AEI models are based on much smaller ecological regions (**Soil Landscape of Canada polygons**) than the CRAM regions. Consequently, it is necessary to make assumptions in order to interpolate across different spatial scales.
- The scenarios and agri-environmental indicators used in the analyses were limited by the availability of existing models, resulting in the exclusion of some important farm management options (e.g. manure management).
- Quantitative assessments of the farm-level economic impacts of environmental management scenarios are limited by the lack of relevant economic information. For many scenarios, rather than allowing the underlying economics of the model to generate results, changes are imposed by making informed assumptions about adoption rates. Information on the costs and benefits of various environmental management practices at the farm level is recognized as being critical to policy development. This limitation will be addressed in future work.
- The existing integrated modelling system does not include any feedback linkages between the economic and environmental components. While outputs from CRAM scenarios are used as inputs to the AEI models to estimate environmental impacts, the reverse is not true. This is a weakness since in some cases environmental impacts could lead to economic impacts.

Future Areas of Work

A revised version of CRAM now being tested incorporates a number of improvements such as a water component (agricultural demand for water for irrigation and livestock production), red meat processing, and a component that explicitly models risk (price and yield risks). Since the AEI models are also being updated and refined, existing linkages between CRAM and the AEIs will require modification. Linkages will also be established for additional AEIs. The integrated modelling framework will continue to be used to provide Environment Canada with GHG emissions estimates for 2020 and 2030 for the agriculture sector. It will also be used to conduct the environmental assessment of BRM programs for 2015 conditions.

Conclusions

Integrated modelling frameworks, such as the CRAM-AEI framework, can permit the modelling of complex issues involving different areas of science in a more realistic and complete manner. Demand for this type of analysis is increasing; however, there are many model development issues to be addressed to further improve capacity. New frameworks may also be developed in the future to expand the number of topics that can be modelled.

References

Agriculture and Agri-Food Canada, 2014. *Canadian Regional Agriculture Model: Description, structure and applications*.

Environment Canada, 2014. *Canada's emissions trends* [2014]. Retrieved from http://publications.gc.ca/collections/collection_2014/ec/En81-18–2014-eng.pdf http://ec.gc.ca/Publications/default.asp?lang=En&xml=E998D465-B89F-4E0F-8327-01D5B0D66885

Gill, R., G. Achuo, B. Junkins, and B. Macgregor, 2010. *GHG abatement cost curves for the agriculture sector: Potential to reduce emissions.* Agriculture and Agri-Food Canada, Strategic Policy Branch. Unpublished.

Government of Canada, 2014. *Canada's sixth national report on climate change: Actions to meet commitments under the United Nations Framework Convention on Climate Change.* Available at http://www.publications.gc.ca/site/eng/456520/publication.html

Government of Canada, 2002. *Government of Canada Action Plan 2000 on Climate Change.*

Horner, G.L., J. Corman, R.E. Howitt, C.A. Carter, and R.J. MacGregor, 1992. *The Canadian regional agriculture model: Structure, operation and development.* Technical Report 1/92. Ottawa, ON, Canada: Agriculture Canada, Policy Branch.

Howitt, Richard E., 1995. *Positive mathematical programming*. Amer. J. Agr. Econ. 77:329-342.

Kulshreshtha, S.N., R. Gill, B. Junkins, R. Desjardins, M. Boehm, and M. Bonneau, 2002. *Canadian Economic and Emissions Model for Agriculture (CEEMA 2.0): Technical Documentation*, CSALE Working Paper # 12. Saskatoon, SK, Canada: University of Saskatchewan.

McRae, H.W., C.A.S Smith, and L.J. Gregorich (eds), 2000. *Environmental sustainability of Canadian agriculture: Report of the agri-environmental indicator project.* Ottawa, ON, Canada: Agriculture and Agri-Food Canada. Available at http://publications.gc.ca/site/eng/9.694775/publication.html

Appendices

Glossary

Aerodynamic diameter: Airborne particles have irregular shapes, and their aerodynamic behaviour is expressed in terms of the diameter of an idealized spherical particle known as aerodynamic diameter (which is essentially a measure of particle size).

Agricultural Policy Framework (**APF**)**:** A five-year (2003-2008) policy framework for Canada's agricultural and agri-food sector, agreed upon by the federal, provincial and territorial governments.

Agri-environmental indicator (**AEI**)**:** A measure of a key environmental condition, risk or change resulting from agriculture; or a measure of management practices used by producers.

Agro-ecosystem: Species and ecosystems under agricultural management; an open, dynamic system connected to other ecosystems through the flow of energy and the transfer of material such as crops, pastures, livestock, other flora and fauna, air, soil and water.

All other land: The All Other Land category is an older (pre-2006) Census category that includes areas of all other land on a farm, including idle land, woodlots, marshes, and wetlands, as well as land containing farm buildings, barnyards, lanes and home gardens. Since 2006, it has been split into two new distinct categories: 'Woodlands and Wetlands', which incorporates woodlots, sugarbush, windbreaks, marshes, bogs, ponds and sloughs; and a new 'All other land' category which now only encompasses idle land, as well as land containing farm buildings, barnyards, lanes, and home gardens. For consistency in calculating the Wildlife Habitat Capacity on Farmland Indicator, as well as the Agricultural Land-Use Change Indicator, the original All Other Land designation has been maintained.

Ammonia: A compound of nitrogen and hydrogen (NH_3) which is formed naturally when bacteria decompose nitrogen-containing compounds, especially urea and uric acid, contained in manures and fertilizers. Emissions of ammonia can be a problem in enclosed livestock facilities and can react with other compounds in the air to produce fine particulate matter. Ammonia is a component of some fertilizers and an important plant nutrient. It can also be used as a refrigerant in the food and beverage industry.

Anaerobic: Characterized by the absence of oxygen.

Anaerobic digester: A facility or containment system in which micro-organisms break down biodegradable material, such as food waste or manure, in the absence of oxygen. One of the end products is biogas primarily consisting of carbon dioxide and methane which can provide heat or power for the farm, or be converted to electricity and sold to local utility companies.

Anthropogenic: Involving the impact of humans on nature; induced or altered by the presence or activities of humans.

Atmospheric deposition: The process by which chemical substances, such as pollutants, are transferred from the air to surfaces – including soil, vegetation, surface water and indoor surfaces. Includes dry and wet processes.

Beneficial management practices (**BMPs**)**:** Methods, measures or practices designed to minimize or prevent environmental risks and negative effects (including pollution) on the environment.

Biodiesel: A biofuel intended as a substitute for diesel.

Biodiversity: The variety of life forms on earth and the natural processes that link and maintain them. Biodiversity has three components: ecosystem diversity, species diversity and genetic diversity. Also called biological diversity.

Biofuel: A gaseous, liquid or solid fuel derived from a biological source, such as methane, ethanol, seed oils, algae or fish liver oil.

Biogas: A gas produced by the biological breakdown of organic matter in the absence of oxygen. Often captured and used as an energy source.

Biomass: Total mass of a species or group of species per unit area; or the total mass of all the species in a community.

Biopesticides: Pesticides that are formulated from organic substances and that will not adversely affect human health.

Bioplastics: Biodegradable plastics made from natural resources such as starch, cellulose and proteins.

Biosolids: Treated sewage sludge used as fertilizer.

Black soil: Grassland soil type occurring on the Canadian Prairies, characterized by a very dark coloured surface layer. These soils are associated with cool, relatively moist climatic conditions.

Bovine spongiform encephalopathy (BSE): Commonly known as "mad cow disease," bovine spongiform encephalopathy (BSE) is a progressive, incurable disease that affects the central nervous system.

Broadcasting: Even and uniform spreading of manure or fertilizer over the entire surface of field either before planting or to the standing crop (this last is referred to as top-dressing).

Brown soil: Grassland soil type occurring on the semi-arid Canadian Prairies, characterized by a brown coloured surface layer. These soils are associated with the dry climatic conditions of the southern prairies.

Carbon (C): Element present in all materials of biological origin.

Carbon dioxide: Major greenhouse gas produced through the decomposition of organic matter in soils under oxidizing conditions; also produced by the burning of fossil fuels. It is one of the three main agricultural greenhouse gases (with methane and nitrous oxide).

Carbon dioxide equivalents: Expression of the effectiveness of a gas to produce a greenhouse effect in the atmosphere in terms that compare it with that of carbon dioxide.

Carbon footprint: The total amount of carbon dioxide (CO_2) and other greenhouse gases emitted during the production and over the lifecycle of a given product

Carbon sequestration: Biochemical process by which carbon is transferred from the atmosphere by living organisms, including plants and micro-organisms to another carbon pool such as soils or forests with the potential to reduce atmospheric carbon dioxide levels.

Census of Agriculture: National agricultural census undertaken every five years to compile information on farm structure and economics, crops and land use as well as livestock.

Cereal: The edible grain of gramineous plants, such as wheat, oats, rye and rice.

Coliform: A group of bacteria that are naturally found in the intestines of humans and warm-blooded animals. Fecal coliforms are used as a marker or indicator, because they indicate the presence of fecal material from agricultural sources, and therefore the risk of contamination of surface water bodies from livestock manure.

Conservation tillage: Any tillage sequence designed to minimize or reduce the loss of soil and water; operationally, a tillage or tillage and planting system that leaves 30% or more crop residue cover on the soil surface.

Continuous cropping: Practice of growing crops every growing season with no fallow years or growing the same crop on the same land year after year.

Contour cultivation/contour farming: Cultivation on the contour of the land, rather than up and down slope, to reduce soil erosion, protect soil fertility and use water more efficiently.

Conventional tillage: Primary and secondary tillage operations normally performed in preparing a seedbed, usually resulting in less than 30% crop residue cover on the soil surface.

Cover crop: Secondary crop grown after a primary crop or between rows of the primary crop to provide a protective soil cover that can minimize soil erosion and leaching of nutrients.

Crop residue: Plant material remaining after harvesting, including leaves, stalks and roots.

Cropland: Census of Agriculture category of agricultural land use denoting the total area on which field crops, fruits, vegetables, nursery crops and sod are grown.

Cyanobacteria: Group of organisms related to true bacteria and belonging to the kingdom Monera.

Dark Brown soil: Grassland soil type occurring on the Canadian Prairies, characterized by a dark brown coloured surface layer. These soils are associated with climatic conditions intermediate between those for the Brown and Black soils of the Prairies.

Decomposition: Breakdown of complex organic matter into simpler materials by micro-organisms.

Drainage: Procedure carried out to improve the productivity of agricultural land by enhancing the removal of excess water from the soil by means such as ditches, drainage wells and subsurface drainage tiles.

Denitrification: A chemical process in which nitrates in the soil are reduced to nitrous oxide or molecular nitrogen, which is released to the atmosphere.

Dryland: Type of farming that depends exclusively on natural precipitation and soil moisture to supply water to crops (i.e. non-irrigated). Sometimes called "rainfed."

Economic allocation: A system of allocation whereby emissions are attributed based on the relative price of the final product

Ecoregion: Mapping unit in Canada's ecological classification system. A subdivision of a larger ecological classification unit characterized by distinctive regional ecological factors, including climate, physical geography, vegetation, soil, water and fauna.

Ecosystem: A unit of land or water comprising populations of organisms considered together with their physical environment and the processes linking them.

Ecosystem services: Services provided by natural systems that result in a benefit for society. Examples of ecological services include nutrient cycling, air and water purification, crop pollination and climate control.

Ecozone: Largest mapping unit in Canada's ecological classification system. An ecozone is an area of the earth's surface representing large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors. Agriculture is carried out in seven of Canada's 15 ecozones.

Emission factor: An estimate or statistical average of the rate at which a contaminant is released to the atmosphere through some activity (e.g. farming, burning of fuel), divided by the level of that activity. Given an emission factor and a known activity level, a simple multiplication yields an estimate of the actual emission.

Emission intensity: An estimate of the amount of greenhouse gas emissions associated with the per-unit production of agricultural products

Enteric bacteria: Group of bacteria that live in the intestinal tracts of humans and other animals.

Enteric fermentation: A digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream of an animal.

Environmental farm plan: Plan outlining the environmental concerns related to a given farm and the steps required to address them. This type of plan is prepared and implemented by farmers on a voluntary basis.

Erodibility: The susceptibility of a soil to erosion.

Erosivity: Measure of the predictable capacity of water, wind, tillage or other agents to cause erosion.

Eutrophication: The process by which excessive growth of algae and other aquatic vegetation occurs in a body of water containing a high concentration of plant nutrients, especially nitrates and phosphates. This nutrient enrichment can lead to depletion of dissolved oxygen and kill aquatic organisms such as fish.

Evapotranspiration: Movement of water into the atmosphere by evaporation from the soil and transpiration from plants.

Fertilizer: Any organic or inorganic material, either natural or synthetic, that is used to supply elements (such as nitrogen, phosphorus and potassium) essential for plant growth.

Fine particulate matter/Fine respirable particulate: Particles with an aerodynamic diameter of less than 2.5 micrometres. These particles are easily inhaled into the lower airways (the gas-exchange regions of the lungs) and deposited in the lungs, causing adverse health effects.

Forage: Grass or legume crop grown to provide livestock feed; may be stored dry as hay or under moist conditions as silage, ploughed into the soil as green manure, or grazed.

Fossil fuel: **Carbon**-based remains of organic matter that have been geologically transformed into coal, oil or natural gas. Combustion of these substances releases large amounts of energy. Fossil fuels are used to supply a large proportion of human energy needs.

Fumigant: A chemical compound used in its gaseous state as a pesticide or disinfectant.

Genetically modified (**GM**)**:** Pertaining to a living organism whose genetic material has been altered, changing one or more of its characteristics.

Global warming potential: Measure of the ability of a greenhouse gas to trap radiation and thus contribute to global warming (rise in global temperatures).

Grassed waterway: Natural or constructed channel, usually broad and shallow, covered with erosion-resistant grasses, used to convey surface water from or across cropland along natural depressions.

Greenhouse gas (**GHG**)**:** Greenhouse gases absorb and trap heat in the atmosphere and cause a warming effect on earth. Some occur naturally in the atmosphere, while others result from human activities. Greenhouse gases include carbon dioxide, water vapour, methane, nitrous oxide, ozone, chlorofluorocarbons, hydrofluorocarbons and perfluorocarbons.

Ground water: Portion of water below the soil surface that has the water table as its upper boundary. This water supplies wells and springs.

Growing Forward: A five-year (2008-2013) policy framework for Canada's agricultural and agri-food sector, agreed upon by the federal, provincial and territorial governments.

Growing Forward 2: A five-year (2013-2018) policy framework for Canada's agricultural and agri-food sector, agreed upon by the federal, provincial and territorial governments.

Hydraulic conductivity: A measure of how easily water can pass through soil or rock: high values indicate permeable material through which water can pass easily; low values indicate that the material is less permeable.

Hydrological connectivity: Water-mediated transport of matter, energy and organisms within or between elements of the hydrologic cycle.

Hydrogen (**H**)**:** Chemical element with chemical symbol H and atomic number 1.

Idle land: Abandoned land which has not been cultivated for some time.

Improved Pasture: Pasture in which the yield has been increased through a combination of measures such as planting higher-yielding grass species, planting legumes, or spreading lime.

Inorganic: Pertaining to a compound that is not organic, usually of mineral origin.

Integrated pest management (**IPM**)**:** Decision-making process that uses all the necessary techniques to suppress pests effectively, economically and in an environmentally sound manner. Integrated pest management, or IPM, is an ecologically based strategy that relies on natural mortality factors such as natural enemies, weather and crop management, and applies control measures that disrupt these factors as little as possible.

Intensive tillage: Intensive tillage leaves less than 15% cover. This type of tillage is often referred to as conventional and involves multiple operations with implements.

Invasive alien species: Alien (non-native) species (plant, animal or micro-organism) whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

Landscape heterogeneity: The variable spatial distribution of landscape elements (such as land cover types).

Leaching: Process by which soluble substances are dissolved and transported through the soil by percolating water.

Live weight: The weight of an animal before it has been slaughtered and prepared as a carcass (whereupon it can be referred to as carcass weight or dressed weight).

Methane (CH_4): Gas produced through anaerobic decomposition of waste in landfills, animal digestion, decomposition of manure, production and distribution of natural gas and oil, coal production and incomplete fuel combustion. It is one of the three main agricultural greenhouse gases (with CO_2 and N_2O).

Minimum tillage: Minimum use of tillage necessary to meet crop production requirements under existing soil and climatic conditions, usually resulting in fewer tillage operations than for conventional tillage.

Moldboard plough: Tillage implement used to break up soil with partial to complete inversion of soil.

Native species: Species known to have existed on a site prior to the influence of humans, possibly including long-established exotic species.

Nitrate (NO_3^-): Soluble form of nitrogen that is used by plants; nitrate is naturally present in ground water and surface water but excess levels may accumulate in water resources (pollution) as a result of human activity.

Nitrogen (N): Chemical element found in most organic substances. An essential nutrient for both plants and animals, it can be a pollutant of water (nitrate, ammonia) or of air (ammonia, ammonium, nitrous oxide).

Nitrogen cascade: The N cascade refers to the multiple linkages among the ecological and human health effects of reactive nitrogen molecules as they move from one environmental system to another.

Nitrogen mineralization: The conversion of organic N in the soil to ammonium as a result of microbial decomposition.

Nitrophilic: Preferring or thriving in a soil rich in nitrogen

Nitrous oxide (N_2O): Potent, naturally occurring greenhouse gas whose emissions are enhanced by anthropogenic activities such as nitrogen fertilization, crop residue decomposition and farming of organic soils as well as the deposition, storage and application of manure to agricultural land. It is one of the three main agricultural greenhouse gases (with CO_2 and CH_4).

No-till: Procedure by which a crop is planted directly into the soil using a special planter, with no primary or secondary tillage after harvest of the previous crop.

Nutrient: Substance required by a living organism for proper growth and development. Nitrogen, phosphorus and potassium are essential crop nutrients.

Oilseeds: Seeds or crops grown mainly for oil, including flaxseed, canola and rapeseed, soybeans, safflower and sunflower seed.

Oligotrophic: The state of a body of water when it has a low nutrient content and is therefore unable to support a large aquatic flora and fauna.

Ozone: Naturally occurring gas, formed from normal oxygen. Ozone in the upper atmosphere protects the earth by filtering out ultraviolet radiation from the sun.

Partial Equilibrium Model: A model which takes into consideration only a part of the market, and tracks the effects of policy action only in that single sector or market (e.g. agriculture only); all other possible market interactions with or in other sectors are ignored. This is in contrast to a general equilibrium model which includes an entire economy.

Particulate matter: Air pollutants composed of minuscule liquid or solid particles temporarily suspended in the atmosphere (e.g. dust, pollen, spores, smoke, organic compounds)

Pathogen: A disease-causing agent.

Perennial forage: Grasses and legumes grown primarily for grazing or stored livestock feed that re-grow each spring from the root of plants from the previous growing season.

Permanent cover: Perennial crop that provides vegetative protection to the soil throughout the year. Can be achieved by successive annual or biennial crops in some cases.

Pesticide: A natural or synthetic chemical that is used to kill or control pests. Pesticides include herbicides, insecticides, fungicides, nematicides, rodenticides and miticides.

Pesticide resistance: The ability of pest populations to develop a tolerance to the recommended application rate of pesticide.

Phosphorus (P): An essential element for all living organisms and a key crop nutrient. Phosphorus can cause eutrophication of fresh water systems when present at levels above a threshold concentration.

Photosynthesis: Process by which plants transform carbon dioxide and water into carbohydrates and other compounds using energy from the sun captured by the plants' chlorophyll.

Polygon: Irregularly shaped, closed delineation on a map; used in the context of mapping units in the Soil Landscapes of Canada map series and superimposed on Census of Agriculture maps to align soil and landscape data with information on agricultural management practices.

Preferential flow: Process whereby water, soluble substances and compounds such as particulate phosphorus and fecal coliforms move through soil macropores to tile drains and water tables.

Primal cut: Piece of meat initially separated from the carcass of an animal during butchering. Beef primal cuts include the chuck, brisket, shank, rib, short plate, loin, flank and round. These are then further divided into sub-primal cuts and fabricated cuts for retail.

Precision farming: The use of technology such as GPS or soil testing to identify and manage variations within fields that can affect crop yields.

Primary PM: Particles that result from processes such as wind erosion and tillage (soil dust), burning (soot), crop harvesting and grain handling (grain dust).

Reduced tillage: Tillage operations that involve less soil disturbance than conventional tillage, either through the use of fewer passes or special equipment, and that leave part of the residue from the previous crop on the soil surface. Includes minimum tillage and conservation tillage.

Rendering: A process that converts waste animal tissue into value-added materials. Rendering can refer to any processing of animal products into more useful materials, or more narrowly to the rendering of whole animal fatty tissue into purified fats like lard or tallow.

Residence time: The duration of persistence of a mass or substance in a medium or place.

Riparian area: Land bordering a stream or other body of water.

Riparian buffer/buffer strip: Narrow strip of vegetated land along a watercourse designed to reduce erosion, intercept pollutants, provide habitat for wildlife and address other environmental concerns.

Row cropping: A production system involving crops that are grown in widely spaced rows and that may involve tilling between the rows for weed control, hilling the rows for root protection, or both. Typical row crops include potatoes, tobacco, vegetables, beans, sugar beets and corn. Usually involves a high level of production per unit area.

Runoff: The portion of precipitation and snowmelt that flows over the land into surface water (e.g. streams, marshes, lakes).

Salinization: Process by which the content of soluble salts increases at the soil surface or within the root zone

Secondary PM: Particles that are formed in the air. For example, ammonia, biogenic volatile organic compounds (VOCs) emitted from plants and nitric oxide from soils can react with other airborne pollutants to form particles that contribute to smog.

Sequestered/Sequestration: Stored separately. Carbon that is removed from the atmosphere and stored in soil in the form of soil organic matter is said to be sequestered carbon.

Shelterbelt: A barrier of trees, shrubs or other perennial vegetation designed to reduce wind erosion. Also called a windbreak.

Sink: In soils, the capacity to assimilate substances and retain them or subsequently provide them as a source for above- and below-ground vegetative growth.

Smog: Unhealthy air caused by smoke, chemical fumes or dust formed in the atmosphere.

Soil Landscapes of Canada (SLC): National series of broad-scale (1:1 million) soil maps containing information about soil properties and landforms.

Soil organic matter: Carbon-containing material in the soil that derives from living organisms.

Soil structure: Physical properties of a soil relating to the arrangements and stability of soil particles, aggregates and pores.

Soybean: An annual leguminous plant (Glycine max) native to East Asia, widely cultivated for its seeds, which are used for food, as a source of oil, and as animal feed.

Stochastic model: A tool for estimating probability distributions of potential outcomes by allowing for random variation in one or more inputs over time. The random variation is usually based on fluctuations observed in historical data for a selected period using standard time-series techniques.

Strip cropping: Erosion control method consisting of growing crops that require different types of tillage, such as row crops and permanent grass or annual crops and fallow, in alternate strips along contours.

Summerfallow: Census of Agriculture category of agricultural land use and general term denoting cropland that is not cropped for at least one year, primarily for the purpose of conserving soil moisture, but is instead managed by cultivating or spraying to control weeds.

Sustainable agriculture: An integrated farming system that will, over the long term, satisfy food and fibre needs, enhance environmental quality, make the most efficient use of resources, sustain the economic viability of farm operations and enhance the quality of life.

Systemic pesticide: A pesticide that is harmless to the organism it is designed to protect, but when absorbed into its sap or bloodstream makes the entire organism toxic to pests.

Tame hay: Alfalfa and alfalfa mixtures cut for hay silage or green feed and other tame hay and fodder crops cut for hay or silage. Includes clovers, fodder crops such as oats, barley, & sorghum.

Tame pasture: Census of Agriculture category of agricultural land use denoting pasture that has been improved by management such as cultivation, drainage, irrigation, fertilization, seeding or spraying of herbicides. Also referred to as “improved pasture” and “seeded pasture.”

Terracing: A soil and water conservation technique consisting of a raised level space supported on one or more sides by a wall or a bank.

Tile Drainage: A common agricultural water management practice typically found on flat, poorly drained fields. In Canada, tile drain systems are commonly found in Eastern Canada and the Maritimes (about 45% of Ontario’s cropland – 10.6 million acres – is tile drained), as well as some parts of Manitoba. The systems are designed to lower a shallow water table and reduce excess water in the field, thereby improving crop productivity. They consist of a series of perforated plastic pipes, placed below the surface of the soil at a specified grade (slope) at some depth below the soil surface (depth depends on water table, but typically between 50-100 cm). Excess water from the crop root zone can enter the pipe through the perforations and flow away from the field to a ditch or other outlet.

Total ammoniacal nitrogen (**TAN**): The combined total of NH_3 (ammonia) and NH_4^+ (ionized ammonia)

Toxicity: Toxicity is the ability of a substance to cause harmful health effects.

Unimproved pasture: Natural land for pasture.

Volatilization: The conversion of a solid or liquid to a gas.

Watershed: The area of land from which a water body receives water. An area of land that drains water, organic matter, dissolved nutrients and sediments into a lake or stream; the topographic boundary is usually a height of land that marks the dividing line from which surface streams flow in two different directions.

Waterways: Channels that contain flowing water year round or for at least part of the year, usually in spring. Examples include drainage ditches, draws or coulees, grassed waterways, streams, creeks and rivers.

Wetland: Area of land inundated by water originating as either surface runoff or ground water. Under the Canadian Wetland Classification System, wetlands are divided into five classes: bogs, fens, marshes, swamps and shallow waters.

Winter cover crop: Crop planted in the fall to provide cover and thus curb soil erosion during winter and spring.

Zero tillage: Procedure by which a crop is planted directly into the soil using a special planter, with no primary or secondary tillage after harvest of the previous crop. Also referred to as no-till.

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