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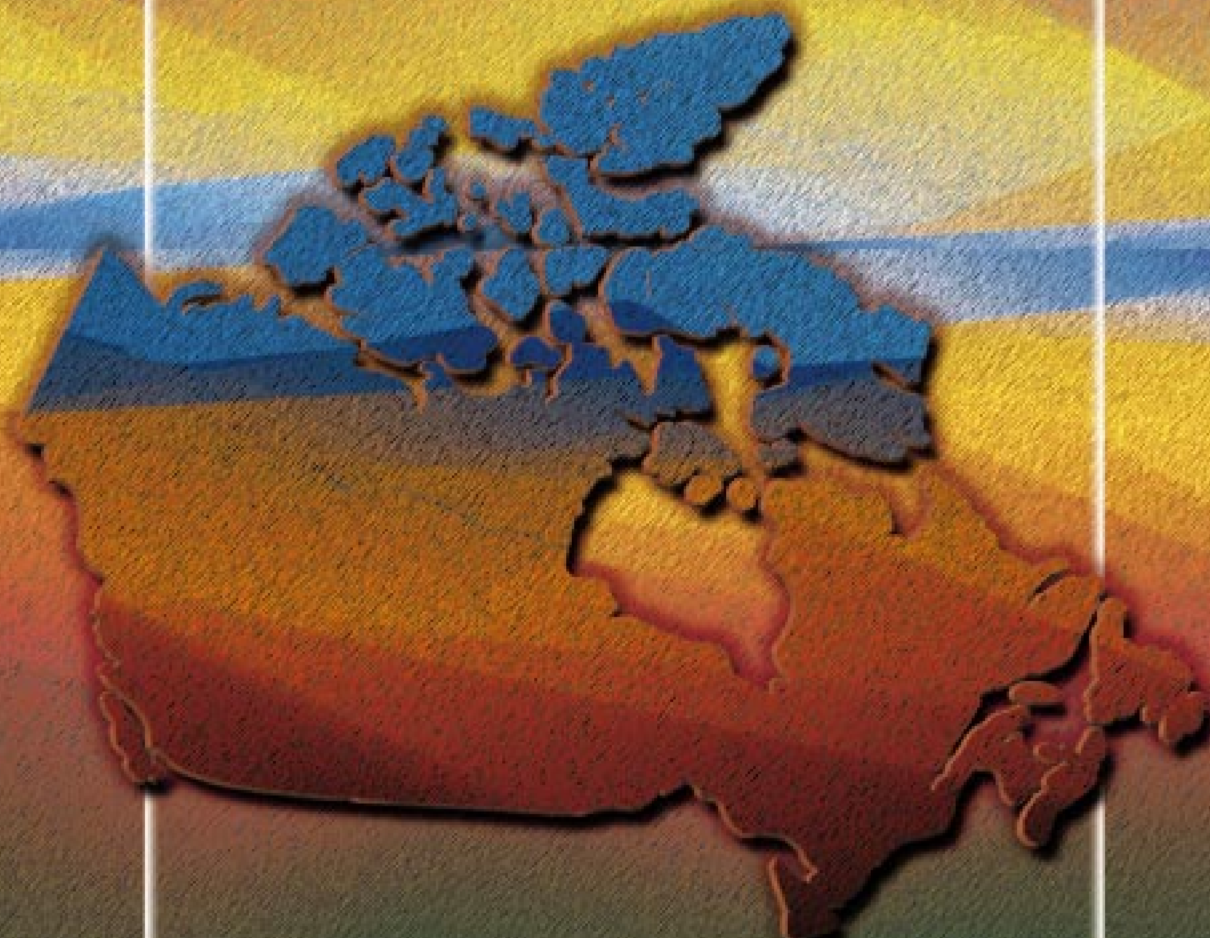
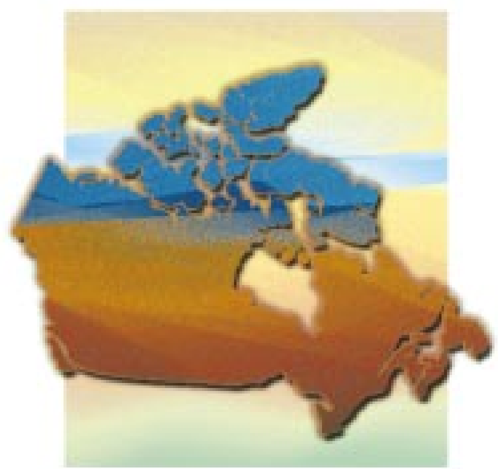
Environmental Sustainability of Canadian Agriculture



Report of the Agri-Environmental Indicator Project

ENVIRONMENTAL SUSTAINABILITY OF CANADIAN AGRICULTURE



Report of the Agri-Environmental Indicator Project

T. McRae, C.A.S. Smith, and L.J. Gregorich (editors)

Research Branch
Policy Branch
Prairie Farm Rehabilitation Administration

Agriculture and Agri-Food Canada
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Contents

Minister
of Agriculture and
Agri-Food

Ministre
de l’Agriculture et de
l’Agroalimentaire

Ottawa, Canada K1A 0C5

A word from
The Minister
on Sustainable Development

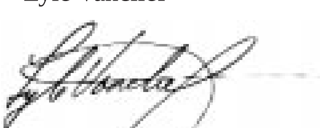
The sustainable production of food is crucial for us all. As Minister of Agriculture and Agri-Food Canada, I am pleased to present *Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project*. In this report, we introduce a new set of tools, agri-environmental indicators, to help guide and assess the environmental performance of our primary agriculture sector.

Agriculture and Agri-Food Canada is pleased to have lead the development of these indicators, which are based on our best understanding of agricultural ecosystems and their interactions with the economy and surrounding environment. Our scientists have worked together with the invaluable assistance of an external Advisory Committee to develop the methods and information, and also to analyze the results. We can now begin to use the indicators to assess the environmental implications of our actions, and we will draw on this and related information as we engage our partners in a dialogue aimed at developing a new Sustainable Development Strategy. Many of the underlying concepts and methods may well be used by others to track the environmental performance of primary agriculture elsewhere, such as in other countries.

Environmental Sustainability of Canadian Agriculture: *Report of the Agri-Environmental Indicator Project* is another important contribution toward our goal of increasing understanding of linkages between the environment and the agricultural economy. The results clearly demonstrate the progress Canadian agriculture has made in conserving the environment, and also focus our attention on where we need to work harder. This publication complements and integrates the information presented in related publications from Agriculture and Agri-Food Canada: *The Health of Our Soil (1995)*, *The Health of Our Air (1999)* and *The Health of Our Water (2000)*.

Agriculture and Agri-Food Canada will continue to work with its partners to encourage sustainable development through basic research, and by developing and transferring the tools producers and other decision-makers need to improve environmental management in agriculture.

Lyle Vanclief



Minister of Agriculture and Agri-Food Canada
and Minister Coordinating Rural Affairs

A word from the Agri-Environmental Indicator Project Advisory Committee

Agriculture is integral to Canadian society, making significant contributions to our economy, rural communities, and food security. It is also intimately connected to the environment. Not only are resources such as soil and water vital to agricultural productivity, but agriculture both affects and is affected by the local, regional, and global environment.

In recent years, Canadians have made significant commitments toward a more sustainable society. The government of Canada has signed international conventions; federal and provincial governments have implemented environmental legislation, policies, and programs; and municipalities have adopted environmental bylaws. Citizens and industry have also contributed through numerous actions. The challenge of achieving a more environmentally sound agriculture has been taken up by farmers, and the agriculture industry has undertaken many initiatives to ensure its sustainability. If more sustainable agriculture is to become a reality, objectives and indicators of progress are needed to guide these efforts.

Recognizing the need for indicators, and in response to recommendations made by several groups, Agriculture and Agri-Food Canada (AAFC) initiated the Agri-Environmental Indicator Project in 1993. The department's Environment Bureau and Research Branch carried out most of the work. Many AAFC scientists and analysts from across the country were involved in developing and using the indicators to generate the findings presented in this report. Many scientists outside of AAFC also contributed to this work.

An advisory committee was established in 1995 to provide input from agencies other than AAFC. Several farm and farm input-supply organizations, conservation groups, universities, scientific bodies, provincial agriculture ministries, and federal departments were represented on this advisory body, which played a significant role in the process of developing the indicators and shaping this report. As a result of the advisory committee's efforts, many indicators were modified, some were dropped, and others were added.

The advisory committee regards the indicator project as a success. The findings of this report confirm that the agricultural industry's efforts to address environmental challenges have yielded many positive results, and also that much remains to be done. This study represents a major step forward in our ability to provide national assessments of the environmental performance of agriculture, based on available information and resources.

We encourage all users to exercise caution in interpreting and using this report. The indicators provide first approximations; their limitations are explained in Chapter 2 of the report, as well as for each individual indicator. More research and effort will be needed to increase the accuracy and scope of the indicators. Also, the utility of the indicators has yet to be fully tested, and this will be the ultimate measure of their success.

We are confident that the indicators will contribute to a more informed debate in Canada regarding the establishment and pursuit of environmental sustainability goals for agriculture, and that this work will contribute to similar initiatives underway elsewhere within Canada and abroad. We urge Agriculture and Agri-Food Canada to ensure the continuous improvement and periodic reporting of the agri environmental indicators in the future.

David Lobb, Marie Boehm, and Jim Farrell
Co-chairs, Agri-Environmental Indicator
Project Advisory Committee

A Introduction and Background

1 Introduction

T. McRae

The priority of environmentally sustainable agriculture

The production of food and fibre will always remain at the core of agriculture. Global population and food demands continue to grow, and Canada's agricultural industry has set ambitious new targets to increase its share of global markets. However, continued increases in agricultural production raise questions about how the benefits of additional production compare with the costs, including environmental costs. Consequently, agriculture today must balance a wide array of demands and environmental challenges that are continually evolving in their nature and complexity.

The long term environmental sustainability of production is one major question facing the agricultural sector. For example, the 1984 report by the Senate Standing Committee on Agriculture, *Soil at Risk: Canada's Eroding Future*, sounded the alarm that soil degradation was undermining sustainable crop production. Later scientific and policy studies, such as the 1990 report of the Federal–Provincial Agriculture Committee on Environmental Sustainability, have raised concerns about the broader environmental costs of agriculture, such as declining water quality, loss of wildlife habitat, reduced biodiversity, and emissions of greenhouse gases. On the other hand, agriculture is increasingly valued by Canadians for its environmental benefits, including its provision of some *wildlife habitat;* the visual beauty of farmland; and environmental services, such as nutrient cycling and the storage and filtering of water.

Environmental issues are not new to agriculture. Governments, farmers, and others have worked together to promote research, programming, and related actions to address environmental concerns. Historically the focus has been the conservation of the natural resource base upon which agriculture depends, particularly soil, water, and genetic resources for crops and livestock. But over the past 15 years, the environmental challenges facing agriculture have broadened as the agricultural sector has adopted new production methods and intensified production to meet society's growing demand for agricultural products.

At the same time, more scrutiny and pressure are being placed on agriculture (and other economic sectors) to maintain acceptable levels of environmental quality and quantity. In some sectors, such as livestock production, environmental concerns now pose a direct constraint to growth. In other sectors, resource degradation remains a constraint over the longer term. Internationally, globalization of markets has exposed Canadian agricultural products to greater numbers of consumers, and environmental performance will increasingly affect agriculture's ability to retain such markets, as well as compete for new ones.

In short, today an environmentally sustainable form of agriculture is more urgently needed. The policy challenge in agriculture — to ensure optimal and sustainable social, economic, and environmental benefits — has become more pressing and complex than ever.

The need for information

Farmers, governments, researchers, environmentalists, and consumers all have a stake in ensuring a sustainable agriculture industry for Canada, and each group can promote environmental sustainability in a variety of ways. For example, governments cooperate with partners in developing the overall policy framework for agriculture and sometimes influence the economic signals that affect farmers' decisions. Researchers develop new technologies and methods to improve productivity and sustainability, and consumers influence the marketplace through their purchasing decisions. The individual decisions taken by Canada's farmers have a direct influence on environmental sustainability, but these decisions are influenced by an array of factors beyond the farm gate.

Information is one of the common needs of all decision makers concerned with sustainability. To be managed effectively, pressures and opportunities must be understood. Decision makers at all levels need information on the performance of a given system, why that system is behaving as it is, whether that performance is satisfactory, and how it is likely to behave in the future in response to potential changes in policies and other driving forces. In agricultural terms, if we genuinely want to practise environmentally *sustainable agriculture,* we must have some idea of whether the path we are on is headed toward or away from this goal. By providing decision makers with the information they need, better decisions about whether and how to change the system are the likely result.

Over the past decades, governments and industry have invested considerable resources to both promote economic development and develop systematic approaches for measuring economic performance. The economic measurement systems in use today are embedded in the United Nations System of National Accounts (SNA), from which economic indicators such as Gross Domestic Product are derived. However, the SNA is largely silent on the environment, and most common economic indicators do not take into account the growing or declining value of environmental assets and services, such as land, water, and wildlife. As a result, decision makers who rely solely on economic indicators risk achieving economic goals at the expense of environmental and other objectives. Over the past 15 years, considerable effort has gone into developing new ways of measuring and valuing environmental assets and services, and understanding the links between the environment and the economy. Environmental indicators are one result of such efforts.

Objectives of this report

In 1993, Agriculture and Agri-Food Canada initiated work to establish a systematic approach to answering questions such as:

- To what extent do farmers use environmentally sound management practices?
- How are environmental conditions and trends within agriculture changing over time, and how can such changes be explained?
- What areas and resources remain at significant environmental risk?

In this report we present the results of this work, based on the concept of ***agri-environmental indicators.*** Agri-environmental indicators are measures of key environmental conditions, risks, and changes resulting from agriculture, and of management practices used by producers. We have worked closely with farm leaders and other stakeholders to select and develop appropriate indicators, and we believe they will benefit Canada's agriculture industry and the environment by

- informing agricultural and other decision makers about environmental performance in agriculture
- demonstrating the progress being made by the agriculture sector in adopting stewardship principles and using environmentally sound practices
- supporting the development of strategies and actions targeted at areas and resources that remain at environmental risk
- facilitating the environmental analysis of policies and programs in agriculture and providing a means of monitoring their performance.

Scope of this assessment

This report is directed at all persons interested in the environmental sustainability of Canadian agriculture, particularly decision makers. Decision makers in agriculture have different concerns and operate at different levels. For example, farmers decide which production strategies to use on their farms. Farm leaders and government policy makers are concerned with broader groups of producers, such as commodity groups or producer groups within particular regions, as well as with outside developments that affect agriculture (such as international environmental and trade agreements). Environmentalists are concerned with developments within specific regions, specific environmental threats from agriculture, or the health of specific components of the environment. Often, different stakeholders desire different policy outcomes and compete for attention on what can be a crowded and complex policy agenda. There are also many links between these levels and interests. Farmers, for example, manage their farm operations but are also interested in national and international developments that affect agriculture.

Given these links, we have attempted an overall assessment of *agroecosystem* sustainability by considering the major environmental conditions within agroecosystems, as well as relationships between agroecosystems and the broader natural ecosystems and driving forces with which they interact. Our focus is on farm management, soil, water, air, biodiversity, and production intensity.

As a federal department we have tried to provide national coverage of agri-environmental sustainability in a manner that is sensitive to the regional variations in agriculture across Canada. However, some of the indicators apply only to specific regions or to selected aspects of broader issues. We acknowledge gaps in our assessment (*see* Chapter 2) that may be addressed in future work. Because of the broad scale of this assessment, the indicators cannot be applied at the farm level, and this report is not intended as a guide to best management practices. Still, interested farmers will find this report useful as an introduction to the subject of environmentally sustainable agriculture and may be alerted to environmental problems and solutions that apply to their farms.

In doing this work, we have also contributed to international efforts to develop agri-environmental indicators and benefitted as a result (*see* Box).

Reading this report

This report is presented in eight parts. Section A gives the background to the study, including the concepts and methods used and the driving forces that affect environmental and other trends in agriculture. By reading the chapters in this section, users of the report will be better placed to situate and understand the findings and conclusions of the overall report. Sections B through G present agri-environmental indicators related to farm management, soil quality, water quality, greenhouse gas emissions, agroecosystem biodiversity, and production intensity. Section H summarizes the indicator findings on a regional basis, presents the overall conclusions of the report, and suggests ways in which this report can be used.

We intend this report to be understood by people who are not scientists or agriculture specialists. However, we have not avoided technical words and concepts completely. These words are italicized the first time they appear in the text and are defined in a glossary at the end of the report. Although each chapter is written to stand alone (each may be cited as an individual document for which the correct citation is given on page II), the reader will benefit most from reading the entire report. For a summary of the key points of interest, see the highlights at the beginning of each chapter.

Readers interested in a more detailed description of the indicators, particularly the method of calculation, are referred to the technical reports for each indicator. These reports, listed in Further Reading at the end of the report along with other general references, also provide a more comprehensive bibliography than is offered here.

International interest in agri-environmental indicators

Over past decades, the earth's life support systems have become increasingly stressed by economic activities that consume resources and generate waste. The world's population and economic activity are now so large that many environmental impacts are felt at the global level. Governments and international organizations have responded with a wide range of regional and global agreements, such as the conventions to protect *biological diversity*, the stratospheric ozone layer, and the earth's climate. Agreements governing economic exchange among nations, such as the North American Free Trade Agreement and the World Trade Organization (WTO) Agreement, are also beginning to include provisions related to the environmental effects of enhanced trade.

The growing focus on global dimensions of the environment has led to several international efforts to develop environmental indicators. At this scale, the use of indicators arises from a need for information to better understand the health of the global environment, to guide and evaluate international efforts to reduce environmental stresses, and to help ensure that countries do not distort global markets and enhance their competitiveness through lax environmental standards or environmentally harmful subsidies. Agriculture is linked to many global environmental issues, and agricultural products are a key element of global trade. Consequently, several international agencies are working to develop and use environmental indicators for agriculture.

The Organization for Economic Cooperation and Development (OECD) is coordinating an effort among its member countries to develop agri-environmental indicators. OECD's indicators are designed to help in reforming domestic and international agricultural policy (such as the WTO's Agreement on Agriculture). About 15 indicators are being developed to help understand and assess the external environmental benefits and costs of agriculture, the relationships between government policies (such as farm income support) and environmental conditions in agriculture, and the underlying causes and effects of agriculture's impact on the environment. The indicators address agri-environmental issues such as farm management, soil and water quality, and agricultural biodiversity.

Several indicator initiatives are being pursued through the United Nations. The secretariats of both the Convention on Biological Diversity and the Framework Convention on Climate Change are working on indicators that involve agriculture (such as the possible role of agricultural soils as a sink of atmospheric carbon). Through related work, the Commission for Sustainable Development has developed a working list of 134 indicators of sustainable development, including several that relate directly to agriculture. Twenty-one countries from all geographic regions of the world have volunteered to test these indicators over the next three years in relation to their own national priorities and interests.

The World Bank is pursuing a rural strategy in developing countries to promote economic growth, enhance food security, and promote sustainable resource management. As part of this strategy, it is leading an international coalition to develop indicators of land quality for application at national and regional scales. Land use intensity, land cover, soil quality, and agro-biodiversity are among the indicators being developed.

The development of environmental indicators at the international level is especially challenging because of differences in environmental conditions, economic activity, and availability of data across countries. Canada actively contributes to such efforts and benefits from the cooperation and exchange that results.

T. McRae, Agriculture and Agri-Food Canada

2 Understanding and Assessing the Environmental Sustainability of Agriculture

C.A.S. Smith and T. McRae

Highlights

- The two main criteria used to judge the environmental sustainability of Canada's agriculture are how well it manages and conserves natural resources that support agricultural production, and how compatible agricultural systems are with natural systems and processes.

- Agri-environmental indicators were selected using a Driving Force–Outcome–Response framework. The environmental outcomes of agriculture can be either beneficial or adverse, and these can be managed by controlling the forces that drive agricultural production. Societal responses to actual and perceived changes in outcomes and driving forces include producer behaviour, consumer reactions, technological development, and government action.

- Fourteen agri-environmental indicators were developed within six categories: environmental farm management, soil quality, water quality, greenhouse gas emissions, agroecosystem biodiversity, and production intensity. Some indicators are summaries of national *Census of Agriculture* data, survey data, or provincial data. Others were calculated using existing or newly developed mathematical models or formulas and an integration of census data, *Soil Landscapes of Canada* information, and, in some cases, custom data sets.

- All indicators are subject to various limitations, including those related to gaps in data and our knowledge base, the quality of the data, and geographical limits. These limitations confine the use of the indicators to depicting trends over time in certain areas and providing a basis for comparison between areas.

Introduction

From the desire to promote sustainable agriculture in Canada grows the need to measure how well agriculture is performing environmentally. In this chapter we describe the underlying concepts and methods used in this study to assess the environmental sustainability of Canada's agricultural industry.

Measuring sustainable agriculture

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their needs. For future generations to be at least as well off as we are today, they must have the capacity to generate those goods and services that contribute to their well-being. The capacity to generate well-being depends on the availability of capital, of which there are three types:

- human capital: levels of education, skill, knowledge, economic wealth, and physical infrastructure
- social capital: the set of rules, relationships, and institutions that allow societies to function effectively
- natural capital: the biophysical environment, its resources and processes.

Depletion of the combined value of capital stocks is clearly not consistent with sustainable development. However, a key question is whether these forms of capital are substitutable, and if so, to what degree? For example, are reductions in natural capital sustainable if these reductions are accompanied by compensating gains in other forms of capital? In many cases the answer would be no. Reductions in the earth's protective ozone layer, for example, could not be offset by gains elsewhere and would leave future generations at significant risk. This implies that all capital stocks must be maintained at some level for sustainable development.

Extrapolating this model to agriculture, the maintenance of a sustainable agricultural production system requires continuing investments in human, social, and natural capital. This report is concerned with natural capital in agriculture. The agri-environmental indicators provide information on whether natural capital stocks in agriculture are being maintained, and whether agricultural outputs are compatible with natural systems in and outside agroecosystems. A complete set of indicators of sustainable agriculture would also consider the social and human aspects of sustainability. Although indicators for each of these areas have been developed, there has been no systematic attempt made to bring them together and understand the many relationships and interactions among them. Such work could be done in the future.

T. McRae, Agriculture and Agri-Food Canada

To provide a context for the indicator chapters themselves, this chapter

- discusses the linkages between agricultural systems and the broader environment
- identifies two key criteria for assessing the environmental sustainability of agriculture
- introduces and describes the indicators reported in this study and why they were selected
- reviews the methods used to develop the indicators
- presents the limitations of this approach.

Agricultural and natural ecosystems

Agroecosystems begin as natural ecosystems and develop under human manipulation. Even under this manipulation they have much in common with natural systems, sharing soils, water resources, natural nutrient supplies, and solar radiation and other aspects of climate. In fact, without the presence of certain natural components, agriculture could not take place at all.

Humans manipulate natural ecosystems in the practice of agriculture to meet their needs for food, fibre, and other products. This manipulation begins when land is first cleared of natural vegetation and planted with domestic crops, and continues when the crop is harvested and taken out of the system. To optimize production, agroecosystems are also manipulated by

- leveling and draining land
- tilling the soil
- re-routing natural watercourses
- supplementing natural precipitation with irrigation
- applying additional nutrients
- controlling weeds and animal pests.

Like natural systems, agroecosystems are dynamic, with various components, such as energy, water, and chemical elements, constantly entering and leaving the system in a cycle (Fig. 2-1). Cycles of climate and biological communities also affect, and are affected by, agriculture. It is through these cycles that agriculture is connected to the broader environment. Left undisturbed, these cycles tend to establish a balance in nature, but when humans intervene, these balances can be disrupted. For example, the water cycle brings the rain needed by crops, but in an agroecosystem, this rainfall may contribute to surface *runoff* and thus to soil erosion and pollution of waterways.

At every point of manipulation agriculture has the potential to change the environment. This is particularly so where agriculture is practised intensively, such as areas of *intensive livestock production* or *intensive row cropping* of cash crops. It is well documented that some agricultural practices degrade the quality of soil, water, and air. Less well known are the ways in which agriculture may enhance the environment by, for example, providing *wildlife habitat* or reducing *greenhouse gas* emissions by storing carbon in soils.

With this basic understanding of the workings of agroecosystems, two main criteria become apparent for judging the environmental sustainability of agricultural systems:

- how well they manage and conserve natural resources
- how compatible they are with natural systems and processes.

Identifying the indicators

The conceptual framework

To identify appropriate indicators of the environmental sustainability of agriculture, we used a conceptual framework characterizing relationships and linkages between agricultural production and environmental, economic, and social factors. This framework, called the *Driving Force–Outcome–Response Framework* (Fig. 2-2), recognizes three broad areas that sustainability assessments must consider:

- driving forces that influence agricultural activities
- outcomes of these activities
- responses by society to shape and ensure desirable outcomes.

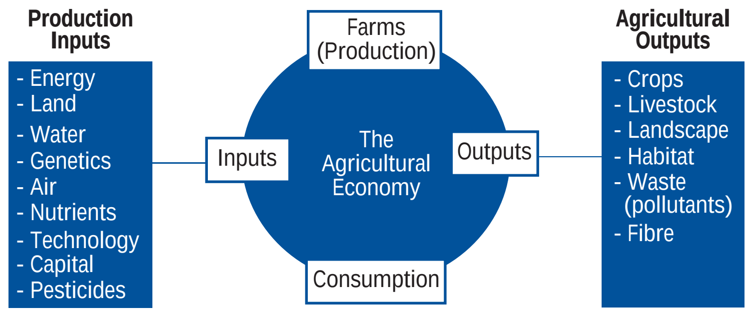
Analysis of the linkages between these components is key to a good understanding of the causes and effects of agriculture's impacts on the environment.

Driving forces

The underlying idea of this study is that environmental risks from agriculture can be controlled, and desirable environmental outcomes achieved, through careful management of the *driving forces* affecting agriculture. Through policy and other means, driving forces can be

Figure 2–1

The environment and the economy in agriculture



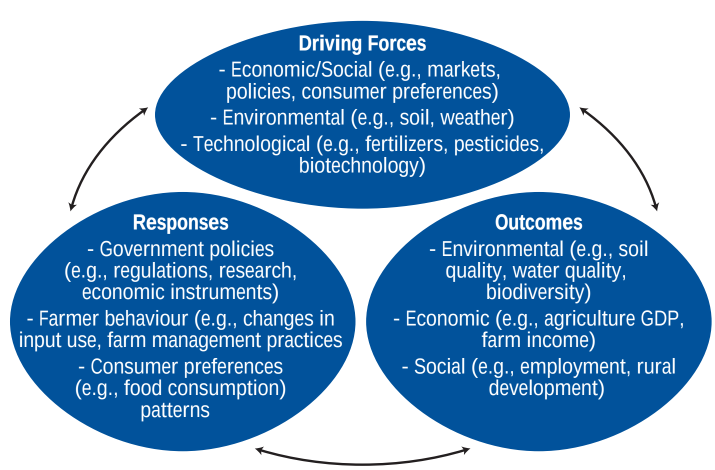
manipulated to achieve social, economic, and environmental goals in agriculture. These driving forces operate at two levels. At the societal level, market signals (e.g., commodity prices, consumer choices), government policies (e.g., income stabilization, supply management, land-use regulations) and production technologies interact to influence the nature, structure, and production mix within agriculture. At the farm level, the production strategies, technologies, inputs, and practices used have a direct influence on environmental resources both on and off the farm. Chapter 3 discusses the nature and evolution of these driving forces in detail.

Outcomes

Outcomes related to agriculture can be either beneficial or adverse. Beneficial outcomes include social benefits (e.g., employment, rural development, and food security), economic benefits (e.g., agri-business and farm income), and ecological benefits (e.g., the provision of wildlife habitat).

Figure 2–2

Driving Force–Outcome–Response Framework for agriculture



Ecological interactions and environmental sustainability in agroecosystems

The ecological processes that occur in agroecosystems, and how these are managed, affect the environmental sustainability of these systems. The key ecological interactions or cycles operating within agroecosystems are the energy cycle, water cycle, and cycling of chemical elements. Living organisms regulate or influence these processes.

Energy: Plants, including agricultural crops, capture energy from the sun during photosynthesis and fix it in organic molecules. Energy is exported from agroecosystems mainly as crops and livestock. Traditional forms of agriculture have relied on human, animal, and solar energy, but as agricultural production has intensified, energy is now supplied to agroecosystems in forms such as mineral fertilizers, pesticides, fossil fuels, seeds, feeds, electricity, and machinery. Energy is lost during agricultural production through respiration, heat, and various other transfer processes, including nutrient leaching. Such losses are unavoidable; keeping them to a minimum by improving the efficiency with which energy inputs are converted into marketable commodities enhances both environmental and economic sustainability.

Water: Water is needed by humans, animals, and plants to live. Water also influences weathering, erosion, and leaching, thus regulating the flow of chemical nutrients through agroecosystems. Agroecosystems receive most water as precipitation, but irrigation can be used to augment water inputs in Canada's drier regions. Water is lost from agroecosystems mainly through evaporation, transpiration, leaching to tile drains or groundwater, and overland flow to surface water bodies. The water cycle is highly dynamic, with inputs and outputs varying considerably over the course of a year. Such fluctuations have considerable influence on crop growth. Efficient use of water, including irrigation water, conserves water resources, helps to optimize crop growth, and reduces the risk of soil erosion and movement of contaminants into groundwater and surface water.

Chemical elements: During photosynthesis, plants take in carbon dioxide from the air and fix the carbon in organic molecules. These molecules are the building blocks of all living things. Carbon is exported from agroecosystems in the form of crops and livestock, through respiration, or by the physical removal of soil organic matter by erosion. The residues of dead plants and animals return to the soil and decompose, supporting soil organisms, adding carbon to storage pools in the soil, and releasing carbon to the atmosphere. Soils with adequate levels of carbon are better able to supply plant nutrients and water to growing plants, less susceptible to processes of degradation (water and wind erosion, compaction), and therefore more productive. Retaining carbon in soils also supports greater biodiversity and helps to reduce levels of carbon dioxide in the atmosphere, contributing to reductions in the greenhouse gas balance.

Two important plant nutrients that cycle through agroecosystems are nitrogen and phosphorus. Most nitrogen comes from the atmosphere and enters agroecosystems in rainfall, through direct plant uptake and subsequent decomposition of plant residues in soil, and by nitrogen fixation by soil micro-organisms. Nitrogen can also be added to the system as mineral fertilizers, animal feeds, and manure. Nitrogen is lost from agroecosystems in crops and livestock, through volatilization into the atmosphere, by leaching into tile drains and groundwater, or in runoff into surface water. Applications of nitrogen that exceed crop requirements or the carrying capacity of the soil increase the risk of water contamination by nitrate and the level of emissions of gaseous forms of nitrogen into the atmosphere. Inefficient use of nitrogen also represents an economic loss to farmers.

Phosphorus comes from terrestrial sources and binds readily to soil particles. Plants take it up from the soil, and it is exported from agroecosystems in crops and livestock. Phosphate is also added to agroecosystems in mineral fertilizer. Phosphorus has a tendency to build up in soils, increasing the likelihood that it will move off farmland into surface water, attached to eroded soil particles or dissolved in surface runoff, particularly in areas with significant slopes. Excess phosphorus causes eutrophication of surface waters, leading to declining water quality.

Reducing the environmental risks associated with nitrate and phosphorus involves good nutrient management, including practices related to manure management, cropping, and erosion control.

Source: Griggs, D.J. and F.M. Courtney, 1985.

Measuring beneficial environmental outcomes or services from agriculture is a topic of growing interest in the agricultural community. Some benefits may be direct, but others are less certain. For example, it can be argued that reductions in environmental harm constitute a benefit (measured as the degree of damage avoided), even though environmental harm may still occur.

Examples of adverse outcomes include declining farm employment and income, rural de-population, and declining environmental quality. Examples of adverse environmental impacts included degraded soils, reduced water quality, species and habitat loss, depletion of aquatic resources, and atmospheric change. Adverse environmental impacts are inherent to agriculture, just as they are to other fields of human activity, and are accentuated where and when the farming methods and technologies utilized are insensitive to the inherent limitations of the landscape.

The adverse effects of agriculture must be assessed in a broader context that considers

- the benefits derived from agriculture, such as food production or economic gain
- the significance of the impact, which is a function of its irreversibility, scale (e.g., area or population affected), and relationship with some defined threshold (such as a water quality standard, a tolerable erosion rate, or an accepted policy objective).

In this report, indicators in this category relate to soil and water quality, agricultural habitats, and agricultural greenhouse gases.

Response

Responses refer to the reaction by groups in society to actual and perceived changes in outcomes and driving forces. These responses include

- producer behaviour, such as changes in the use of farm management practices, use of inputs, changes in outputs, and other approaches to managing environmental resources on the farm
- consumer reactions, through changes in food consumption patterns
- responses by the sector, such as changes in technology to produce less-toxic *pesticides*, more-efficient crops and better production processes
- government actions through changes in policy measures including regulatory approaches, training and information initiatives, and research and development.

Responses link closely to driving forces, as they frequently involve attempts to manipulate or manage key driving forces to achieve desired outcomes. In this report, indicators in this category relate only to farm practice. No other indicators of other responses, such as government policy or private expenditure directed at environmental improvements, are presented, although related research in Agriculture and Agri-Food Canada is beginning to use agri-environmental indicators to assess the environmental impacts of departmental policies and programs.

Indicator descriptions

Six broad groups or clusters of agri-environmental indicators have been developed. These groups relate to issues of

- environmental farm management
- soil quality
- water quality
- greenhouse gas emissions
- agroecosystem biodiversity
- production intensity.

Some of these groups have many sub-components, to yield a full set of 14 indicators. A general description of each indicator, its relationship to the Driving Force–Outcome–Response framework, and the general calculation method used are presented in Table 2-1.

Many of the indicators presented in this report focus on risk rather than state. *Risk indicators* are derived using models or mathematical formulas that estimate environmental impact or the potential for environmental impact by considering the contributing factors. *State indicators* measure the actual presence and degree of an impact, such the concentration of nutrients in *groundwater* or the amount of soil eroded into streams. We selected several risk indicators because

- they are more readily calculated at broader spatial scales and can isolate the potential impact of agriculture on the environment
- detailed field data are generally not available on a national scale for most state indicators.

However, when this detailed information is available, usually from regional studies, we present it in boxed text to provide context for the broader indicator.

Generally, improvements (a positive trend or change) in the indicators presented in this report indicate reduced environmental stress

Table 2–1

National agri-environmental indicators

Indicator Group	Agri-environmental indicator	Description	Framework Element	Coverage	Method Type[1]
Environmental Farm Management	Soil Cover by Crops and Residue	Number of days per year when soil is left exposed under specific crop and land management regimes.	Driving Forces Response	National	2
	Management of Farm Nutrient and Pesticide Inputs	Adoption of best management practices for handling fertilizer, manure, and pesticides.	Driving Forces Response	National	3
Soil Quality	Risk of Water Erosion	Potential for soil loss in surface runoff under prevailing landscape and climatic conditions and management practices.	Outcome	National	1
	Risk of Wind Erosion	Potential for soil loss under prevailing landscape and wind conditions and management practices.	Outcome	Prairie Provinces	1
	Soil Organic Carbon	Estimate of change in organic carbon levels in soils under prevailing management practices.	Outcome	National	1
	Risk of Tillage Erosion	Potential for soil redistribution under prevailing landscape conditions and tillage and cropping practices.	Outcome	National	2
	Risk of Soil Compaction	Potential for change in degree of compaction of clay-rich soils estimated from inherent soil compactness and cropping system.	Outcome	Ontario, Maritime Provinces	2
	Risk of Soil Salinization	Potential for change in the degree of soil salinity estimated from land use, hydrologic, climatic, and soil properties.	Outcome	Prairie Provinces	2
Water Quality	Risk of Water Contamination by Nitrogen	Potential for nitrogen levels in water leaving farmland to exceed Canadian drinking water standard.	Outcome	Humid ecozones	2
	Risk of Water Contamination by Phosphorus	Potential for phosphorus to move off farmland into surface waters.	Outcome	Quebec	1
Agroecosystem Greenhouse Gas Emissions	Agricultural Greenhouse Gas Budget	Estimated emissions of nitrous oxide, methane, and carbon dioxide from agriculture production systems; summary balances expressed in carbon dioxide equivalents.	Outcome	National	2
Agroecosystem Biodiversity	Availability of Wildlife Habitat on Farmland	Number of habitat-use units for which habitat has increased, remained constant, or decreased.	Outcome	National	2
Production Intensity	Energy Use	Energy content of agricultural inputs and outputs.	Driving Forces	National	3
	Residual Nitrogen	Difference between the amount of N added to farm soils and the amount removed in harvested crop.	Driving Forces	National	2

[1] Number refers to definitions presented in the section on **Calculation methods.**

from agriculture, the provision of environmental benefits from agriculture, or both. Declines (negative trends or change) in the indicators indicate the reverse. In order to assess the significance of the conditions and changes identified by the indicators, we incorporate reference thresholds (such as policy objectives or environmental quality standards) into the calculation and interpretation of indicators where possible. Where there is little change or no consistent direction in the indicator over time, we have taken this as no change. A summary of indicator trends for specific regions of the country is presented in Chapter 18.

Calculating the indicators

Ecological classification system

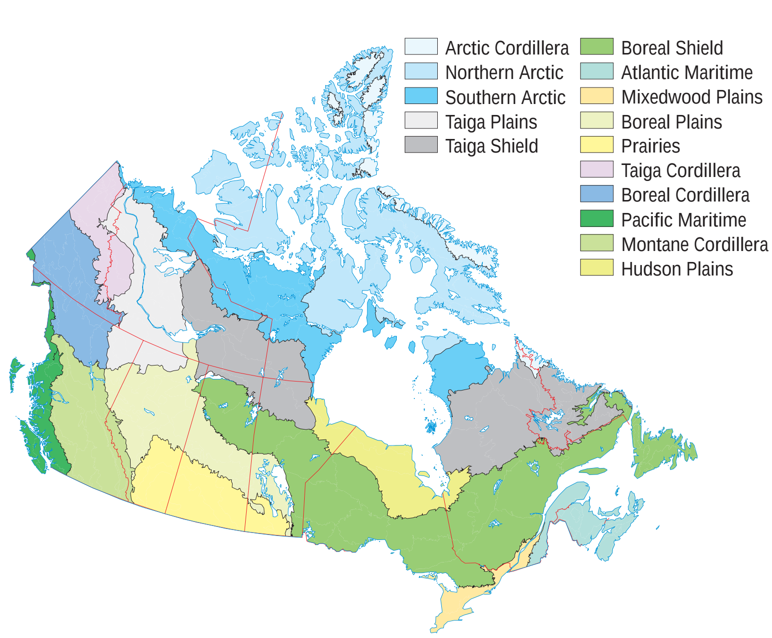
When possible, indicators were calculated and portrayed on an ecological basis using the national ecological classification system for Canada (Fig. 2-3). This system comprises three levels of detail: *ecodistricts, ecoregions*, and *ecozones*. Ecodistricts were subdivided further by superimposing mapping units, called *polygons*, from *Soil Landscapes of Canada* (SLC) maps (Fig. 2-4). Care was taken to match the scale of an indicator application to the appropriate level of the classification system. The size and number of units in each level of the system are given in Table 2-2, and a brief description of each level follows.

SLC polygons: Mapping units from Agriculture and Agri-Food Canada's generalized soil maps of Canada (scale = 1:1 000 000). Polygon size varies throughout the country. Many indicators in this report are calculated using these mapping units, whose level of detail allows data about soils and landforms to be integrated with farm management data derived from *Census of Agriculture* enumeration area summaries.

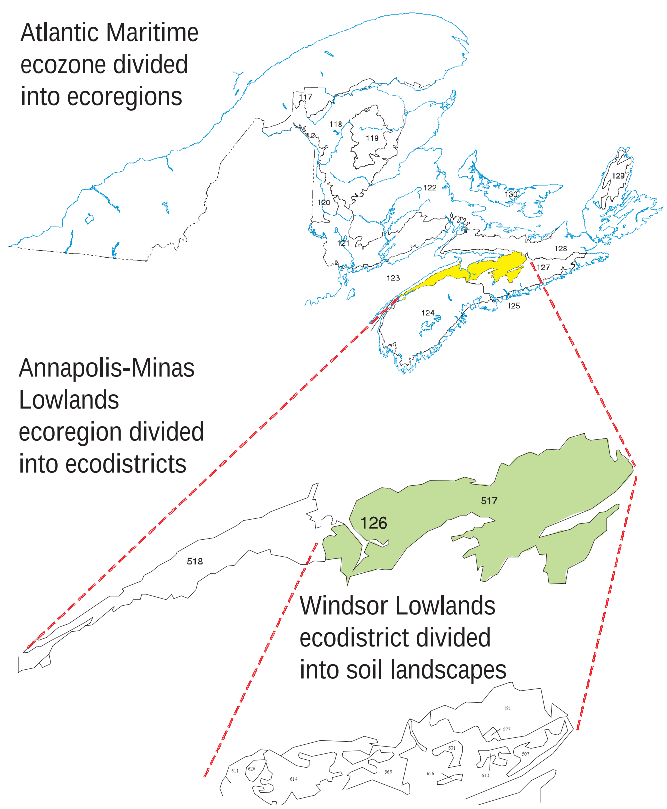
Ecodistricts: Groupings of soil landscape polygons with similar climate and topography. Ecodistricts are a suitable level for storing generalized data about climate and cropping systems and sometimes for presenting the results of indicator calculations made at the more detailed SLC polygon level.

Ecoregions: Groupings of ecodistricts with a similar range of regional climate and topography. Ecoregions have been used at the spatial level to summarize regional crop management practices in order to estimate soil cover conditions through the year for all agricultural production systems in the country.

Terrestrial ecozones of Canada — **Figure 2–3**



Nesting of levels in the ecological classification system — **Figure 2–4**



Ecozones: Broadest ecological class in the classification system, based on continental-scale physical geography and climate. Most agriculture in Canada is practised in two of Canada's 15 ecozones, the Prairies and Mixedwood Plains.

Calculation methods

All indicators are based on calculations of *bio-physical* and farm management information generalized to portray an environmental condition on the landscape at a given time. These calculations can be repeated over time to estimate changes and trends in the indicators. Indicators using *Census of Agriculture* data were calculated for the census years 1981, 1991, and 1996.

Table 2-2

Mapping units used for the national agri-environmental indicators

Level	No. of map polygons	Average size (000's ha)	Typical Range of sizes (000's ha)
SLC	3123*	37	10–1000
Ecodistrict	386	590	100–5000
Ecoregion	70	4620	1000–15 000
Ecozone	7	60 250	17 000–190 000

* based on polygons with more than 5% farmland by area, 1991 *Census of Agriculture*

Most of the indicators were calculated by area using *Soil Landscapes of Canada* polygons or another level of the spatial framework, which enabled subsequent roll-ups of information in either maps or tables. Geographic Information Systems were used to refine the data in these cases. Where location-specific calculations were possible, the results could be presented at any level in the ecological framework, but where this locational information was lacking (e.g., energy use data), indicator results were simply summarized by province.

Three principal methods were used in this study. Table 2-1 identifies the methods used to calculate each indicator.

Method 1: Integrating information on soil, climate, and landscape from *Soil Landscapes of Canada* with data from the *Census of Agriculture* using existing or modified mathematical models or formulas, including

- the Century model, used to calculate changes in the amount of soil carbon over time
- the methodology of the Intergovernmental Panel on Climate Change, used to estimate soil emissions of *nitrous oxide*
- the Revised Universal Soil Loss Equation for Application in Canada, used to estimate the risk of soil erosion by water.

Method 2: Integrating information on soil, climate, and landscape from *Soil Landscapes of Canada* with data from the *Census of Agriculture* and custom data sets (from provincial agencies, private sector, or other sources), using mathematical formulas developed specially for these applications.

This method, most commonly used in the study, was necessary in cases for which process models or formulas did not already exist. Examples of this method include the calculation of

- soil-water nitrate concentrations
- the risk of soil compaction
- the extent of *tillage erosion* associated with various farm production systems.

Method 3: Summarizing information from the *Census of Agriculture*, special surveys, or combinations of these two sources, and depicting the results of calculations at the provincial or ecozone scale. Examples of this method include

- the portrayal of changes in land use over time
- the adoption of environmentally sound farm input management practices
- energy use.

Applying the methods

Assigning census data

The Census of Agriculture provides information on crops, land use, land management, and livestock that was used to calculate the indicators. Census data at the level of enumeration area (an area for which Statistics Canada summarizes data, varying in size according to the number and concentration of respondents in an area) were used. Assigning census data to the SLC polygons took special care. Although SLC polygons always remain the same, census enumeration areas may change from census year to census year. Thus the assignments of census data to the SLC polygons had to be recalculated for each census year. As well, the simple overlay of census information on the polygons using Geographic Information System software

Terrestrial ecozones of Canada

Ecozones are broad areas of Canada having similar subcontinental-scale geography, climate, and ecology. Canada was first subdivided into 15 ecozones to meet the reporting requirements of the first State of the Environment Report for Canada in 1986. The boundaries of these 15 ecozones were refined by a team of land resource specialists from government agencies across Canada in 1995 and linked to the *Soil Landscapes of Canada* polygons and databases in the process. Commercial agriculture is practised widely in the seven ecozones described below, and to a very limited extent in two others (Boreal Cordillera and Taiga Plains).

Pacific Maritime: Covering the mainland Pacific coast and offshore islands of British Columbia, this ecozone has some of the mildest and wettest climatic conditions in Canada. Native vegetation is dominated by conifer forests composed of mixed western red cedar, western hemlock, and Douglas fir. Most of the province's population and agricultural production are located in a few major valleys and lowland plains within this mountainous ecozone, producing strong competing demands for land resources. The ecozone totals 207 930 km^2 in area, with farmland comprising less than 1% of the area, all of which is confined to the Fraser Valley and eastern coastal area of southern Vancouver Island.

Montane Cordillera: This ecozone comprises most of interior southern British Columbia and a portion of southwestern Alberta. The most diverse of all of the ecozones, its vegetation ranges from alpine tundra to dense conifer forests to sagebrush-dominated grasslands. Tree fruit production and viticulture dominate under the mild climate of the semi-arid valleys of the southern-most portions of the ecozone; extensive beef cattle production is common in the more northerly valleys and higher-elevation plateau regions. The ecozone totals 487 900 km^2 in area, of which only 2% is farmland.

Boreal Plains: This ecozone extends as a wide band from the Peace River country of British Columbia to the southeastern corner of Manitoba. It supports productive agriculture north of the Prairies ecozone in what is often referred to as the grey wooded soil zone. The native vegetation is mixed forest composed of white and black spruce and aspen. *Cereals*, *oilseeds*, and *forages* are the principal crops grown. The ecozone totals 737 290 km^2 in area, with about 20% as farmland.

Prairies: Incorporating all of the grasslands and aspen parkland from the foothills of the Rocky Mountains to the Canadian Shield country east of Lake Winnipeg, this ecozone is characterized by relatively level topography and a semi-arid climate with cold winters and warm summers. Agriculture dominates most landscapes. The ecozone totals 465 090 km^2 in area, of which 90% is farmland; about two-thirds of all farmland in Canada is located in the Prairies.

Boreal Shield: The largest of all ecozones, the Boreal Shield extends from northern Saskatchewan east to Newfoundland, passing north of Lake Winnipeg, Lake Superior, and the St. Lawrence Lowlands. Agriculture is practised in a few locations in the southern portions of the ecozone and in scattered locations throughout Newfoundland and Labrador. Farmlands have been cleared from mixed conifer and poplar forests, and agriculture is mixed. The ecozone totals 1 937 520 km^2 in area, with less than 1% as farmland.

Mixedwood Plains: The ecozone extends from southwestern Ontario through to the Ottawa Valley and the St. Lawrence Lowlands of southern Quebec. It encompasses most of the primary agricultural lands of the provinces of Quebec and Ontario. The extent of agricultural production is second only to that of the Prairies ecozone, but agricultural output is Canada's largest in economic terms. The relatively warm, humid climate is conducive to the production of a wide range of products, including most of Canada's dairy products, vegetables, and specialty crops. Agriculture competes with industrial land uses, transportation routes, and urban and suburban residential development for land. The ecozone totals 168 200 km^2 in area, of which about 40% is used as farmland.

Atlantic Maritime: The ecozone incorporates the Eastern Townships and Gaspé regions of Quebec along with all of the Maritime Provinces. Agriculture is the dominant land use on Prince Edward Island and elsewhere is concentrated in particular valleys (e.g., the St. John River Valley in New Brunswick, the Annapolis Valley in Nova Scotia, and the Sherbrooke–Lennoxville region in Quebec) or exists as a secondary land use on otherwise forested landscapes. Cool-season vegetables, forage, and dairy production are the major outputs. The ecozone totals 213 860 km^2 in area, of which about 10% is farmland.

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resulted in some errors of assignment (e.g., assigning corn production to a soil landscape polygon dominated by rock outcrops or forest plantations would be incorrect). To improve precision and ensure a better match between census and SLC information, other data sources, such as satellite imagery, were used to verify site-specific land use when possible. Accurate and appropriate spatial integration of agricultural production data with the biophysical landscape base was a key challenge in many of the indicator calculations.

Defining the limits of agriculture

In regions of the country where agriculture is the dominant land use, conducting landscape-level assessments of environmental risk is fairly straightforward. Agricultural activities are assumed to occur over the entire landscape, and indicator calculations are based on the dominant soil type(s) listed for the SLC polygon. However, much of Canada's agricultural production takes place on landscapes where agriculture is not the dominant land use. For these regions, calculations had to be monitored to verify that the correct soil type (not necessarily the dominant type), drainage condition, and landforms within the landscape were considered and that *Census of Agriculture* inputs and values were rationally assigned to the correct SLC polygon.

Readers should note that in map presentations of indicator results, an entire SLC polygon is assigned a value on the map. However, these results apply only to the agricultural portion of each polygon. In fringe areas of agriculture, such map presentations could be misleading if this treatment is not kept in mind.

A common set of SLC polygons was used to calculate all indicators involving an integration of SLC and census data. To be included in the set, polygons had to have

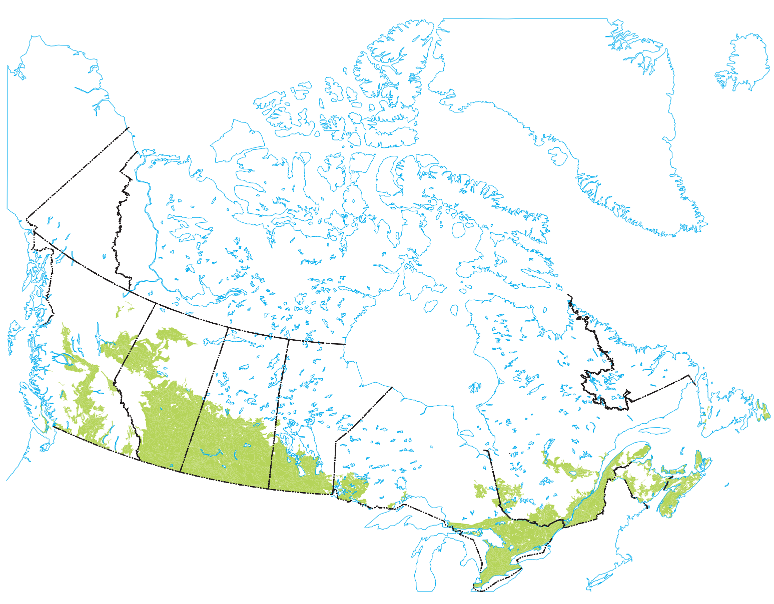
- at least 5% of their area as farmland according to the 1991 census
- records for all three census years: 1981, 1991, and 1996.

In 1991, 3123 SLC polygons met the first qualification (Table 2-2), defining a study area shown in Figure 2-5.

As a result of the cut-off, many polygons in the fringe areas where agricultural activities are highly dispersed were excluded from the calculations. Agriculture in the Yukon Territory, Northwest Territories, and Nunavut was not included in this study, nor was the agriculture along the northern fringes or in outlying areas of the provinces. Some, but not all indicators, report results for areas in Newfoundland and Labrador for the same reasons.

Figure 2–5

Extent of soil landscape units with at least 5% of area as farmland



Indicator limitations

The indicators presented in this report are subject to several limitations, a description of which follows. Because of these limitations, the indicators are best suited to portray estimates of environmental change and to make regional comparisons, but they do not necessarily give an accurate picture of the farming or environmental conditions at specific locations.

Knowledge and data gaps

Some indicators were calculated using mathematical models that were developed and tested at the field level. These models give the indicators a good theoretical foundation and help to define how management practices interact with landscape conditions and ecological processes to produce an environmental effect. However, they must usually be validated and calibrated at the field level, presenting problems with reliability when the models are used at broader scales.

The data needed to estimate processes associated with the indicators were often missing from the soil or *Census of Agriculture* databases. In this case, the missing information had to be either estimated or left out of the indicator calculation. In other instances, there were entire areas of agricultural farm inputs for which data were not available. For example, information on the use of pesticides at specific locations is generally not available in Canada, so it is impossible to make spatial assessments of the risk associated with pesticide use at any level of the ecological framework.

Census of Agriculture data are subject to the quality controls applied by Statistics Canada, but misinterpretation of particular questions on the census and survey forms by farmers can lead to erroneous responses about farm management practices. Such has been the case with questions on the extent of summerfallow and *conservation tillage*. We have examined regional management practices to see if there are discrepancies with census findings (especially related to conservation tillage in potato production in eastern Canada, and summerfallow reported outside of the Prairie Provinces) and modified these data as needed, but errors may still remain.

For reasons of confidentiality, Statistics Canada suppresses data when only a few instances of a particular farm activity occur in an enumeration area. When tallied over an entire province or ecozone, considerable data may be lost and results skewed. Most commonly, livestock numbers and associated land areas are suppressed. At the SLC polygon level, specific operations may be excluded from the census data set, and site-specific environmental risks may be missed entirely. This limitation applies particularly to indicators that use multiple census attributes in their calculations, such as the risk of water contamination by nitrogen and phosphorus. Suppression of data reduces the area available to make indicator analyses. As a result, the total farmland area considered varies from indicator to indicator. Techniques to overcome these limitations imposed by data suppression need to be developed.

Data quality and quality control

Data on specific chemical and physical properties of soil were needed to calculate many of the indicators. These data generally come from the

Using the Census of Agriculture to develop agri-environmental indicators

To develop reliable agri-environmental indicators, credible and relevant data are needed. New opportunities and funding to collect data nationally are few. Data to address environmental problems must often be location-specific (i.e., geographically positioned on the earth's surface), but such data can be costly to collect. Consequently, using existing datasets is important in developing indicators, as is filling data gaps as opportunities and funds permit.

One such existing national database is the *Census of Agriculture.* The census has great potential to support analytical studies on indicators but is limited by its lack of locational precision and by the availability of data only for politically defined spatial units (e.g., enumeration areas, census subdivisions, or crop-reporting districts). *The Soil Landscapes of Canada* database stores data on the inherent nature of Canada's agricultural soils (e.g., texture, slope, depth), which cannot be used alone to calculate indicators. However, when these two information sources are brought together, indicators can be developed.

The *Census of Agriculture,* reporting every 5 years on a wide variety of variables for all farms, provides a comprehensive picture of the major characteristics of Canada's agricultural industry at one point in time. It also supplies detailed information on small geographic areas not available from other sources. Data collected by the census is generally subdivided into four sections:

- farm structure, relating to farm size and ownership characteristics
- crops and land use, detailing the distribution and area of crops, pasture, and other land
- livestock, relating to the type of animals and the size of herd
- economics, covering capital investment levels and the dollar value of inputs and sales.

In 1991, in response to the need to track the adoption of various management practices by farmers, a section was added to the census on land management dealing with tillage practices (conventional, conservation, and *no-till*), summerfallow management, and the use of erosion controls such as windbreaks, winter cover crops, and grassed waterways. An additional question dealing with manure application methods was added in 1996.

The type of information collected on the census is reviewed between census periods. Modifications to provide more information about environmental farm practices are being evaluated now for inclusion in the 2001 census. The *Census of Agriculture* provides an excellent list from which to draw a representative sample to conduct follow-up surveys and collect data using other techniques, such as personal interviews or computer-assisted telephone interviews. Techniques to collect on-farm environmental data are constantly being explored and tested. The *Census of Agriculture* and Statistics Canada will continue to be a main source of data for future indicator work.

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SLC database. Many indicator calculations are based on only the dominant soils in a landscape, yet many more soil types often exist in an SLC polygon. In such cases, indicator results reflect estimated conditions on the dominant portion of the polygon, but the entire polygon is assigned this value, resulting in some misrepresentation of results. Furthermore, the recorded value for a soil property may be based on an estimate or a single measurement, or may be the average of several measurements. Because the reliability of the input data was highly variable or unknown, we were unable to use statistical methods to determine the probabilities, significance, or reliability of most indicator calculations.

To date we have not been able to apply rigorous quality control to the assignment of *Census of Agriculture* data to the SLC polygon base at a national scale. This careful evaluation involves the use of satellite data, manual data checks, and validations against field observations. Time and resources have been sufficient to undertake this evaluation for only a handful of landscapes across the country. High-resolution land use information is key to the correct assignment of agricultural production data to the land base, but this information is not yet available nationally.

Geographic coverage

Most indicators were calculated on a national basis. Some indicators were calculated regionally because they related to processes specific to those regions (e.g., wind erosion and soil *salinization* in the Prairies). For a few indicators in the early stages of development, data were available for only some regions of the country. For example:

- Soil-test phosphorus data were readily available only for Quebec, confining application of the risk of water contamination by phosphorus to that province.
- Assessment of the risk of soil compaction was limited to humid regions of eastern Canada with non- swelling clay minerals because of the lack of analytical methods to deal with other types of clay. As a result, the clay soils of southern Quebec and the Ottawa Valley, the Red River Valley of southern Manitoba, and the Lower Mainland of British Columbia, all of which have problems with soil compaction, were not covered by this indicator.
- The indicator of the risk of water contamination involved calculating seasonal surplus water in the soil rooting zone, a condition common only in the more humid regions of the country. So, although contamination of local water systems is a recognized problem in some localities in the Prairie Provinces or the southern interior of British Columbia, no indicator results are reported for these parts of the country.

Coverage over time

Census of Agriculture data are collected at 5-year intervals, and this report presents indicator results for three census years (1981, 1991, and 1996). It is difficult to identify trends with only three data points, though apparent trends may be confirmed by future updates. This is particularly true for indicators with a great degree of seasonal variation, such as the risk of soil salinization.

Statistics Canada takes a full year to process census data before it is released, and then more time is needed to use this information to generate agri-environmental indicator values. As a result, the indicators reflect risks or conditions of 2 to 5 years in the past. To develop policy, more timely and forward-looking information is often needed.

Use and interpretation

To make national assessments it is necessary to work at broad temporal (time) and spatial (area) scales. However, broad scale analysis is not precise, tending to average out extreme conditions. For example, the erosion impacts of short but intensive spring rains are underestimated, because such events are averaged out over longer time periods. Similarly, individual provinces, or even the ecological units of ecoregions and ecozones, are not homogeneous in terms of either farm management practices or biophysical conditions, but broad scale analyses tend to make them seem so. Thus, non-point source environmental problems are better addressed by the agri-environmental indicators than point source problems. Furthermore, the lack of a dramatic indicator result does not necessarily indicate the absence of a problem. For example, the potential environmental effects of intensive livestock operations are not picked up at this level of analysis, concentrated as they are in a specific locale.

Agriculture's interaction with the environment is complex, so care is needed in making overall interpretations from trends in individual indicators. Positive trends in one indicator may lead to negative trends in another. For example, reduced tillage operations that reduce soil erosion may result in a greater need to use herbicides for weed control. Also, greater utility and efficiency of nitrogen fertilizers and manures may result in higher emissions of nitrous oxide from cultivated soils.

The indicators presented in this report largely reflect a biophysical perspective. No attempt has been made to quantify the costs and benefits of the conditions and changes estimated by the indicators in economic terms. Some aspects of environmentally sustainable agriculture are not covered by the indicators, including trends in environmental risks associated with pesticide use, changes in the nature and quality of *soil organic matter*, trends in plant and animal biodiversity both on and surrounding agricultural land, and the risk of water contamination by bacteria and sediments. Some of these gaps and limitations could be addressed in future work.

Conclusion

Agriculture, perhaps more than most other economic activities, is intimately linked to the natural environment. The fundamental aspects of the ecology of agriculture and its interaction with the surrounding environment are understood. But the details of the processes that drive both natural ecosystems and those modified by humans to produce food and fibre are not well understood. Furthermore, agriculture in Canada is carried out under diverse landscape and climatic conditions and is controlled by a variety of environmental, technological, social, and economic forces. As a result we do not always know precisely what the long term outcomes of our manipulations of natural systems will be, nor what shape our manipulations will take in the future. In the context of these uncertainties, we have used the information and methods available to us to develop and present, for the first time, a national set of agri-environmental indicators for Canada.

Most indicators were calculated by merging information on the biophysical landscape with agricultural production data. This report demonstrates the application of this method to large databases. In the process of this work, it became evident that important information was often lacking and that much research and development must take place before a more comprehensive and reliable set of indicators can be constructed. In particular, more research is needed into ways to scale up site research, to use site models reliably at broader scales, and to better integrate production data with attributes of the landscape upon which agriculture is practised. More work is also needed to refine the procedures and model applications and improve the reliability of input data so that we may place greater confidence in these calculations.

Despite these limitations, we are encouraged by the results of this project. The indicators appear sensitive to changing farm practices and show patterns of environmental risk that reflect the intensity of agricultural production in some areas. They establish a baseline against which future assessments can be compared. And they will be useful in developing and evaluating agricultural policy, directing future research, and providing producers with a report card on broad trends in their environmental performance.

3 Driving Forces Affecting the Environmental Sustainability of Agriculture

R.J. MacGregor and T. McRae

Highlights

- Driving forces influence the nature of environmental and other outcomes in agriculture. Key driving forces are the economic and social signals received from the marketplace, government policy, and technology. Over time these have evolved considerably, and in recent years, have become more complex.

- Global demand for agricultural products has grown and will continue to do so. The nature of that demand has also changed. Growth and evolution in demand has been accompanied by globalization of markets, increased trade liberalization, and competition among countries.

- Canada's agriculture has responded by increasing output and adopting new production methods and technologies to improve its productivity and competitiveness. Structural changes have also occurred, such as greater farm size and specialization, and more intensive use of land and other resource inputs. Many of these changes have increased the potential environmental risks from agriculture. At the same time, society's environmental expectations and preferences have evolved. New environmental regulations and agreements have been enacted, placing additional demands on agriculture to meet environmental as well as economic goals.

- Government agricultural policy has traditionally focussed on economic and production objectives. More recently, policy reform has been guided by environmental considerations, along with more traditional social and economic criteria. The sector has also responded to driving forces with a wide array of voluntary initiatives and changes in management practices.

- Driving forces will continue to evolve and influence environmental trends in agriculture. Potential risks to the environment will continue to increase as output expands. Ongoing responses will be required by industry, governments, and Canadians so that social, economic, and environmental objectives for agriculture are achieved.

Introduction

Agriculture is situated within the broader economic, social, and environmental systems of the world. These systems are inextricably linked to one another, interacting and giving rise to various driving forces that influence the nature and direction of agricultural production. This process in turn influences agriculture's relationship with the environment.

Driving forces are one component of the Driving Force–Outcome–Response framework used to identify appropriate indicators of environmentally sustainable agriculture for this report (*see* Chapter 2). Besides the natural environment in which a farmer operates, the principal types of driving forces are

- the economic, social, and policy signals to which farmers respond
- the technologies available to farmers.

Throughout the past century these forces have evolved, in recent years becoming more complex and changing more quickly. To a large extent, farmers take as given the overall operating environment shaped by these forces and select production strategies that allow them to achieve desired outcomes most efficiently. In this chapter we review changes in these driving forces and discuss their environmental implications.

Societal forces

Market demand

Signals arising from the marketplace are among the most influential of driving forces affecting agriculture. World population, currently around 6 billion, has grown rapidly in the past century and will reach 7.3 to 10.7 billion by 2050 (assuming certain fertility trends). Agriculture worldwide is thus continually challenged by the need to meet the ever-increasing global food demand. The nature of this demand has also changed as family incomes have risen, particularly in western countries. Today, diets are more varied and include more expensive (and energy intensive) livestock products along with the more traditional cereals, fruits, and vegetables. Industrial demand for agricultural products such as alcohols and non-edible oils has also grown.

The growth and change in food demand has been accompanied by globalization of markets and increased *trade liberalization*, with profound effects on agriculture worldwide. As a large exporter of agricultural products, Canada is working hard to increase its share of global agricultural trade, especially processed products (*see* Box).

New target for Canada's share of world export markets

Agri-food production policy influences the nature and amount of agricultural production. The Canadian Agricultural Marketing Council recently established a target for Canada of 4% of world trade for primary agricultural and agri-food products by the year 2005. This target was accepted by the federal and provincial ministers of agriculture in July 1998 and is now a key policy goal for growth and development. Canadian agri-food exports must increase from $21 billion in 1998 to $30–40 billion to achieve this goal.

The new export target has environmental implications, as additional resources and inputs will be required to boost production. Future updates of economic and environmental indicators will show whether the sector achieves the export target, and whether environmental costs are incurred as a result.

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These market changes may result in

- greater competition among countries, leading to the development and use of new production methods and processes aimed at enhancing competitiveness and productivity
- overall increases in agricultural production and changes in the mix of commodities produced, with a marked rise in the production of livestock products
- declines in real prices for some commodities (Fig. 3-1) and cyclical changes in prices, increasing the pressures on farmers to improve productivity, efficiency, and management of economic risks
- greater farm size, farm specialization, and production intensity to capture economies of scale (Fig. 3-2)
- new global trade rules that place additional constraints on government support policies for the sector.

The need to increase competitiveness and productivity in a world economy has spawned initiatives in research, changes in government policies (such as income support programs), and marketing efforts. Overall, Canada's agricultural sector has responded successfully to the demands of the marketplace. However, market signals will continue to fluctuate and competitive pressures will likely increase, forcing an ongoing process of adaptation. The structural changes that have occurred, and will continue to occur, in Canadian agriculture have environmental implications related to the use of land (*see* Box), water, inputs, and other resources.

Social preferences

Society's overall preferences and expectations are an important group of influences on agriculture. Canadians' chief expectation of agriculture is an abundant and safe supply of food. Other important expectations are rural development, employment, and contributions to national income and trade. However, the public's environmental expectations have also evolved, and these increasingly affect agriculture.

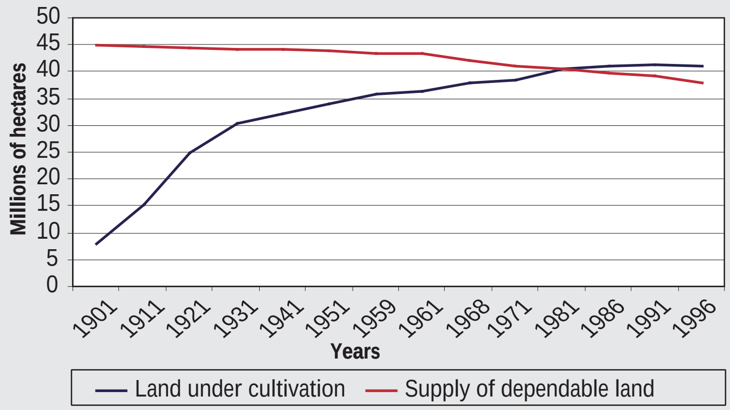
Canada is today a largely urban society, with a greater appreciation of the economic and ecological value of its environmental assets, such as soils, wildlife, forests, fisheries, and water. Canadians are concerned about threats to the environment and support an array of initiatives to preserve and protect it. Consumers in other countries have similar concerns and have in some cases boycotted products whose production was felt to have caused environmental damage (e.g., European boycotts of Canadian forest products).

Recent public opinion polling reveals that the public is concerned with agriculture's effects on environmental quality, especially from the use of farm chemicals (*see* Box, page 24). Governments have responded to such concerns by supporting research, implementing policies and programs to promote environmentally sustainable agriculture, and passing regulations to protect the environment where deemed necessary (Table 3-1). Industry has also responded with a series of voluntary initiatives (often with government support), such as environmental farm plans and changing farm practices as new information became available. For the most part, producers are not paid directly for efforts to control environmental risks, even when costs are imposed through regulations governing the use of resources and management practices employed.

Agricultural land use and supply

Market prices for crops and livestock directly affect land use decisions on the farm. Many of these land use decisions have implications for soil and water quality, wildlife habitat, and other environmental aspects of agriculture.

Over the past 30 years, Canada's total supply of farmland has remained fairly constant at around 68 million hectares. However, important changes have occurred over the years in how this land is used. For example, between 1901 and 1996, Canada's cultivated land area (land under crops and summerfallow) expanded five-fold. In contrast, the supply of dependable agricultural land (Classes 1, 2, and 3 of the Canada Land Inventory Capability Classification for Agriculture) dropped by an estimated 16% over this period because of conversion to urban and other non-agricultural uses. In the 1980s, the area of land under cultivation in Canada surpassed the supply of dependable land. This situation indicates that agricultural production is becoming more reliant on marginal land, with possible effects on productivity, soil quality, wildlife habitat, and other environmental aspects.



D. Trant, Statistics Canada

Figure 3-1

Trends in grain prices

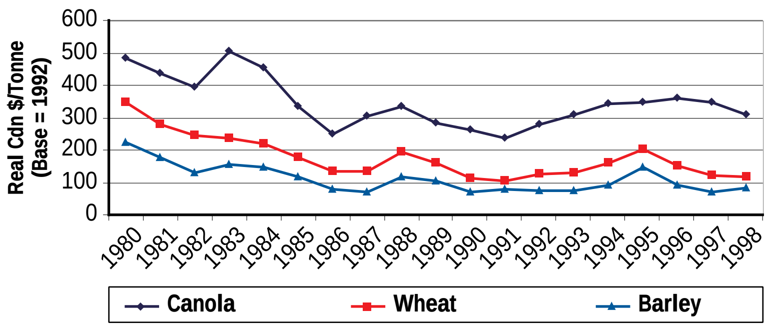
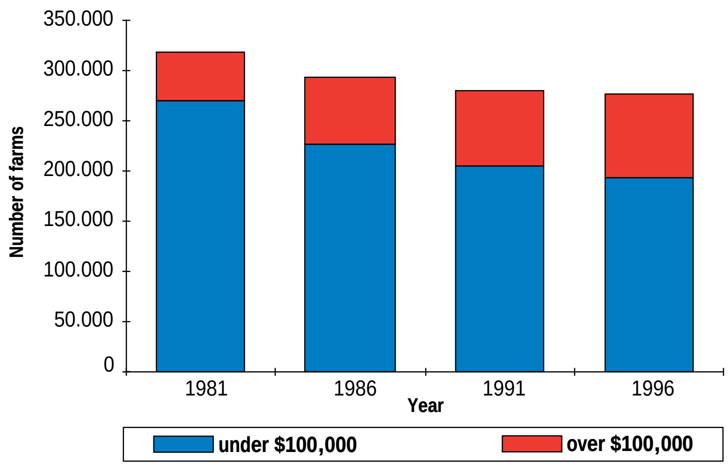


Figure 3-2

Number of farms and proportion of small versus large farms based on gross farm receipts



Source: Statistics Canada,1997

A more recent and still-evolving social influence on agriculture is the public's growing recognition that agriculture can provide environmental benefits. Leading examples of these benefits are wildlife habitat, reductions in greenhouse gas emissions, a pleasing landscape, and ecological services such as recycling of nutrients. *Agrotourism* is one way in which farm families can capitalize on these benefits. In some cases, public interest groups and programs (e.g., North American Waterfowl Management Plan) have demonstrated a willingness to pay producers for such benefits.

Public perceptions of agriculture and the environment

Overall, Canadians have a relatively favourable environmental image of the agriculture and food industry. When asked to rate the degree of environmental damage caused by 12 industries, agriculture was rated 11th, followed only by the computer software industry. Compared with other resource industries (energy, fisheries, and forestry), Canadians see agriculture as being the closest to sustainability.

When it comes to the impacts of agricultural activities on the environment, Canadians (60%) are most concerned about the use of chemical fertilizers and pesticides. A much smaller share of people are most concerned about water pollution from livestock wastes (19%), the impact on wildlife habitat and wetlands (13%), and odours from livestock operations (4%). There is some regional variation in these responses. For example, a higher proportion (8%) of people in Quebec, Saskatchewan, and Alberta expressed concern about livestock odours.

Public perceptions about agriculture and the environment have evolved. Ten years ago, loss of farmland to urban development was cited as the most important agri-environmental issue. Concern about this issue has decreased steadily as attention has shifted to the use of farm chemicals.

Source: The Environmental Monitor, 1998

Government policy

Government policy operates at local, regional, provincial, national, and international levels, affecting how resources are used through the manipulation of market price signals, regulation, or initiatives to provide information and raise awareness. Economic policies can have important environmental implications, and environmental policies can in turn affect economic performance.

Early in this century, the overall aim of government was to create as much wealth and income as possible from the agricultural sector. Government support of agriculture involved

- financing infrastructure, such as transportation networks and irrigation and drainage systems
- enacting legislation to help reduce the economic risks of agricultural production, especially related to product marketing
- funding agricultural research
- providing long term capital to finance growth, adjustment, and the acquisition of new technology.

Concerns about the natural resource base began to emerge in the 1930s. It was recognized that existing practices threatened the long term health of the western economy, and the Prairie Farm Rehabilitation Administration was created to deal with poor land conditions on the Prairies during that decade.

Subsequently, government intervention in the agricultural economy grew (*see* Box). Through the 1960s, 1970s, and 1980s, the level of intervention in agriculture expanded till federal and provincial governments were providing direct support of about $4 billion annually. Along with a host of other policies related to supply management and trade restrictions, total support rose to about 30% of the value of production. At this time, OECD countries were supporting their agricultural sectors with a total of about $US 300 billion annually. As production and income support mounted, so too did concerns that excess production caused environmental damage, such as inappropriate use of marginal land, excessive use of inputs, and drainage of wetlands.

Evolution of government support for agriculture

Government support for agriculture can have important effects on production levels, and thus on the environment. Of most concern are support payments directly linked to production, such as payments based on crop area, which can provide incentives to use marginal lands or drain wetlands.

Government support is often measured by the Producer Support Estimate, an indicator that includes production subsidies, as well as other forms of support. Support is measured relative to the value of production. Support in 1998 in the member countries of the Organization for Economic Cooperation and Development was 14% above the 1986–1988 reference period. In the United States and European Union-15, 1998 support exceeded that provided during this reference period by 13% and 28%, respectively, partly in response to low world grain and oilseed prices. In Canada total support remains below 70% of the 1986–1988 reference period.

Government support for agriculture in Canada has evolved considerably in recent years. Through reforms such as the elimination of grain transportation subsidies on the Prairies, overall levels of support have been reduced, and farm income safety nets are now largely decoupled from production in the grain and oilseed sectors, leaving producers to respond to prevailing market signals.

Some countries use farm income support programs to promote both economic and environmental goals. In the United States, for example, access to some forms of income support is conditional on farmers' meeting specified environmental criteria, such as conservation of wetlands and grasslands, a practice often referred to as cross compliance.

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Table 3–1

Examples of environmental policy initiatives and regulations affecting agriculture

Initiative	Scale	Implications for Agriculture
U.N. Framework Convention on Climate Change (and its Protocols)	Global	National response strategy being developed; possible limitations on agricultural emissions of greenhouse gases.
U.N. Convention on Biological Diversity	Global	Canadian Biodiversity Strategy developed, promoting conservation of crop and livestock diversity, habitats, and species in agriculture; federal endangered species legislation pending.
Montreal Protocol on Substances that Deplete the Ozone Layer	Global	Limits in place on use of methyl bromide (an agricultural fumigant), elimination by 2005.
U.N. Economic Commission For Europe (UNECE; includes Canada and U.S.): Protocol to Abate Acidification, Eutrophication and Ground-level Ozone	Regional	Possible limitations on ammonia emissions (agricultural sources are fertilizer and livestock) and nitrogen oxide emissions from farm vehicles.
UNECE Protocol on Persistent Organic Pollutants (POPs)	Regional	Some pesticides are POPs; most have been banned from Canadian agriculture; lindane still used.
North American Agreement on Environmental Cooperation (Canada, U.S., Mexico)	Regional	Broad agreement to cooperate to control substances with transboundary effects. Chemicals management program could affect pesticide use.
Canadian Environmental Protection Act (CEPA)	National	Ammonia and particulate matter (including airborne soil) being assessed under CEPA; limitations on emissions are a possibility.
Federal *Fisheries Act*	National	Prohibits pollution of waters inhabited by fish; could affect management of irrigation and drainage canals and ditches.
Federal *Pest Control Products Act*	National	Controls registration and designates use of pesticides based on environmental, human health, and other factors.
Canadian Environmental Assessment Act	National	Requires consideration of environmental impacts of projects prior to their implementation; could affect agriculture on federal lands or in cases where federal funds or regulations support or approve projects on private lands.
Numerous provincial acts and regulations and municipal bylaws and provisions	Provincial, Municipal	Controls imposed on a wide range of agricultural activities (e.g., separation distances to wells, conversion of agricultural land, spreading of manure, manure storage capacity, maintenance of buffer strips); regulations vary by province and municipality.

Realizing that most of this support simply offset the negative results of what other countries were doing, most developed countries agreed under the auspices of the World Trade Organization and the Agreement on Agriculture (ratified in 1995) to reduce measures that distort trade.

In Canada, direct support has been reduced to about $1 billion, leaving most commodity sectors subject to changing world market conditions. Remaining government support applies mainly to the supply-managed sectors of dairy and poultry. This support likely results in a smaller industry and smaller farms whose locations would change if the policy was removed.

Not all government policy is geared to expanding production. In response to rising public concern about agriculture's impacts on the environment, governments are focussing more on producing agricultural goods and services in ways that are compatible with the environment. A wide range of government policies and initiatives has resulted at all levels (Table 3-1), with considerable effect on agriculture in Canada and other countries.

In Canada and other western economies, government's role in affecting how resources are used will likely continue to diminish as greater emphasis is placed on market forces. Support policies are to be designed so as not to distort market signals. Governments still have as an objective a healthy and growing agricultural sector, and policies support these goals through research, market promotion and trade policy reform to gain greater access to overseas markets. With regard to the environment, agriculture remains, for the most part, largely unregulated. However, the overall trend is toward increased government intervention (particularly at the provincial and municipal levels) to influence how agriculture is practised, and to limit impacts on the environment. The federal government remains involved through research, funding of agri-environmental programs, the provision of information, and the domestic application of international commitments.

Technological change

Social preferences and government policies have influenced agricultural activities and outcomes. But at the farm level, it is changing technology that has principally altered the way in which producers have used resources over the last 200 years. This has been particularly true during the technology explosion of the last part of the twentieth century (*see* Box). All new technologies have helped to shift agriculture away from being a mainly physically based activity to a more knowledge based activity. Modern agriculture is characterized by a replacement of physical labour, specialization, concentration, consolidation, and locational change.

Specialization has occurred not only on individual farms, but also in whole regions that at one time may have been highly diverse to supply local markets. For most commodities, distance to market is no longer the most important

Technological change and agriculture

Before 1900s	• beginning of mechanization • scientific process for plant and animal genetics and breeding
Up to the 1930s	• on-farm use of combustion engines
1930s to 1960s	• electrification, electric motors
1940s to 1950s	• rise of chemical and pharmaceutical industries, growth of input supply industries (e.g., compound feed manufactures) • refrigeration • availability of cheap testing (feed, soils) • development of hybrids
After 1970s	• *genetic engineering* • *information technology* • computerization • management systems and technology • targeted breed development for market (e.g., canola) • *precision farming* systems

R. J. MacGregor, Agriculture and Agri-Food Canada factor in deciding where production should take place. Selecting the correct physical and economic environment provides the greatest opportunities to succeed in today's world marketplace.

The environmental effects of technological change are the subject of considerable debate. Some technologies have had unanticipated, adverse effects on the environment. For example, DDT was an effective insecticide, but its harmful effects on wildlife were soon discovered. Similarly, the fumigant methyl bromide had initial benefits for agriculture, but its use is being phased out because of negative effects on stratospheric ozone. Once these adverse effects became known, a new driving force for change was created, both to control the widespread use of these chemicals and to search for better alternatives.

On the other hand, the use of technology has allowed farmers to produce more food on a limited land base. There are many examples of technologies that reduce environmental risks, such as biological control methods for pests and improved manure management systems. Canada's hog industry provides an example of a sector currently undergoing fundamental structural changes because of technological advances in management systems (*see* Box).

Procedures to assess the environmental risk of new technologies are improving, but risk assessment continues to be an imprecise science. Debate continues over the relative benefits and costs of emerging technologies such as the use of hormones, genetically modified organisms, and cloning. Still, Canadian agriculture today is a product of technological change, and further developments will affect decisions made by producers and have some environmental effects.

Environmental implications of structural changes in Canada's hog industry

Canada's hog industry illustrates how recent economic, technological, and policy developments have resulted in structural change in the sector, with environmental implications. Pork is one of the most important agricultural commodities, and the industry generates $2.2 billion in farm income and $1.5 billion in hog and pork exports.

Over the past decade, global demand for pork has grown, especially in East Asia, because of rising personal incomes. Increased demand boosted pork prices. At the same time, removal of transportation subsidies for western Canadian grain led to a drop in grain prices, making the Prairies more competitive for hog production. Hog production technologies and management processes also evolved, allowing operations to shift from the traditional farrow-to-finish farms with 100 to 300 sows to larger units with 1200 or 2400 sows (or more), in which piglets are farrowed at one site, raised in a nursery at another, and finished at a third. Overall, the number of pigs per hectare on hog farms rose by about 20% between 1988 and 1997. These and other factors have resulted in a larger and more specialized and concentrated hog industry.

The magnitude of the expansion, combined with the new size and nature of hog operations, has raised a number of social and environmental issues in rural areas. The environmental issues include odours, impacts on soil and water quality (from nitrogen, phosphorus, and other potentially harmful substances) and emissions of greenhouse gases and ammonia (which contributes to smog and can pose a risk to human health under certain conditions).

Both industry and governments are responding with actions to manage environmental risks and to ensure that further expansion of hog production occurs in an environmentally sound fashion. Industry has been active in developing and promoting best management practices, working on improving public communications, and funding research to develop technical solutions to current problems. Many provincial governments have been developing extension and education, adjusting the regulatory environment to ensure environmentally sound growth, and working with municipalities to resolve land use issues. The federal government's role has been primarily in conducting research and providing technical services through the Prairie Farm Rehabilitation Administration and its cost-shared environmental programming. Recently the federal government and the Canadian Pork Council launched the Hog Environmental Management Strategy to coordinate efforts across the country in addressing hog environmental issues.

E.R. Pidgeon, Agriculture and Agri-Food Canada

Conclusion

Driving forces affecting agriculture have evolved considerably in this century. Globalization, market pressures, and technological innovations have spurred Canadian agriculture to increase output and productivity in response to increased domestic and world demand. To achieve this, the sector has undergone structural changes, some of which have environmental implications. Examples include changes in agricultural land use, the number and size of farms, commodities produced, production methods, and technologies, resulting in an overall intensification of agriculture.

Over the past 20 years, the social preferences of Canadians have also evolved. Concerns have been raised about the environmental costs of food production, and non-food outcomes from agriculture (e.g., landscapes) are increasingly valued. Canadians have supported a growing array of domestic and global agreements and regulations designed to protect the environmental systems with which agriculture interacts.

The sector has responded to these driving forces in many ways. More and more, agriculture is looking for ways to integrate environmental factors into decision-making processes on the farm. The sector is continually adopting new technologies and is developing and carrying out voluntary initiatives to improve environmental outcomes. Examples include the adoption of reduced tillage techniques and use of environmental farm plans.

The indicators presented in this report identify how driving forces have shaped key environmental conditions and trends in agriculture today. Driving forces will continue to evolve, and risks to the environment will continue to increase as output expands. Policy, technology, and other instruments will be required to shape and respond to these driving forces so that both economic and environmental objectives are achieved.

B

Environmental Farm Management

B Environmental Farm Management

Farms, by their very nature, are managed systems. Management may involve altering the physical form of the landscape; using irrigation, drainage, or other means to adjust the water balance; adding energy to the system in the form of fuel, chemicals, machinery, and human labour; boosting the nutrient and organic additions to soil by adding animal manure, *mineral fertilizers*, *compost*, or *green manure*; and controlling natural populations of weeds, insects, fungus, and other organisms that pose an economic threat to crops.

How farms are managed influences both the economic and environmental sustainability of agriculture. Poor management can lead to inefficient production, adversely affecting farm profitability. It can also result in environmental costs, such as degraded soils and excessive losses of materials and energy to the surrounding environment. Farmers, agricultural firms, and governments all pursue activities aimed at improving farm management, because it is so important to agricultural sustainability.

In recent years, much has been learned through research about the relationship between various farm management practices and environmental health. For example, the practice of summerfallow has declined significantly over the past 15 years, in part because it is now recognized that leaving the soil bare contributes to erosion and other forms of soil degradation. Research has also developed an array of new production technologies and processes, such as field implements for reduced tillage, that contribute to improved economic and environmental conditions on farms. Precision farming is an example of an emerging management technology that holds promise for improving the efficiency with which fertilizers are applied. Effective solutions often deal with many issues at once and require the simultaneous consideration of inputs, land use, and risk factors. New farm management processes such as environmental farm plans and nutrient management plans have recently emerged to help farmers manage the environmental risks and assets on their farms holistically.

In this section of the report, we present indicators dealing with two components of resource management for the environmental sustainability of agriculture: soil management and input management. Chapter 4 presents an indicator of soil cover based on the period of time that soil is left bare, and thus exposed to the elements. Chapter 5 presents a series of indicators of the management of farm nutrients and pesticides, including aspects of fertilizer application, the methods of storing and applying manure, and aspects of pesticide application and the use of non-chemical pest controls.

Indicators presented in Sections C through G of this report are influenced by farm management practices. Management practices that lead to negative indicator trends are often presented in the issue and interpretation sections of each chapter, and practices that improve the trends are noted in the section on response options.

4 Soil Cover by Crops and Residue

E. Huffman

Geographic scope: National, provincial
Time series: 1981, 1991, 1996

Highlights

- Soil left exposed by various cropping practices is vulnerable to erosion. The canopy of the crop and crop residues protect the soil from wind and water erosion and the resulting conditions of soil degradation. The less soil that is left exposed, the smaller the risk of erosion.

- An indicator was developed to estimate the amount of Soil Cover by Crops and Residue on Canada's agricultural land. The indicator was based on an index of bare-soil days that accounted for the number of days in a year that soil would be bare under specific cropping and tillage practices in various regions of Canada. The performance objective for the indicator is to have a steady trend toward fewer bare-soil days under all cropping systems, while aiming for zero bare-soil days.

- Between 1981 and 1996 the average number of bare-soil days in Canada's agricultural regions dropped by 20%, from 98 to 78. All the provinces and all the ecoregions except the St. Lawrence Lowlands also showed a drop in the number of bare-soil days, indicating an improvement in soil cover during this period.

- Most areas associated with improvements in soil cover of greater than 20% have less land under agriculture and less intense agriculture. Areas showing less than 10% improvement in soil cover were the St. Lawrence Lowlands in central Canada, New Brunswick's Uplands and St. John River Valley, and Prince Edward Island. These regions have large areas in row crops, such as silage corn, soybeans, potatoes, and vegetables, which are associated with low levels of soil cover.

- Although the indicator shows considerable improvement in soil cover between 1981 and 1996, this trend could reverse as economic signals cause a shift to crops that provide less soil cover. More work is needed to promote the benefits of soil cover and to develop new methods and equipment to provide soil cover, especially in areas of intensive farming of row crops.

The Issue

One way in which agroecosystems differ from *native ecosystems* in the same region is in the area of bare soil that exists at any one time of the year. Bare soil is more susceptible to wind and water erosion and thus to all the processes of soil degradation — loss of organic matter, breakdown of soil structure, and loss of fertility, among others.

When land is first brought into agriculture, *native vegetation* is removed and the soil is broken. Native plants are replaced with cultivated plants. Some of these plants offer good *soil cover*, particularly forages such as alfalfa and hay, but others leave a good deal of soil exposed, especially row crops.

Another factor that influences the amount of soil cover is the method of tillage. *Conventional tillage* turns most of the *crop residue* into the soil to leave a clean surface for seeding. Conservation tillage, including no-till, leaves more crop residue on the soil surface, where it offers cover.

Increasing the amount of soil cover in agroecosystems has many benefits, including

- offering protection against wind and water erosion
- adding organic matter to the soil, which helps to maintain soil structure and fertility
- promoting *carbon sequestration* in soil, which helps to reduce levels of atmospheric carbon dioxide
- providing better wildlife habitat, which helps to support wider biodiversity.

An indicator is needed to estimate the amount of soil cover on Canada's agricultural land based on cropping systems, crop distributions, and *residue management*.

The Indicator

Description

Assessing national and provincial trends in soil cover requires compiling crop types and tillage practices over area and time, all within the framework of expanding farmland area, increasing share of cultivated land and intensity of production, and shifting summer-fallow ratios. We developed an indicator of Soil Cover by Crops and Residue that assesses how many days of the year agricultural soils are left bare. In effect, it combines the soil cover offered by a crop's canopy with that offered by crop residues on the soil surface (*see* Box on residue management). A decline in the number of bare-soil days over time indicates an improvement in soil cover and less likelihood that soils will become degraded themselves or contribute to degradation of the broader environment. The performance objective for this indicator is to have a steady trend toward fewer bare-soil days under all cropping systems, while aiming for zero bare-soil days.

Method of calculation

The indicator is based on an index of bare soil calculated using field data collected to estimate the risk of soil erosion under different cropping and tillage practices. These data were checked for validity by agricultural specialists familiar with production practices in each region of the

Management of crop residues

When a crop is harvested, most of the plant stalks are left in the field. Management of crop residues involves leaving some of these stalks on the soil surface rather than tilling them into the soil. In recent years, researchers and farmers have come to recognize that careful residue management is the most cost effective way of controlling erosion. Leaving 20% of crop residues on the soil surface can reduce erosion by about 50%; leaving 30% raises this value to about 65%.

Besides curbing erosion, management of crop residues

- protects the soil surface from the impact of rain
- helps rain to soak into the soil
- reduces soil crusting and sealing
- adds organic matter to the soil
- reduces the evaporation of soil water into the air
- improves soil structure
- conserves and recycles nutrients from previous crops.

Source: Ontario Ministry of Agriculture and Food, 1992 country, and then extended to cover all cropping systems and tillage practices. The bare-soil index shows the number of days in a year that there would likely be bare soil under each crop and typical management scheme. One day of bare soil is equivalent to one day of no cover, two days of 50% cover, ten days of 90% cover, and so on.

Tillage practices were defined according to *Census of Agriculture* definitions for conventional, conservation, and no-till tillage. For example, conventional tillage for corn assumes fall moldboard plowing; conventional grain tillage assumes one fall pass with a field cultivator. Conservation tillage refers either to the use of field equipment designed to leave most of the crop residue on the surface or to fewer passes with a conventional cultivator.

In estimating the number of bare-soil days, we accounted for

- the day on which significant changes occur in soil cover (e.g., planting, harvesting, and tillage) and the percentage of soil cover upon completion of the operation
- canopy development between planting and full canopy
- the degradation of residue over the winter
- the total number of days of snow cover.

The amount of time associated with each proportion of soil cover was then calculated and summed to give the total number of days of bare soil for the year. Table 4-1 gives examples of the number of bare-soil days under several different cropping and tillage practices in different regions.

About 2700 bare-soil day tables were needed to cover all the crops and ecoregions in Canada. Data for 90% of the crop area were drawn from field studies and verified by local field staff. For very small areas or rare crops, it was sometimes necessary to estimate data from known values for similar areas, crops, and management.

The index was then applied at the level of *Soil Landscapes of Canada* mapping areas. The area under each tillage practice as reported in the *Census of Agriculture* for 1991 and 1996 was calculated as a share of the total cropland area (*see* Box on tillage), and these values were used to calculate the area of each crop under each tillage routine. The area in each crop–tillage combination was multiplied by the appropriate number of bare-soil days and then summed to provide a single value for each mapping area. Conservation tillage has been widely used only in the past 10 to 20 years, so all summerfallow land was considered to be under conventional management (tillage only) and all cropped land under conventional tillage in 1981. This treatment allows interpretation of within-province differences in soil cover trends as a result of different cropping and tillage practices.

Table 4-1

Number of bare-soil days per year for selected regions and crops under various tillage practices

Region and crop	Number of bare-soil days per year		
	Conventional tillage	Conservation tillage	No-till
Lower Mainland (B.C.)			
Vegetables (2 crops/yr: lettuce, celery)	221	(winter cover crop) 159	N/A
Potatoes	213	(winter cover crop) 185	N/A
Aspen Parkland (Prairies)			
Spring wheat	63	38	27
Canola	98	90	82
Summerfallow	177	128	102
Lake Erie Lowland (Ontario)			
Grain corn	131	95	57
Soybeans	177	141	101
Prince Edward Island			
Potatoes	140	117	N/A
Spring grain	153	93	60

Limitations

Although the soil cover index provides a good indication of trends and relative differences between regions, the data and calculations are not appropriate for field- or farm-level interpretations. The bare-soil days tables developed for crop and tillage combinations and crop residue levels are based on information from regional agricultural authorities for typical crop management and yield scenarios and do not necessarily relate to all operations nor to all years.

For example,

- higher-than-average yields would generally result in higher levels of residue
- progress in crop development and plant density varies from field to field within a region
- tillage implements and their effect on residue varies
- snow cover may vary from year to year
- the timing of field operations varies from field to field and season to season.

In addition, innovative and less common options for improving soil cover, such as intercropping, are not considered.

Results

The average number of bare-soil days for Canada and the provinces is shown in Table 4-2. Between 1981 and 1996, this number dropped by 20% in Canada and by up to 44% in the provinces. Figure 4-1 shows the distribution of bare-soil days in Canada's farmland.

Table 4–2

Average number of bare–soil days in a year

Province	Cropland area (1000 ha)	Number of bare-soil days per year: 1981	1991	1996	% reduction from 1981 to 1996
British Columbia	566	45	37	34	25
Alberta	9547	86	73	67	22
Saskatchewan	14 399	111	93	88	21
Manitoba	4699	81	65	65	20
Ontario	3545	113	110	96	16
Quebec	1739	63	61	62	0
New Brunswick	135	66	59	57	14
Nova Scotia	112	50	35	34	31
Prince Edward Island	170	103	96	94	9
Newfoundland	7	43	25	24	44
Canada	34 919	98	83	78	20

Interpretation

At the more detailed level of data compilation, all 34 agricultural ecoregions in Canada except the St. Lawrence Lowlands showed an improvement in soil cover between 1981 and 1996. The number of bare-soil days dropped by up to 52% between 1981 and 1996. Twenty-two ecoregions showed more than 20% improvement in soil cover; 17 of these were areas with a small amount of farmland and low farming intensity. Reduced intensity of farming, as evidenced by a decline in the area of annual cereal crops, explains the high level of improvement in areas such as

- Cascade Ranges (B.C.)
- Thompson–Okanagan Plateau (B.C.)
- Western Alberta Uplands (Alta.)
- Boreal Transition (Alta., Sask., Man.)
- Algonquin–Lake Nipissing (Ont.)
- Rainy River (Ont.)
- Appalachians (Gaspé, Que.)
- Fundy Coast (N.B. and N.S.)
- Nova Scotia Highlands (N.S.).

A more detailed look at the changes in land management and the effect they have on soil cover is taken for four ecoregions that feature representative forms of agriculture. These regions are British Columbia's Lower Mainland, the Moist Mixed Grassland of Alberta and Saskatchewan, central Canada's St. Lawrence Lowlands, and the St. John River Valley of New Brunswick (*see* Box).

This analysis shows that improvements in soil cover have been attained through the adoption of conservation management practices such as *chem-fallow*, reduced summerfallow, and conservation tillage. However, in most cases these improvements have been significantly reduced by shifts to crops that provide less cover, such as soybeans and canola. It appears that economic conditions are driving the shift to more profitable crops, with the result that soil cover is lost.

Response Options

Several options exist to enhance soil cover, but education and extension effort is needed to promote the benefits of greater soil cover. Improving the adoption of soil cover involves

- developing new equipment and techniques and making these available to farmers, such as is being done for *straw mulching* in Prince Edward Island and *residue anchoring* in the Prairies
- developing and promoting methods of maintaining soil cover under intensive crop production, especially after snowmelt and prior to crop canopy development and in areas of low snow cover (e.g., sowing high-*biomass* crops late in the summer or in the fall, maintaining the crop through the spring, and sowing the new summer crop directly into the cover crop).
- exploring incentives that will encourage farmers to modify their cropping practices to increase soil cover.

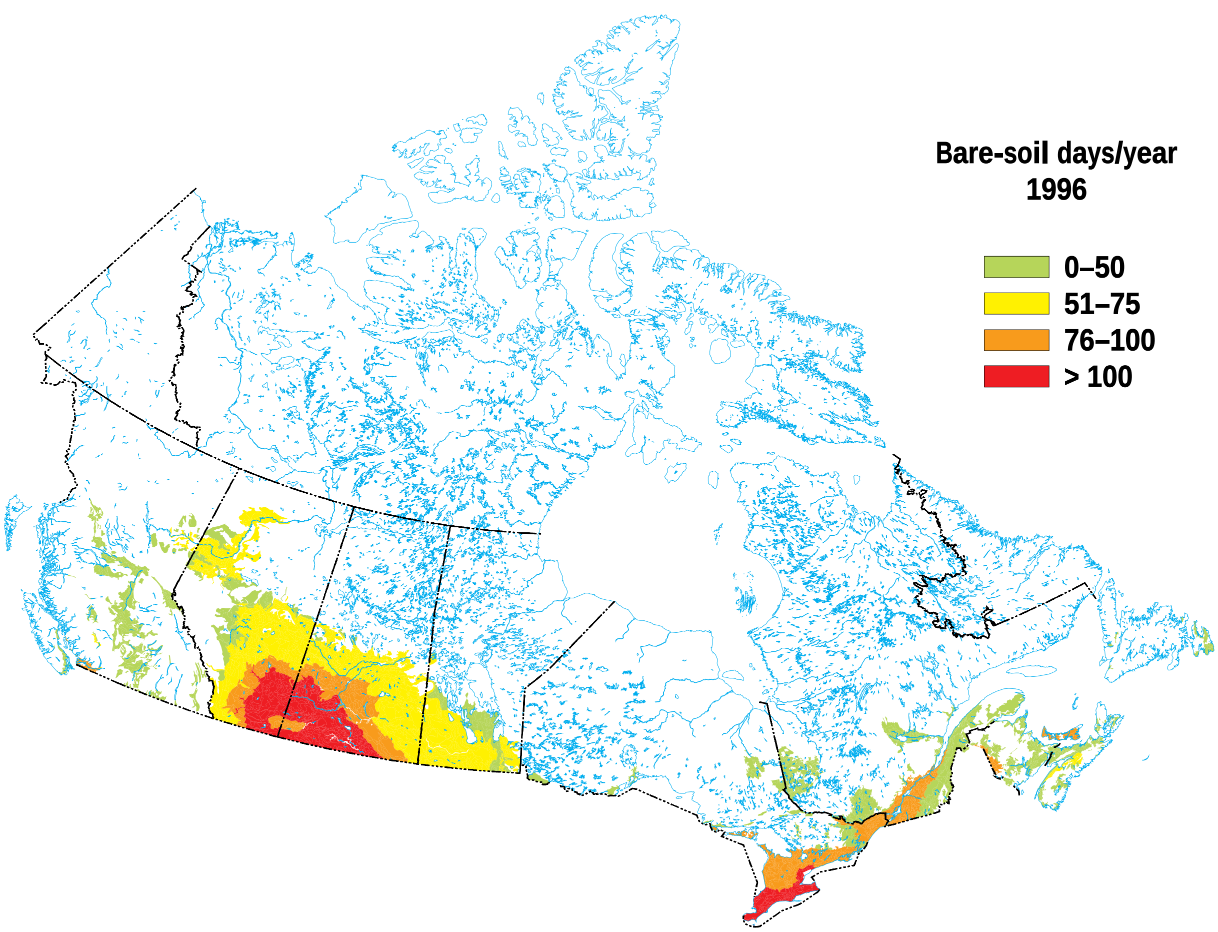
Conclusion

Although there was a general improvement in soil cover between 1981 and 1996, with good implications for environmental sustainability, it is unclear whether that trend will continue. There is still considerable potential for the adoption of conservation tillage, especially no-till in crop production in most regions of Canada, but crop shifts may offset the conservation benefits of those practices.

Continued extension and education efforts may generate greater acceptance of residue management and increase its importance in standard cropping practices, but further adoption of this practice may require considerable investment in equipment and techniques. Soil cover is expected to remain low or to decline in some regions of the country, such as the St. John River Valley, where few low-cost methods to

Figure 4–1

Number of bare-soil days in Canada's farmland in 1996



Effects of tillage on soil cover

Interpreting trends in land use in terms of soil cover is complicated by the management practices used by farmers. In particular, the way weeds are controlled on summerfallow and the method of tillage on cropland determines how much crop residue is left on the soil surface. When tillage is used to control summerfallow weeds, much of the crop residue is turned into the soil, leaving the soil bare. Chemical weed control or a combination of chemicals and tillage improves soil cover by keeping more crop residues on the soil surface. Conservation tillage and no-till also provide better soil cover than conventional tillage.

The share of cropland under these tillage practices and the share of summerfallow under the various methods of weed control are shown in the table below for 1991 and 1996 (conservation practices were less common before 1991 and were first required to be reported in the 1991 *Census of Agriculture*). In Canada, the use of no-till more than doubled between 1991 and 1996, with adoption of this practice especially marked in the Prairie Provinces and Ontario. In that time, the share of cropland under conservation tillage grew by about 30% in Canada and in all provinces except Manitoba, where climatic and soil conditions are not always suited to this practice. Chemical control of weeds was used on two and a half times the share of summerfallow in 1996 as in 1991 in Canada, a trend supported in the Prairie Provinces but not in British Columbia.

Share of cropland and summerfallow under various tillage practices in 1991 and 1996

PROVINCE	BC		AB		SK		MB		ON		PQ		NB		NS		PEI		CAN	
YEAR	91	96	91	96	91	96	91	96	91	96	91	96	91	96	91	96	91	96	91	96
TILLAGE PRACTICE																				
% of cropland area																				
Conventional	83	77	73	58	64	46	66	63	78	61	85	79	85	76	88	80	92	82	69	55
Conservation	12	17	24	32	26	33	29	28	18	22	12	16	13	20	8	16	8	16	24	30
No-Till	5	6	3	10	10	21	5	9	4	17	3	5	2	4	4	4	0	2	7	15
SUMMERFALLOW	% of area																			
Till only	66	92	58	58	57	55	73	62	N/A		N/A		N/A		N/A		N/A		58	55
Till+Chemical	31	8	37	32	39	36	24	33	N/A		N/A		N/A		N/A		N/A		38	35
Chemical only	3	0	5	10	4	9	3	5	N/A		N/A		N/A		N/A		N/A		4	10

E. Huffman, Agriculture and Agri-Food Canada

maintain soil cover exist, and the St. Lawrence Lowlands, where new cold-tolerant and high-yield soybean varieties are being developed. Further research and market development are needed for fall and winter cover crops that protect against winter and early spring runoff, particularly in humid areas with mild winters.

Related Indicators

Soil cover is related to several other indicators because bare soil is susceptible to, or contributes to, a number of degradative processes. Soil cover is one of the main factors in a soil's susceptibility to erosion, so this indicator is related to the three erosion indicators, Risk of Water Erosion, Risk of Wind Erosion, and Risk of Tillage Erosion. With greater erosion there is also greater movement of nutrients from the soil, and thus there is a relationship between soil cover and the Risk of Water Contamination by Phosphorus and Risk of Water Contamination by Nitrogen. Soil cover helps to reduce the evaporation of water from the soil's surface, thus reducing the Risk of Soil Salinization. By maintaining organic matter at the soil's surface, the rate of organic matter decomposition in the soil is reduced, and thus soil cover is related to the level of Soil Organic Carbon.

Soil cover in selected ecoregions of Canada

British Columbia's Lower Mainland

The Lower Mainland ecoregion consists of the lower Fraser River Valley of British Columbia and is characterized as an area of high-intensity crop production dominated by vegetables, berries, specialty and root crops, grain, hay, and pasture. Bare-soil calculations indicate an improvement of 20% in soil cover between 1981 and 1996.

Factors contributing to this improvement include the adoption of conservation and no-till on 2% of cropland, a significant decline in spring cereal production, and an increase in All Other Land (farmsteads and idle land). Spring cereal production with conventional tillage in this area left soil bare for an average of 153 days of the year, but by 1996 only 2% of cropland was still in spring cereal production. All Other Land is considered to be fully covered year round.

The Lower Mainland ecoregion also showed an increase in winter cereals and tree fruits and a decline in silage corn production (181 days of bare soil even under conservation tillage). Factors negatively affecting soil cover include a decline in pasture (which has zero bare soil) and less cropland under conservation and no-till in 1996 than in 1991.

The Prairie's Moist Mixed Grassland

The Moist Mixed Grassland ecoregion (Dark Brown Soil Zone) in Alberta and Saskatchewan is farmed in a typical prairie fashion, with a predominance of spring wheat, other grains (barley, oats), and summerfallow; a significant area of canola, hay, alfalfa, and pasture; and smaller amounts of winter wheat and specialty crops (flax, lentils, millet, peas, etc.). Soil cover improved by 23% between 1981 and 1996, compared to 24% in the Black Soil Zone and 17% in the Brown Soil Zone.

The improvement in soil cover was mainly the result of adopting conservation tillage and no-till on cropland (practised on 33% and 24% of cropland in 1996) and adopting conservation tillage practices (reduced tillage and chem-fallow) on summerfallow (practised on 39% of summerfallow in 1996). Contributions to soil cover also came from increases in the amount of hay and alfalfa and a decrease in the amount of summerfallow.

The potential improvement in overall soil cover that these changes could have produced was negated to a considerable extent by an increase in cropland area, a decrease in winter wheat area, and a dramatic increase in canola acreage. Canola grown in this region using conventional tillage leaves the soil bare for 105 days per year compared to spring wheat, which has only 68 bare-soil days per year. The number of bare-soil days per year drops under conservation tillage to 43 for spring wheat and 95 for canola.

Central Canada's St. Lawrence Lowlands

The St. Lawrence Lowlands ecoregion covers eastern Ontario and western Quebec. Its agricultural cropping activities focus on corn, spring cereals, soybeans, hay, alfalfa, and pasture, with smaller areas of vegetables, potatoes, tobacco, tree fruits, and berries. This ecoregion is the only one in Canada to show a decline in average soil cover levels (0.4% increase in bare soil) between 1981 and 1996.

Grain corn, soybean, and spring grain production under conventional tillage leaves the soil exposed for a total of 125, 189, and 145 days respectively. Conservation tillage reduces these numbers to 83, 160, and 110 days. Some improvement in soil cover was provided by the use of conservation tillage on 19% of cropland in 1996 and increases of 21% in alfalfa and 17% in winter cereals. However, increases of 3% in cropland, 86% in corn, and 1500% in soybeans, along with decreases of 26% in hay, 44% in spring grain, and 38% in pasture, effectively negated any improvement in soil cover.

New Brunswick's St. John River Valley

The St. John River Valley ecoregion in New Brunswick is the potato belt of the province. Potatoes are typically grown in rotation with spring cereals and in association with hay, pasture, and some vegetables. Maintaining and improving soil cover in a potato rotation is difficult, and the region showed a decrease of only 5% in bare soil from 1981 to 1996.

Most of that improvement came as the result of adopting conservation tillage on spring cereals (conventional tillage leaves soil bare for 144 days, whereas conservation tillage leaves it bare for 92 days) and using winter cereals as a cover crop (potatoes grown without winter cover have 147 days of bare soil, but grown with winter cover, this number drops to 107). Cropland expanded slightly at the expense of woodland and pasture, but it was essentially used for more spring cereals. The area in potatoes, alfalfa, and hay remained constant, while that in vegetables decreased.

5 Management of Farm Nutrient and Pesticide Inputs

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Geographic scope: ecozones
Time Series: 1995

Highlights

- Crop nutrients and pesticides are added to agroecosystems to improve crop production. When not used wisely, these amendments can reduce the quality of soil, water, and air and affect biodiversity. Indicators are needed to assess how well these inputs are being managed in Canadian agriculture.
- Several indicators were developed to evaluate the Management of Farm Nurtient and Pesticide Inputs on Canadian farms. These indicators are as follows. For fertilizer management: Method of Fertilizer Application, Timing of Nitrogen Application, Reduction of Fertilizers Applied to Offset Nutrient Content of Manure, and Use of Soil Testing. For manure management: Storage Method for Solid Manure, Storage Method for Liquid Manure, Liquid Manure Storage Capacity, and Manure Application Method. For pesticide management: Timing of Herbicide Applications, Timing of Insecticide and Fungicide Applications, Sprayer Calibration, and Use of Non-chemical Pest Control Methods. The performance objective is to have all Canadian farmers using best management practices for nutrient and pesticide management.
- Indicators were calculated using data from a 1995 Statistics Canada survey of 6000 producers across Canada, except for the indicator on manure application methods, for which data from a new *Census of Agriculture* question were used. Data were analyzed by ecozone and major farm type.
- In 1995, mineral fertilizers were used on 72% of Canadian farms. Nationally, fertilizer application methods that reduce nutrient losses were quite prevalent: injection was used on 22% of cropland receiving fertilizer, banding on 43%, and application with seed on 55%. Broadcasting, the most environmentally risky application method, was still widely used, except in the Prairie and Boreal Plain ecozones. The national figure for the timing of nitrogen fertilizer application on cropland was largely driven by the situation in the Boreal Plains and Prairies (which account for about 80% of all farmland in Canada), where nitrogen fertilizer is applied before planting on 70% and 61% of cropland, respectively. Farmers are more likely to apply nitrogen after planting in ecozones where leaching is a problem. Better account should be taken of the nutrient content of manure when it is applied along with mineral fertilizer. Soil testing, a useful tool for managing nutrient inputs, was carried out by 60% of Canadian farmers in 1995.
- Although the indicators identify areas where fertilizer management can be improved, results suggest that manure is the nutrient source most needing improved management. In general, both liquid and solid storage methods are less than optimal, and improvements are needed in the sector both currently and as the industry expands. Some regions showing less development in this management may be at a lower environmental risk because of their topography, climate, and soil type.
- Herbicides were used on about 67% of Canadian farms in 1995, and insecticides and fungicides were used on about 31% of farms. Herbicide application was triggered by the level of economic injury to the crop on about 20% of cropland receiving these treatments. Farmers were more likely to apply herbicides at a certain stage of crop growth or to use the first sign of pests (weeds, insects, disease) to time pesticide applications. About 68% of farmers using their own sprayers calibrated them only at the beginning of the crop season. Crop rotation was used as a non-chemical control of pests on 56% of Canadian cropland, and tillage on 27%. No alternatives to chemical controls were used on about 33% of cropland treated for pests.

The Issue

Farmers apply *nutrients* and pesticides to their crops to increase productivity and economic returns. Applied in the right amounts and using the correct method, these inputs help to produce a robust crop that resists disease and pests and yields a good harvest. But applied in excess or under the wrong conditions, nutrients and pesticides can contribute to environmental degradation.

An adequate supply of nutrients, especially *nitrogen*, *phosphorus*, and *potassium*, is essential to good plant growth. An undersupply can lead to a depletion of the amount of nutrients held in the soil, and in turn to a decline in soil quality and productivity, and economic losses to farmers. Nutrients may be added to soil in the form of *mineral fertilizer*, manure, or compost. The cost of adding inputs to soil — the costs of purchase, transportation, and application — is a significant part of the farm budget.

The environmental costs of applying nutrients can also be high. Excess nutrients can leave farmland, creating such environmental problems as

- surface and groundwater pollution
- deposition of ammonia and acid rain
- emissions of nitrous oxide (a potent greenhouse gas).

Chemical pesticides are used to control the damage to crops and economic losses caused by crop pests. Pesticide use has helped to increase crop yields and value, but it too contributes to environmental degradation. Poor choice of pesticides and inappropriate timing and method of application may result in

- reduced soil and water quality because of the presence of pesticide residues
- reduced air quality from spray drift and vapour from *volatilized* spray materials
- impacts on biodiversity because of the effects on non-target species and interference with normal predator–prey relationships.

Although the use of mineral fertilizers, animal manure, and pesticides pose some risk to the environment, farmers can opt to use *best management practices* that maintain or improve productivity while keeping costs down and protecting the environment. Assessing to what extent Canadian farmers are using such practices to manage these inputs provides an indicator of how farming techniques in Canada are being adapted to achieve the goals of sustainable agriculture.

The Indicators

Description

To select appropriate indicators of farm input management, we reviewed the literature and identified

- methods of managing mineral fertilizer, animal manure, and pests that have broad application across Canada
- best practices for *input* management.

Consultations were also held with farm groups and others. The following 13 indicators were then selected for development.

Mineral Fertilizer

1) Method of Fertilizer Application, expressed as the percentage of crop area receiving fertilizer by the following placement methods (ranked generally from best to least environmentally safe): *injected* into soil (liquid fertilizers and *anhydrous ammonia*) or *banded* (dry fertilizer), applied with seed, *broadcasted*, other. Injection reduces odours and volatilization of nitrogen and increases crop uptake, and banding increases crop uptake by placing fertilizer near the root.

2) Timing of Nitrogen Application, expressed as the percentage of nitrogen applied before planting (least appropriate), at planting (second best), and after planting (best). Application after planting increases crop uptake of nitrogen and reduces the risk of losses to the environment.

3) Reduction of Fertilizers Applied to Offset Nutrient Content of Manure, expressed as the percentage of crop area receiving reduced amounts of fertilizer to account for manure nutrients. Accounting for manure inputs reduces the risk of oversupplying nutrients and subsequent losses in the environment.

4) Use of Soil Testing, expressed as the percentage of farms that conduct soil tests at specified intervals (annually, every 2 to 3 years, every 4 to 5 years, over 5 years). The greater the frequency of soil testing, the greater the likelihood that nutrient application rates are matched to crop needs. Soil testing at least once every 3 years is desirable.

Animal Manure

5) Storage Method for Liquid Manure, expressed as the percentage of animals (cattle, hogs, poultry) for which various storage systems are used: sealed covered tank (optimal), tank below slatted floor, open tank, lined lagoon, unlined lagoon (riskiest).

6) Storage Method for Solid Manure, expressed as the percentage of animals (cattle, hogs, poultry) for which various storage systems are used: covered storage pad (optimal), open pad with runoff containment, open pad without containment, manure pack, covered open pile, uncovered open pile (riskiest), other methods.

7) Liquid Manure Storage Capacity, expressed as the percentage of animals (cattle, hogs, poultry) for which liquid manure storage systems of varying capacity are used: 100 days or less, 101 to 150 days, 151 to 200 days, 201 to 250 days, more than 250 days. Capacity should be sufficient to hold manure until the optimum time for spreading, which varies regionally. However, a minimum of 200 days is considered a good benchmark.

8) Manure Application Method, expressed as the percentage of crop area receiving manure by various application systems. For solid manure, surface application followed by incorporation into the soil is the best practice. For liquid manure, injection into the soil is the best practice. Surface and irrigation application of liquid manure produces odours and is more susceptible to runoff and losses of ammonia nitrogen.

9) Timing of Liquid Manure Application, expressed as the percentage of manure applied each season (winter, spring, summer, fall). Application after planting (in summer) increases crop uptake of nutrients and reduces the risk of losses in the environment. Applications in spring and fall entail some risk of nutrient loss. Winter applications are considered inappropriate and are prohibited in some jurisdictions.

Pesticides

10) Timing of Herbicide Applications, expressed as the percentage of crop area treated on which treatment is timed according to: when weeds exceed economic injury levels (optimal practice), regional monitoring of weeds, crop growth stage, the first sign of weeds, calendar dates (riskiest practice). Applying herbicides only when weed pressures approach or exceed economic injury levels reduces the use, cost, and environmental risks of using herbicides.

11) Timing of Insecticide and Fungicide Applications, expressed in the same way as for Indicator 10 and using the same decision making tools, except for crop growth stage.

12) Sprayer Calibration, expressed as the percentage of field crop area treated with pesticides using equipment that has been calibrated at specified intervals: between applications of different pesticides (optimal), at the start of the crop season, when the sprayer breaks down or major parts are replaced, and other. Calibration before application of a different pesticide helps ensure that application is at the correct rate.

13) Use of Non-chemical Pest Control Methods, expressed as the percentage of crop area on which the following non-chemical pest control methods are used: tillage, crop rotation, biological control, *pheromones* (natural chemical attractants), hand weeding, other methods, none. There is no single optimal practice among these methods. *Integrated pest management* uses a suite of pest control methods, both chemical and non-chemical.

The performance objective is to have all Canadian farmers using best management practices for nutrient and pesticide management.

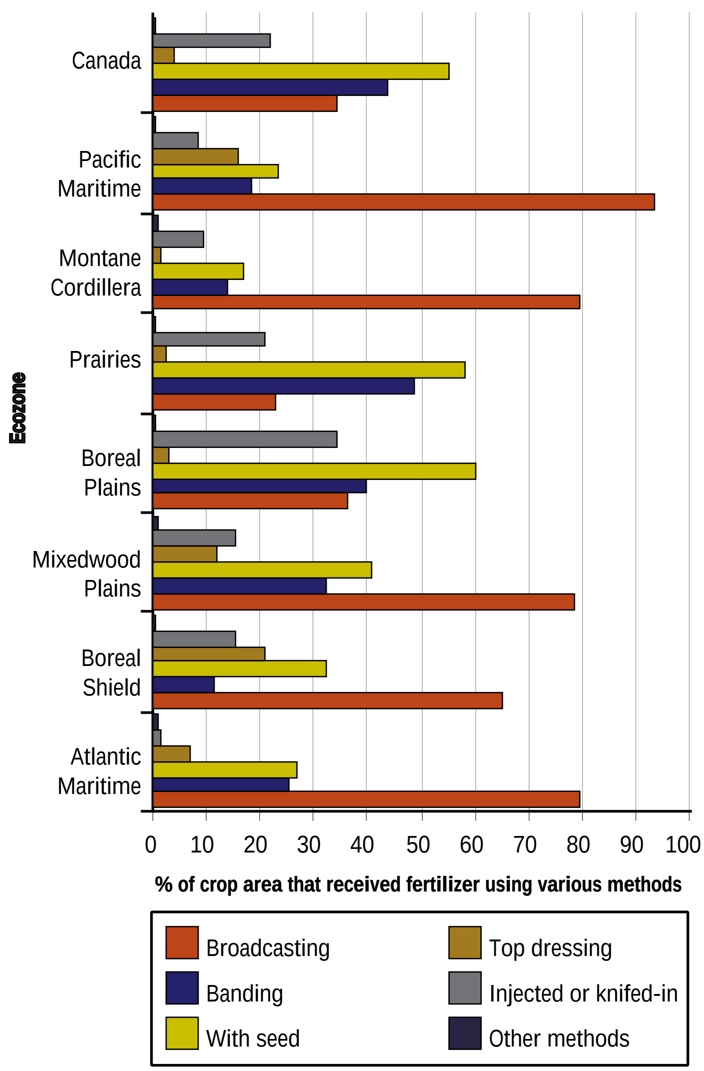
Method of calculation

In December 1995, Statistics Canada, in partnership with Agriculture and Agri-Food Canada, conducted a survey of 6000 producers across Canada to obtain the information needed to develop these indicators. A new question on manure application practices was also added to the 1996 *Census of Agriculture*.

We analyzed data from the survey and the census question on animal manure regionally and by major farm type (i.e., cattle, hogs, chickens). Data are presented as the share (percentage) of land area or animal population associated with specific practices. They are reported for the seven main Canadian ecozones in which agriculture is practised. Some columns in the bar graphs add up to more than 100%, because some cropland received inputs by more than one method.

Figure 5–1

Method of commercial fertilizer application in 1995



Limitations

The farm inputs management survey on which the indicators were built was limited in sample size as well as in the number of questions asked of producers. Thus, statistical accuracy can be assured only at the national, provincial, and ecozone levels, and not at more detailed spatial levels. Because the survey has been run only once, it provides only a snapshot of conditions in 1995 and cannot be used to comment on trends in input management practices.

Although a standard set of input management practices was identified nationally, there is considerable variation in how agriculture is practised regionally, as well as in the nature and vulnerability of the environment. This regional variation makes it difficult to interpret the indicators in a consistent way. Practices that entail higher risks in one region may well be acceptable in others. Also, the use of a poor management practice does not necessarily result in a negative impact on the environment, nor do best practices always provide environmental benefits. Environmental effects at any given site are also influenced by many other factors.

Also, information for many of these indicators is available as the number of farms reporting a practice rather than the area of farmland on which a practice is used, limiting their interpretation.

Results and Interpretation

Indicator results and the interpretation of them are presented in separate sections for the management of fertilizer, animal manure, and pesticides.

Mineral Fertilizer

Results

In 1995, mineral fertilizers were used on about 72% (148 000) of Canadian farms that grew crops. Figure 5-1 shows the share of cropland that received fertilizer by various application methods. Broadcasting was the most common method used in all ecozones except the Boreal Plains and Prairies, where fertilizer was more frequently applied with the seed. These two ecozones comprise 83% of Canada's farmland and greatly influence national results for this indicator. Thus, in Canada as a whole, 55% of cropland received fertilizer with seed, 43% by banding, and 34% by broadcasting.

Of the farms that applied mineral fertilizers, 67% reported applying mineral nitrogen in 1995. Figure 5-2 shows the timing of nitrogen application. Farmers in the Boreal Plains and the Prairies reported the highest share of cropland receiving most nitrogen before planting, at 70% and 61% respectively. Pacific Maritime (41%) and Atlantic Maritime (40%) had the largest share of cropland receiving nitrogen after planting.

About 35% of farms that applied mineral fertilizer to cropland also applied animal manure. Figure 5-3 shows that for about 24% of cropland in Canada that received both mineral fertilizer and animal manure, the amount of fertilizer was reduced to offset the nutrient content of the manure. This share of cropland was lowest in the Boreal Plains (19%) and Prairies (21%) and highest in the Boreal Shield (48%) and Mixedwood Plains (41%).

About 60% of Canadian farmers conducted soil tests in 1995, but not necessarily on all of their cultivated land area. Figure 5-4 shows how often producers do soil tests. The highest share of farms reporting annual soil testing were in the Atlantic Maritime (46%) and the Prairies and Pacific Maritime (39% each). Farms in the Montane Cordillera reported the lowest share of farmers testing soil annually (22%) and the highest share waiting longer than 5 years to do tests (21%).

Interpretation

Nationally, fertilizer application methods that reduce the risk of nutrient loss were quite prevalent, although room for improved management exists. Injection and banding (the optimal practices) were used on 22% and 43% of cropland receiving fertilizer, respectively, and application with seed on 55%. However, fertilizer was still broadcasted on about one-third of the area fertilized. In general, better application practices were more widely used in the prairie region, whereas riskier practices were more common in the areas more susceptible to nutrient leaching.

Figure 5-2

Timing of nitrogen application in 1995

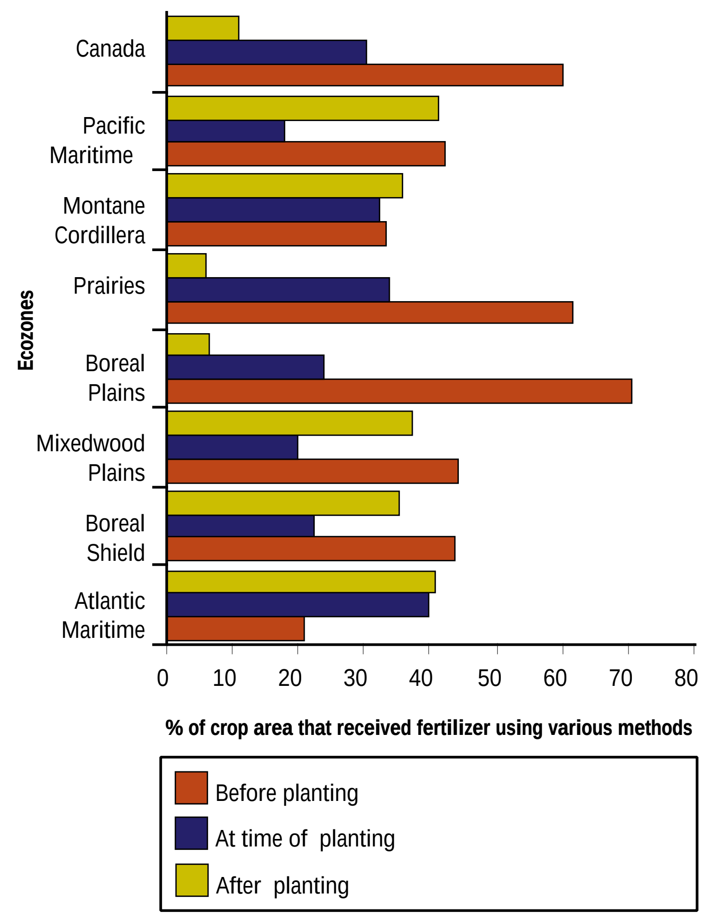


Figure 5-3

Percent of crop area for which fertilizer applications were reduced to offset nutrient content of manure in 1995

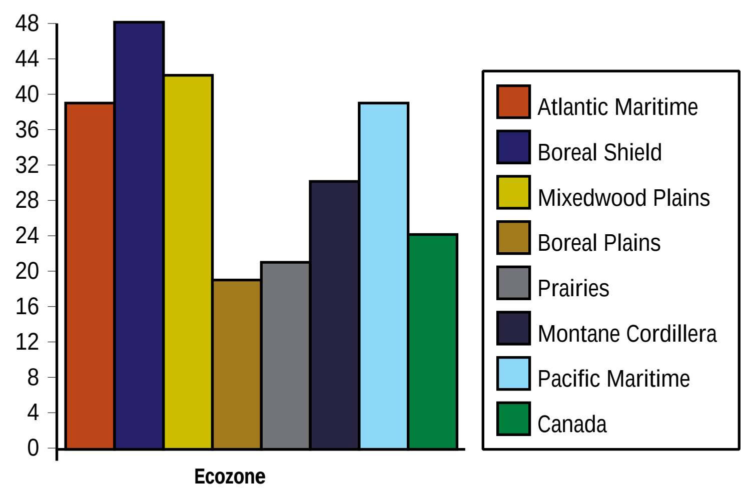
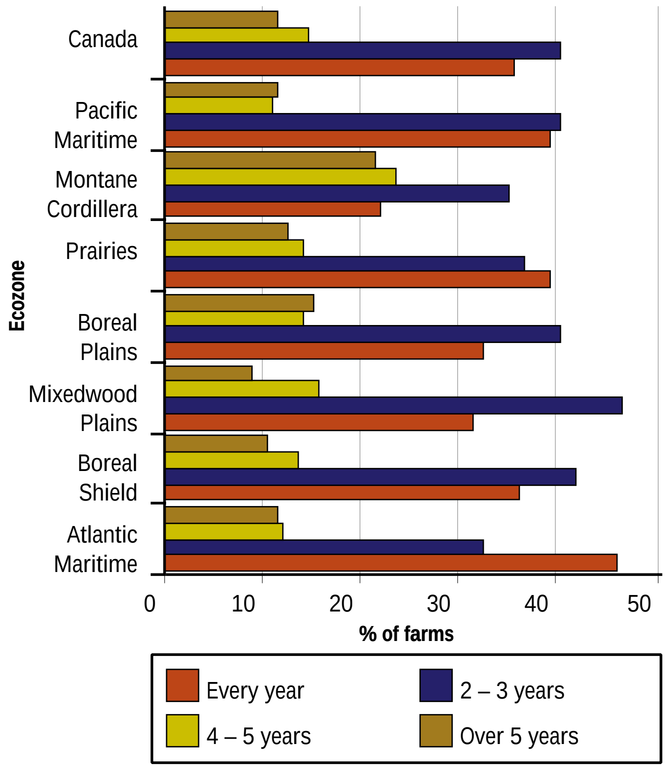


Figure 5–4

Frequency of soil testing among the 60% of farmers that conducted soil tests in 1995



Farm conservation clubs in Quebec

Quebec's farm conservation club initiative is one innovative way in which agriculture in the province is responding to environmental concerns. A farm conservation club is a voluntary association of producers with a shared interest in improving environmental management on their farms. The initiative was begun under the Green Plan and continues to receive support from the federal government's Canadian Adaptation and Rural Development Program; the provincial Ministry of Agriculture, Fisheries and Food; and farmers.

Conservation clubs are organized on a regional basis and typically include about 20 to 70 farmers, although some are larger. Members determine the overall direction and activities of the clubs, and each club retains the services of a dedicated advisor with specialized knowledge of environmental management in agriculture. Some of the larger clubs have several such advisors on staff.

Farm members of conservation clubs benefit from advice on a wide variety of agri-environmental issues, such as how to prepare and implement an integrated fertilization plan, improve efficiency in farm operations, and conserve environmental resources both on and off the farm. Members also benefit from information exchange and are able to keep abreast of the latest developments in agri-environmental practices, technologies, and services.

Today about 72 farm conservation clubs are in place across the province, representing about 3069 farms. A target of 4000 farms participating in conservation clubs by 2001 has been established.

S. Marmen, Coordination des clubs-conseils en agroenvironnement

Applying fertilizer when the crop needs it is another way to prevent losses of nutrients to the environment. About three-quarters of cropland in the Boreal Plains and Prairies received fertilizer before planting (the riskiest practice), but the topography and climate in these areas reduce the environmental risk of this practice. Fertilizer was applied after planting (the optimal practice) more often in the other ecozones, where leaching is a greater concern. Both the Pacific Maritime and Atlantic Maritime had about 40% of their fertilized cropland under this treatment.

Applying both manure and fertilizer on the basis of nutrient needs enables producers to reduce both fertilizer costs and environmental risk. The amount of fertilizer was cut back to account for nutrients in the manure on only about 25% of Canadian cropland receiving both manure and fertilizer. This result was mainly influenced by practices in the Boreal Plains and Prairies. On the other hand, farmers in the Boreal Shield and Mixedwood Plains, two areas active in both crop and livestock production, used this practice on almost half of cropland receiving both fertilizer and manure (48% and 41%, respectively).

Soil testing gives accurate readings of nutrient levels in the soil and is thus a good tool for nutrient management. Carrying out soil testing every 1 to 3 years is considered good practice. Of the 60% of Canadian farmers that conduct soil tests, 75% followed this timing, indicating that the farming community is generally aware of the benefits of frequent soil testing and willing to use it. Farmers in the Montane Cordillera were the most likely (44%) to wait at least 4 years between soil tests. However, 40% of farmers do not use soil tests at all, representing a high potential for inefficiency in production, either through over- or under-fertilization of crops. Either case is cause for environmental concern, because underfertilization can lead to poor soil quality and overfertilization to water pollution and higher emissions of nitrous oxide. Many soil experts also believe that the quality of soil testing has dropped in recent years and that more attention is needed to improve test procedures as well as to encourage more farmers to test soils regularly.

Table 5–1

Liquid manure storage method in 1995

		Share (%) of animals treated with each method, by ecozone							
		Atlantic Maritime	Boreal Shield	Mixedwood Plains	Boreal Plains	Prairies	Montane Cordillera	Pacific Maritime	Canada
Cattle (beef & dairy)	Unlined lagoon	47.0	46.0	26.0	12.0	34.0	24.0	51.0	33.0
	Lined lagoon	5.0	6.0	7.0	27.0	25.0	0.0	19.0	11.0
	Open tank	41.0	12.0	39.0	28.0	15.0	76.0	18.0	32.0
	Tank below slatted floor	2.0	28.0	14.0	33.0	21.0	0.0	0.0	13.0
	Sealed covered tank	6.0	8.0	14.0	0.0	5.0	0.0	12.0	11.0
	Other liquid storage	0.0	0.0	0.0	0.0	< 1	0.0	0.0	< 1
Hogs	Unlined lagoon	35.0	57.0	30.0	69.0	21.0	NA	50.0	33.0
	Lined lagoon	3.0	3.0	3.0	17.0	16.0	NA	0.0	10.0
	Open tank	59.0	39.0	30.0	5.0	4.0	NA	0.0	19.0
	Tank below slatted floor	2.0	< 1	12.0	5.0	34.0	NA	0.0	19.0
	Sealed covered tank	0.0	< 1	22.0	0.0	24.0	NA	50.0	18.0
	Other liquid storage	0.0	0.0	3.0	4.0	< 1	NA	0.0	1.0
Hens and Chickens	Unlined lagoon	32.0	58.0	21.0	0.0	13.0	NA	4.0	18.0
	Lined lagoon	< 1	19.0	0.0	1.0	0.0	NA	0.0	< 1
	Open tank	68.0	0.0	37.0	76.0	2.0	NA	96.0	25.0
	Tank below slatted floor	0.0	12.0	13.0	24.0	3.0	NA	0.0	9.0
	Sealed covered tank	< 1	11.0	29.0	0.0	76.0	NA	0.0	45.0
	Other liquid storage	0.0	0.0	0.0	0.0	6.0	NA	0.0	3.0

Note: Totals may not equal 100% due to rounding.

Animal Manure

Results

Survey results showed that animal manure was stored on about 60% of Canadian farms (133 700) in 1995. About 11% of these farms stored manure in liquid form. Table 5-1 shows liquid manure storage methods used on hog, chicken, and cattle farms. Hog farms were most likely (91%) to store liquid manure, followed by chicken farms (38%), and cattle operations (9%). Of cattle farms storing liquid manure, 33% used an unlined lagoon and 32%, an open tank. Of hog farms storing liquid manure, 32% used unlined lagoons and 12%, lined lagoons.

Of Canadian farms storing manure, 95% stored solid manure. Table 5-2 details the method of solid manure storage for various livestock. Open storage methods (the riskiest methods) were used on a large majority of farms.

The capacity of storage systems for liquid manure is shown in Table 5-3. This capacity was 200 days or more (the optimal capacity) on 50% of Canadian hog farms, 43% of cattle farms, and 31% of chicken farms. In the Prairies, more than half of all cattle, hog, and chicken farms could store liquid manure for fewer than 100 days.

Table 5-4 shows the methods used to apply manure. Application of solid manure was the most common method, used on 78% of cropland receiving manure. Only in the Pacific Maritime ecozone was the share of cropland receiving manure by this method less than 70% (48%). Surface application was the main method of applying liquid manure. Injection of liquid manure (the optimal method) was little used.

The timing of liquid manure application is shown in Figure 5-5. On Canadian farms, more manure (46%) was applied during the fall than in each of the other seasons. This was true for all ecozones, except for the Pacific Maritime and Montane Cordillera, in which spring applications were more common. Only 19% of manure was applied in summer (the optimal practice, as it corresponds to the time of maximum plant growth) on Canadian farms.

Soil manure storage in 1995

Table 5-2

		Share (%) of animals treated with each method, by ecozone							
		Atlantic Maritime	Boreal Shield	Mixedwood Plains	Boreal Plains	Prairies	Montane Cordillera	Pacific Maritime	Canada
Cattle (beef & dairy)	Open pile, no roof	71.0	69.0	53.0	70.0	45.0	40.0	78.0	54.0
	Open pile, with roof	1.0	2.0	3.0	3.0	2.0	1.0	0.0	2.0
	Manure pack	7.0	14.0	8.0	34.0	61.0	61.0	2.0	42.0
	Open pad, no containment	8.0	6.0	23.0	< 1	0.0	0.0	7.0	5.0
	Open pad, with containment	12.0	6.0	13.0	< 1	< 1	0.0	7.0	4.0
	Covered storage pad	1.0	< 1	2.0	0.0	0.0	0.0	0.0	< 1
	Other solid storage	2.0	5.0	2.0	< 1	1.0	< 1	6.0	1.0
	Method not specified	2.0	3.0	5.0	8.0	9.0	2.0	0.0	7.0
Hogs	Open pile, no roof	17.0	NA	24.0	65.0	68.0	71.0	69.0	44.0
	Open pile, with roof	0.0	NA	1.0	2.0	3.0	0.0	0.0	2.0
	Manure pack	1.0	NA	1.0	34.0	22.0	30.0	31.0	12.0
	Open pad, no containment	0.0	NA	54.0	0.0	0.0	0.0	0.0	20.0
	Open pad, with containment	0.0	NA	20.0	0.0	0.0	0.0	0.0	8.0
	Covered storage pad	29.0	NA	0.0	0.0	0.0	0.0	0.0	4.0
	Other solid storage	54.0	NA	1.0	6.0	9.0	0.0	0.0	12.0
	Method not specified	0.0	NA	0.0	7.0	0.0	0.0	0.0	0.0
Hens and Chickens	Open pile, no roof	46.0	48.0	65.0	29.0	86.0	4.0	1.0	60.0
	Open pile, with roof	0.0	0.0	0.0	1.0	0.0	95.0	< 1	3.0
	Manure pack	< 1	52.0	1.0	72.0	2.0	2.0	1.0	5.0
	Open pad, no containment	0.0	< 1	29.0	0.0	< 1	0.0	98.0	22.0
	Open pad, with containment	0.0	0.0	3.0	0.0	0.0	0.0	< 1	2.0
	Covered storage pad	53.0	0.0	3.0	0.0	0.0	0.0	0.0	7.0
	Other solid Storage	0.0	0.0	4.0	0.0	12.0	< 1	< 1	4.0
	Method not specified	0.0	0.0	6.0	0.0	0.0	0.0	0.0	4.0

Note: Totals exceed 100% in cases where several storage methods are used on farms.

Interpretation

Animal manure is the farm nutrient source for which the indicators suggest the greatest need for improved management. In general, both liquid and solid storage methods were less than optimal and improvements are needed as this sector of the industry expands. Liquid manure storage capacity is more adequately developed. Only a relatively small proportion of Canadian farmers stored manure in liquid form. Liquid manure management practices differed most between types of livestock production and less so between geographic regions. Open storage systems are more prone to losses and thus the least environmentally safe, but were the most used. The exception to this is chicken farms, 45% of which used a sealed, covered tank.

Most Canadian farmers storing manure did so in solid form, and most of these used open storage systems that pose some environmental risk. The method used seems to be influenced regionally. The open pile system, which poses the highest risk of runoff and leaching of nutrients and bacteria, was used most in eastern Canada.

Having a large storage capacity for liquid manure reduces the need to apply manure in the winter or under other unsuitable conditions. This indicator is most meaningful for hog operations, which frequently use liquid manure storage systems. Farms accounting for 88% of hog production in the Boreal Shield had a storage capacity of more than 250 days. The

Table 5–3

Liquid manure storage capacity in 1995

		Share (%) of animals with access to each level of storage capacity							
		Atlantic Maritime	Boreal Shield	Mixedwood Plains	Boreal Plains	Prairies	Montane Cordillera	Pacific Maritime	Canada
Cattle (beef & dairy)	100 days or fewer	14.0	0.0	5.0	0.0	54.0	24.0	7.0	14.0
	101 to 150 days	5.0	20.0	12.0	38.0	0.0	76.0	9.0	11.0
	151 to 200 days	15.0	5.0	30.0	27.0	34.0	0.0	33.0	28.0
	201 to 250 days	16.0	25.0	10.0	0.0	0.0	0.0	0.0	8.0
	More than 250 days	51.0	42.0	38.0	10.0	12.0	0.0	48.0	35.0
	Unspecified	0.0	8.0	5.0	25.0	0.0	0.0	3.0	4.0
Hogs	100 days or fewer	0.0	0.0	4.0	9.0	63.0	NA	0.0	29.0
	101 to 150 days	0.0	4.0	15.0	16.0	6.0	NA	0.0	9.0
	151 to 200 days	3.0	8.0	16.0	0.0	6.0	NA	0.0	8.0
	201 to 250 days	5.0	0.0	18.0	2.0	0.0	NA	50.0	7.0
	More than 250 days	87.0	88.0	41.0	73.0	24.0	NA	0.0	43.0
	Unspecified	5.0	0.0	6.0	0.0	1.0	NA	50.0	4.0
Hens and Chickens	100 days or fewer	0.0	0.0	0.0	76.0	67.0	NA	4.0	30.0
	101 to 150 days	0.0	30.0	3.0	24.0	18.0	NA	0.0	10.0
	151 to 200 days	< 1	10.0	58.0	< 1	0.0	NA	0.0	30.0
	201 to 250 days	0.0	0.0	19.0	0.0	0.0	NA	0.0	10.0
	More than 250 days	100.0	48.0	20.0	0.0	16.0	NA	96.0	21.0
	Unspecified	0.0	12.0	0.0	0.0	< 1	NA	0.0	< 1

Note: Totals may not equal 100% due to rounding.

Prairies had a much smaller liquid manure storage capacity for both hog and chicken operations.

Farmers tend to apply manure when other field work is not pressing, mainly in the fall, and this trend was supported both nationally and in all ecozones. It is much better to apply manure at the peak of a crop's need for nutrients, in the summer. More work is needed across the country to improve the timing of manure application.

Further refinement of the Manure Application Method indicator is needed to better assess the application of solid manure, particularly whether applied solid manure is then incorporated into soil. The indicator does suggest there is considerable room for improvement in the application of liquid manure to cropland.

Pesticides

Results

Methods used by farmers to determine when to apply herbicides are shown in Figure 5-6, and when to apply insecticides and fungicides in Figure 5-7. Both graphs include the method

Table 5–4

Manure application method in 1995

	Share (%) of crop area that received manure treated with each method							
	Atlantic Maritime	Boreal Shield	Mixedwood Plains	Boreal Plains	Prairies	Montane Cordillera	Pacific Maritime	Canada
Solid manure application	74.0	79.0	70.0	89.0	89.0	90.0	48.0	78.0
Irrigated manure application	0.0	< 1	3.0	0.0	< 1	0.0	1.0	1.0
Surface liquid manure application	27.0	21.0	26.0	11.0	11.0	10.0	51.0	21.0
Injected liquid manure application	0.0	0.0	< 1	< 1	< 1	0.0	0.0	< 1

Note: Totals may not equal 100% due to rounding.

Environmental farm plans

In 1991 more than 30 Ontario farm organizations came together to form the Ontario Farm Environmental Coalition with the main commitment to put into place the Environmental Farm Plan Program. Through this program, it was the hope that every farmer in the province would choose to address environmental concerns on his or her farm by voluntarily developing an environmental farm plan.

The program centres on completion and review of a workbook with two parts: a qualitative, self-administered risk assessment that covers farmstead and fields, and woodlands, wetlands, and streams where applicable; and an action plan that the farmer develops to deal with specific concerns identified in the assessment. This workbook was created with the help of scores of technical experts from many federal and provincial government departments and the University of Guelph.

The Ontario Soil and Crop Improvement Association coordinates the program, offering about 100 workshops to farmers each fall and winter. By April 1999, the program had attracted 16 000 workshop participants, with about half of these going on to complete the peer review process. Almost 6000 of these farmers have received an environmental farm plan incentive — a grant of up to $1500 to offset the capital cost of completing an on-farm project that addresses a concern identified in the farm assessment. Incentive payments of about $7 million have been made to date. A recent audit showed that, on average, recipients of the incentive addressed 11 action items, spent $12 000 of their own funds beyond the incentive value, and contributed 56 hours of their own labour in attending to environmental concerns on their farms.

Ontario's Environmental Farm Plan Program is recognized internationally as an industry driven, nonregulatory approach to environmental protection on the farm. Attracted by the success of this program, agricultural representatives in Atlantic Canada began in 1994 to discuss the prospect of running a similar program there through the Atlantic Farmers Council. It was quickly discovered that the Ontario workbook needed restructuring and adaptation to Atlantic production systems, and this was done with the help of farmers, government experts, and organizations such as the Eastern Canada Soil and Water Conservation Centre. Completed in December 1995, the workbook was given to each Atlantic province to use in a program of its own making.

By April 1999, about 500 New Brunswick farmers had participated in environmental farm planning workshops, with attendance doubling after the 1998 introduction of an incentive (up to $3000 or 75% of a project cost). The program is administered by the New Brunswick Agriculture Environmental Council, with incentive funds coming from the National Soil and Water Conservation Program and the Canadian Adaptation and Rural Development Fund. A similar program is coordinated in Prince Edward Island by the P.E.I. Federation of Agriculture, and about 300 farmers have attended workshops to date. A new assistance package, the Agriculture and Environmental Resource Conservation Program, was recently introduced, with the government contributing two-thirds of project costs, up to $30 000 per farm. Newfoundland and Labrador have had an environmental farm plan program since 1996, coordinated by the Newfoundland and Labrador Federation of Agriculture. Plans are now in place on 70 farms, and an incentive program is being developed to attract more participants. Nova Scotia also began its program in 1996, and about 130 farmers have attended workshops to date. Invitations were extended to these farmers to participate in a confidential, on-farm review in the summer of 1999, and incentives are being explored. As in Ontario, environmental farm planning in Atlantic Canada is being led and carried out by farmers with the continuous cooperation and assistance from various provincial and federal government departments.

D. Armitage, Ontario Federation of Agriculture
W. Omvlee, New Brunswick Agriculture Environmental Council
S. Smale, Nova Scotia Federation of Agriculture
L. Halliday, Prince Edward Island Federation of Agriculture
Y. Rideout, Newfoundland and Labrador Federation of Agriculture

of using calendar dates to determine when to make these applications. Applying herbicides according to the stage of crop growth was the most common method (38%) on Canadian farms using herbicides. The first sign of weeds was an important decision-making factor in the Pacific Maritime and the Boreal Shield. The level of economic injury to plants (the optimal practice) prompted herbicide application on 20% of Canadian cropland receiving herbicides.

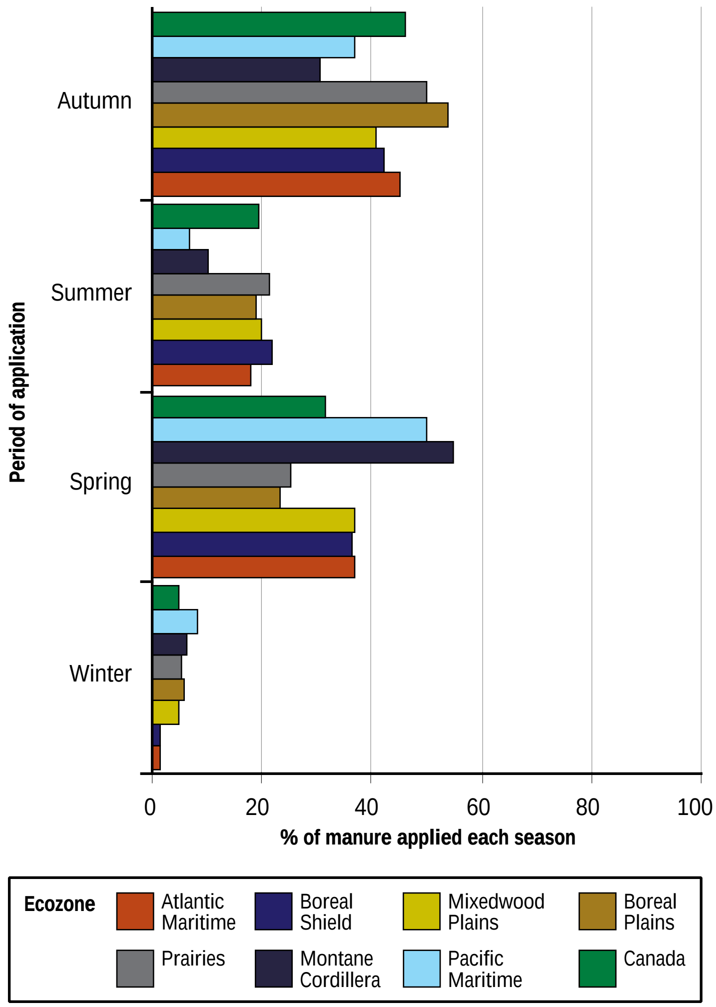
Of the farms with cropland in 1995, about 31% (62 300 farms) reported applying insecticides and about 19% (40 000) reported applying fungicides. Nationally, the level of economic injury was the deciding factor on 25% of crop-land receiving these chemicals, and the most commonly reported method in the Boreal Plains and Prairies. Farmers in the Atlantic Maritime ecozone were more inclined to use the first sign of disease or pest as the cue to apply these chemicals.

About 76% of farms reporting the use of pesticides in 1995 operated their own sprayers. Figure 5-8 shows calibration methods for these sprayers. About 68% of these, representing 54% of Canadian cropland, calibrated their sprayers at the beginning of the crop season. Calibrating the sprayer between applications of different pesticides (the best practice) was used for only 16% of Canadian cropland.

Figure 5-9 shows the share of cropland treated for pests using non-chemical methods. Crop rotation (56%) and tillage (27%) were the most

Figure 5–5

Timing of manure application in 1995



Integrated pest management

The codling moth was accidentally introduced to British Columbia in the early 1900s. Since then it has caused untold damage to apple and pear crops, threatening a tree fruit industry that employs 5000 people and generates $700 million each year.

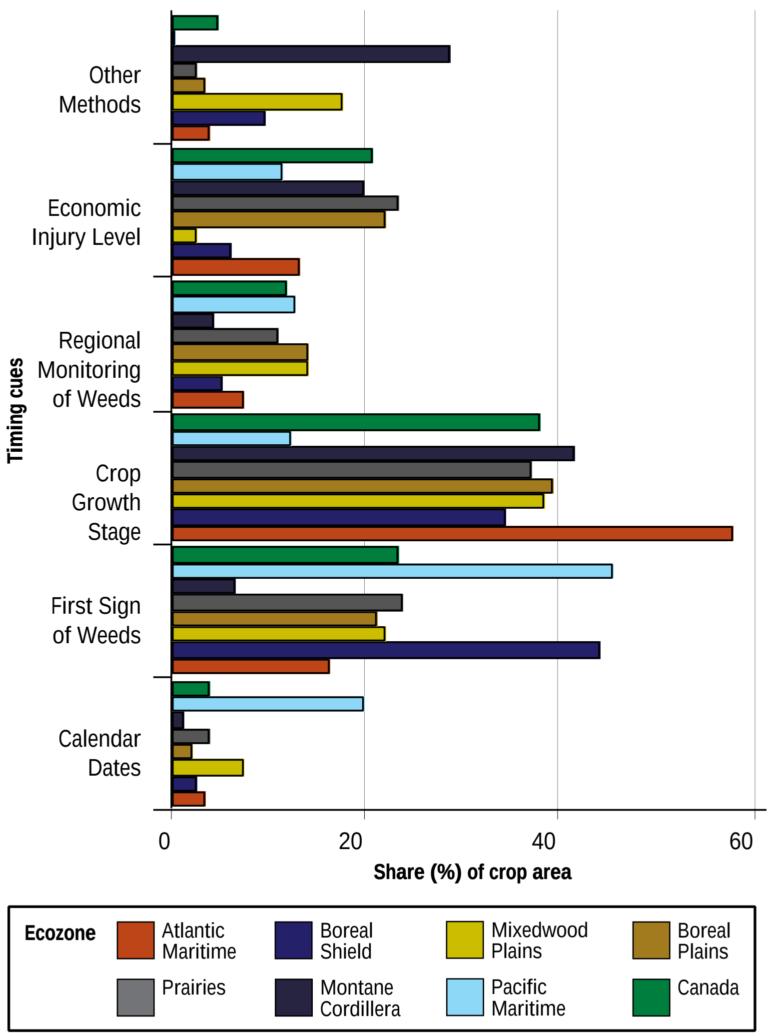
The Sterile Insect Release Program brings together the efforts of governments, the tree fruit industry, fruit growers, and property owners in the province to deal with this pest problem. Under the program, 12 to 14 million sterile moths are released each week during the growing season in 1700 commercial orchards in southern British Columbia. Sterile moths mate with fertile wild moths, but the resulting eggs do not develop and the moth population drops.

Moths are reared at a $7.4-million facility opened in 1993 near Osoyoos, and the $3.4-million operating costs are shared by local growers and owners through taxes. Moth release began in 1994, and in 1998 more than 3000 million moths were released from April to October. In combination with other techniques, such as intensive monitoring, mating disruption, and the use of less toxic pesticides, this program aims to reduce codling moth populations to levels for which chemical control is not needed.

C.A.S. Smith, Agriculture and Agri-Food Canada

Figure 5–6

Decision tools used to decide timing of herbicide application in 1995



commonly used alternative methods. No alternative method was used on 34% of cropland.

Interpretation

Between 1981 and 1996, the farmland area treated with herbicides grew by 53% and that treated with insecticides or fungicides grew by 78%. Although new pesticide products generally pose fewer environmental risks, concerns remain about the impact of pesticides on non-target species and water quality. New biotechnologies, such as pest-resistant crops, and techniques, such as integrated pest management (*see* Box), offer opportunities to manage the environmental risks associated with pesticide use.

Herbicides are most efficiently used at the stage of weed growth at which economic losses to the farmer match the cost of spraying. About 20% of Canadian farmers used estimates of the level of economic injury to decide when to apply herbicides. Since 60% of farmers applied herbicides at the first sign of weeds or at a certain stage of crop growth, there is considerable room for improvement in this indicator.

Scouting for insect and fungus infestations and assessing the level of economic injury both ensure that insecticides and fungicides are used only when and where most needed. Prairie producers used this method for 30% of their cropland, but this share was much lower in the other ecozones. Because 40% of the data fell in the category of other methods, this indicator probably needs further refinement.

Proper calibration of sprayers improves the efficiency of pesticide use and reduces environmental risk. The best management practice is to calibrate equipment between applications of different pesticides. The common practice across all ecozones was to calibrate only at the beginning of the crop season, showing considerable room for improvement in this indicator.

Farmers can use a variety of non-chemical methods to control pests that help to reduce pesticide use and reduce environmental risk. The wide use of crop rotation and tillage across Canada to control pests is a positive step toward the goal of using a range of non-chemical pest control methods on cropland.

Response Options

Further adoption of best management practices for nutrient and pesticide management is needed in all parts of the country, especially in areas of intensive crop or livestock production and where landscape and climatic conditions raise the risk of water carrying nutrients and pesticides off farmland into neighbouring waters. Ongoing research is also required to

- develop new pest control products and methods
- refine non-chemical pest controls
- update existing recommended fertilizer rates and develop them for new crops
- improve application practices.

Figure 5–7

Decision tools used to decide timing of insecticide and fungicide application in 1995

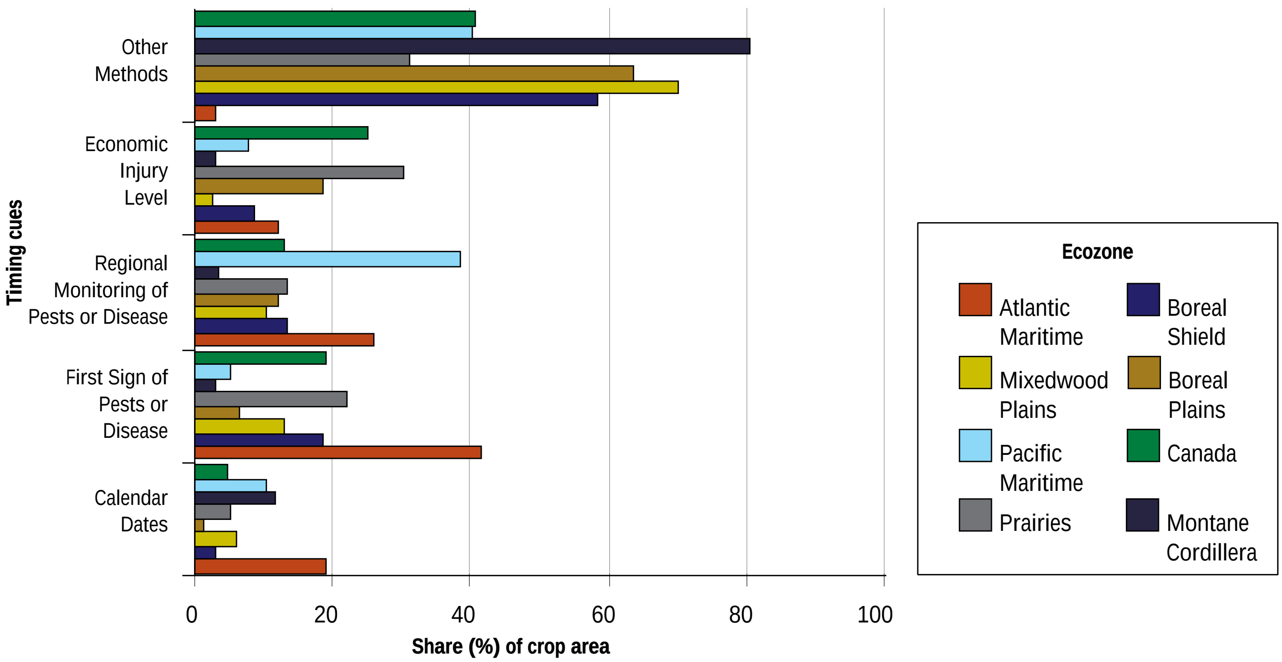


Figure 5–8

Frequency of sprayer calibration in 1995

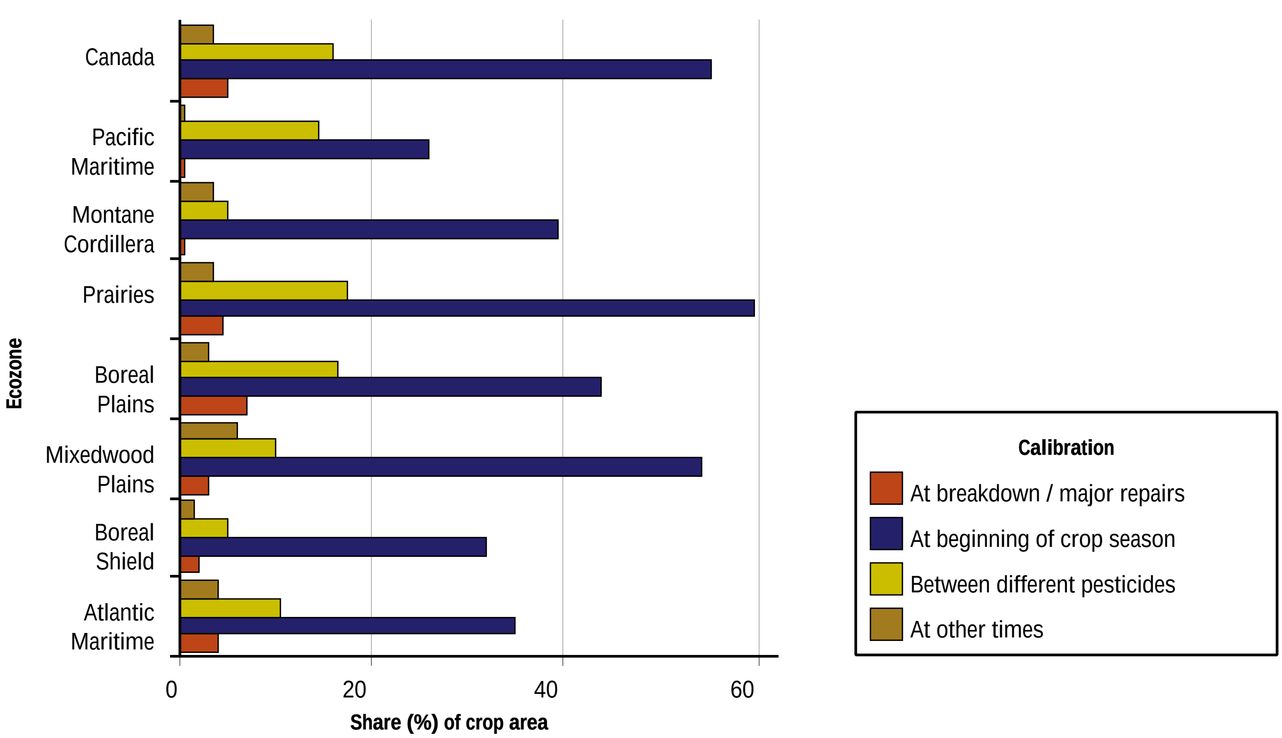
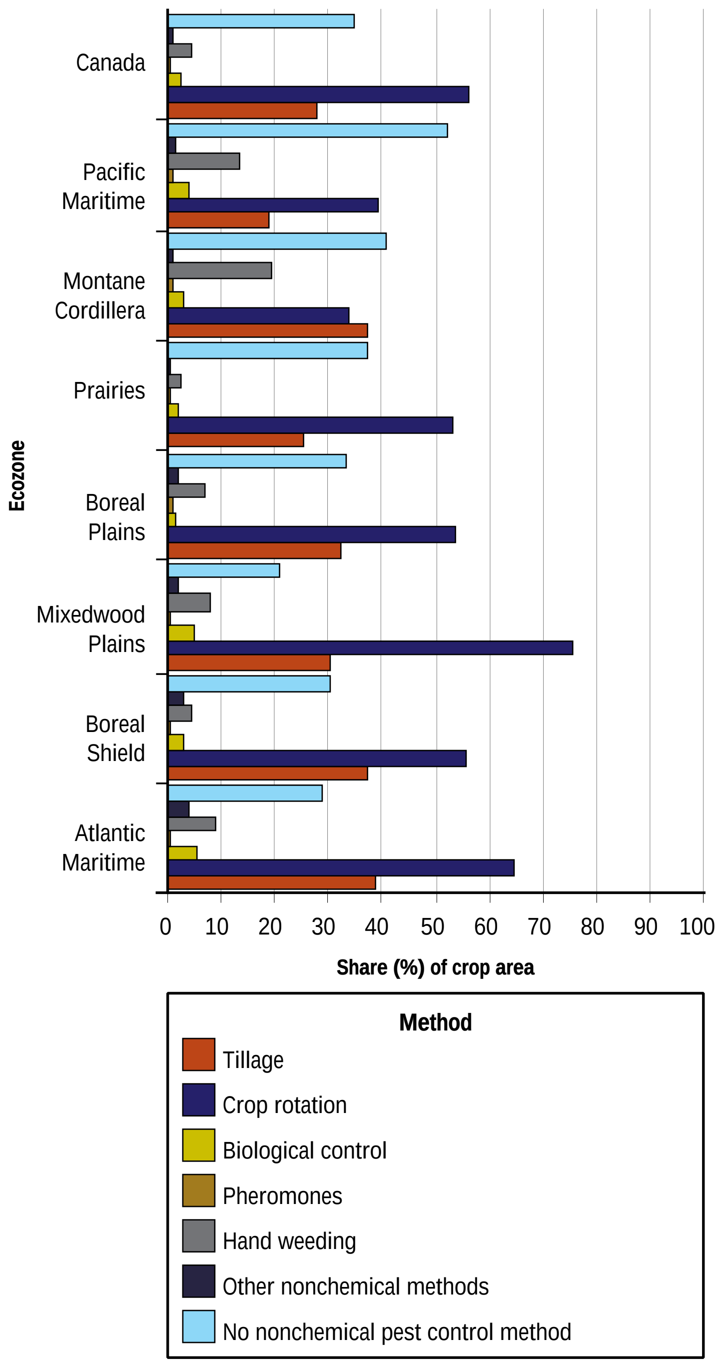


Figure 5–9

Alternative use of pest control methods in 1995



Nutrient and pesticide management planning are important components of the *environmental farm plans* that many Canadian producers are voluntarily using. These plans involve

- using only the amount of nutrients and pesticides needed, based on soil testing or pest monitoring
- applying these amendments when and where they will do the most good
- handling, storing, and applying nutrients and pesticides in ways that reduce environmental risks.

Conclusion

Although the indicators presented in this chapter show that good farm practices are being applied across Canada, they also suggest room for improvement when viewed in terms of environmental protection. The overall trend in Canadian agriculture is toward increased specialization and intensification of production, and the use of more sophisticated processes and technologies. As agriculture continues to move to larger and more-intensive operations, sound input management practices will be critical for both environmental protection and farm profitability. In most cases, reducing the environmental risk associated with input management goes hand in hand with farm profitability.

Related Indicators

How much, and how, fertilizer and manure nitrogen are applied affects the level of Residual Nitrogen left in soil after crops are harvested, the nitrous oxide component of the Agroecosystems Greenhouse Gas Budget, and the Risk of Water Contamination by Nitrogen. How much, and how, fertilizer and manure phosphorus are applied affects the Risk of Water Contamination by Phosphorus. Good nutrient management builds healthy soils, which have good levels of Soil Organic Carbon and a reduced Risk of Wind Erosion, Risk of Water Erosion, and Risk of Tillage Erosion, and support greater Availability of Wildlife Habitat on Farmland.

C

Soil Quality

C Soil Quality

Soil quality is defined as the ability or capacity of a specific soil to function for a specific purpose. In the context of agriculture, soil quality, or soil health, is the soil's fitness to support crop growth without resulting in soil degradation or otherwise harming the environment. Soil quality has both an inherent or natural element determined by geological materials and soil formation processes (such as chemical and physical weathering) and a dynamic element determined by farm management practices. The natural quality of soil can be degraded by natural processes, such as erosion and the subsequent loss of organic matter, compaction, and salinization. Agriculture can accelerate these processes through various land uses and management practices, hastening the symptoms and effects of soil degradation. On the other hand, some agricultural land uses and management practices (such as various tillage methods, cropping systems, and nutrient management plans) help to stabilize or improve soil quality. Some researchers suggest that soil quality can also be measured in economic terms. We have chosen to concentrate on the environmental aspects of soil quality on a broad landscape basis in our assessments.

The following six chapters examine agricultural soil quality using indicators of the risk of soil degradation by various processes. Chapters 6 to 8 assess the risk of soil erosion by water, wind, and tillage. Chapter 9 evaluates the status of soil organic carbon, which is largely a function of the erosion process. Chapters 10 and 11 present the risks of compaction and salinization.

Soil erosion is a natural process, the wearing away of the land's surface by water, wind, or ice. Agricultural management practices can accelerate natural rates of erosion. Erosion removes topsoil and deposits it elsewhere. These changes result in a general decline in soil quality because of changes in physical, chemical, and biological properties that ultimately reduce crop quality and yield. Agricultural soils can tolerate a certain amount of erosion without adverse effects on soil quality or long term productivity, because new soil is constantly being formed to replace losses. In Canada, this tolerable limit is estimated at about 5 tonnes of soil per hectare per year on well developed agricultural soils and a lesser amount on shallow or already degraded soils. Thus, the tolerable risk class has been defined as less than 6 tonnes per hectare for the indicators of the risk of water and tillage erosion.

The shape of the landscape affects the rate of all three types of erosion. Soil cover by plants and their residues protects soil from the impact of raindrops and wind, reducing soil losses. This factor is directly determined by agricultural management decisions such as those related to crop selection, rotations, and tillage practices.

Effects of erosion on and off the farm

On-farm effects

- lower fertility levels
- poorer crop yields
- less water infiltration into soil
- more soil crusting
- more runoff in the spring and after storms
- higher soil pH
- development of rills and gullies in the field

Off-farm effects

- deposition of eroded soil in depressions and adjacent fields
- decline of downstream water quality and aquatic ecosystems because of sedimentation and the addition of nutrients, pesticides, and bacteria
- costly physical problems, such as clogged drainage ditches

A major component of the topsoil removed by erosion is soil organic matter. Organic matter offers many benefits to soil. When soil organic matter is lost, soil structure breaks down and the soil becomes less permeable to air, water, and nutrients. It may compact and show surface crusting. As this happens, the soil becomes more vulnerable to all types of erosion, further compounding the problem by removing even more topsoil. As soil fertility and productivity drop off, greater amounts of inputs (e.g., fertilizer) are needed to produce a reasonable crop, and eventually the soil reaches an unproductive state. Carbon is the leading component of soil organic matter. An assessment of soil carbon levels in agricultural soils gives an indication of soil quality.

Soils have a natural state of compactness, the degree of which depends on the nature of their deposition and the parent materials from which they were formed. Fine-textured soils, such as clays, are naturally more compact than coarse-textured soils, such as sands. Some soils laid down directly by glacial ice sheets have highly compacted subsoils. Certain agricultural practices compound the problem. Practices that result in the loss of soil organic matter contribute to soil compaction. Heavy farm machinery presses the soil down, especially when it is wet (e.g., in early spring or late fall). The more field traffic there is, the more compaction will result.

Soil salinity is a natural condition in which soluble salts are found in the root zone of plants, hindering their growth. This condition is largely controlled by the movement of water through the soil and is found in a good deal of the agricultural land in the Prairie Provinces. Producers can do very little to curb the tendency of some soils to become saline, other than alter land use. Reducing summerfallow area helps to control soil salinization, but severely saline lands probably need to be retired from regular cultivation and converted to pasture.

Reducing the risk of erosion, loss of soil organic matter, compaction, and salinization is accomplished by changes at different levels of responsibility. Most important are activities that take place at the farm level, as farmers continue to modify their cropping and tillage practices. However, this change must be supported by research and development of management practices, programs to monitor and predict the outcome of management changes, and education. Programs initiated by producers appear to be a key factor in the adoption and success of conservation practices aimed at the long term sustainability of agriculture in all parts of Canada.

6 Risk of Water Erosion

I.J. Shelton, G.J. Wall, J.-M. Cossette, R. Eilers, B. Grant, D. King, G. Padbury, H. Rees, J. Tajek, and L. van Vliet

Geographic scope: National, provincial
Time series: 1981, 1991, 1996

HIGHLIGHTS

- Water erosion is a natural process that is accelerated by various agricultural management practices. Erosion results in the loss or redistribution of topsoil in a landscape, usually causing soil degradation and reducing crop quality and yield on-site. If the eroded sediment is transported off-site into waterways, it can cause an increase in turbidity and sedimentation. Attached to the eroded soil particles may be nutrients, pesticides, and bacteria, which also contribute to declining water quality. Thus, controlling erosion helps to protect both soil quality and water quality.

- An indicator was developed to assess the degree to which Canada's cropland was at Risk of Water Erosion in 1981, 1991, and 1996. The risk was expressed in five classes: tolerable (associated with erosion that is offset by soil building and is thus sustainable), low, moderate, high, and severe (all of which are considered unsustainable). The change in risk between 1981 and 1996 was calculated to evaluate the effects of prevailing land use and tillage practices. The performance objective for the indicator is to have all cropland in the tolerable risk class.

- Between 1981 and 1996, cropping measures and increased use of conservation tillage were responsible for decreases in water erosion risk in Alberta, Saskatchewan, Manitoba, Ontario, and New Brunswick. The risk remained the same in British Columbia and Prince Edward Island, where the benefits of conservation tillage and other conservation measures were offset by intensified agricultural production in some areas. The risk rose in Quebec, mainly because of the intensification of cropping practices, and in Nova Scotia, mainly because of expanded potato production.

- By 1996, Alberta, Saskatchewan, Manitoba, Quebec, and Nova Scotia had more than 70% of cropland in the tolerable risk class, while the share of cropland in this risk class ranged from about 50 to 70% in British Columbia, Ontario, Prince Edward Island, and New Brunswick.

- The indicator does not reflect other erosion control practices, such as the use of grassed waterways and terraces, cross-slope cultivation, strip and contour cropping, and winter cover cropping, because the land base on which these practices are used is not reported in the *Census of Agriculture.*

The Issue

Rainfall and surface runoff are the driving forces behind water erosion. The greatest potential for water erosion is during spring melt (especially when the soil surface is thawed, saturated, and readily moved and the underlying soil is frozen and impermeable) and heavy summer storms. Still, erosion can take place at any time, resulting in large losses of soil from farm fields over time and contributing to soil degradation.

Soil is carried in runoff to agricultural drains and other waterways, where it adds to the sediment load. Water quality decreases as suspended soil particles increase the *turbidity* (cloudiness) of the water and add to the sediment buildup on the bottom. This *sedimentation* reduces the water's suitability as habitat for fish and other aquatic organisms, alters the flow of the water, and may eventually clog the channels, making cleanout necessary.

Crop nutrients, pesticides, and bacteria, are often attached to the eroding soil particles and so are carried into waterways too. Their presence adds to the problem of declining water quality. Thus, curtailing water erosion helps to protect both soil quality and water quality. In recent years, many management practices have been employed to control water erosion. An indicator is needed to identify areas still at risk of water erosion and to assess how this risk is changing over time under prevailing management practices.

The Indicator

Description

We developed an indicator, Risk of Water Erosion, to estimate the extent of cultivated land at risk of water erosion and to monitor changes in this risk over time, particularly as a result of changes in management practices. This risk is expressed in the following five classes: tolerable (less than 6 tonnes per hectare per year), low (6 to 11 t/ha/yr), moderate (11 to 22 t/ha/yr), high (22 to 33 t/ha/yr), and severe (greater than 33 t/ha/yr). Areas in the lowest class are generally considered at *tolerable risk* of soil erosion and able to sustain long term crop production. The other four classes represent the risk of conditions that are unsustainable and for which soil conservation practices are needed to support crop production over the long term.

The indicator can be viewed as an indirect measure of soil quality. Because water erosion is a process of soil degradation that results in decreased soil quality, a declining erosion risk is considered positive in terms of soil quality. The performance objective for this indicator is to have all cropland in the tolerable risk class.

Method of calculation

The rate of water erosion was estimated using the Revised Universal Soil Loss Equation for Application in Canada. Information from the *Soil Landscapes of Canada* maps and other sources on climate, soil, and topography was used to tabulate rainfall, soil, and landscape (slope) factors for each mapping area. The *inherent erodibility* represented by these factors was assumed to remain constant over the study period. The change in erosion risk over time was calculated by considering the effects of changes in land use and tillage practices across Canada, such as fluctuations in cropland areas, shifts in the types of crops grown, and the use of conservation tillage and no-till. This information was obtained from the *Census of Agriculture* for 1981, 1991, and 1996.

All but the tolerable rating indicate areas where soil and water conservation practices are needed for the sustained production of agricultural crops. The share of cropland falling in each of the risk classes outlined above was calculated for each province and for each distinctive agricultural or ecoregion within each province. Changes over time in the percent value for each class in each area provided an indicator of whether the overall risk of erosion was increasing or decreasing.

Limitations

The indicator is subject to the following limitations:

- calculations did not account for improvements resulting from the use of erosion control practices such as *grassed waterways*, *terracing*, *contour cultivation*, *strip cropping*, and winter cover crops.
- census data are not detailed enough to adequately reflect the geographic distribution of management practices in landscapes where farmland is fragmented, and some calculation errors may occur
- the indicator is based on long term average annual rainfall data that may not reflect single high intensity rainfall events that can cause significant soil erosion.

Results

The risk of water erosion in each province is shown for 1981, 1991, and 1996 in Table 6-1. Figures 6-1 and 6-2 show the distribution of the various risk classes in 1996. The change in cropland area at risk of tolerable levels of erosion between 1981 and 1996 is shown in Figure 6-3.

In British Columbia there was a shift of about 7% of cropland into the moderate risk class, mainly from the low risk class. Although the share of cropland at a tolerable risk of water erosion remained constant between 1981 and 1996, there were areas in the south and central regions of the province where the risk of water erosion increased slightly, despite improvements in farming practice and the use of conservation tillage. There was also a 2% increase in cropland area between 1991 and 1996.

Saskatchewan showed the most improvement of all provinces, with a shift of 26% of its cropland into the tolerable risk class from higher risk classes between 1981 and 1996. Alberta parallelled this trend, but to a lesser extent, with a gain of 8% of cropland in the tolerable risk class. Although some areas of the Manitoba Prairie region showed slight increases in risk,

Figure 6–1

Risk of water erosion on cropland in the Prairie Provinces under 1996 management practices

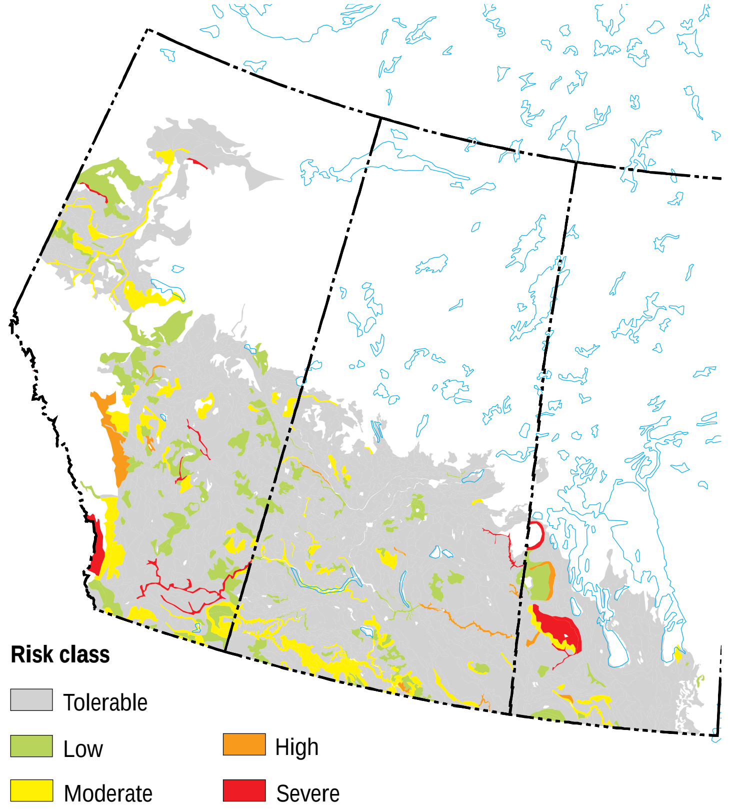


Table 6–1

Risk of water erosion on Canadian cropland under prevailing management practices

Province	Cropland area* (million ha)	Share (%) of cropland in various risk classes														
		Tolerable			Low			Moderate			High			Severe		
		1981	1991	1996	1981	1991	1996	1981	1991	1996	1981	1991	1996	1981	1991	1996
British Columbia	0.52	56	59	56	25	22	19	12	13	19	5	4	5	2	2	1
Alberta	10.6	75	80	83	15	11	11	8	7	6	2	1	1	<1	<1	<1
Saskatchewan	18.8	64	72	90	24	19	5	7	5	5	4	4	1	2	1	<1
Manitoba	4.9	88	87	89	5	4	4	3	4	4	1	1	1	3	2	2
Ontario	3.4	51	56	58	26	23	27	13	11	6	10	10	10	<1	<1	<1
Quebec	1.6	89	89	88	7	8	9	4	3	3	0	0	0	0	0	0
New Brunswick	0.1	43	45	48	23	32	30	22	14	14	6	6	5	6	3	3
Nova Scotia	0.1	74	71	72	14	15	15	10	12	10	<1	<1	<1	2	3	2
Prince Edward Island	0.1	59	60	59	23	22	23	14	15	19	4	4	0	<1	<1	0

*Cropland area is an average of values for 1981, 1991, and 1996

Figure 6–2

Risk of water erosion on cropland in Central Canada and the Maritime Provinces under 1996 management practices

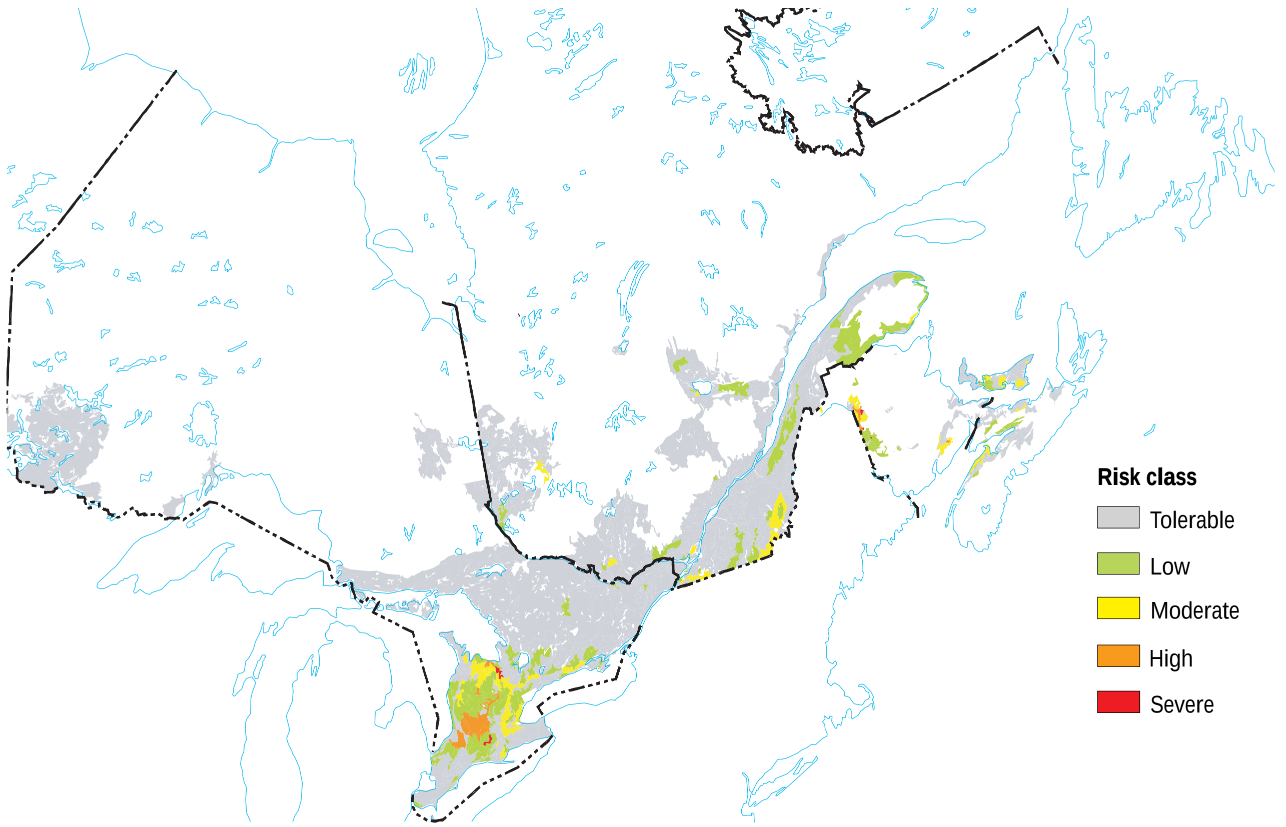
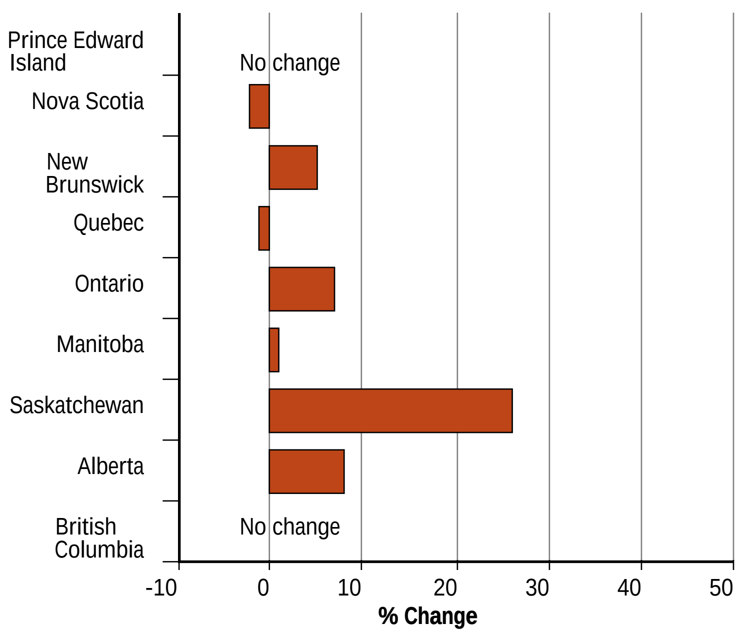


Figure 6–3

Change in the area of cropland at risk of tolerable level of water erosion between 1981 and 1996



overall the province showed a 1% increase in the share of cropland in the tolerable risk class.

Ontario showed an overall reduction in the risk of water erosion between 1981 and 1996, with most of this improvement coming from a shift of about 7% of cropland from the moderate to lower risk classes. In Quebec, the share of land in the tolerable risk class fell slightly (1%) between 1981 and 1996. Of all the provinces, Quebec, Manitoba, and Saskatchewan had the largest share of cropland (about 90%) in the tolerable risk class in 1996, but Quebec also had no cropland in the highest two risk classes (*see* Box on conservation tillage in Quebec).

New Brunswick had the largest share of cropland at severe in 1981 (6%), but halved this figure by 1996. This improvement, along with a shift of cropland from the moderate and high risk classes to lower risk classes gave a reduction in overall erosion risk between 1981 and 1996. In Prince Edward Island, about 4% of cropland shifted from the high to moderate risk class, although the share of land at tolerable risk remained constant from 1981 to 1996.

Although an overall improvement in water erosion risk was noted in most of the provinces, some regions of some provinces showed an increased risk of water erosion. These regions included

- the South Coastal and Central Interior regions of British Columbia
- the Prairie region of Manitoba (which showed a change in risk of less than 5%)
- the Algonquin–Lake Nipissing region of Ontario (less than 5% change)
- the St. Lawrence Lowland, Appalachian (each less than 5%), and Central Laurentian regions of Quebec.

Interpretation

The general trend of decreasing risk of water erosion between 1981 and 1996 in Canada reflects the degree to which changes have been made in cropping systems and tillage practices. A combination of reduced tillage, less-intensive crop production, decreased summerfallow, and removal of marginal land from production all contribute to lower erosion rates. In the following provincial descriptions, changes in erosion risk are stated for the period 1981 to 1996.

Adoption of no-till in British Columbia offset the increased risk of erosion caused by greater intensification of farming in many regions. However, the South Coastal region, comprising 10% of the province's cropland, showed an increase in risk. About 70% of the annual precipitation there falls in October through March, when crop cover is often absent and soils are exposed. Intensive row cropping of vegetables and berries contributes to the erosion risk in this region. Although winter cover cropping is widely practised here, greatly reducing the risk of water erosion, information on this practice is not collected by the *Census of Agriculture*, and thus the indicator values do not account for the benefits of this practice (*see* Box).

In the Prairies, particularly Saskatchewan and Alberta, the risk of water erosion dropped substantially because of the growing use of conservation tillage, the reduction in summerfallow area, and shifts in the type of crops grown. This improvement was particularly marked in regions of less-intensive agriculture, such as the Eastern Continental Ranges (foothills area) and Western Alberta Uplands (Grey Wooded zone) ecoregions of Alberta. Areas remaining in the high risk class tend to be those with erosion-prone soils that would benefit from greater adoption of conservation practices. In Manitoba, the drop in erosion risk is attributed to expanded continuous cropping and the recent trend of greater *crop diversification*. This trend has resulted in more land being used to produce annual crops, as well as longer rotations because of the inclusion of new crops.

Conservation tillage to control soil erosion in Quebec

Although it rarely reaches very severe levels, soil erosion is a widespread problem throughout Quebec. Annual crops that leave the soil unprotected for extended periods of time create the greatest risk. The area devoted to these crops has significantly increased over the last decade. For example, the area in grain corn grew from 293 000 to more than 331 000 ha between 1991 and 1996. The area in mixed grain increased by nearly 25%, and soybean and canola production are booming.

Accelerated soil erosion takes place particularly as a result of high intensity rainfall during the growing season and runoff from partially frozen soils in the early spring.. The result is a loss of soil material from cultivated fields and the entrance of pollutants (sediments, nutrients, pesticides) into receiving surface waters.

Research on conservation tillage has shown the potential for these practices to control losses of soil, water, and nutrients (phosphorus) off-site to waterways (*see* Table below). The use of conservation tillage practices is growing in Quebec. In 1996, nearly 130 000 ha were under reduced tillage, 24% more than in 1991, and more than 35 000 ha were under no-till, an increase of 63% since 1991. In 1996 conservation tillage was used on 15% of the area under annual crops.

Annual runoff, erosion, and phosphorus losses under conventional and conservation tillage practices in Quebec

Crop	Tillage practice	Runoff (cm)	Soil loss (Tonnes/ha)	Total P loss (kg/ha)
Grain corn	Conventional	5.3	6.6	3.9
	Chisel	2.9	1.5	1.1
	Ridge till	3.2	1.8	1.4
Grain corn	Conventional	4.9	16.9	3.0
	No-till	1.8	1.3	0.2
Barley	Conventional	2.9	1.3	2.9
	No-till	2.6	0.9	1.1

C. Bernard, Institut de recherche et de développement en agroenvironnement

In Ontario, although the overall risk of erosion dropped, more than 40% of cropland remained in the intolerable risk classes (low risk and higher) in 1996. The Manitoulin–Lake Simcoe ecoregion, comprising about 40% of Ontario's cropland, showed the greatest improvement in erosion risk, with 13% of its area shifting to lower risk classes by 1996. However, this ecoregion still had a low share of cropland at tolerable risk (43%) in 1996. The Lake Erie Lowlands, also comprising about 40% of Ontario's cropland and used mainly to grow corn, soybeans, tobacco, vegetables, and soft fruits, had only 57% of its cropland in the tolerable risk class in 1996, but still improved in risk by 3%.

Despite the overall drop in the risk of water erosion in Quebec, its St. Lawrence Lowland, Appalachian, Central Laurentian, and Southern Laurentian ecoregions all showed a shift of cropland area from the tolerable to unsustainable classes of erosion risk. This increased risk is likely the result of intensified production of row crops, such as soybeans, grain corn, silage corn, and vegetable crops, and a concurrent reduction in crops that provide better erosion protection, such as alfalfa and spring cereals. The increase in row crops was offset somewhat by an increase in hay. Still, Quebec has a generally low overall risk compared to the other provinces, mainly because most agriculture is carried out on gentle landscapes and soils that are not naturally prone to erosion.

New Brunswick's rolling, moderately long slopes present the most erodible topography in the Maritimes. This province had the lowest share of cropland at tolerable risk of water erosion, and 8% of cropland was still in the high to severe risk classes in 1996. High risk lands are generally those under potato production in the northwest of the province. Soil erodibility associated with spring cereals planted after potatoes is greater than that associated with spring cereals planted after a forage crop. The drop in erosion risk between 1981 and 1996 is a measure of the success of adopting conservation tillage and, to a lesser extent, growing crops that are less erosion-prone, such as hay.

Generally, Nova Scotia has the most precipitation of the Maritime Provinces and thus the greatest potential for erosion by rainfall, snowmelt, and winter runoff. It has a smaller area of potato production than New Brunswick or Prince Edward Island, but larger areas under vegetables and berries. The erosive effects of the greater production of berries, grain corn, and silage corn in 1996 were offset by increases in the area in fruit trees, tame hay, spring cereals, and winter wheat. In Prince Edward Island, fine sandy loam soils that erode easily are most common. The area of erosion-prone crops increased by 1996, raising the risk of water

Winter cover cropping cuts erosion in south coastal British Columbia

The exposed soil between the rows of crops such as strawberries and corn is at risk of loss by water erosion. In the South Coastal region of British Columbia, this risk is greatest during the fall and winter. About 70% of the annual rainfall occurs from October through March, often in prolonged storms. Other factors that promote water erosion in the rolling upland area where many row crops are grown are the silt loam-textured soils, steep slopes, and up- and down-slope cultivation and planting of row crops.

The British Columbia Ministry of Agriculture and Food, in cooperation with Statistics Canada, conducted a farm practices survey in 1999. Twenty-three percent of Fraser Valley vegetable producers reported that areas of their croplands were affected by erosion. Of those affected, 50% used cover crops as a control measure.

Agriculture and Agri-Food Canada researchers compared field plots with no erosion control (strawberries and silage corn cultivated and planted up- and down-slope) with field plots under a winter cover crop planted in between the rows, both on moderately sloping land. The field plots received all the fertilizer applications, tillage, and weed and disease control practices commonly used in growing strawberries and silage corn commercially. Substantial reductions in soil loss were found on plots with the winter cover crop (*see* Table below). Winter cover cropping is the preferred erosion control practice for row crops in this region. Besides controlling erosion, cover crops help improve soil quality when they are incorporated into the soil as green manure in the spring, which adds organic matter and nutrients to the soil.

Soil loss on strawberry and corn fields with and without winter cover crops in south coastal British Columbia

Crop	With up- and down-slope cultivation and planting and no erosion control	Winter cover crop planted in between the rows	Reduction in soil loss under the winter cover crop
	Soil loss (kg/ha)	Soil loss (kg/ha)	(%)
Strawberries (1991–1992)	6451	1382	78
Silage corn (1996–1998)	7729	184	76

L.J.P. van Vliet, Agriculture and Agri-Food Canada
R. Bertrand, B.C.Ministry of Agriculture and Food

Controlling water erosion on potato land in the Maritimes

Land under potato production in the Maritimes is particularly vulnerable to soil erosion by water, because row crops like potatoes leave much of the soil's surface exposed to the elements for long periods. Other factors that promote water erosion include

- high rainfall
- light-textured soils, with low organic matter content and poor drainage
- dense, compact subsoils
- cultivation on long, steep slopes
- inadequate inclusion of soil-improving crops in crop rotations
- up- and down-slope cultivation.

A wide range of conservation practices is needed to control the severe water erosion on Maritime potato lands. The most common methods are cross-slope cultivation, terracing, grassed waterways, and surface water inlets. Other complementary conservation practices include strip cropping, conservation tillage and residue management, cover cropping, and *mulching.*

In a comparison of two New Brunswick potato fields, Agriculture and Agri-Food Canada researchers found substantial reductions in soil lost from the field with diversions and grassed waterways compared to the field under up- and down-slope cultivation and no erosion controls (*see* Table below). Runoff from fields under potatoes was 4% of accumulated rainfall with erosion controls and 30% without.

Mulching (a new practice of spreading hay or straw on the field after potatoes are harvested) is being readily adopted in Prince Edward Island and experimented with in New Brunswick. One study showed that 4 tonnes of straw mulch per hectare reduced soil loss to 1.8 tonnes per hectare, compared to 3.1 tonnes of soil lost under 2 tonnes of straw mulch per hectare. Another mulching study showed that as little as 2.3 tonnes of hay mulch per hectare could reduce soil loss by 75%.

Seasonal runoff and soil loss from potato rotations under different management in New Brunswick

Crop and year	Accumulated rainfall[1] (mm)	Diversions and grassed waterways		Up- and down-slope cultivation	
		Runoff (mm)	Soil loss (kg/ha)	Runoff (mm)	Soil loss (kg.ha)
Grain/rye grass[2], 1990	707	32	106	25	285
Potatoes, 1991	582	42	1678	203	15 604
Potatoes, 1992	652	20	1156	159	21 825
Barley, 1993	687	8	63	34	489
Potatoes, 1994	583	14	200	182	24 852

[1] between 1 May and 30 November
[2] diversions/grassed waterway site was in grain, up- and down-slope cultivation site was in rye grass.

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G. Fairchild, J.-L. Daigle, and J. Damboise, Eastern Canada Soil and Water Conservation Centre

erosion. Doubling the use of conservation tillage and increasing the area in tame hay did not completely offset the negative effects caused by intensification of cropping, notably the large expansion of area in potato production (an estimated 39% of potato land is under conservation tillage).

Response options

Soils in the wetter regions of Canada should be the focus of remedial measures, because these areas

- have the greatest share of cropland in the classes of unsustainable erosion
- are generally the most prone to erosion because of precipitation patterns, intensive row crop production, and the unsuitability of some conservation methods such as no-till in some areas.

Erodible landscapes are often localized and relatively small but are a major site of soil loss. These areas are sometimes neglected or overlooked in broad scale conservation programs and should be targeted with practices, programs, and policies designed specifically for their needs. Such a targeted approach is particularly needed for the following key agricultural areas

- the Southern Coastal and Southern Interior regions of British Columbia, where the risk of water erosion appears to be increasing
- areas of intensive cropping in Ontario and Quebec
- the potato belt of northwestern New Brunswick and Prince Edward Island and the broader areas of Nova Scotia used to grow potatoes, vegetables, corn (both silage and grain), and berries.

Targeting the agronomic and engineering practices to erosion-prone sites in these areas would help to reduce water erosion. Management practices that help in controlling erosion include

- using conservation tillage and managing crop residues
- including forages in rotations
- planting row crops across the slope or following the land's contours
- strip cropping
- growing cover crops
- *interseeding* row crops with other crops, such as red clover
- winter cover cropping where soils are prone to erosion by winter runoff.

Research is needed into alternatives to no-till for areas where this practice is not viable, such as areas of intensive horticultural or potato production. Where water erosion is severe, conservation tillage and cropping systems might be inadequate to control erosion and runoff. Soil conservation structures, often more costly and labour intensive than using management practices, might be needed. These include

- terraces, or steps, to reduce a slope's steepness and length
- permanent small earth berms or diversions running along the contour
- grassed waterways, which trap sediment moving off the field.

Conclusion

Water erosion of soil has long been recognized as a serious threat to agricultural sustainability in the wetter areas of Canada — British Columbia, Ontario, Quebec, and the Maritime Provinces — and to a lesser extent on the Prairies. The reduced risk of water erosion shown by the indicator presented here is a positive trend resulting from shifts in farming practice (e.g., tillage and cropping), attitudes towards land stewardship, and management strategies. However, the trend could quickly reverse under changing economic conditions and policies.

A large share of Canadian farmland is still subject to the unsustainable loss of soil resulting from water erosion. Generally, these areas are used for intensive row crop or horticultural crop production, except for some smaller areas with natural limitations of topography or soil. It can be concluded that improvement is needed in farming practice, management strategies, policies, delivery of information, monitoring of impacts, or all of these in these areas. One facet of the erosion problem that cannot be addressed with simple cropping and tillage strategies is the link between intensifying farming and erosion. Work is needed to identify what factors motivate increased intensification and to formulate programs that deal with the impact of broad scale economic issues on erosion risk.

The next steps in further reducing the risk of water erosion include

- setting goals for the share of farmland in the tolerable risk class in various agricultural areas of Canada.
- targeting programs and policies at areas that are particularly erosion-prone or have large areas in the unsustainable risk classes.

Related Indicators

The Risk of Water Erosion is one component of the overall risk of soil erosion, along with the Risk of Wind Erosion and the Risk of Tillage Erosion. Water erosion, like wind and tillage erosion, contributes to a loss of organic matter from the soil, thus affecting the amount of Soil Organic Carbon. Surface runoff can also carry agricultural nutrients into waterways, linking this indicator particularly to the Risk of Water Contamination by Phosphorus and also to the Risk of Water Contamination by Nitrogen. As soil becomes eroded, more fertilizer may be needed to maintain fertility, thus affecting the Management of Farm Nutrient and Pesticide Inputs, and more energy may be needed to support production, altering Energy Use. A key way to control erosion is by increasing Soil Cover by Crops and Residue.

7 Risk of Wind Erosion

G. Padbury and C. Stushnoff

Geographic scope: Prairie Provinces
Time series: 1981, 1991, 1996

Highlights

- Wind erosion is a natural process that removes topsoil from cultivated agricultural lands, contributing to an overall decline in soil health, including a breakdown of soil structure and reduced soil fertility.

- An indicator was developed to estimate the Risk of Wind Erosion on cultivated land. It can also be used as an indirect measure of a change in soil quality. The indicator is based on soil, climate, and management factors. Five classes of risk were identified: negligible, low, moderate, high, and severe. The indicator was applied to the Prairie Provinces, the Canadian region most prone to wind erosion. The performance objective is to have all agricultural soils in the negligible and low risk classes.

- Calculation of the risk of wind erosion showed that about two-thirds of cultivated land in the Prairies is at moderate to severe risk of wind erosion without the use of any soil conservation practices.

- Between 1981 and 1996, the share of cultivated land at high to severe risk of wind erosion dropped from 15% (5 million hectares) to 6% (2 million hectares) because of changes in management practices. Implementation of reduced tillage technologies, coupled with a decline in the use of summerfallow in the Prairies, resulted in an overall decline of 30% in the risk of wind erosion during this period. The share of cultivated prairie land at negligible risk of wind erosion grew from 41% to 64% in this period. Improvements were greatest where sandy, highly erodible lands were converted from annual crops to perennial forages. Most of the land still at risk is located in the Brown and Dark Brown soil zones of southern Alberta and Saskatchewan.

- If the trend toward reduced tillage and less summerfallow continues in the Brown and Dark Brown soil zones, the risk of wind erosion is expected to decline even further. Further reduction in this risk is less likely in the Black and Gray soil zones, where summerfallow area is already relatively small and the inherent risk of soil erosion is less.

The Issue

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. However, it is in the arid Prairies, where large tracts of agricultural land lie unprotected from the wind, that the risk is by far the greatest. In fact, about two-thirds of the prairie region would be at moderate to severe risk of wind erosion if soil conservation measures were not taken. This fact was vividly borne out during the dust bowl years of the 1930s.

Measuring wind erosion

At an experimental site near Lethbridge, Alta., researchers measured soil losses of up to 30 tonnes per hectare as a result of a single erosion event, and losses of about 122 tonnes per hectare over a 7-month fallow period. Although the site was tilled excessively to promote erosion, the soil was of a type (clay loam) not particularly susceptible to erosion, and the field had previously been under no-till for 6 years. These results point to the susceptibility of the land in this region to wind erosion if protective measures are not taken. Based on the fastest rate of natural soil renewal for cultivated land and assuming no further erosion, it would take about 15 years to restore the lost topsoil. Data from this study, shown below, formed the basis for defining the class limits of the Risk of Wind Erosion indicator.

Soil losses during wind erosion events near Lethbridge, Alta.

Date	Duration of wind (h)	Maximum wind speed (km/h)	Soil loss (tonnes/ha)
1991 6 December	8	58	23
9 December	12	55	20
10 December	5	56	14
11 December	8	57	14
16 December	7	53	6
1992 3 April	7	58	30
4 April	3	50	6
5 April	8	47	5
9 April	2	43	1
13 April	1	51	2
18 April	10	55	12

F. Larney, Agriculture and Agri-Food Canada

Since that time the risk of wind erosion has been substantially reduced through the use of various land management practices. For example, many of the most susceptible lands have been seeded to perennial forages, and modern techniques of less summerfallow and improved residue management have further reduced the risk. An indicator is needed to assess how changes in management affect the risk of wind erosion over time, and to identify areas where this risk is of particular concern.

The Indicator

Description

We developed the Risk of Wind Erosion indicator to monitor the extent of cultivated land at risk of wind erosion, particularly as a result of changes in management practices. The risk of wind erosion was expressed in five categories: negligible, low, moderate, high, and severe. The indicator can also be viewed as an indirect measure of a change in soil quality. Because wind erosion is a process of soil degradation that results in decreased soil quality, a declining erosion risk is considered positive in terms of soil quality. The performance objective is to have all agricultural soils in the negligible and low risk classes.

Method of calculation

Pertinent climate data (e.g., wind speed and precipitation), along with information on land use and management, were linked to *Soil Landscapes of Canada* maps to provide an integrated land resource database. The risk of wind erosion was calculated using estimates of cropping systems and tillage practices from the *Census of Agriculture*. Linking the census data to the soil landscape maps provided an estimate of the change in land use and management on specific soil types. Using an erosion model, these estimates were in turn used to estimate the effect of these changes on the risk of wind erosion. This methodology is still evolving.

Estimating the risk of wind erosion involved two steps:

- estimating the erosion risk on bare, unprotected soil
- reducing that risk value according to the amount of crop residues left on the soil surface and their effectiveness in controlling erosion.

Wind erosion in the Fraser Valley, British Columbia

Wind erosion is not solely a prairie concern. In South Coastal British Columbia, Arctic high pressure systems occurring from time to time in the winter months cause strong winds to flow from the province's interior through coastal valleys to the ocean.

Before the 1980s, these outflow winds caused serious erosion on farms in the Abbotsford area of the Lower Fraser Valley. The cost of cleaning ditches to remove eroded soil was about $1.43 per metre. To deal with this issue, the Sumas Prairie Soil Conservation Group was formed, funded mainly under the National Soil Conservation Program and the agricultural component of the Green Plan, with some funds from local farmers and the City of Abbotsford. After the conservation group had been in operation for 7 years, the cost of ditch cleaning was $0.55 per metre. The drop in costs was attributed to the extensive use of cover crops promoted by the conservation group. Cover crops protect the soil from wind and keep it where it belongs — on the field, not in adjacent ditches.

R. Bertrand, British Columbia Ministry of Agriculture and Food

The wind erosion rate for bare unprotected soil was calculated using an erosion model based on soil texture and aggregation, along with climatic factors such as wind speed and precipitation. Crop residues were estimated at harvest, based on average yields and crop specific ratios of straw-to-grain yield. These values were then reduced according to cropping system, type and frequency of tillage, and a factor for overwinter decomposition to arrive at the amount of residue present during the April–May period when the risk of wind erosion is highest.

Limitations

Although the above procedure is considered accurate in assessing the change in erosion risk over time, the actual erosion risk may be underestimated in some cases. For example in using the generalized *Soil Landscapes of Canada* maps, small areas of highly erodible sandy soils and, to a lesser extent, clayey soils are often not included. Also, residue calculations are based on average management and weather conditions and thus do not account for excessive tillage or for abnormally low residue levels resulting most commonly from drought.

Results

Estimates of the relative risk of wind erosion on bare, unprotected soil across the Prairies show that about two-thirds of the cultivated land is at moderate to severe risk. Most soils in the highest risk class are sandy. Soils in the moderate risk class are generally sandy loam, although some clayey soils in the more southern regions are also considered at moderate risk. Otherwise, the risk generally decreases from south to north, reflecting northern conditions of

- lower wind speeds
- cooler temperatures
- higher precipitation.

Because these estimates pertain to bare, unprotected soil, they represent a theoretical condition. Still, they emphasize the potential risk of erosion if protective measures are not adopted and maintained.

Under present day land use and management practices, the potential erosion risk is dramatically less than that on bare, unprotected soils.

Figure 7–1

Risk of wind erosion on cultivated land in the Prairie Provinces under prevailing management practices

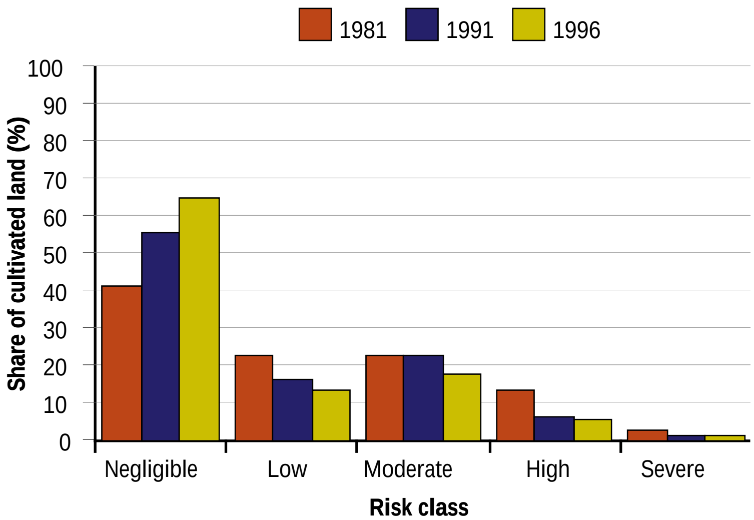


Figure 7-1 shows the share of cultivated prairie land in the five risk categories in 1981, 1991, and 1996. The share of cultivated farmland at high or severe risk of wind erosion declined from 15 to 6% between 1981 and 1996, a reduction of about 3 million hectares. Most of the areas that continue to be susceptible are found in the *Brown* and *Dark Brown soil zones* of southern Alberta and Saskatchewan (Fig. 7-2).

The risk of wind erosion in the Prairies declined by about 30% from 1981 to 1996, with about two-thirds of the decline occurring between 1981 and 1991 (Table 7-1). About three-quarters of the reduction can be attributed to a change in tillage practice. The remainder is mainly the result of a change in cropping practices, specifically less summerfallow.

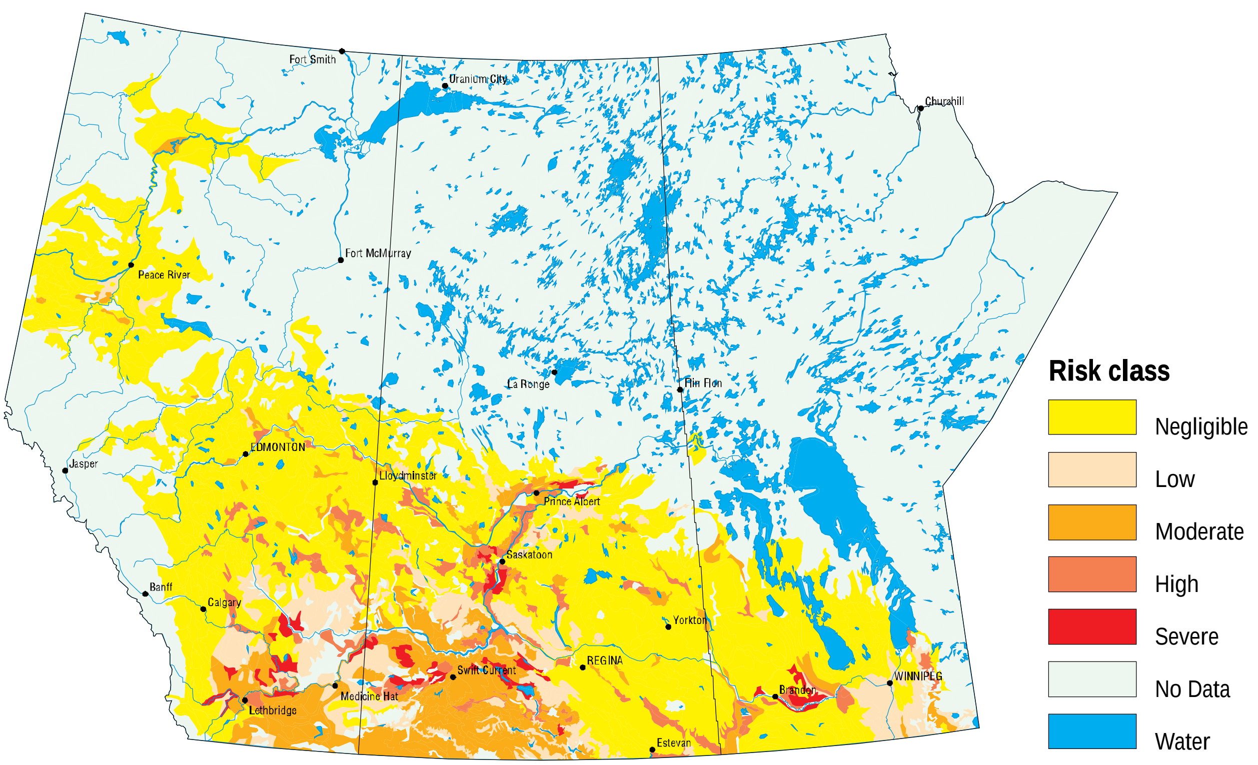
Interpretation

Over the past 20 years, the use of tillage in the Prairies has declined significantly. In 1996 almost half of cultivated farmland was managed under some type of reduced tillage, with about 15% being under no-till or *direct seeding* (*see* Box on tillage). Overall the reduction in tillage across the Prairies over the past 20 years or so has resulted in a 20 to 25% decline in the risk of wind erosion.

Changes in cropping practices, including the type of crops grown and the frequency of summerfallow, can also have a significant, and in some cases a dramatic, effect on wind erosion. According to census data, the change in cropping systems in the Prairies from 1981 to 1996 comprised about a 10% decrease in the area of summerfallow and a compensating increase in the area of oilseeds, *pulse crops*, and forages, with cereals remaining relatively stable (*see* Box on cropping). Overall, the change in cropping systems from 1981 to 1996 resulted in about a 5 to 10% decrease in the wind erosion risk.

Figure 7–2

Risk of wind erosion on cultivated land in the Prairie Provinces under 1996 management practices



Tillage in the Prairies

For thousands of years, farmers have used mechanical devices to improve land for agricultural purposes. From primitive hand cultivators to today's sophisticated tillage implements drawn by powerful tractors, these devices have been used to prepare soil for seeding and to keep weeds under control.

Early in this century most Canadian farmers relied extensively on the plow, an implement that incorporated virtually all of the crop residue into the soil in one pass, leaving it highly susceptible to erosion, particularly by wind. Following the dust bowl era of the 1930s, soil conservation practices designed to preserve residues were quickly adopted. These practices involved the use of newly developed implements, such as the Noble blade and rod weeder, and greater use of cultivators in place of the plows or disk-type implements.

In the early 1980s, the development of implements such as air seeders that could seed directly into standing stubble (direct seeding), coupled with the use of an array of affordable chemicals for weed control, significantly reduced the need for tillage itself. Reduced tillage leaves more crop residues on the soil surface, which help to

- protect against wind and water erosion
- trap snow
- conserve soil moisture
- provide a protective canopy for the growing crop
- maintain soil organic matter
- improve habitat conditions for soil organisms and larger wildlife.

The table below shows the extent to which these practices have been adopted in the Prairie Provinces prior to 1991 and between 1991 and 1996 — today nearly half of all prairie farmers use these methods. The decline in conventional tillage and the growing use of direct seeding is significantly greater in Saskatchewan than elsewhere in the Prairies. This trend is at least partly the result of the efforts of soil conservation organizations that have aggressively promoted direct seeding as an effective method of soil conservation, particularly the control of wind erosion.

Change in tillage practices in the Prairie Provinces between 1991 and 1996

Cultivated land (million ha)		Cropland (% of total area seeded)						Summerfallow (% of area)					
		Conventional tillage		Conservation tillage		Direct seeding		Conventional tillage		Conservation tillage		Zero tillage	
		1991	1996	1991	1996	1991	1996	1991	1996	1991	1996	1991	1996
Alberta	10.6	74	59	23	32	3	10	58	51	37	38	5	11
Saskatchewan	18.6	64	45	26	33	10	22	57	55	39	37	4	9
Manitoba	3.3	67	63	28	28	5	9	73	61	24	34	3	6
Prairies	32.5	68	53	25	32	7	16	58	54	38	37	4	9

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Table 7–1

Reduction in the risk of wind erosion in the Prairie Provinces between 1981 and 1996

Region	Cultivated land (million ha)	1981 to 1991 Change in risk (%) due to:			1991 to 1996 Change in risk (%) due to:			1981 to 1996 Change in risk (%) due to:		
		Cropping system[1]	Tillage practice[2]	Total	Cropping system	Tillage practice	Total	Cropping system	Tillage practice	Total
Soil Zone										
Brown	6.7	– 4	– 15	**– 19**	– 3	– 4	**– 7**	– 7	– 18	**– 25**
Dark Brown	7.1	– 4	– 22	**– 26**	– 4	– 12	**– 16**	– 8	– 31	**– 39**
Black	12.3	– 5	– 15	**– 20**	– 3	– 15	**– 18**	– 8	– 28	**– 36**
Dark Gray/Gray	6.4	– 5	– 9	**– 14**	– 9	– 10	**– 19**	– 14	– 18	**– 32**
Province										
Alberta	10.6	– 2	– 16	**– 18**	– 4	– 11	**– 15**	– 6	– 25	**– 31**
Saskatchewan	18.6	– 4	– 17	**– 21**	– 4	– 9	**– 13**	– 8	– 25	**– 33**
Manitoba	3.3	– 10	– 16	**– 26**	+ 3	– 5	**– 2**	– 7	– 20	**– 27**
Prairies	32.5	– 4	– 17	**– 21**	– 4	– 9	**– 13**	– 8	– 25	**– 32**

[1] related to the types of crops grown and amount of summerfallow
[2] related to the adoption of reduced tillage systems

Response Options

Although the trend toward less tillage and less summerfallow has markedly reduced the risk of wind erosion over the past 20 years or so, there are still about 2 million hectares of cultivated land in the prairie region that are at a high to severe risk. About 75% of this land is in the high risk class and consists mainly of sandy loam to loam-textured soils in the Brown and Dark Brown soil zones of southern Alberta and Saskatchewan. The most appropriate response options for these lands is the adoption of enhanced residue management strategies through reduced tillage (e.g., direct seeding, chemical summerfallow). The remaining area in the severe risk class comprises extremely sandy-textured soils scattered throughout the prairie region. The only practical response option on these lands is to plant perennial forages.

Conclusion

It is generally agreed that the recent trend toward reduced tillage and less summerfallow in the Prairies is the result of several factors besides the obvious benefits of soil conservation, including

- reduced labour, energy, and machinery requirements
- increased moisture use efficiency
- higher yields
- better options for weed control.

These benefits, coupled with the fact that only about half the area is currently under reduced tillage, suggests that the current trend is likely to continue.

If the trend of tillage and summerfallow reduction continues, particularly in the Brown and Dark Brown soil zones where the wind erosion risk is highest, the risk of wind erosion will decline further. However it must be kept in mind that climatic conditions over the past 15 years have been abnormally moist throughout a large part of these zones, and a return to more

Cropping practices in the Prairies

Farmers usually change their cropping practices in response to changing market and crop prices. The following table shows changes in cropping practice in the Prairie Provinces between 1981 and 1996.

The reduction in summerfallow is significantly greater in Saskatchewan than in Manitoba and Alberta, undoubtedly reflecting the proportionally greater use of summerfallow in Saskatchewan. It is also likely related to the greater use of direct seeding, because one of the side benefits of direct seeding is a reduced reliance on summerfallow due to improved moisture use efficiency.

The area of forage crops also increased slightly between 1981 and 1996, with the greatest increase occurring in the *Dark Gray* and Gray soil zones, where climatic conditions favour forages over annual crops. A notable exception, however, was the shift from annual crops to perennial forage in some of the highly erodible sandy areas of southern Saskatchewan and Alberta prior to 1991. This shift, which reduced the erosion risk in these areas by as much as 20 to 25%, was at least partly the result of government programs, such as the Permanent Cover Program, that paid producers to convert marginal erosion-prone annual crop land into pasture or permanent forage.

Change (%) in cropping practices in the Prairie Provinces between 1981 and 1996

	Cultivated land (million ha)	Fallow	Cereal	Oilseed	Pulse	Forage
Alberta	10.6	-8	-4	6	1	5
Saskatchewan	18.6	-13	1	7	3	2
Manitoba	3.3	-5	2	5	1	4
Prairies	32.5	-10	-1	7	2	3

Note: The share of cultivated land under the various crops in 1996 was: Fallow, 18%; Cereal, 55%, Oilseed, 12%, Pulse, 3%; Forage, 10%.

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normal or abnormally dry conditions could see a return to shorter rotations and more summerfallow. Moreover, economic conditions that favour the production of low residue oilseeds and pulse crops in place of cereals, or a significant increase in herbicide-resistant weeds, could also slow or perhaps even reverse the trend.

In the *Black* and *Gray soil zones*, further reductions in wind erosion risk are less likely. The area of summerfallow there is already minimal, accounting for only about 10% of the total cropland. And although summerfallow declined markedly from 1981 to 1991, there was only a minimal decline from 1991 to 1996, suggesting that further declines are unlikely (summerfallow actually increased in the Black soil zone in Manitoba from 1991 to 1996). Because of the generally low inherent risk of wind erosion, long rotations, and high crop yields in this region, residues levels are often enough to control erosion even with conventional tillage. Thus, although the trend toward reduced tillage generally enhances crop residue levels, this trend may not affect the risk of wind erosion very much in the Black and Gray soil zones, except for a few sandy, erosion-prone soils.

In the event of global climate change, particularly global warming with its presumed side effects (e.g., more chaotic weather and extreme events), the inherent risk of erosion would undoubtedly increase. What this will mean in terms of the actual risk of soil erosion is unpredictable, however, since the actual risk includes the component of human management. Technological and other advances may produce the means of coping with the potential pressures imposed on agriculture as climate changes. Documented and verifiable changes in climatic parameters should be included to the extent possible in future calculations of the indicator.

Related Indicators

The Risk of Wind Erosion is one component of the overall risk of soil erosion, along with the Risk of Water Erosion and the Risk of Tillage Erosion. Wind erosion, like water and tillage erosion, contributes to a loss of organic matter from the soil, thus affecting the amount of Soil Organic Carbon. As soil becomes eroded, more fertilizer may be needed to maintain fertility, thus affecting the Management of Farm Nutrient and Pesticide Inputs, and more energy may be needed to support production, altering Energy Use. Like the Risk of Soil Salinization, the Risk of Wind Erosion is a concern mainly for the Prairies. A key way to control erosion is by increasing Soil Cover by Crops and Residue.

8 Risk of Tillage Erosion

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Geographic scope: Provincial, ecoregion
Time series: 1981, 1996

Highlights

- Tillage erosion is caused when tillage implements loosen soil and move it downslope with the help of gravity. Over time, this movement results in large losses of soil from the tops of hills and knolls, and accumulation of soil downslope. Tillage erosion is a measure of the amount of soil lost from these upper slope areas.

- An indicator was developed to estimate the Risk of Tillage Erosion on Canada's cropland and to assess how this risk changed between 1981 and 1996 as a result of changes in agricultural management practices. The risk of soil loss from hilltops was expressed in five classes: tolerable, low, moderate, high, and severe. The performance objective is to have all cropland in the tolerable risk class.

- The risk of tillage erosion dropped in all provinces between 1981 and 1996 by values ranging from a high of 26% in Ontario to a low of 9% across the Maritime Provinces. During this period the amount of cropland at tolerable risk grew in all provinces except Prince Edward Island, which had little overall change. Quebec continued to have the largest share of cropland (75%) in the tolerable risk class in 1996, while Saskatchewan continued to have the smallest share (35%). Only New Brunswick (9%) and Prince Edward Island (10%) continued in 1996 to have a significant share of land at high to severe risk of tillage erosion.

- Areas showing limited improvement or an increased risk of tillage erosion between 1981 and 1996 include British Columbia's South Coastal and Southern Interior regions; Alberta's Parkland and Mid Boreal Upland; Manitoba's Prairie soil zone; Ontario's Algonquin–Lake Nipissing region; Quebec's St. Lawrence Lowlands, Central Laurentians, Southern Laurentians, Lac Temiscamingue Lowlands, Abitibi Plains, and Riviere Rupert Plateau; New Brunswick; Nova Scotia; and Prince Edward Island. These areas were characterized by higher inherent erodibility, intensive cropping, or both.

- Lower risk of tillage erosion is associated with conservation tillage and no-till practices, reduced area in summerfallow, increased area in forages, and the taking of marginal land out of production. In some cases, intensive cropping and inherent erodibility of the land offset the benefits of these practices. The risk of tillage erosion is expected to drop further in areas not limited by cropping options and complex topography, but may rise with market opportunities to intensify production of cash crops, especially on sloping land.

The Issue

Soil erosion is usually considered a natural process carried out by water and wind. However, erosion is also caused by agricultural practices, particularly tillage, independent of these natural processes. Tillage implements move soil mechanically, and on sloping land this movement is aided by gravity. The resulting progressive downslope movement, called tillage erosion, redistributes soil unevenly within a landscape. Typically soil is lost from the curved upper slope (convex) positions of the landscape and accumulates in the curved lower slope (concave) positions.

The mechanical movement of soil by tillage may contribute to subsequent losses of soil by natural means. For example, tillage erosion is an important means of delivering soil to areas of concentrated water flow, thus contributing to water erosion. Related as it is to wind and water erosion processes, tillage erosion may significantly affect the long term prospects of agriculture in terms of soil quality and crop production.

The removal of topsoil from convex areas in a field by tillage erosion changes the soil conditions in these areas by mixing in *subsoil*. This mixing

- reduces soil organic matter levels, soil fertility, and water-holding capacity
- increases droughtiness and alters the pH of the soil.

As soil quality diminishes on high points of a field, the crop yield from these areas drops off dramatically. Subsoil exposed on knolls or crests can also erode and be deposited downslope, where it covers more-productive soil and further reduces the yield potential in a field. In

The benefits and drawbacks of tillage

Throughout the history of agriculture, tillage has been used to prepare the soil for seeding. Breaking up the clods of soil not only makes a better seedbed, but also causes a rapid release of nutrients from the organic material in the soil, resulting in a surge of growth by the crop. However, continued tillage results in a loss of valuable organic matter and the eventual breakdown of soil structure. As soil is pulverized, it becomes more vulnerable to erosion and other processes of soil degradation.

Even with the availability of herbicides today, tillage is commonly used to control weeds on cropland. Shallow tillage disrupts weed roots, killing the weed or reducing its ability to compete with the crop. Although tillage reduces weed pressure, it also spreads weed seeds and rhizomes around the field and brings old weed seeds to the soil surface where they can germinate. In contrast, in an untilled field, weeds are more localized and can be managed by spot spraying with a herbicide. Under no-till, perennial weeds gain dominance over annual weeds, and different management strategies must be used.

Tillage is also used to deal with soil compaction. It breaks up the dense structure of a compacted soil, loosens the soil for easier root penetration, and aerates and dries the soil in the till layer, improving the seedbed conditions on poorly drained soils. These benefits are short lived though. Tillage does not make the soil less susceptible to compaction, and the problem soon returns, sometimes worse than before. The compressive force of tillage tools and tires may cause compaction below the till layer in the subsoil. Tillage pans are the result of many years of subsoil compaction. They prevent proper drainage of the soil and form a barrier to roots. Deep tillage, or *subsoiling*, can relieve subsoil compaction for a time, but again, it is a short term improvement to a persistent problem and may also bring unproductive subsoil into the till layer, reducing its productivity.

In the past, crop residues on the soil surface were considered unsightly and a barrier to good seed germination. Tillage was used to bury crop residues, resulting in a clean soil surface that made seeding and fertilizer application easier. But soil left bare in this way is more susceptible to the agents of erosion, so modern methods of reduced tillage leave some crop residues on the soil surface to protect it. Tillage is also used to incorporate manure into the soil.

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parts of southern Ontario, tillage erosion accounts for yield losses of 40 to 50% in such eroded landscape positions and can be more damaging than water erosion on some hilly terrain. Recent studies to measure the amount of tillage erosion provide information that can be used to assess the risk of tillage erosion on cropland. An indicator is needed to assess the effects of tillage on sloping farmland in Canada.

The Indicator

Description

We developed an indicator, Risk of Tillage Erosion, to estimate the extent of cultivated land at risk of tillage erosion and to monitor changes in this risk over time, particularly as a result of changes in management practices. This analysis is the first attempt at assessing the risk of tillage erosion in all regions of Canada. This risk is expressed in the following five classes: tolerable (less than 6 tonnes per hectare per year), low (6 to 11 t/ha/yr), moderate (11 to 22 t/ha/yr), high (22 to 33 t/ha/yr), and severe (greater than 33 t/ha/yr). Areas in the lowest class are generally considered at tolerable risk of soil erosion and able to sustain long term crop production. The other four classes represent conditions that are unsustainable, for which soil conservation practices are needed to support crop production over the long term. Erosion rates pertain only to the convex portion of the field, which rarely exceeds 25% of the field. The change in risk over time under prevailing management practices was expressed as a percentage change in the share of cropland in each class.

The indicator can be viewed as an indirect measure of soil quality. Because tillage erosion is a process of soil degradation that results in decreased soil quality, a declining erosion risk is considered positive in terms of soil quality. The performance objective for this indicator is to have all cropland in the tolerable risk class.

Method of calculation

The risk of tillage erosion was estimated as the product of *tillage erosivity* and the *tillage erodibility* of the landscape, based on the shape and gradient of the land. Tillage erosivity is a measure of the degree to which a tillage implement moves the soil and is a function of the type of implement, its operation, and the number of tillage passes made.

A representative tillage sequence was developed for each crop reported for each *Soil Landscapes of Canada* mapping area. These sequences accounted for the tillage erosivity associated with each crop under conventional, reduced, and no-till tillage systems. Data on crops and tillage practices were taken from the *Census of Agriculture* for 1981 and 1996. These data reflected fluctuations in cropland areas, shifts in the types of crops grown, and the implementation of conservation tillage and no-till practices over time. Because conservation tillage and no-till were used very little in 1981 and not reported in the 1981 census, it was assumed that changes in the risk of tillage erosion between 1981 and 1996 were the result of changes in management practices. Data were not available for 1986.

For each mapping area, landscape erodibility values were determined for the dominant and subdominant soil landscape and surface form associated with each landform. Slope gradient, length of convex slope, and the proportion of the landscape that is convex were assigned to each surface form. Landscape erodibility, tillage erosivity, erosion rate, and percent change in erosion rate were estimated for each qualifying mapping area.

The share of cropland falling in each risk class was calculated for each province and agricultural region or ecoregion. Results are presented provincially, and regional results are highlighted in the interpretation. Changes in the erosion values in each province over time show a trend of improvement or decline.

Limitations

In calculating soil loss using the indicator, it was assumed that tillage was conducted up- and down-slope for all operations. The model used for the indicator does not consider the contribution of lateral soil movement, tillage depth and speed, and tractor and implement factors, as they have not been fully developed and described yet. Information about the effect of soil properties that may affect the resistance of soil to displacement was insufficient and not included.

The soil loss reported occurs only on the convex portion of the landscape and was assumed to be uniform over that area. The impact of complex-sloped landscapes and slope discontinuities, which may result in greater soil losses at specific locations, was not taken into account. As more research is carried out on the factors contributing to tillage erosion, the model will be adjusted to improve the estimates of soil loss.

Results

The risk of tillage erosion in 1981 and 1996 is shown in Table 8-1 by province. The change in the risk of tillage erosion between 1981 and 1996 is summarized in Table 8-2. The changes reflect the reduction in the type and number of tillage operations used in recent years.

Between 1981 and 1996 the overall risk of tillage erosion dropped by 24% in Canada. This drop was greatest in Ontario (26%), mainly because of large decreases in the Lake Erie Lowland and Manitoulin–Lake Simcoe ecoregions, which comprise 84% of the province's cropland. The Prairie Provinces were similar in their change, with a drop of about 24% in tillage erosion risk. Although two of Quebec's ecoregions showed an increase in the risk of tillage erosion during this period, this increase was offset in the province as a whole by decreased risk in other ecoregions, to give an overall drop of about 10%. Most provinces saw a rise in the share of cropland at tolerable risk of tillage erosion between 1981 and 1996, as well as a drop in the share at high to severe risk. The exceptions were New Brunswick and Prince Edward Island, which still had almost 10% of their cropland at high to severe risk of tillage erosion in 1996.

Despite this overall improvement, several regions showed an increase in the risk of tillage erosion on at least 5% of their cropland between 1981 and 1996. These regions are

- British Columbia's South Coastal (16%) and Southern Interior (12%) regions
- Alberta's Mid Boreal Upland (6%)
- Quebec's St. Lawrence Lowlands (14%), Central Laurentians (13%), Southern Laurentians (6%), Lac Temiscamingue Lowlands (27%), Abitibi Plains (10%), and Rivière Rupert Plateau (70%)
- New Brunswick (17%) and Prince Edward Island (17%).

Because of the increased risk of tillage erosion in these regions, significant improvements in other areas of these regions were less apparent.

Interpretation

The trend in tillage erosion risk between 1981 and 1996 essentially reflects the degree to which farmers have changed the type of tillage equipment and reduced the number of

Table 8-1

Risk of tillage erosion on Canadian cropland

	Share (%) of cropland* in various risk classes									
	Tolerable		Low		Moderate		High		Severe	
Province	1981	1996	1981	1996	1981	1996	1981	1996	1981	1996
British Columbia	30	50	42	36	28	14	0	0	0	0
Alberta	47	62	24	19	26	19	3	0	0	0
Saskatchewan	29	35	14	19	52	46	5	0	0	0
Manitoba	22	44	53	38	24	18	1	0	0	0
Ontario	33	41	21	35	43	24	3	0	0	0
Quebec	68	75	21	16	11	9	0	0	0	0
New Brunswick	33	38	26	32	32	21	3	8	6	1
Nova Scotia	40	66	52	28	8	6	0	0	0	0
Prince Edward Island	50	50	29	30	10	10	11	10	0	0

* Although percentages refer to total area of cropland, ratings for the risk of tillage erosion actually pertain only to convex parts of slopes on this land, where tillage erosion is likely to occur.

Table 8-2

Change in the risk of tillage erosion in Canada between 1981 and 1996

Province	Overall change (%)	Share (%) of cropland* for which the risk of tillage erosion changed between 1981 and 1996				
		Increase	No change	Decrease		
		> 5%	+/– 5%	5–15%	15–25%	> 25%
British Columbia	– 19	5	10	22	33	30
Alberta	– 25	0	1	16	39	43
Saskatchewan	– 24	0	0	0	74	26
Manitoba	– 24	1	3	12	45	39
Ontario	– 26	0	2	13	34	51
Quebec	– 10	12	34	32	15	7
New Brunswick	– 8	17	19	35	18	11
Nova Scotia	– 15	3	9	29	41	18
Prince Edward Island	– 2	17	40	43	0	0

* Ratings apply to convex parts of slopes on this land. Data for 1986 were not available.

tillage passes. Adoption of conservation tillage and no-till practices has been made possible by the advent of direct-seeding equipment and a wide array of chemicals to control weeds on untilled fields. Less-intensive crop production, reduced area under summerfallow, and the removal of marginal land also contributed to lower erosion rates.

The landscape's erodibility also contributed significantly to estimates of the risk of tillage erosion. Regions in each province with the greatest tillage erosion risk in both 1981 and 1996 were those with the greatest inherent erodibility, except for Saskatchewan. Still, this influence may be overshadowed by cropping practices. For example, Ontario's level to gently sloping Lake Erie Lowland had the lowest regional landscape erodibility value in the province yet showed the second highest risk of erosion because of the area's intensive crop production. In British Columbia, moderate to steep slopes on rolling landscapes in the Central Interior generated a high inherent erodibility value, but large areas of low-intensity cropping moderated the region's tillage erosion potential.

In British Columbia, increased intensification of crop production in some areas accounts for the growing risk of tillage erosion in the South Coastal and Central Interior regions. Cereal production on steep slopes in the Central Interior resulted in moderate erosion losses, but these were offset to some extent by the production of forages. Widespread adoption of conservation tillage and no-till resulted in doubling the share of Peace River cropland at tolerable risk of tillage erosion (from 31 to 60%).

Soil translocation on sloping land in Ontario

Tillage erosion is a major cause of the loss of topsoil from knolls in the rolling landscape of Ontario's farmland. In a study in southwestern Ontario, soils along several hillslopes were labelled with a radioactive tracer and then tilled up- and down-slope. Tillage consisted of conventional tillage operations, which included plowing with a moldboard plow, two passes with a tandem discer, and one pass with a C-tine cultivator.

When movement of the labelled soil was measured, it was found that upslope tillage moved 90 kilograms of soil up the hill for every 1 metre of slope width. Downslope tillage moved 142 kilograms of soil down the hill for every 1 metre of slope width. Combining these results, there was a net movement of 52 kilograms of soil downhill for every up- and down-slope operation. Assuming that one sequence of tillage operations occurs every year and is carried out upslope and downslope equally often, soil would move downslope at a rate of 26 kilograms per metre of slope width each year.

The soil displaced from this area was estimated at 54 tonnes per hectare per year. Tillage erosion accounted for at least 70% of all erosion that took place in this area.

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In the Prairie Provinces, the share of cropland at tolerable risk of tillage erosion doubled in Manitoba and grew by 15% in Alberta and 6% in Saskatchewan between 1981 and 1996, mainly as a result of adopting conservation tillage and no-till, reducing the area under summerfallow, and increasing the area in forages. Some regions, such as the Mixed Grassland and Parkland ecoregions of Saskatchewan, had high inherent erodibility, which continued to place a good share of their cropland at moderate risk of tillage erosion in 1996.

Ontario and Quebec increased their share of cropland at tolerable risk of tillage erosion by 7 to 8% between 1981 and 1996, giving Quebec the largest share of cropland in this class (75%). Some areas, such as Ontario's Manitoulin–Lake Simcoe region, had slightly higher erosion risk than other regions in 1996 because of high inherent erodibility. Other regions faced a growing risk of tillage erosion because of increased cropping intensity or a reduction in the area under grains or alfalfa.

In the Maritime Provinces, the risk of tillage erosion dropped largely as a result of adopting conservation tillage (no-till data for this region were unreliable) and changing crop rotations. In New Brunswick and Prince Edward Island, continuing high risk of tillage erosion is particularly associated with potato production on steep slopes. The lower erosion risk in Nova Scotia is partly attributed to the smaller area of cropland used to produce potatoes and the larger area used to produce berry crops.

Response Options

As a process controlled by humans, tillage erosion can be stopped by not tilling. However, this option is not suitable in all agricultural settings, although reducing the number of primary and secondary tillage passes is often possible.

As well, the risk of tillage erosion can be reduced by

- reducing the speed and depth of tillage
- varying the tillage pattern (depth and direction)
- reducing the size of implements (tillage implements tend to level soil and will do so less if they are smaller; *see* Box on tillage implements)
- switching to other tillage systems, using mulch or no-till if possible
- contour cultivation (tilling across the slope instead of up-and down-slope), which reduces the variation in tillage depth and speed
- keeping knolls covered with vegetation as long as possible
- replacing soil that is lost from knolls by moving it back up from lower slope positions with up-slope tillage.

Altering tillage practices is only part of soil conservation management. Erosion can also be reduced by changing cropping systems. For example, including forage crops in rotations reduces tillage requirements and also contributes to rebuilding soil structure and organic matter levels. Growing cover crops also helps to rebuild soil organic matter. In some cases it

Tillage implements move soil

Tillage implements move a large amount of soil in agricultural landscapes. Under intensive tillage systems, they may move as much as 10 million kilograms of soil per hectare annually. Even under conservation tillage systems, this figure may be as much as 4 million kilograms. It is important to know how far the soil is moved as well as how much is moved. Most tilled soil moves only a short distance, but some soil moves more than 150 centimetres during each tillage pass. Translocation is a measure of how much soil moves, and how far.

The table below gives typical translocation measurements for four tillage implements. Translocation is broken down into the amount that occurs on level ground and the additional amount that occurs for every percent of slope gradient from level. Upslope tillage results in a decrease in translocation, and downslope tillage results in an increase in translocation, the effect of gravity.

Tillage implement	Translocation on level ground (kg / m of tillage width)	Additional translocation on sloping ground (kg / m per percent of slope gradient)*
Moldboard plow	75	1.3
Chisel plow	50	0.9
Tandem disc	50	2.1
Field cultivator	60	0.6

* These numbers are positive or negative depending on whether tillage is up- or down-slope.

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may be necessary to retire the land or plant it to permanent cover if it is too badly damaged by erosion to be productive any longer. Research is needed to develop erosion control practices that suit agricultural conditions in Canada's various regions.

Targeting the following susceptible areas would help to reduce the risk of tillage erosion in Canada:

- steeply sloping convex areas, such as those of New Brunswick's potato land and British Columbia's interior regions
- complex, hummocky regions under conventional tillage, such as those in Saskatchewan and Ontario
- small regional cropland areas with high inherent erodibility, such as in Quebec.

Conclusion

Tillage erosion has only recently been recognized as an important component of the erosion that takes place on Canada's agricultural lands. This indicator analysis shows the potential effects of tillage erosion on agricultural sustainability wherever cropland is cultivated. Most of Canada's cropland is susceptible to tillage erosion under conventional crop management practices. However, the drop in the risk of tillage erosion between 1981 and 1996 shown by this indicator is a positive trend resulting from shifts in land stewardship attitudes, crop production practices, and the availability of conservation management strategies. This change is necessary to maintain both long term productivity and short term economics.

In some parts of Canada, however, crop production is intensifying, and there has been little if any improvement in the risk of tillage erosion. Producers may want to control erosion but are met with limitations in crop rotations or tillage practices because of local growing conditions or market demands.

Dramatic improvements over the last 20 years with the introduction and wide acceptance of conservation practices are most noticeable where landscape and crop options are not as limiting. In the short term, regional differences across the country will likely continue, with inherent landscape factors and regional cropping limitations influencing the degree to which the risk of tillage erosion continues to decline.

The fact that there are still significant portions of all agricultural areas in Canada that do not fall in the tolerable risk class for tillage erosion indicates that further measures to reduce the risk are needed. Generally, these measures should be targeted at higher-risk areas, such as those of high inherent erodibility and intensive row cropping or horticultural production. These measures include encouraging the adoption of currently known conservation practices and management strategies, developing new technologies for erosion control, improving the delivery of information to producers, monitoring changes in erosion risk, and directing policy to this issue. Soil erosion control programs in all provinces have targeted water and wind erosion but now need to consider tillage erosion as well.

Related Indicators

The Risk of Tillage Erosion is related to the Risk of Water Erosion in that tillage erosion displaces soil from upper slope positions and delivers it to lower slope positions where water erosion can continue the transport of sediments from a field. This in turn affects the Risk of Water Contamination by Nitrogen and the Risk of Water Contamination by Phosphorus. This indicator is also related to the Risk of Wind Erosion, because both wind and tillage erosion act mostly on the soil at upper slope positions to move soil downslope. As tillage erosion removes topsoil from upper slope positions and deposits it in lower slope positions, it alters the distribution of Soil Organic Carbon and may call for different Management of Farm Nutrient and Pesticide Inputs. It also alters micro-habitats for soil organisms, thus affecting the Availability of Wildlife Habitat on Farmland. As soils become degraded under erosion, more energy may be needed to keep them productive, thus altering Energy Use.

9 Soil Organic Carbon

W.N. Smith, G. Wall, R. Desjardins, and B. Grant

Geographic scope: National, provincial
Time series: 1970–2010

HIGHLIGHTS

- Carbon (C) is the main component of soil organic matter, the presence of which is a major factor in soil quality. Loss of soil organic matter, and thus of soil organic carbon, results in the breakdown of soil structure, greater vulnerability of the soil to erosion, and reduced fertility, all leading to reductions in yield and sustainability of the soil resource. Building up carbon stores in soils may help curb the accumulation of carbon dioxide, a greenhouse gas, in the atmosphere.

- An indicator was developed to estimate the change in Soil Organic Carbon levels in Canada's agricultural soils from 1970 to 2010. Indicator values were generated using the Century model, a computer simulation model that uses simplified soil–plant–climate interactions to describe the dynamics of soil carbon and nitrogen in various ecozone types. The performance objective is to stabilize the loss of soil organic carbon in all agricultural soils and to begin storing carbon in those soils for which this is feasible.

- Agricultural soils typically lose 15 to 35% of their original organic carbon in 10 to 20 years after they are first broken for agriculture. At this point, a new soil carbon balance is reached that may be further altered under various management practices. However, these changes are much smaller than those associated with first bringing a native ecosystem into cultivation. Carbon-rich soils, such as those of the parkland region of western Canada, may take much longer to reach the new agricultural balance of soil organic carbon.

- Using the Century model, it was estimated that Canadian agricultural soils lost organic carbon at a rate of 70 kilograms per hectare in 1970 and 43 kg/ha in 1990. They will stop losing organic carbon in 2000 and will accumulate it at a rate of 11 kg/ha in 2020. Accumulation is predicted to continue beyond 2010, reaching a limit within about 20 years from now. The share of Canadian farmland accumulating soil organic carbon is predicted to be 52% in 2010.

- The model estimates that Saskatchewan has been accumulating soil organic carbon since about 1994, but most other provinces will continue to lose soil carbon at different rates for many years. The situation in Saskatchewan heavily influences the national picture. Soil organic carbon losses in eastern Canada are lower than those in the west, because eastern soils have been cultivated longer and tend to be closer to equilibrium.

- The rate at which soil organic carbon is lost has dropped considerably in most parts of Canada since 1990 as a result of greater adoption of no-till, reduced area in summerfallow, and increased crop yields. No-till is most effective in enhancing levels of soil organic carbon in fine-textured soils.

- Erosion has a significant effect on the change in organic carbon in the soils of eastern Canada. Assuming that no soil is lost to waterways because of erosion, the model predicts that in 2000 eastern Canadian soils would gain 94 kilograms of soil organic carbon per hectare. In the same year, if 15% or 100% of eroded soil is lost to waterways, soils would lose 19 or 94 kg C/ha, respectively.

The Issue

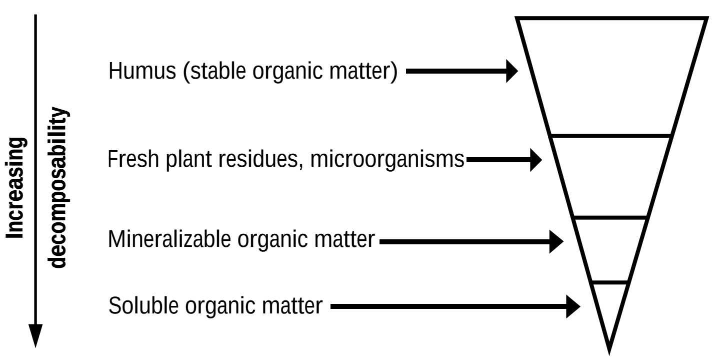
Carbon (C) is the basic building block of the organic matter that makes up all living things. Carbon is first captured from the air as carbon dioxide by plants during *photosynthesis* and then moves through the food chain as animals eat plants and other animals. Eventually all carbon returns to the soil as plants and animals die and their organic matter decomposes, or to the atmosphere as animals respire carbon dioxide or decomposing material emits gases that contain carbon. Organic matter offers many benefits to soil (*see* Box).

Composition of organic matter in soil

Soil organic matter makes up about 5 to 10% of most agricultural soils. Like the plants and animals from which it derives, it is composed of carbon chains and rings to which other atoms are attached. The terms *soil organic matter* and *soil organic carbon* are often used interchangeably, because carbon, the key component of organic matter, is readily measured in the laboratory. Soil organic matter typically contains about 50% carbon, 40% oxygen, 5% hydrogen, 4% nitrogen, and 1% sulphur.

Soil organic matter consists of compounds or fractions that decompose at different rates. The decomposability of organic matter varies along a continuum, but current methods identify at least two fractions — stable organic matter and active organic matter. Humus — a dark brown, porous, spongey material with a pleasant, earthy smell — makes up most of the organic matter in soil and is considered stable, because it has been processed by micro-organisms. Active soil organic matter receives inputs from fresh plant residues and micro-organisms that are susceptible to decomposition. This active fraction releases nutrients for plant growth. It also releases compounds (e.g., nutrients, pesticides, greenhouse gases) to aquatic systems and the atmosphere.

Fractions of soil organic matter



E.G. Gregorich and B.H. Ellert, Agriculture and Agri-Food Canada

The benefits of soil organic matter

Organic matter offers many benefits to soil and is a key component of good soil health. For example, it

- holds soil particles together and stabilizes the soil's structure, making the soil less prone to erosion
- improves the ability of the soil to store and transmit air and water
- stores and supplies many nutrients needed for the growth of plants and soil organisms
- maintains soil in an uncompacted, workable condition
- binds potentially harmful toxins, such as heavy metals and pesticides
- retains carbon from the atmosphere.

E.G. Gregorich,
Agriculture and Agri-Food Canada

Agriculture involves removing native vegetation and cultivating the soil to prepare it for seeding. Researchers now know that about 15 to 35% of the carbon contained by native soils was lost within about 10 years after they were first cleared and developed for agriculture. Over the years of agriculture, some farming practices have contributed to further losses of organic matter and thus of *soil organic carbon* (carbon drived from organic sources), making the soil structurally unstable, erodible, and less fertile and productive in many agricultural areas of Canada.

Conservation farming practices used over the past 15 to 20 years have now stabilized the organic matter levels in many agricultural soils in Canada. They have done this by

- increasing the amount of organic matter added to soil, such as by adding manure and fertilizing to produce a more robust crop that returns more unharvested material to the soil
- reducing losses of organic matter and carbon, such as by managing crop residues and controlling erosion.

Agroecosystems capture carbon dioxide from the atmosphere, bind carbon in organic matter, and return some of it to the soil where it can be stored.

A benefit of accumulating soil carbon is the reduction of atmospheric carbon dioxide. Carbon dioxide is a major greenhouse gas that is building up in the atmosphere and is contributing to *global warming*, one of today's most serious environmental concerns.

An indicator is needed to assess how soil organic carbon levels are changing over time. Such an indicator is useful in identifying long term trends in soil quality and estimating the ability of agricultural soils to help offset terrestrial emissions of carbon dioxide.

The Indicator

Description

We developed an indicator that measures the rate of change in Soil Organic Carbon from 1970 to the present and projects to 2010. The indicator provides an estimate of current levels of soil organic carbon, considers the effects of current management practices on these levels, and predicts how these will interact to produce future levels of soil organic carbon. The performance objective for this indicator is to stabilize the loss of soil organic carbon in all agricultural soils and to begin storing carbon in those soils for which this is feasible.

Method of calculation

We used the Century model (*see* Box) to predict the rate of change in soil organic carbon in Canada's agricultural soils. Simulations were performed on a representative sample (15%) of Canadian landscapes (numbering 180). The study landscapes were selected to be representative of a

- major soil group (Brown, Dark Brown, and Black Chernozems; Gray, Gray Brown, and Dark Gray Luvisols; Gleysolic; and others)
- textural class.

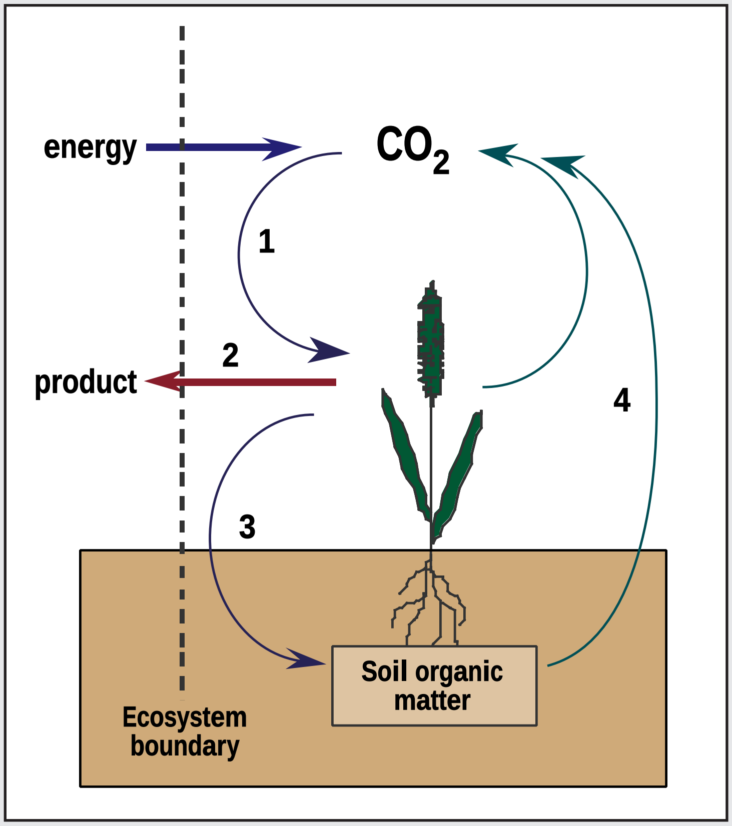
Erosion values used in the model were taken from calculations of the indicator Risk of Water Erosion, also presented in this report. Erosion was not included in calculations for western Canada, because it is generally thought that erosion there mainly redistributes soil in the agricultural landscape rather than removes it. Calculations for humid regions of British Columbia and eastern Canada were carried out using the landscape erosion values and the further assumptions that 0%, 15%, and 100% of

The carbon cycle in agriculture

When crops carry out photosynthesis, they convert carbon dioxide from the atmosphere (1) and water from the soil into carbon-rich compounds, called carbohydrates, to help them grow. In agriculture, part of the mature plant is harvested, so some carbon is exported out of the agricultural system (2). The rest of the plant — roots and stem — is left to decompose.

Soil microbes carry out decomposition of the crop residues, changing them into soil organic matter (3). During this process, the microbes decompose the residues and respire carbon dioxide as a waste gas, releasing it back into the atmosphere (4). The rate of decomposition is controlled by the quality of the crop residues, the type and number of soil organisms, and the physical and chemical environment in the soil. Another way that carbon is removed from soil is the erosion of soil organic matter.

The amount of organic carbon held in soil is the difference between how much is added to the soil (as crop residues, manure, sewage sludge) and how much is lost (through respiration, mineralization, or erosion). Some soil experts believe that by using certain management practices, such as no-till, more carbon can be stored in agricultural soils, thus helping to curb the buildup of carbon dioxide, a greenhouse gas, in the atmosphere.



E.G. Gregorich and H.H. Janzen, Agriculture and Agri-Food Canada

The Century model

The Century model is a site-specific computer simulation model that makes use of simplified relationships of soil–plant–climate interactions to describe the dynamics of soil carbon and nitrogen in grasslands, croplands, forests, and savannas. It simulates above- and below-ground production of plant material as a function of soil temperature, available water, and nutrient availability.

This model has been extensively evaluated under different soil, climatic, and agricultural practices. These practices include planting, fertilizer application, tillage, grazing, and organic matter addition. Century has been tested in eastern and western Canada, the United States, northern Europe, and under tropical conditions.

W.N. Smith, Consultant

the eroded soil may be transported by waterways from the agricultural landscape.

Simulations were run for

- two tillage practices (conventional/minimum till and no-till)
- two to five crop rotations
- six time periods (four periods dating from agricultural conversion to 1986 for which management data were obtained from the literature; 1986–1992, based on 1991 *Census of Agriculture* data; 1993–2050, using yearly provincial core data from Statistics Canada to modify crop rotations).

No-till runs were added for only the last two periods, since no-till was used very little in Canada before 1986. No-till data were obtained from the 1991 and 1996 *Census of Agriculture*. Predicted values for the share of farmland under no-till were taken from a 1997 Agriculture and Agri-Food Canada survey of professionals (Table 9-1).

Rates of fertilizer application were obtained from the literature. The change in application rates for 1986–1992 and 1993–2050 was based on fertilizer consumption in 1990 and 1995, respectively.

The rate of change in soil organic carbon was calculated for the years 1970, 1980, 1985, 1990–1996, 2000, 2005, and 2010. Estimates were determined every year in the early to mid-1990s because of the rapid changes taking place in management practices at that time. We used the slope of a 10-year regression centred on each year to account for multi-year rotations. For rotations of longer than 5 years, the regression was done for twice the length of the rotation.

Four to ten Century runs were carried out for each mapping area, depending on the number of crop rotations and tillage practices used in each. The results were weighted by tillage type and crop rotation to calculate the rate of change in soil organic carbon for each mapping area. Model predictions are presented nationally and provincially or regionally (Ontario, Quebec, and the Atlantic Provinces are grouped as eastern provinces).

Actual and predicted use of no-till on Canadian cropland

Table 9–1

	Share (%) of cropland under no-till				
Province	**1991**	**1996**	**2000**	**2005**	**2010**
British Columbia	5	10	13	16	20
Alberta	3	10	17	23	28
Saskatchewan	10	22	30	35	38
Manitoba	5	9	12	15	20
Ontario	4	18	20	20	20
Quebec	3	4	7	9	11
Atlantic	2	2	2	2	2
Canada	**7**	**16**	**22**	**26**	**30**

Limitations

Estimating the dynamics of soil carbon is a very difficult task, involving a great deal of uncertainty. Very limited long term data sets exist to characterize soil organic carbon dynamics in the field. Existing field data have large statistical errors associated with the procedures of sampling and laboratory analysis, and thus are not useful for validating model predictions in the field. The use of a single model across the widely varying conditions of soil, climate, and farming practice throughout Canada also undoubtedly results in errors.

The indicator does not account for additions of manure or irrigation. Century simulations were carried out using 30-year climate normals, because they were to be run until 2050. Thus, the indicator is not responsive to climate change.

Results

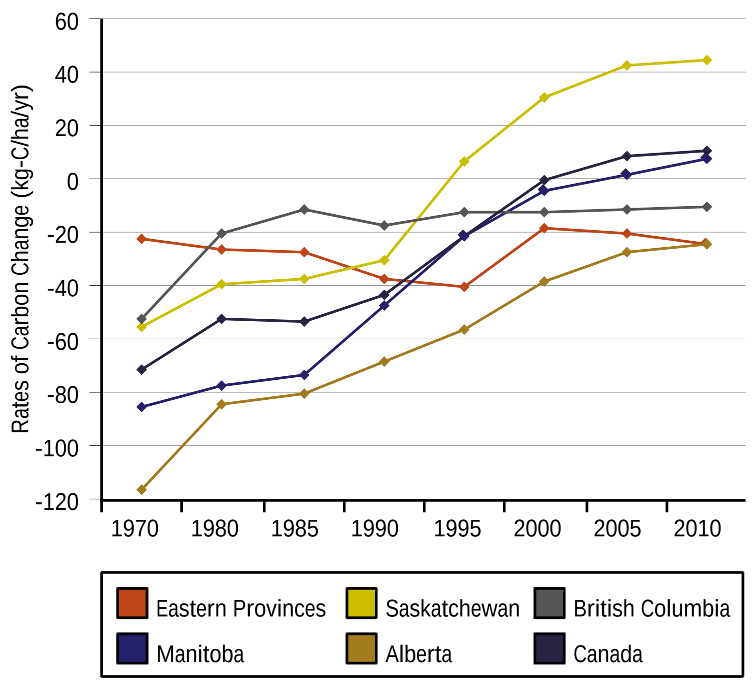
Figure 9-1 shows the estimated rate of change in soil organic carbon levels for Canada as a whole and the provinces (with the eastern provinces combined) from 1970 to 2010. Century estimates indicate that most provinces are continuing to lose soil organic carbon. In 2000, Alberta will be losing about 40 kilograms of soil carbon per hectare, the eastern provinces about 23 kg C/ha, British Columbia 15 kg C/ha, and Manitoba 5 kg C/ha. Still, all the western provinces show a steady trend of a decreasing rate of soil organic carbon loss, and Saskatchewan is predicted to have already begun reversing the trend and to be well into a period of accumulating soil organic carbon.

The model estimates that in 1990, Canadian soils were losing about 43 kg/ha of organic carbon, giving a net loss of about 1.8 *teragrams* of soil organic carbon from all Canadian farmland. The trend for Saskatchewan has a major influence on the Canadian trend, and the loss of soil carbon from Canadian soils is predicted to reach zero by 2000. In 2010, the model predicts that Canadian soils will be accumulating organic carbon at an annual rate of 11 kg/ha.

The model estimates that in 1970 about 13% of Canadian soils were accumulating carbon and that since 1990, this proportion has risen to about 46% (Fig. 9-2). The model predicts that by 2010, 52% of Canadian agricultural soils will be accumulating carbon.

Figure 9–1

Rate of change in organic carbon levels in Canada's agricultural soils



Century modelling indicates that adopting no-till has a significant effect on changes in the levels of soil organic carbon. When the model was run with actual and projected values for no-till, it was estimated that 2.2 teragrams of soil organic carbon would be lost overall from Canadian agricultural soils from 1990 to 2010.

Figure 9–2

Share of Canada's farmland accumulating soil organic carbon

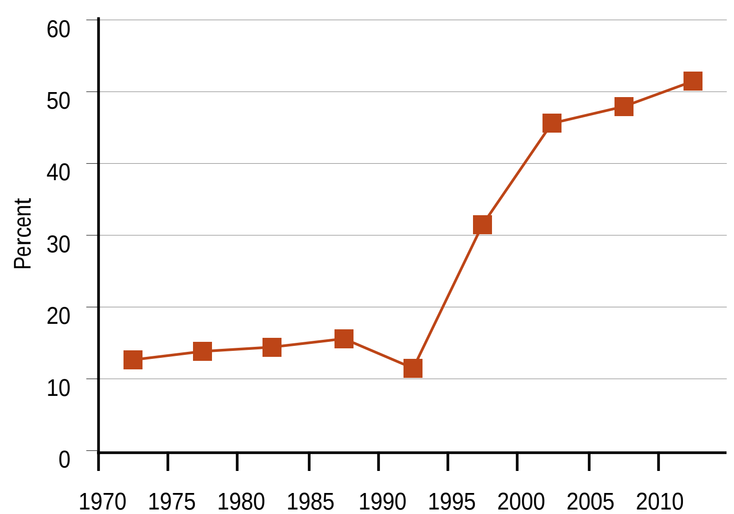
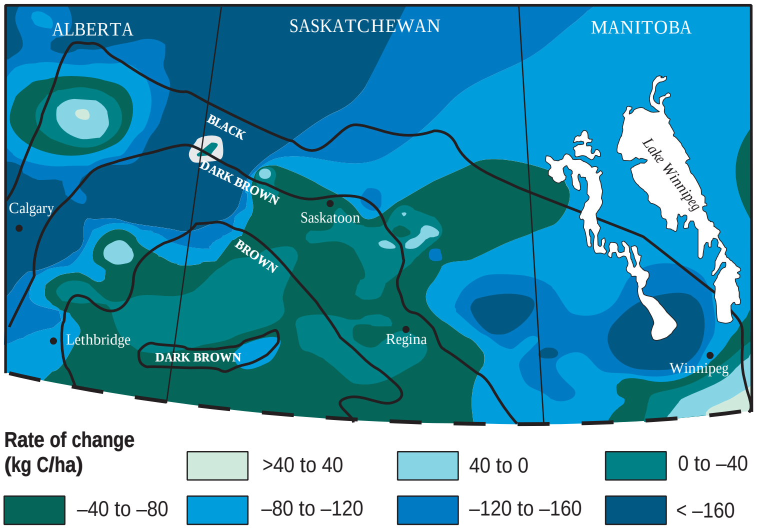


Figure 9–3

Rate of change in organic carbon levels in prairie soils in 1990



When the model was run assuming that 100% of Canadian cropland was under no-till for this period, it was estimated that soils would gain 30.3 teragrams of organic carbon.

About 80% of Canadian farmland is located in the Prairie Provinces. Figure 9-3 shows the distribution of the various rates of change in soil organic carbon in the Prairies in 1990. Estimates for northern agricultural regions of Manitoba are not as reliable as for other areas, because few mapping areas were used to characterize these regions. Areas of greater loss of soil organic carbon are evident in central Alberta and central Manitoba.

Carbon losses in eastern Canada were generally less than in the west. Most eastern land has been under cultivation for much longer, and the soils tend to be closer to equilibrium. Erosion was found to play a large role in soil organic carbon dynamics in eastern soils. When the model was run assuming no loss of eroded soil to waterways, the annual gain of soil organic carbon in eastern Canada was estimated at about 2 kg/ha in 2000. With a 15% loss of eroded soil to waterways, soil carbon would be lost at a rate of 18 kg/ha, and with a 100% loss, the rate of loss jumps to 98 kg/ha.

Interpretation

After 1990 the trend for the rate of change in soil carbon levels shows a marked upward turn for the Prairie Provinces and Canada as a whole, and more of a plateau for British Columbia and eastern Canada. The decrease in soil carbon losses from Canadian soils reflects a similar decrease in the Prairies, which has resulted from

- growing use of no-till
- reduced area under summerfallow
- increased use of fertilizer.

Since 1910 Canadian agricultural soils have lost about 1000 of a total 4300 teragrams of carbon. Levels of soil organic carbon declined rapidly during the first 20 years after cultivation, followed by a slower decline from 1930 to 1980. In comparison to early losses, the loss after 1980 is minimal (total losses of soil organic carbon since the land was first broken for agriculture are estimated at 23.8%, 24.2%, 24.4%, and 24.3% in 1980, 1990, 2000, and

Losses of soil organic carbon in real terms

It is important to keep the rates of carbon change reported in this chapter in perspective. Levels of soil organic carbon are currently approaching equilibrium, and estimated carbon losses from 1970 to 2010 are low in comparison to: 1) rates of loss in previous years, particularly shortly after first cultivation and, 2) the total amount of organic carbon in the soil.

In Canada, the rate of carbon loss shortly after soils were converted to agriculture was greater than 1000 kilograms per hectare per year in many soils. Most mineral soils in Canada contain 20 000 to 150 000 kg/ha of soil organic carbon. Our Century simulations for 2000 estimated rates of carbon loss of 2, 18, and 98 kg/ha/yr in eastern Canada when there was no loss of eroded soil to waterways, a 15% delivery rate, and a 100% delivery rate, respectively. The highest rate, 98 kg/ha/yr, amounts to about 0.2% of the carbon in the soil.

As well, there is at best a 1% error in determining total organic carbon content in soils in the laboratory. Such errors amount to more soil organic carbon than is reflected in current estimates of yearly rates of carbon change.

About 25% of the carbon in agricultural soils in Canada has been lost since cultivation. Carbon levels have almost stabilized, and unless there is a substantial change in farming practices, we expect there will be very little additional loss, and possibly minimal gain beyond the year 2000.

W.N. Smith, Consultant

2010, respectively). Most experts agree that further declines in the rate of soil organic carbon losses will be the result of management practices. If there are no major changes in farm management practices, it is expected that the limit of accumulating soil organic carbon will be reached about 10 to 20 years from now. Agricultural soils in Canada are predicted to gain soil organic carbon in 2010.

The prediction that Canada's agricultural soils will no longer lose soil organic matter after 2000 is based on our projection of management practices. The development of new technologies for farm management, as well as changes in consumer demand for crops, will most likely give rise to actual management practices in the future that differ significantly from what we have predicted.

Areas of the Prairie provinces that show continuing high rates soil organic carbon loss are those that had high levels of soil carbon before the land was broken for agriculture. Thus, these areas had more carbon to lose and have not yet reached the new soil carbon balance typical of agricultural ecosystems.

Although the practice of no-till helps to prevent the loss of soil organic carbon, cropping systems and other practices that build levels of soil organic matter are needed to optimize the ability of Canadian agricultural soils to sequester carbon. Researchers have found that the ability of no-till to improve levels of soil organic carbon depends to a great extent on soil type and texture (*see* Box). Controlling erosion is an important factor in reducing losses of soil organic carbon in eastern Canada. Furthermore, no-till has been associated with greater emissions of nitrous oxide, the greenhouse gas of greatest concern today. Thus, the benefits of this practice must be weighed against its potential negative effects on the environment.

Soil texture and changes in soil organic carbon

Research has shown that soil texture has a great deal to do with the effects of management practices such as no- till. Coarse-textured soils are more aerated than fine-textured soils, and thus provide a climate for greater decomposition of organic matter by soil microbes. Changes in soil organic carbon dynamics estimated by Century modelling are shown for some soil textures in the table below. Typically, sandy soils show the greatest rates of carbon loss. Only some finer-textured soils show a trend to begin accumulating soil organic carbon in this century.

Estimated rate of change in soil organic carbon (kg/ha/yr)

Soil texture	1980	1985	1990	1995	2000	2005	2010
Clay	–6	–8	1	21	37	40	38
Silty clay loam	–20	–18	14	33	48	55	56
Silty loam	–30	–32	–17	–16	–13	–9	–9
Fine sandy loam	–90	–82	–60	–36	–14	–4	0
Loamy sand	–89	–84	–91	–76	–34	–23	–25
Fine sand	–175	–147	–165	–153	–138	–128	–120

W.N. Smith, consultant

Response options

Farmers in many parts of the country have already begun to use management practices that build up organic carbon in soil. More effort is still needed, however, to raise their awareness of the long term benefits of maintaining good levels of soil carbon. Management options that contribute to building the level of organic carbon in soil include

- reducing the area in summerfallow
- increasing the use of reduced tillage systems and improved residue management
- controlling erosion
- rotating with crops that contribute more biomass to soil, including forages and legumes (*green manure*) in rotations.

Conclusion

The accurate estimation of the rate of carbon change in Canada's agricultural soils is a difficult undertaking. The models available to predict organic carbon dynamics in soil are *empirical*, and the use of a single model to describe the many different types of soil, climate, and agricultural practices across the country has its limitations. Still, the indicator gives a reasonable assessment of how soil carbon has been changing since the onset of agriculture and how it is predicted to change over the next 10 years or more.

Model predictions showed sensitivity to changes in agricultural management practices during the 1990s, particularly the greater use of no-till, reduced area in summerfallow, and increased fertilizer application in some parts of the country.

Technological development and changing markets may significantly change the way farmland is managed in the future. Calculation of this indicator uses a projection of future land management based on the current situation and trends. If this projection proves incorrect, estimates of the rate at which soil organic carbon is accumulating in Canadian soils will also be incorrect.

Building up carbon levels in soil is a worthy agricultural goal, both to protect the soil resource and sustain the industry's productivity, and to help curtail potential climate change by capturing atmospheric carbon in soils. At the same time, it must be remembered that efforts to build up soil carbon may have other results that are less desirable. For example, amending soil with animal manure or green manure may help to build up levels of soil carbon but may also contribute to the emissions of nitrous oxide, a greenhouse gas that is much more potent than carbon dioxide. Thus management decision making must take a holistic approach, considering a wide range of soil characteristics and functions and weighing the benefits and costs of any management practice for the agroecosystem as a whole and the environment beyond that system.

Related Indicators

Soils at a high Risk of Water Erosion and Risk of Wind Erosion are susceptible to the loss of Soil Organic Carbon. The loss of soil organic carbon on upper slope positions in the field is related to the Risk of Tillage Erosion. On the other hand, a greater degree of Soil Cover by Crops and Residues will help to protect and build soil organic matter. Adding organic matter to soil may involve applications of animal manure and mineral fertilizer, which may call for changes in the Management of Farm Nutrient and Pesticide Inputs. Soils with low levels of organic matter have less ability to retain nutrients, thus increasing the Risk of Water Contamination by Nitrogen and the Risk of Water Contamination by Phosphorus. Accumulating organic carbon in soils can also help improve the Agricultural Greenhouse Gas Budget

10 Risk of Soil Compaction

R.A. McBride, P.J. Joosse, and G. Wall

Geographic scope: Ontario, Maritime Provinces
Time series: 1981, 1991, 1996

Highlights

- Soil compaction caused by wheel traffic and tillage is one form of soil degradation. This process leaves the soil denser, less permeable to air and water, slower to warm up in the spring, more difficult to till, and more resistant to the penetration of plant roots. Compaction is a particular problem in fine-textured soils and causes millions of dollars in lost crop yield each year.

- An indicator was developed to assess the Risk of Soil Compaction for the major agricultural soils in Ontario and the Maritime Provinces. The degree of compactness of soil (low, moderate, high) was first estimated, and then it was determined whether these soils were likely to become less compacted, stay the same, or become more compacted over time based on trends in the cropping systems used between 1981 and 1996. The performance objective is to have a decrease over time in the area of row crops planted on soils susceptible to compaction, and an increase in the area of forage crops planted on highly compacted soils.

- Many of the study soils with fine-textured subsoils were estimated to be significantly compacted, especially in southern Ontario. The risk of further compaction in these subsoils is not as great as for many other soils in eastern Canada. Different cropping systems or other management practices may help to reduce the degree of compactness in these soils and improve crop yields.

- Between 1981 and 1996, the area of farmland with both highly compacted subsoils and cropping systems capable of improving soil structure and reducing soil compactness (e.g., forage, pasture) shrank by 15% in Ontario, 21% in New Brunswick, 18% in Nova Scotia, and 11% in Prince Edward Island. There was little change in the distribution of these areas during this 15-year period.

- Between 1981 and 1996, the area of farmland with both soils susceptible to compaction and cropping systems likely to degrade soil structure and induce further soil compaction (e.g., corn, soybeans, vegetable or root crops) grew by 61% in Ontario, 47% in Nova Scotia, and 81% in Prince Edward Island, and shrank by 16% in New Brunswick. Areas of particular concern were central and eastern Ontario, Nova Scotia's Annapolis Valley, and much of Prince Edward Island.

The Issue

Soils with good structure have an arrangement of soil particles and air spaces that allows adequate movement of air, water, and nutrients through the soil. Soil compaction is a process that alters soil structure by packing soil particles and aggregates more closely together. Compaction reduces the volume of air spaces in the soil and increases its dry *bulk density*.

When soils become compacted, they are

- less permeable to water and thus more vulnerable to erosion
- poorly aerated
- slower to warm up in the spring and more difficult to till
- more resistant to the penetration of crop roots
- unable to produce a robust, high-yielding crop.

An estimated 50 to 70% of fine-textured soils in southwestern Ontario, covering about 2 million hectares (almost all cultivated), have been adversely affected by compaction. About 75% of this affected land is rated as moderately compacted and 25% as severely compacted. Corn producers in southern Ontario often cite soil compaction as the leading problem of soil and water conservation on their farms. Soil compaction is also perceived as a serious problem in some other agricultural regions of eastern Canada, including the St. Lawrence Lowlands of Quebec and intensively cultivated areas of the Maritime Provinces. Economic losses resulting from soil compaction by heavy machinery run into millions of dollars each year in both Ontario and Quebec.

An indicator is needed to estimate the extent and distribution of compacted soils in many of these regions of eastern Canada and to assess how certain farmland management practices are likely to affect this soil condition over time.

Compaction of agricultural soils in Quebec

The loss of soil organic matter, the deterioration of soil structure, and compaction were studied from 1981 to 1990 in Quebec as part of a larger study of the degradation of agricultural soils. The study focused on mineral soils, representing about 1.7 million hectares under crops. About 200 soil series were studied, broken into three major groups based on criteria such as soil texture.

Soil compaction was evaluated using indirect measures of the extent to which certain soil physical properties were modified. Significant increases in soil bulk density were taken as the sign that compaction had occurred. Compaction was not assessed on sandy soils, as it is not considered a limiting factor for crop production on such soils.

Overall, soil compaction was ranked as the fifth most important concern of soil degradation in Quebec. Study results indicated that about 100 000 hectares of soils in the province were affected by significant compaction. Two-thirds of these soils were located in the Monteregie (Richelieu, Saint-Hyacinthe, and south-west of Montreal) and central Quebec regions. Degradation of soil structure, the beginning of both compaction and erosion problems, was more widespread in these regions.

P. Beaudet, Ministère de l'Agriculture, de Pêcheries et de l'Alimentation du Québec

The Indicator

Description

We developed the Risk of Soil Compaction indicator to assess the likelihood that major agricultural soils in Ontario and the Maritimes would become more compacted, stay the same, or become less compacted under prevailing cropping systems in 1981, 1991, and 1996. The indicator was calculated using estimates of the actual degree of compactness of these soils (low, moderate, or high), followed by consideration of the likely effects of management over this 15-year period. The degree of soil compactness represents the maximum stress that has acted on a soil in the past, expressed in units of pressure (kiloPascals, kPa), and also identifies the maximum wheel load to avoid further significant compaction. Table 10-1 shows these three classes, along with the three corresponding classes of susceptibility to further soil compaction. The performance objective is to have a decrease over time in the area of row crops planted on soils susceptible to compaction, and an increase in the area of forage crops planted on highly compacted soils.

Method of calculation

The indicator is based on a numerical approach for interpreting soil survey data (called a *pedotransfer function*) that eliminates the need for an extensive and costly soil compaction testing program. This approach makes use of data on basic soil properties — organic carbon content, dry bulk density, and soil texture. Because this study was concerned only with mineral soils, only the second (the upper mineral layer of mineral soils) and third (the subsurface layer of mineral soils) soil layers noted on the *Soil Landscapes of Canada* maps were included in the analysis.

Classes of compaction risk were developed by linking the susceptibility classes (Table 10-1) to information on cropping systems derived from the *Census of Agriculture*. The Risk of Soil Compaction indicator was used to identify areas most likely to undergo a change in the state of soil compaction over time based on trends in cropping systems. The indicator was applied to the dominant soil components in Ontario, New Brunswick, Nova Scotia, and Prince Edward Island, and risk maps were generated.

Although many management practices can be used to protect against further soil compaction or help reduce existing problems with soil compactness, data on cropping systems were the most pertinent and easily obtained. *Census of Agriculture* data made it possible to review trends in cropping system categories between 1981 and 1996 and judge whether they were likely to lead to improvements in soil structure and the state of soil compaction (e.g., alfalfa, hay, improved and unimproved pasture) or have detrimental effects on these soil conditions (e.g., corn, vegetables, root crops such as potatoes). Soybeans would normally have been included in the latter group, but the area of this crop was first reported separately in the 1996 census, making it difficult to draw comparisons with earlier census data.

Areas with more than one-third of the farmland under cropping systems that help to decompact soil were superimposed on areas showing a high degree of soil compactness (thus with a

Table 10-1

Classes of soil compactness and susceptibility to further compaction

Soil compactness	Susceptibility to soil compaction
Low (0 to 20 kPa)	High
Moderate (20 to 100 kPa)	Moderate
High (greater than 100 kPa)	Low

Compaction of clay soils in Manitoba

Soil compaction is not the problem on the Prairies that it is in moister areas of Canada, mainly because most agricultural soils there are naturally less susceptible to this form of degradation and are usually dry when worked. What risk of compaction there is as a result of vehicle traffic on the field has dropped over the past 15 years with reductions in summerfallow area, the adoption of conservation tillage, and the use of wide (20-metre) tillage equipment.

However, in Manitoba a large share of arable land has heavy clay soils. These soils have low permeability, limited aeration, and high water-holding capacities. These properties produce an inherently compact and massive soil structure. A few recent studies suggest that natural soil consolidation processes play an overwhelming role in developing compact soil layers in the root zones of Manitoba soils. The same studies demonstrated that conventional and no-till practices occasionally affect soil physical properties, but much of this effect is confined to the tilled layer. By the end of the growing season, however, natural soil compaction processes can often obliterate the subtle differences brought about by tillage in this layer.

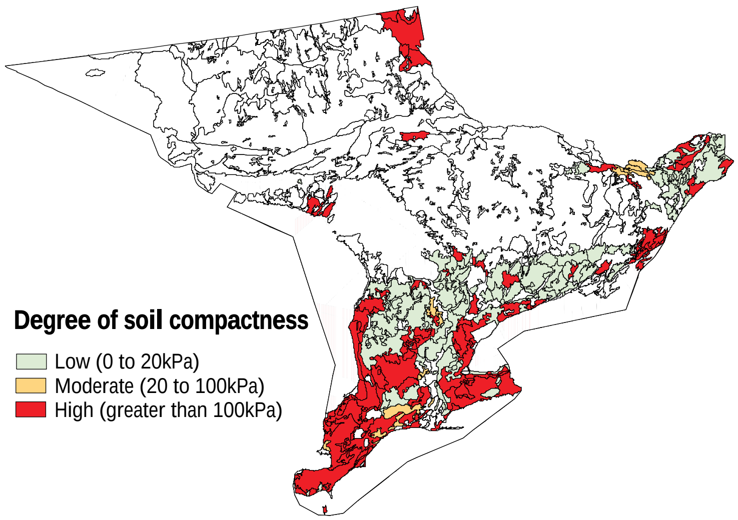
In Manitoba's Red River Valley, clay soils may be subjected to heavy traffic when very moist because of wet conditions during seeding or harvest. Because of the low permeability of these soils, moisture levels in the upper soil layer are often too high for significant soil compaction to occur in lower soil layers. Rut formation is more likely to cause soil compaction in these layers.

Where sufficient fall moisture occurs, yearly freeze–thaw cycles appear to be very effective in alleviating compaction that could be attributed to wheel traffic on clayey soils. In spite of the high mechanical stresses sometimes observed on many soils, crop roots tend to make use of macropores and fissures in the soil to grow to considerable depths. Consequently, soil compaction by vehicles in the Prairies rarely reduces crop growth or yields.

S. Tessier, Manitoba Agriculture

Figure 10–1

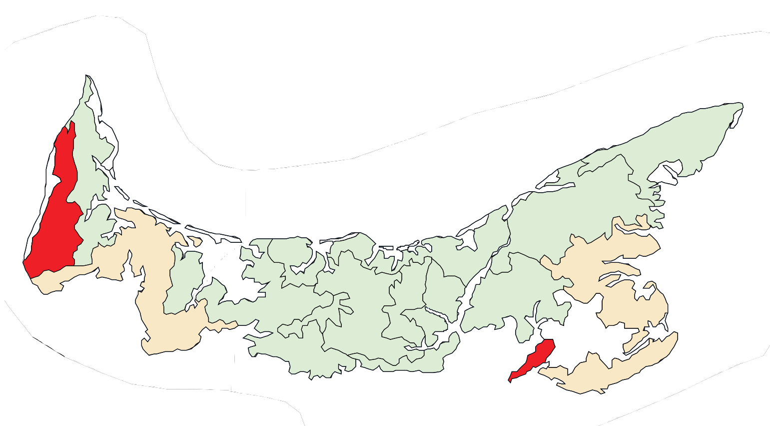
Degree of compactness of Ontario's agricultural soils



low susceptibility to further compaction). Areas with more than one-fifth of the farmland under cropping systems likely to cause compaction (or one-third if soybeans were included) were superimposed on areas showing a low to moderate degree of soil compactness (moderate to high susceptibility). Together these results were used to identify areas where the state of soil compaction might be expected to be improving, unchanged, or deteriorating.

Figure 10–2

Degree of compactness of Prince Edward Island's agricultural soils



Limitations

The indicator was initially developed using soil data from southern Ontario. Without further research and development, the indicator can be reliably applied only to the following types of soils:

- mineral soils (with an organic carbon content of less than 5%)
- *plastic* soils (i.e., soils containing at least 10% clay)
- soils for which the clay mineralogy is dominantly clay mica and chlorite (thus eliminating southern Quebec, some areas in eastern Ontario, and many regions of western Canada from the study).

Results

The most interesting and revealing results from this study were found for

- southern Ontario and Prince Edward Island (because agriculture was the principal land use)
- the untilled subsoil (subsurface) layers.

Many of the following results and much of the discussion relate to these locations and soil layers.

Figures 10-1 and 10-2 show the distribution of soil compactness classes in the agricultural regions of Ontario and Prince Edward Island. The three classes also represent the maximum wheel load (in kiloPascals) to avoid further compaction. In Ontario, the areas with the highest estimated degree of soil compactness were those regions where the clay content of the subsurface layers is high.

In New Brunswick, highly compacted soils were located in the upper Saint John River Valley and in some areas of the southeast. In Nova Scotia, highly compacted soils were concentrated in the Annapolis Valley, the Truro area, and along parts of the Gulf of St. Lawrence (Northumberland Strait) shoreline. In Prince Edward Island, only two areas were identified with highly compacted soils (Fig. 10-2).

Table 10-2 shows trends in provincial farmland areas under cropping systems that are likely

- to contribute to compaction of highly susceptible soils, or

Table 10–2

Farmland area for which the risk of soil compaction increased, remained the same, or decreased between 1981 and 1996, by province

Province	Farmland area (1000 ha)							
	Soils susceptible to compaction under cropping systems that cause compaction				Highly compacted soils under cropping systems that reduce soil compactness			
	1981	1991	1996	% Change 1981–1996	1981	1991	1996	% Change 1981–1996
Ontario	192.6	176.8	310.3	61	430.1	366.6	364.5	–15
New Brunswick	6.6	5.6	5.5	–16	24.7	19.1	19.5	–21
Nova Scotia	1.3	1.2	1.8	47	28.8	24.4	23.7	–18
Prince Edward Island	12.7	14.8	23	81	5.8	4.9	5.2	–11

Note: A positive number in the first % Change column is a negative trend for the indicator. A negative number in the second % Change column is also a negative trend for the indicator.

- to help decompact highly compacted soils (i.e., lower the dry bulk density).

All four provinces showed a relatively uniform and substantial drop (11 to 21%) between 1981 and 1996 in the area of highly compacted soils under cropping systems that improve soil structure and thus reduce soil compactness. Of equal or greater concern was the large increase (47 to 81%) in three provinces over the same period in the area of soils susceptible to compaction that were under cropping systems often associated with the degradation of soil structure and thus with increased soil compaction. Only New Brunswick showed a decrease (16%).

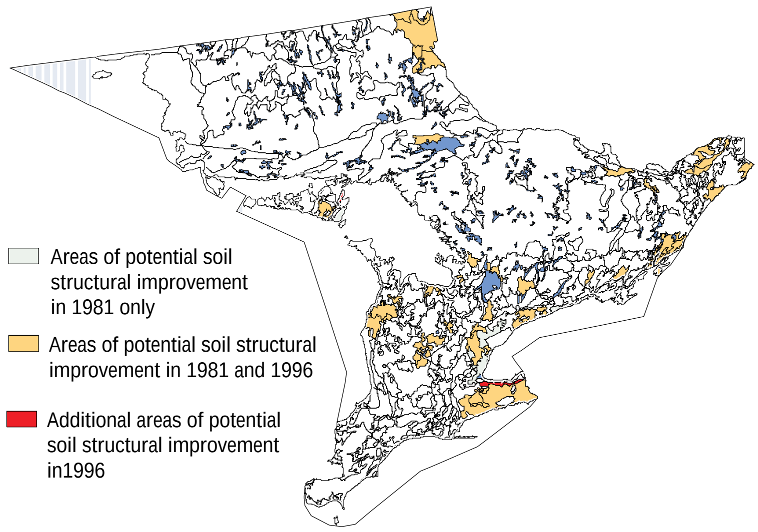
Between 1981 and 1996, most of the areas of highly compacted soils in northern and eastern Ontario maintained cropping systems that help reduce soil compactness over time (Fig. 10-3). Areas of highly compacted soils in some counties also retained more than one-third of farmland in such cropping systems. However, none of the areas with highly compacted soils in the extreme southwestern part of Ontario had more than one-third of farmland area under cropping systems that help reduce soil compactness over this 15-year period.

Over the 15-year period, many areas in southwestern and central Ontario with subsoils vulnerable to compaction (i.e., in the moderate- to high-susceptibility class) had more than one-fifth of farmland under cropping systems likely to cause compaction (Fig. 10-4). A small area of farmland showed a decrease below the row crop threshold between 1981 and 1996, but a much larger area (mostly in eastern Ontario) showed an increase. Soybean production was first reported separately in the 1996 census, and including this crop in the indicator analysis greatly increased the farmland area that was deemed to be at risk of soil compaction.

Between 1981 and 1996 in New Brunswick, most areas with highly compacted soils maintained at least one-third of the farmland under cropping systems that help reduce soil compactness, including areas in the Saint John River Valley and the southeastern portion of

Figure 10–3

Areas of Ontario's farmland where subsoils are highly compacted but cropping systems may alleviate soil compaction over time



the province. The distribution of areas at risk of further soil compaction (i.e., potato production areas in the Saint John River Valley) did not change in this 15-year period. In 1996 in New Brunswick, potatoes occupied more than 93% of the area under cropping systems that contribute to compaction.

All areas with highly compacted soils in Nova Scotia and Prince Edward Island maintained at least one-third of farmland under cropping systems that help reduce soil compactness between 1981 and 1996 (although the total area under such cropping systems decreased during this time). The area at risk of further compaction in Nova Scotia and Prince Edward Island expanded by about 50% between 1981 and 1996, although the actual area of land involved was comparatively small. In Nova Scotia, these areas were confined to the Annapolis Valley, whereas the eastern and central parts of Prince Edward Island were most affected. This increased risk of soil compaction in Prince Edward Island has resulted mainly from the expansion of the area under potato production. In 1996 in Prince Edward Island, potatoes occupied more than 96% of the area under cropping systems that contribute to compaction.

Soil management on a New Brunswick potato farm

Different soils, rolling terrain, and potato production combine to make soil erosion and compaction the two main concerns of soil management on a potato farm in St. Andre, N.B. With 210 hectares of owned cultivable land and up to 120 rented hectares, the farm produces potatoes, grain, and peas.

Soils in the area are naturally compacted (because they are formed from fairly dense glacial till), but farm machinery traffic has contributed to the problem. Potato production may involve several passes over the fields for planting, spraying, and harvesting. Harvesting must sometimes be carried out on wet soil, and harvesting equipment can be especially heavy with 200 barrels of potatoes on board. This traffic has created plow pans (very dense layers of soil) that reduce water infiltration and potato yields on some fields. In 1987, chisel plowing was introduced on these fields to reduce soil compaction and break up the *plow pan* that had formed at a depth of about 20 centimetres. Potato yields increased by as much as two times in the first years after this method was used, but after 8 years the problem of soil compaction returned, this time with a plow pan at a depth of about 30 centimetres. The farmer purchased a subsoiler tillage implement to break up this deeper pan. Water infiltration improved in the fields that were subsoiled.

About 160 hectares of the farm have terraces and grassed waterways that intercept surface runoff and eroding soil. Maintenance of these features occupies a good deal of the farmer's time. Periodically soil must be removed from lower terraces and waterways, where it collects. About 55 hectares is tile drained, improving water infiltration and reducing surface runoff and erosion.

Continuous potato production would contribute to further compaction of the soil, so potatoes are grown in a 2-year rotation (potatoes–grain or potatoes–peas with a winter rye cover crop). New land is being cleared to expand production, improve crop rotations, and make more efficient use of large equipment. As it is cleared, it is surveyed for terraces, grassed waterways, and drainage to conform to the field's topography and soil types.

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Eastern Canada Soil and Water Conservation Centre

Interpretation

Areas at the greatest risk of increasing soil compaction are scattered throughout southern Ontario (Fig. 10-4) and Prince Edward Island but are confined to the Annapolis Valley in Nova Scotia. This enhanced risk may have resulted in part from the development of varieties of grain corn that can grow in a cooler, shorter growing season, allowing the expansion of corn production into more areas of eastern Canada. There is also a trend in some areas to expand the acreage of higher-value specialty crops, such as potatoes and vegetables, that do well in cool climates and coarser-textured soils. The expansion of areas under intensively cultivated cash crops has occurred largely at the expense of areas under cereals and forage crops over the past 15 years.

In southwestern, central, and eastern Ontario (Fig. 10-1), there are substantial areas where the dominant agricultural subsoils are susceptible to compaction. If trends observed in some of these areas over the last 15 years continue, the amount of agricultural land under cropping systems that cause soil compaction is likely to increase significantly over the next 5 years. These increases may come from expansion of the area under grain corn and soybeans (as advances are made to develop soybean varieties adapted to cooler regions with a shorter growing season). Of particular concern is the sustainability of farming practices on Prince Edward Island with respect to soil structural conditions, as most of the province appears to

Draining land to reduce the risk of compaction in British Columbia's Lower Fraser Valley

The mild maritime climate of British Columbia's Lower Fraser Valley allows for a wide range of crops to be grown. However, heavy winter precipitation makes the soil very wet in the spring, and working wet soils can lead to significant soil compaction. About 23% of the valley's soils are at high risk of compaction, including all poorly drained clay and clay loam soils and some loamy soils on which the impact of tillage is severe.

Drainage systems that control the water table are critical to reducing the risk of soil compaction. A long term drainage study found that drained soils had 85 opportunity days (days between January 1 and March 31 when the water table is sufficiently low to allow soil to be worked without undue risk of soil compaction) and winter wheat yields of 6.8 tonnes per hectare. Similar undrained soils had only 20 opportunity days and winter wheat yields of 0.5 tonnes per hectare.

This study found that crops planted in the fall for winter cover on undrained soil have a very low survival rate. Yet without winter cover, the impact of rain drops destroys the structure of surface soil, resulting in surface compaction and ponding. These conditions in turn contribute further to excess soil water in the spring and even fewer opportunity days. Thus, the presence or absence of subsurface drainage is an indicator of the risk of compaction in the soils of southwest British Columbia.

R. Bertrand, British Columbia Ministry of Agriculture and Food

have subsoils that are susceptible to soil compaction in varying degrees (Fig. 10-2). The risk of soil compaction will continue to increase over the next 5 years if the cropping systems that contribute to soil compaction (e.g., potatoes) expand to new areas.

The distribution of areas where the degree of soil compactness is likely to improve over time has not changed significantly throughout eastern Canada during the past 15 years (Fig. 10-3). Characteristics of highly compacted soils, such as poor internal drainage, slow warming, restricted root penetration, and poor aeration, likely restrict the selection of crop types to those that can tolerate these conditions, such as forage and pasture crops. Crops capable of improving soil structure appear to have maintained a prominent role in the crop rotations used in these areas, but the overall provincial-level decrease (11 to 21%) in the area under such crops over the 15-year study period is a troubling trend. A continuing and major concern is that the areas of southwestern Ontario identified previously by farm producers and researchers as being highly compacted (corroborated by this study) still do not have even one-third of the farmland under cropping systems that can help alleviate this soil condition.

Response Options

A proven method in Canada of reducing soil compaction on agricultural land is to use longer crop rotations that include deep-rooting forage crops for at least 2 consecutive years. In areas of intensive row cropping, such as southwestern Ontario, this practice is likely to improve the prospects for achieving sustainable crop production systems. Practices that add organic matter to the soil (e.g., residue management, manure application, cover cropping, and interseeding) also improve soil structure and reduce the risk of compaction.

Other practices that protect soil from compaction include

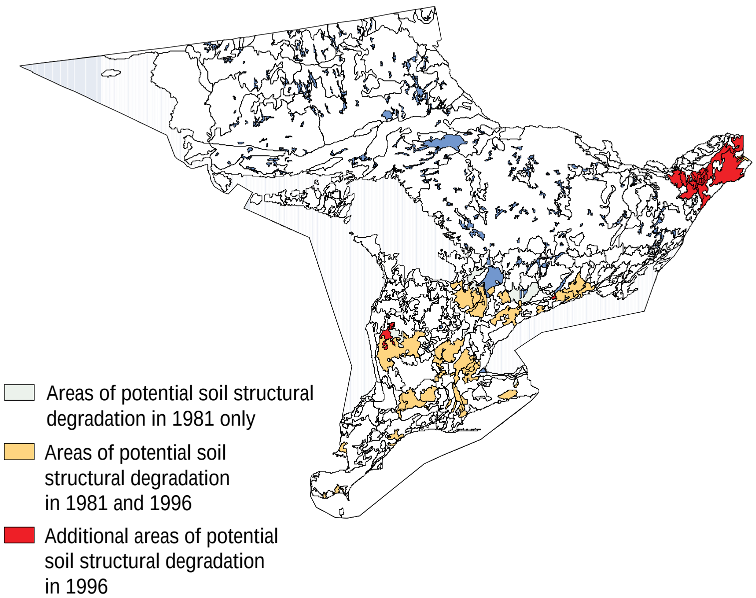
- avoiding field work when the soil is still wet
- installing field drainage systems to reduce excess soil moisture
- restricting axle loads and using flotation tires and tandem running gear.

Conclusion

Information from the Risk of Soil Compaction indicator presented in this chapter is based on the soil characteristics recorded in the current *Soil Landscapes of Canada* (SLC) database. A comparison of the degree of compactness

Figure 10–4

Areas of Ontario's farmland where soils are susceptible to compaction and cropping systems are likely to cause further soil compaction over time



estimated from the SLC database with values derived from detailed soil survey databases in sizable regions of Ontario and

New Brunswick indicates that the generalized SLC data are adequate and reliable enough to undertake this type of analysis.

Tillage systems were not examined in this study because existing data did not cover a long enough period to assess possible changes in soil structural characteristics. As more data become available with time, researchers will be better able to assess the effects of tillage practices on soil structural conditions. It is known, for example, that reduced tillage systems tend to increase the degree of compactness of the soil while other aspects of structural quality may be improved. The limited amount of research that has been done in eastern Canada on the effectiveness of deep tillage systems in decompacting subsoils has been inconclusive. More research is required on crop responses to subsoiling and *deep ripping* operations.
Of interest in the future would be updating the estimates of the degree of soil compactness to reflect changes in dry bulk density and organic carbon content under different cropping or tillage systems. As it is impractical to conduct an extensive survey of changes in dry bulk density measurements on a provincial scale, it is likely that data from national databases will continue to be the benchmark against which to assess future changes in farm practices. New approaches may also be needed to predict changes in the dry bulk density and other key properties of soil types under different cropping or tillage systems in order to evaluate the state of soil compaction in a more dynamic way.

Related Indicators

As soil structure breaks down, the Risk of Soil Compaction becomes greater, as does the Risk of Water Erosion and the Risk of Wind Erosion. The Risk of Soil Compaction also becomes greater as the level of Soil Organic Carbon declines. As soil becomes degraded by compaction, crop productivity is reduced and producers may need to apply more fertilizer to promote better yields. Crops may not be as robust, thus making them more susceptible to disease and pests and increasing the need for pesticide applications. Thus, soil compaction may influence a producer's Management of Farm Nutrient and Pesticide Inputs. Compacted soils are less permeable to water and thus more susceptible to surface runoff. As more fertilizer is added to boost crop yields, the Risk of Water Contamination by Nitrogen and the Risk of Water Contamination by Phosphorus also grows, as does the potential for emissions of nitrous oxide, which alters the Agricultural Greenhouse Gas Budget.

Alleviating soil compaction in reduced tillage systems in Ontario

Soil compaction in reduced tillage systems must be alleviated without significantly reducing the amount of protective crop residue or causing large increases in tillage costs. To accomplish this, producers and researchers in Ontario have been examining systems that perform tillage in narrow strips. The idea is to prepare strips of soil in the fall that are loosened, cleared of residue, and ideally somewhat elevated, while leaving the rest of the field covered and protected by residue. These strips are drier, less dense, and more suited to single-pass corn planting in the spring.

University of Guelph and Agriculture and Agri-Food Canada researchers are studying various equipment designs and operating depths to assess the impact of in-row soil loosening on corn performance. Most of this strip tillage equipment has a single lead coulter for cutting residue, a shank for in-row loosening that operates at depths of 15 to 45 cm, and additional coulters or discs for containing the disturbed soil in the row area. Another option being explored is combining fertilizer placement with the strip tillage operation. The ongoing challenge in this work is to develop cropping systems that reduce costs, increase environmental protection, and improve yields while providing techniques for dealing with factors such as heavy crop residues or compacted soils.

G.A Stewart, Ontario Ministry of Agriculture, Food and Rural Affairs

This Trans-till™ unit is one of a range of tools designed to offer the advantages of reduced tillage while providing a means to reduce soil compaction and optimize corn growth.

11 Risk of Soil Salinization

R.G. Eilers, W.D. Eilers, and T. Brierley

Geographic scope: Prairie Provinces
Time series: 1981, 1991, 1996

Highlights

- Soil salinity is a state in which soil contains excess soluble salts in the root zone, hindering plant growth. Moderate to severe salinity reduces annual yields of most cereal and oilseed crops by about 50%. An indicator is needed to assess how current land use affects the risk of cropland becoming more saline.

- An indicator was developed to assess the Risk of Soil Salinization under dryland agriculture in the Prairies. The indicator was expressed in three risk classes: low, moderate, and high. Components of the indicator include long term average climate, soils, and landscape characteristics, hydrology, and land use. Only land use is controlled by humans. The performances objective is to have a declining share of land in the moderate and high risk classes.

- In the Prairies as a whole, about 60% of cropland remained in the low risk class in all three census years. About 3% of cropland shifted from the high risk to the moderate risk class between 1981 and 1996, showing an overall positive trend for this indicator. Changes in agricultural practice, including adoption of conservation tillage and reduction of area under summerfallow, likely contributed to this gradually declining risk.

- About 76% of Alberta's cropland was at low risk of increasing soil salinization during the census years, as was about 44% of Saskatchewan's cropland. Alberta had little change in the share of cropland at moderate or high risk between census years, but Saskatchewan had a shift of 4% of cropland out of the high risk class in 1991, maintained in 1996. In contrast, in Manitoba the improvement in risk between 1981 and 1991 was reversed between 1991 and 1996, and there was a sizeable shift of cropland from the low risk to moderate risk class.

- Differences between the provinces in the distribution of cropland in the risk classes mainly reflects the extent to which summerfallow is practised. Alberta and Saskatchewan continued to show a downward trend for this land use, whereas Manitoba showed a slight increase in 1996.

- The indicator gives a snapshot picture of the risk of soil salinization, reflecting annual variations in weather, markets, and local management decisions, as well as the timing of the census and reported land use. Thus, the indicator may not accurately reflect long term trends but is useful to target areas where increasing salinization may be a problem under prevailing management practices. The indicator also indirectly reflects the extent to which soil conservation practices are being adopted by the agricultural industry.

The Issue

Soil salinity is a state in which soil contains excess soluble salts in the root zone, hindering plant growth. Moderate to severe salinity reduces the annual yields of most cereal and oilseed crops by about 50%.

Soil salinization, the accumulation of salts in the root zone, is generally caused when water lost from the soil by *evapotranspiration* exceeds that replaced by infiltration of precipitation. This water deficit occurs naturally in much of the agricultural area of the southern Prairie Provinces. A 1990 assessment of surface salinity in the Prairies found that most (62%) of prairie farmland had a low extent of salinity (less than 1% of the land affected), 36% had a moderate extent (1 to 15% of the land affected), and 2% had a high extent (more than 15% of the land affected).

The process of salinization is controlled by several factors other than water deficits, including

- topography
- inherent salt content of the soil parent material and underlying geology
- hydrology (soil drainage)
- land use.

Although soil salinization is mainly controlled by nature, land use (including practices that affect soil-water management) is under human control. The use of summerfallow contributes most to increasing soil salinization (*see* Box on land use). An indicator is needed to show how changes in land use, notably the use of summerfallow, affect the risk of an area becoming more saline.

Effects of land use on salinization

Salinization is the process by which soluble salts accumulate in the rooting zone of soils. As soil materials are weathered and broken down, soluble salts are slowly released. These salts can then dissolve in water in the soil and be transported to areas in the landscape where the water evaporates and the salts are then concentrated to levels detrimental to plant growth.

In arid agricultural land in the Prairies, some land is pulled out of production and left fallow in order to conserve soil moisture. Under summerfallow, the plant cover is absent, allowing water to infiltrate the soil better. If more water enters the soil than can be held there, the excess water can pick up salts and move them through the landscape to areas where conditions are favorable to concentration by evaporation, increasing salinization in these areas. Thus, summerfallow is considered to be a land use that promotes soil salinization.

Land management for the efficient use of soil water is thought to be the most important factor in reducing soil salinization. Keeping agricultural land under permanent cover or a continuous crop provides a biological control of salinization by allowing plants to capture some of the water that could otherwise carry salts to more sensitive parts of the landscape. Permanent cover is associated with the lowest risk of salinization because plants are in place all year. Land under summerfallow is considered to be at the highest risk, and land under annual cropping is at a risk level somewhere between the two.

W.D. Eilers, Agriculture and Agri-Food Canada

The Indicator

Description

An indicator was developed to track the change in the Risk of Soil Salinization in the dryland Prairies as a function of changes in land use. The indicator does not measure the actual area of saline lands, but rather the level of risk that results from the agricultural land use of the day. Thus it relates agricultural practice to the potential for increasing soil salinity and reflects how the agricultural industry is performing with respect to the goals of sustainable agriculture, specifically the long term quality of agricultural soils. The indicator is expressed in three risk classes: low, moderate, and high. The performance objective for the indicator is to have a declining share of land in the moderate and high risk classes.

Method of calculation

The indicator was based on the calculation of a salinity risk index. This index was used to rank individual land areas according to the chance that they will become more saline. Factors included in the calculation were

- status of salinity present in the landscape
- topography
- soil drainage
- climatic moisture deficits
- agricultural land use.

The status of salinity was derived from existing soil salinity maps. Values for topography and soil drainage were derived from the databases for existing *Soil Landscapes of Canada* maps for each of the Prairie Provinces. An expert committee for salinity on the Prairies subsequently developed a relative weighting for each factor to use in calculating the index, based on the influence each of these components has on the process of soil salinization. The index values were then subdivided into three classes and used to generate risk maps for the Prairies. These maps were reviewed by the expert committee for accuracy in portraying the relative risk of salinization.

For this analysis we considered that the soils, landscapes, and hydrology factors did not change over time. Although the climatic moisture deficit varies from year to year, there is a consistent annual deficit. To isolate the impact of land management on the risk of soil salinization, the long term average climatic moisture deficit assigned to each mapping area was used for each year of analysis. Thus, agricultural land use, determined from each census, was the only factor to change, and changes in the risk of soil salinization were attributed to these changes in land use. The weighting for the land use factor was based on the ratio between the share of cropland in summerfallow and that in permanent cover in individual mapping areas in each of the Prairie Provinces. The information on extent of cropland and summerfallow was obtained from the *Census of Agriculture* in the three census years. Indicator results were compared between years using 1981 as the baseline (i.e., 1981–1991 and 1981–1996) and also between 1991 and 1996.

Limitations

The effects of non-agricultural land uses on soil salinization are not reflected in this broad scale analysis. Such land uses mainly affect the soil drainage factor in the index.

Climatic variability can have significant impacts on the risk of salinization. However, to isolate the impact of human activity, long term average data were used in this analysis. A similar analysis could be performed to isolate the change in risk due to climatic variability if sufficient climatic data were available for each census year.

This analysis produces snapshots of conditions reported in the census. Because of yearly changes in land use, this series of snapshots may not be indicative of actual trends in salinity risk.

Location and signs of salinization

Salinization takes place where the following conditions occur together:
- the presence of soluble salts in the soil
- a high water table
- a high rate of evaporation (water evaporates from the soil surface faster than it is received through precipitation).

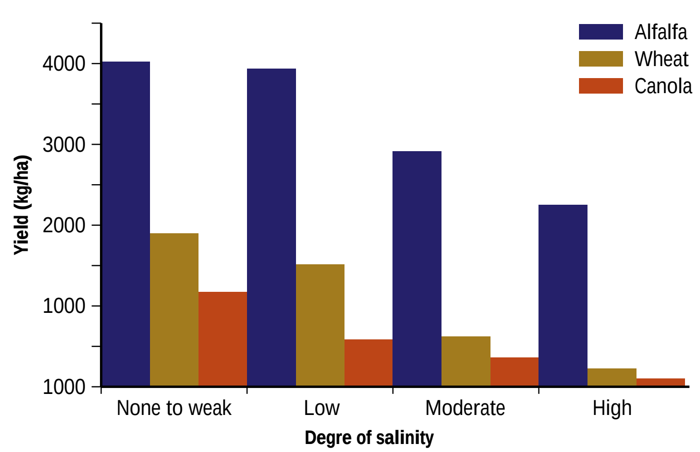
These features often exist in depressions and drainage courses, at the base of hillslopes, and in flat, low lying areas surrounding sloughs and shallow water bodies. Soil salinity can be widespread in areas receiving regional discharge of groundwater.

It may be possible to identify saline soils before they become seriously affected. The early signs of soil salinity include
- a surge in crop growth, producing high yields
- increased soil wetness, to the point that the area becomes inaccessible
- the growth of salt-tolerant weeds, such as kochia *(Kochia scoparia)* in the crop.

As salt levels in the soil increase, the signs become more obvious. They include
- irregular crop growth patterns and lack of plant vigour
- white surface crusting
- a broken-ring pattern of salts next to a water body
- white spots and streaks in the soil, even where no surface crusting shows
- the growth of highly salt-tolerant plants, such as red samphire *(Salicornia rubra).*

High levels of salt in the soil have the same effect as drought, making water less available for uptake by plant roots. This effect is caused by the difference in salt concentrations between the plant and the soil. Depending on the degree of salinity, this effect reduces the soil's ability to produce crops and lowers crop yields.

Effect of soil salinity on crop yield



Source: Eilers et al., 1995

For example, rapid swings in commodity prices or weather conditions such as late spring flooding may cause unplanned and unusual changes in land use for a particular area or region. These conditions may occur in any particular year and affect the results of the analysis.

Results

Table 11-1 shows the share of cropland at various levels of risk of increasing salinity. Across the Prairies as a whole, the risk of dryland soil salinization declined somewhat between 1981 and 1991, with 3% of cropland moving from the high risk class to the low risk class. The same share of farmland moved from the low to moderate risk class by 1996. Thus, there was still an improvement in 1996 over 1981, but this improvement was less than in 1991. The trend for the Prairies was strongly influenced by the change in land use values for Manitoba.

In Alberta, the risk of increasing salinity changed very little between 1981 and 1996. Most cropland (75%) remained at low risk during this period. In Saskatchewan, a relatively large share of cropland remained at low (44%) and moderate risk (40%) of increasing salinity, while there was a decline of about 4% in the share of cropland in the high risk class between 1981 and 1996. In Manitoba, there was considerable improvement in the risk between 1981 and 1991, with a marked increase in the share of cropland at low risk and decreases in the shares at moderate and high risk. However, this situation reversed by 1996, so that there was a marked increase in the share of land at moderate risk between 1981 and 1996, coming mostly from the low risk class (8%) and a little from the high risk class (1%).

In each of the Prairie Provinces, the share of cropland in the low risk class grew between 1981 and 1991 and declined between 1991 and 1996, most notably in Manitoba. In Manitoba the share of land in the moderate risk class increased at a faster rate than in the other provinces. These observations are shown in Table 11-2.

The distribution of agricultural land in the various risk classes on the Prairies in 1996 is shown in Figure 11-1. The pattern generally reflects the soil zonal boundaries, with the

Table 11-1

Risk of soil salinization on cropland in the Prairie Provinces under prevailing management practices

Province	Share (%) of cropland in various risk classes								
	Low Risk			Moderate Risk			High Risk		
	1981	1991	1996	1981	1991	1996	1981	1991	1996
Alberta	75	78	76	21	18	20	4	4	4
Saskatchewan	43	45	44	39	41	42	18	14	14
Manitoba	50	58	42	28	25	37	22	17	21
Prairies	56	59	56	30	30	33	14	11	11

Table 11-2

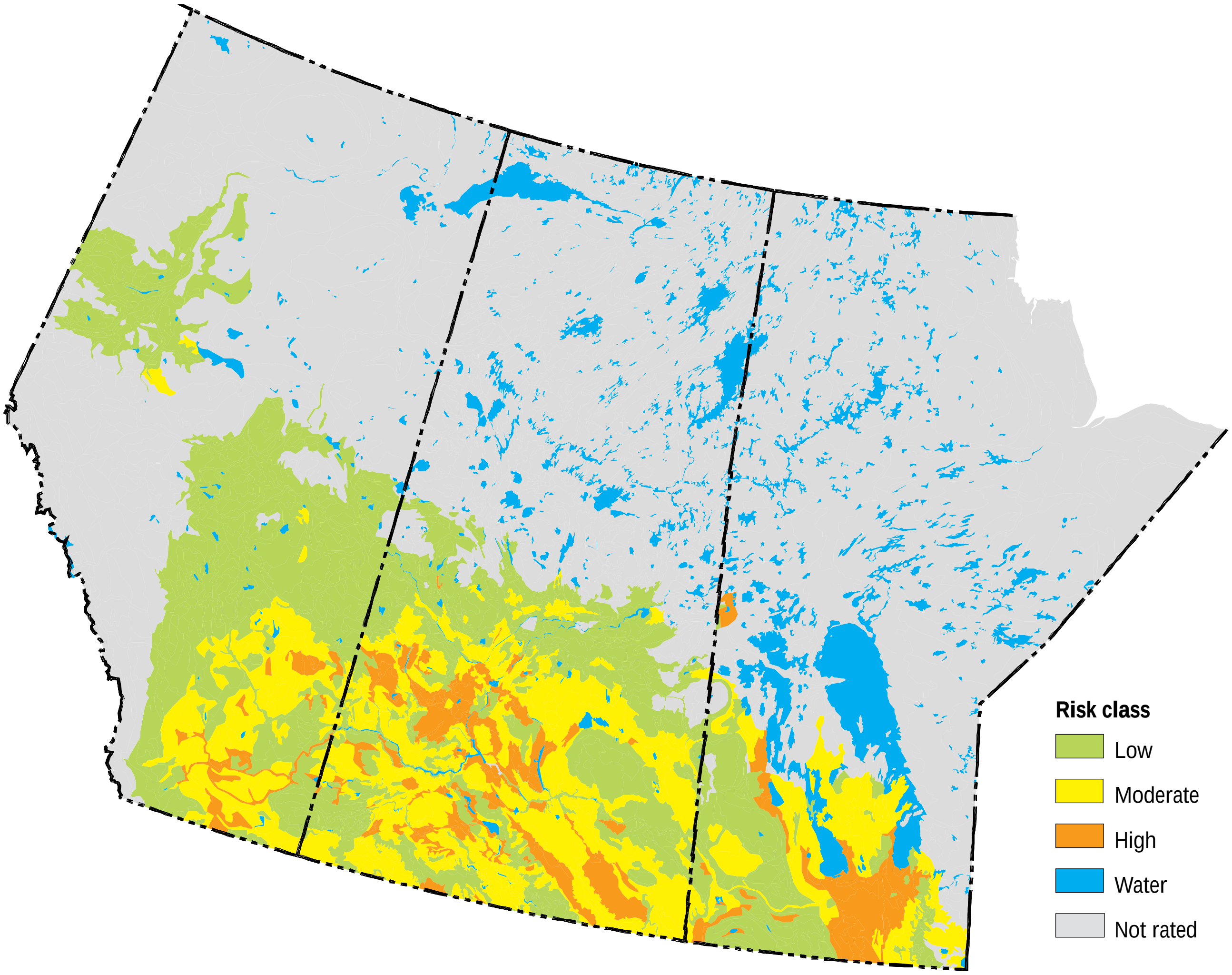
Change in the risk of soil salinization between census years

Province	Change in risk (%)								
	Low Risk			Moderate Risk			High Risk		
	1981-91	1981-96	1991-96	1981-91	1981-96	1991-96	1981-91	1981-96	1991-96
Alberta	3	1	–2	–3	–1	–2	—	—	—
Saskatchewan	2	1	–1	2	3	1	–4	–4	—
Manitoba	8	–8	–16	–3	9	12	–5	–1	4
Prairies	3	—	–3	—	3	3	–3	–3	—

Note: A positive number means the share of cropland in that category grew by that percentage, a negative number means the share fell, and a dash means there was no significant change.

Figure 11–1

Risk of soil salinization on cropland in the Prairie Provinces under 1996 management practices



lower risk class corresponding to the more humid Black Soil zone. The exception is Manitoba, where lack of relief and poorer drainage in the soil landscapes place the central part of the province at inherently higher risk of soil salinization.

Interpretation

Values shown in Table 11-1 do not reflect actual increases or decreases in lands classified as saline, but rather the change in risk to which these lands are exposed as a result of agricultural practices of the day. These values are too few to indicate strong trends in actual salinization. More correctly they reflect the levels of risk of salinization under the management practices in place. Positive values shown in Table 11-2 for changes in the low risk class reflect a desirable change, as do negative values for changes in the moderate and high risk classes.

The greater change in the share of cropland at moderate and high risk of increasing salinization in Manitoba between 1991 and 1996 compared to the other Prairie Provinces reflects the general trends in the declining area under summerfallow reported by individual provinces. Saskatchewan and Alberta continue to show a declining trend in this land use. Manitoba has probably reached the limit in the annual downward trend, and annual variations may be up or down, depending on local weather conditions and management considerations.

Benchmark monitoring of salinity

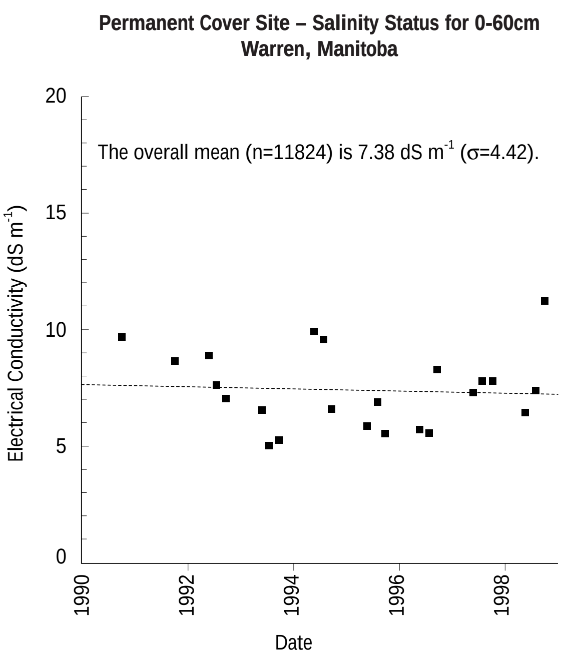
In 1990, the prairie region of Agriculture and Agri-Food Canada's Land Resource Research Units established a series of benchmark sites across the Prairies to monitor the dynamics of soil salinity and to observe trends in the extent and severity of soil salinity. One site was established near Warren, Man., on a salt-affected area of lacustrine clay sediments originating from glacial Lake Agassiz.

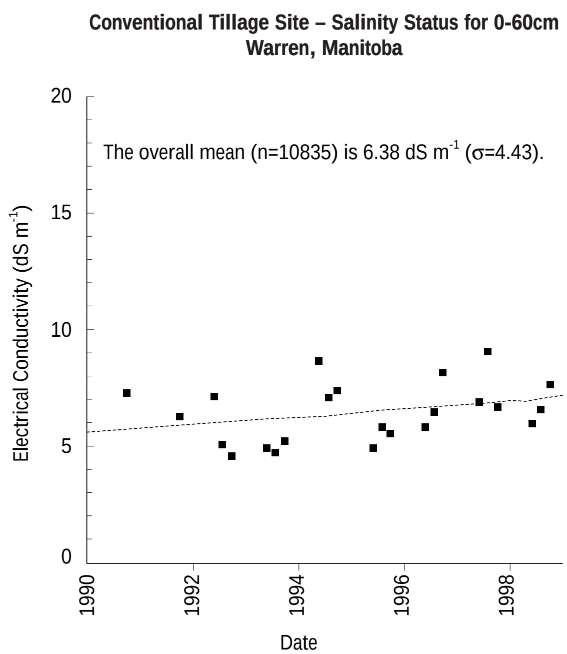
The site consists of two plots, each measuring about 100 metres by 450 metres. One plot has been continuously cultivated for annual crops, with no summerfallow. Tillage has been carried out conventionally, with three to four passes each year using a deep-till cultivator, harrows, and a discer. The other plot is located immediately adjacent, but across the road. It was seeded to alfalfa and grass and has not been cultivated since 1984.

Both sites were monitored three times a year using an electro-magnetic induction instrument that measures the salinity status in the field. Levels of soil salinity fluctuate dramatically throughout a single season, mainly as a result of changes in the weather. Despite this seasonal variability, the trend of the average salt content for the upper 60 centimetres of the root zone over the whole plot under permanent cover appears to have stabilized during the last 8 years, at about 7 decisiemens/metre (a unit for measuring the electrical conductivity in soil, which indicates soil salinity). In contrast, the average salt content for the annually cropped plot has gradually and steadily increased at a rate of about 0.14 dS/m per year over the last 8 years (*see* graphs below). If the management had included summerfallow, the rate of increase would be expected to be even greater. This study indicates that long periods under a particular land use can influence the status of dryland soil salinity in sensitive locations in susceptible prairie landscapes.

Because of the seasonal fluctuations in salinity levels, differences between two consecutive graph points can be greater than the change registered between 1990 and 1998. This feature of salinity makes it difficult to identify trends with any certainty when only a few samples are taken over a short period of time. Thus, long term monitoring is essential to get an accurate picture of trends in salinity.

Soil salinity over time under conventional tillage and permanent cover in Manitoba





R.G. Eilers, Agriculture and Agri-Food Canada

In Manitoba the risk increased in the southeast, interlake, and west lake areas. The extent of actual saline land in the southeast and interlake areas is very small. All of these areas have level topography and heavy clay-textured soils and are very prone to having excess water in the spring. These features may have contributed to their inclusion as summerfallow land in 1996. However, there are likely several reasons for reporting land as summerfallow in a given year in any province, including

- changing crop rotations
- weed problems in previous years
- low temperatures in late spring
- excess wetness due to flooding
- late fall harvests, which prevent preparing the land for spring seeding.

Many unforeseen events can significantly change the specific mix and extent of cropping in a given year. For example, cold and wet weather may delay spring seeding beyond the date eligible for crop insurance coverage. Thus, land may be allowed to lie fallow or may be subsequently seeded to a cereal for harvest as a hay crop, resulting in a very short cropping season in terms of consumptive water use. Changing markets and commodity prices can influence crop mix and extent from year to year and certainly between one census and another.

Expansion of special crops for local processing can significantly alter the annual and seasonal consumptive use of soil water. For example, a significant increase in short-season crops, such as beans and lentils, canola, and specifically potatoes, in the Prairies can alter the risk of salinization in specific landscapes. Low-residue, deep-tillage potato crops leave the land exposed for significant portions of the season during which excess rainfall may be added to the local water tables. This change in water conditions may result in a change in the risk of soil salinization in surrounding and adjacent areas.

This analysis is based on the probable influence of land use on the risk of changing the status of salinity on a landscape basis. The actual occurrence of salinity is typically site specific within fields. The processes that cause salinity take a long time and involve many factors that must come together under suitable physical and climatic conditions. Our data show that the risk of salinity has changed, but the extent of saline land has likely changed very little during the study period. Ongoing research related to monitoring salinity change at long term benchmark sites across the Prairies shows that the change in salinity levels over a single season can be greater than that between years (*see* Box).

This analysis has rated areas according to relative risk of increasing salinity. This information could be used by soil conservation specialists, extension personnel, local conservation organizations, and producer groups for soil conservation planning, program development, and technology transfer.

Response Options

Changing land use, and thereby soil-water management, is the only real and practical solution available to producers for reducing the risk of soil salinization. Diagnostic programs and education will improve producers' awareness and understanding of what causes salinization and indicate how they can respond.

Prior to the 1990's, changes in land use for saline soils were strongly influenced by short term economic and political climates rather than long term deliberate efforts to sustain soil quality or address environmental concerns. This attitude may be changing. Values other than agriculture are being accepted for some of our more sensitive landscapes or portions of them. Areas that are saline or at high risk of salinity under agriculture may have significant value for natural habitat and environmental diversity.

Land and water management practices that help producers to reduce the risk of dryland salinization include

- increasing minimum tillage or no-till
- increasing the area of forages, pastures, and tree crops
- reducing summerfallow area
- including crops that are more salt-tolerant in rotations
- using inputs such as mineral fertilizers and animal manure more effectively
- using new technologies, such as those of precision farming
- ensuring adequate surface drainage of temporarily ponded waters
- installing interceptor forage strips or strategic subsurface tile drainage.

Efforts are also needed to improve the awareness of the spread of soil salinity due to the construction of infrastructures such as roads, ditches, canals, drains, lagoons, and storage reservoirs. These structures are designed to impound, convey, or restrict water, thus affecting local hydrologic and geologic conditions. However, these structures often leak or result in seepage and cause salinization in adjacent agricultural soils. These conditions are commonly observed only years after construction and after much of the damage to the soil productivity has already be done. Management options are needed at the time of construction to prevent this type of soil salinization.

Conclusion

Agricultural land use changes the risk of soil salinization in some regions and landscapes of the Prairies. This effect varies from year to year and thus from one census to another. The actual change in the extent of salinity is relatively slow compared to changes in land use, thus the impacts of broad scale change in land use are not readily observed.

This analysis does, however, provide a means of targeting management. Some landscapes are much more sensitive than others to land use changes and soil salinization. For example, some level landscapes have a greater potential for increase in the extent of salt-affected areas, while other landscapes with greater relief are more prone to increased severity of existing salinity. Soils, geology, topography, and aridity are the main controlling factors in these cases.

The long term outlook for changing land use to minimize the risk of dryland soil salinization is quite positive. Increased awareness and growing use of sophisticated technologies for agricultural land management help to lower the risk of salinization. Currently, precision farming is focused on variable inputs, but in the future it may be adapted to consider the management requirements of other variables, including those related to the control of dryland soil salinity.

Periodic regional analysis, such as described here, is a useful monitoring tool. Combined with ongoing monitoring and research at saline sites, the salinity risk index helps to reflect the general extent to which the agricultural industry is working to protect and sustain the productive capacity of prairie soils.

Related Indicators

This indicator reflects soil quality, as do the Risk of Water Erosion, Risk of Wind Erosion, Risk of Tillage Erosion, Soil Organic Carbon and Risk of Soil Compaction. The Risk of Salinization is mainly related to the management of water, as is the Risk of Water Erosion. Like the Risk of Wind Erosion, the Risk of Soil Salinization applies mainly to the Prairie Provinces. Severely saline lands that are unsuitable for agriculture provide unique wildlife habitat, improving the Availability of Wildlife Habitat on Farmland.

D

Water Quality

D Water Quality

In the water cycle, water passes through various stages or uses on the earth before it returns to the oceans or evaporates back into the atmosphere. When the cycle is in balance, water proceeds from one use in sufficient quantity and quality to be suitable for the next use. For each use there is an acceptable range of water quality characteristics, and outside this range there are undesirable effects, including environmental degradation. When water is contaminated, its chemical, physical, or biological characteristics are altered in some way to make it unsuitable for some uses.

Water quality is one of Canadians' chief environmental concerns. Agricultural production in Canada has intensified over the past three decades, and some management practices have contributed to a decline in water quality through the addition of sediments, crop nutrients, pesticides, and pathogens (e.g., bacteria). Nutrient loading is usually considered the most serious effect of agriculture on water quality. The two nutrients of greatest concern with respect to water quality are nitrogen and phosphorus.

Nitrogen is an essential crop nutrient that is added to soil mainly through the decomposition of natural organic matter (dead plant and animal material), the fixation of atmospheric nitrogen by nitrogen-fixing organisms (e.g., legumes), and the application of animal manure and mineral fertilizer. Nitrogen becomes available for crop use when it is in water soluble forms, such as nitrate. Because it is soluble, nitrate that is not used by the crop can be leached by water below the root zone into groundwater. Nitrate is naturally present in all groundwater, but agriculture can contribute to elevated levels of this substance. In many parts of Canada, groundwater is the chief source of water for drinking and other human purposes. Nitrate concentrations in groundwater may reach levels that are harmful to humans and animals. Although nitrate itself is relatively nontoxic, it can be converted in the digestive tracts of human infants and ruminant animals (e.g., cows and sheep) to nitrite, which is toxic.

Phosphorus is also an essential crop nutrient, added to soil mainly in animal manure and mineral fertilizer. Phosphorus can dissolve in water or remain in particulate form, attached to soil particles. It can move off farmland dissolved in runoff water or attached to eroding soil. Because erosion selects the finest particles at the soil's surface, to which phosphorus attaches, sediments that reach surface waters are usually richer in phosphorus than the soils from which they came. Phosphorus moving off farmland may raise concentrations of this nutrient in surface waters enough to cause eutrophication. In this condition, algae and other aquatic plants grow excessively, depleting the supply of oxygen in the water and altering its pH (acidity). Eutrophication affects both the ecological and economic value of surface waters. For example,

- the diversity of fish and other aquatic species may decrease
- drinking water sources may decline in quality
- water recreation, such as swimming and boating, may be hampered by algae and weeds.

Nitrate-laden groundwater and surface runoff can also reach surface waters and contribute to eutrophication, but phosphorus is usually the limiting nutrient. In some inland waters, elevated levels of phosphorus promote the growth of blue-green algae (cyanobacteria) that are toxic to animals and humans. Acute poisoning of humans from eating shellfish has been traced to algal blooms caused by agricultural nitrate in east coastal waters.

In this section, two chapters present the risk of water contamination as a result of agriculture. Chapter 12 looks at the risk of water contamination by nitrogen and Chapter 13, the risk of water contamination by phosphorus. Future indicator development could include the risk of sedimentation and contamination by pesticides and pathogens.

12 Risk of Water Contamination by Nitrogen

K.B. MacDonald

Geographic scope: Provincial
Time series: 1981, 1991, 1996

Highlights

- Nitrogen is an essential nutrient that becomes available for crop use when it is in soluble form, such as nitrate. Nitrate can be leached into groundwater, an important source of drinking water, where it may reach levels harmful to humans. Nitrate can also enter surface waters, contributing to nutrient loading and possible eutrophication.

- An indicator was developed to assess the risk of water contamination by nitrogen (N) from farmland based on the *Canadian Water Quality Guidelines* safe limit for nitrate-nitrogen in drinking water (10 milligrams per litre). The indicator was calculated by dividing the amount of nitrogen that could potentially move off farmland (residual nitrogen) by the amount of excess water. The performance objective is to have all Canadian farmland pose little or no risk of water contamination by nitrogen.

- Excess water exists only in the humid regions of Canada, so the indicator was calculated only for agricultural areas in British Columbia, Ontario, Quebec, and the Atlantic Provinces. Risk was expressed in three classes: low, intermediate, and high. In areas without excess water (comprising 90% of Canada's agricultural land), water contamination by nitrogen under current management practices is associated with specific events, such as storms or moisture accumulation under summerfallow, or with intensive livestock or crop production.

- In the humid agricultural region of British Columbia, about 70% of farmland was in the high risk class. Measures are being taken to remedy this situation, possibly explaining the finding that British Columbia had the lowest share of farmland (57%) in the category showing increasing risk.

- In central Canada, Ontario had the largest share (17%) and total area of farmland at the highest risk of water contamination by nitrogen. Between 1981 and 1996 the estimated nitrogen content of water increased by at least 1 mg/L on 68% of Ontario's farmland. Areas at high risk were southwestern Ontario, the areas around Lake Simcoe, and the South Nation watershed. In Quebec, 6% of farmland was in the high risk class, located mainly in the St. Lawrence Lowlands region and the area south of Quebec City. Between 1981 and 1996 the estimated nitrogen content of water increased by at least 1 mg/L on most (77%) of Quebec's farmland.

- In the Atlantic Provinces, more than 80% of farmland was at low risk of water contamination by nitrogen in 1996, but the estimated nitrogen content of water increased by at least 1 mg/L on about 60% of farmland between 1981 and 1996.

- The indicator is subject to limitations of data but is still useful for making regional comparisons, highlighting areas where field testing is advisable, and providing an early warning that some areas may face greater risk of water contamination by nitrogen if appropriate management practices to curtail this risk are not put into place.

The Issue

Contamination of water by nitrogen from farms is of greatest concern in areas of intensive agriculture and excess soil moisture. Under these conditions, high levels of nitrogen (which converts to the soluble form nitrate) are often added to the soil to maintain optimal crop production, and water is more likely to move off farmland into neighbouring waters.

As the world demand for food and fibre pressures farmers to be more productive, the trend toward increased intensification of agriculture in these humid areas of Canada will continue. Thus the risk of water contamination by nitrogen is a growing concern. An indicator is needed to assess this risk in susceptible parts of the country and to monitor how this risk is changing over time.

Ontario groundwater survey

In 1991 and 1992, a survey of farm drinking water wells was conducted throughout the province of Ontario. The objective of the survey was to determine the quality and safety of drinking water for farm families and to determine the effect of agricultural management on groundwater quality at a provincial scale.

Four farm wells were chosen in each township in which more than 50% of the land area was used for agricultural production. Elsewhere, one well per township was usually sampled. Each participating household completed a questionnaire about their well construction, distance to potential point sources of contamination (septic system weeping beds and tanks, feedlots or exercise yards, and manure storages), use of manure and fertilizers, cropping system, pesticide use, and petroleum storage.

About 40% of the 1292 farm wells tested contained one or more of the target contaminants. Nitrate-nitrogen concentrations above the safe limit for drinking water (10 milligrams per litre) were found in 14% of the wells, and bacteria and nitrate-nitrogen were found together in 7% of wells. The survey results for nitrate contamination were not significantly different from those reported for a survey of Ontario wells during 1950 to 1954, but the incidence of bacteria had almost doubled since the earlier survey.

M. Goss, University of Guelph

The Indicator

Description

We developed an indicator to assess the Risk of Water Contamination by Nitrogen from farmland. The potential for farm nitrogen in the form of nitrate to contaminate water is directly related to the movement of water off farmland, either in overland flow or by leaching through the soil profile into groundwater. Thus, the indicator is based on estimates of the potential concentration of nitrate-nitrogen in water leaving farmland. The level of risk associated with various concentrations is based on the *Canadian Water Quality Guidelines* safe limit for drinking water of 10 milligrams of nitrate-nitrogen per litre. The performance objective for the agricultural industry is to ensure that the quality of water moving off agricultural land to groundwater and surface waters is not seriously impaired by agricultural activity.

Method of calculation

The potential concentration of nitrogen in water leaving farmland was determined by dividing the amount of nitrogen by the amount of water available to dilute this nitrogen (called excess water). The quantity of nitrogen that is potentially available to move off farmland, called residual nitrogen, was calculated as described elsewhere in this report for the indicator Residual Nitrogen. As outlined in that chapter, values for residual nitrogen are directly related to crop production and provide a reasonable estimate of nitrogen loading under average land uses. They include the input of nitrogen from animal manure, but the results were averaged over areas that were usually too large to show the impacts of localized areas of intensive livestock production, where manure nitrogen values may be much higher.

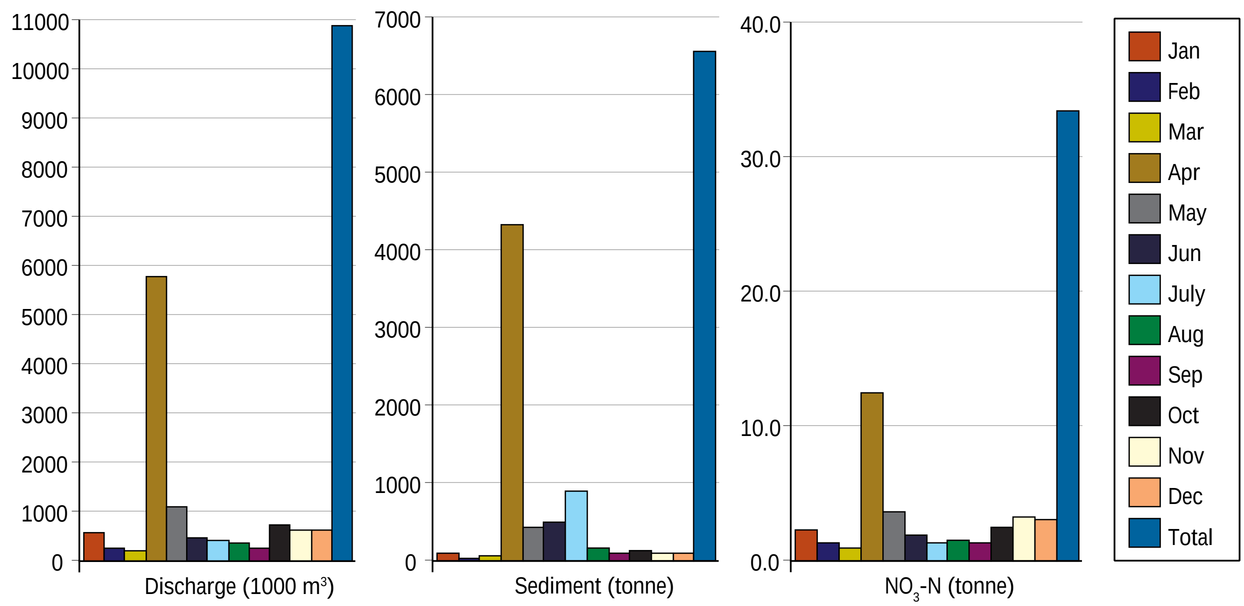
The amount of water that is potentially available to move off farmland was calculated by devising a moisture budget based on 30-year averages for precipitation (moisture input) and potential evapotranspiration (moisture output). The difference between these two values was used as the estimate of *water surplus* or *water deficit*. Only mapping areas with a water surplus were used to calculate the indicator. These areas are located in the agricultural regions of British Columbia, Ontario, Quebec, and the Atlantic Provinces.

Nitrate losses under New Brunswick potato production

Nitrate contamination of surface water and groundwater is a major environmental concern for potato farmers in Atlantic Canada. Potatoes are often grown on sloping lands that are subject to erosion and input requirements are fairly high. Combined with the moist maritime climate of this area, these production conditions often result in significant erosion and loss of nutrients from farmland.

A monitoring program being run in the Black Brook watershed, located in an area of intensive potato production in New Brunswick, follows the groundwater quality and movement of sediment and nutrients to surface streams in the catchment. Cumulative surface water flows and the accompanying sediment and nitrate-nitrogen content for 1992 to 1994 are shown in the graph below. About half of the annual discharge occurred during the freshet in April. Annual nitrate loading represented about 6% of the amount of nitrogen applied as mineral fertilizer. Nitrate-nitrogen concentrations in runoff consistently ranged from 2 to 9 milligrams per litre and twice exceeded the safe limit for drinking water (10 mg/L) in that period. Nitrate-nitrogen concentrations in groundwater are near 10 mg/L throughout the whole watershed. Concentrations do not decrease appreciably with depth, suggesting a long term condition of equilibrium. The lowest concentrations of nitrate-nitrogen are measured at the watershed's outlet, where the combined effects of all land uses, both agricultural and non-agricultural, would be detected.

Cumulative surface water discharge and sediment and nitrate losses from the Black Brook watershed, N.B., 1991 to 1994



T.L. Chow, P.H. Milburn, H.W. Rees, Agriculture and Agri-Food Canada

The capacity of the soil to hold available water was also an important factor in the water budget. This capacity was estimated at 100 millimetres for sand or sandy loam, 150 mm for loam, 200 mm for clay loam, and 250 mm for clay. If the available moisture (precipitation – potential evapotranspiration) is less than the available water-holding capacity, the soil profile is not saturated and movement of nitrogen into groundwater or the tile flow is unlikely. The opposite is also true.

The Risk of Water Contamination by Nitrogen was expressed in three risk classes: low (0–6 milligrams of nitrogen per litre), which is below the drinking water guideline; intermediate (6.1–14 mg N/L), showing areas where nitrogen levels in water may approach

Table 12-1

Risk of water contamination by nitrogen on farmland in Canada's humid regions under prevailing management practices in 1996

Province	Farmland area* (million ha)	Share (%) of farmland in various water contamination risk classes		
		Low (0–6 mg N/L)	Intermediate (6.1–14 mg N/L)	High (> 14 mg N/L)
British Columbia	0.1	6	**25**	**69**
Ontario	4.2	39	**44**	**17**
Quebec	1.9	58	**35**	**6**
Atlantic Provinces	0.4	82	**15**	**3**

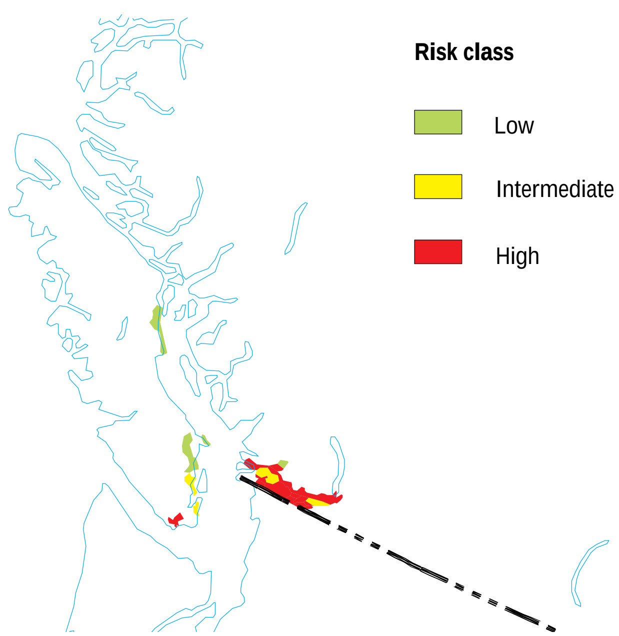
* Farmland area here is the sum of all *Census of Agriculture* land classes except. All Other Land. Value for British Columbia is for the south coastal region only.

or exceed the drinking water guideline; high (14.1 mg N/L or greater), showing areas where exceeding the drinking water guideline is likely.

To show trends in the indicator, changes (increases or decreases) by more than 1 mg/L were used, representing 10% of the drinking water standard. The performance objective of the indicator is to have all Canadian farmland pose little or no risk of water contamination by nitrogen.

Figure 12-1

Risk of water contamination by nitrogen on British Columbia's farmland under 1996 management practices



Limitations

Calculation of this indicator was subject to the same limitations described for the calculation of residual nitrogen, described in the chapter on the indicator Residual Nitrogen. The procedure used to calculate excess moisture underestimates the true value because potential evapotranspiration is always greater than actual evapotranspiration. Thus, values of the indicator are in turn overestimated.

Results of the excess water calculations show that about 90% of Canada's agricultural land (the semi-arid agricultural areas of the Prairie Provinces and British Columbia) is generally not at risk of causing water contamination by nitrogen. However, in these regions there are localized areas of intensive agriculture (chiefly livestock operations, but also irrigated farmland) close to susceptible water resources, with resulting water contamination. The procedure described here is not sensitive enough to identify these areas. Neither can it capture the nitrogen contamination of water associated with major storms and runoff events in semi-arid regions, because indicator calculations are based on data for climatic normals.

Results

Table 12-1 presents values for the risk of water contamination in 1996 for the agricultural areas of British Columbia and eastern Canada, where there is generally a moisture surplus. Only a small share (about 5%) of British Columbia's farmland has an average annual moisture surplus, but the risk of water contamination from agricultural activities is high in most of this area. In eastern Canada, the risk of water contamination is low or intermediate on most farmland. However, 17% of Ontario farmland, 6% of Quebec farmland, and 3% of Atlantic farmland was at high risk.

Areas particularly at risk of water contamination by nitrogen in 1996 are shown for British Columbia (Fig. 12-1), and central Canada and the Atlantic Provinces (Fig. 12-2).

These areas include

- the Lower Mainland and Vancouver Island in British Columbia
- southwestern Ontario, the areas around Lake Simcoe and in the South Nation watershed
- the St. Lawrence Lowlands of Quebec and the region south of Quebec City.

Between 1981 and 1996, the estimated nitrogen content of water increased by at least one milligram per litre on 57 to 77% of the farmland assessed by this indicator (Table 12-2).

Table 12-2

Share of farmland for which the estimated nitrogen content of water changed between 1981 and 1996

Ecozone	Farmland area* (million ha)	Share (%) of farmland for which the nitrogen content of water changed		
		Content decreased by at least 1 mg N/L	No change (–1 to +1 mg N/L)	Content increased by at least 1 mg N/L)
British Columbia	0.1	31	12	57
Ontario	4.2	2	30	68
Quebec	1.9	1	22	77
Atlantic Provinces	0.4	2	36	62

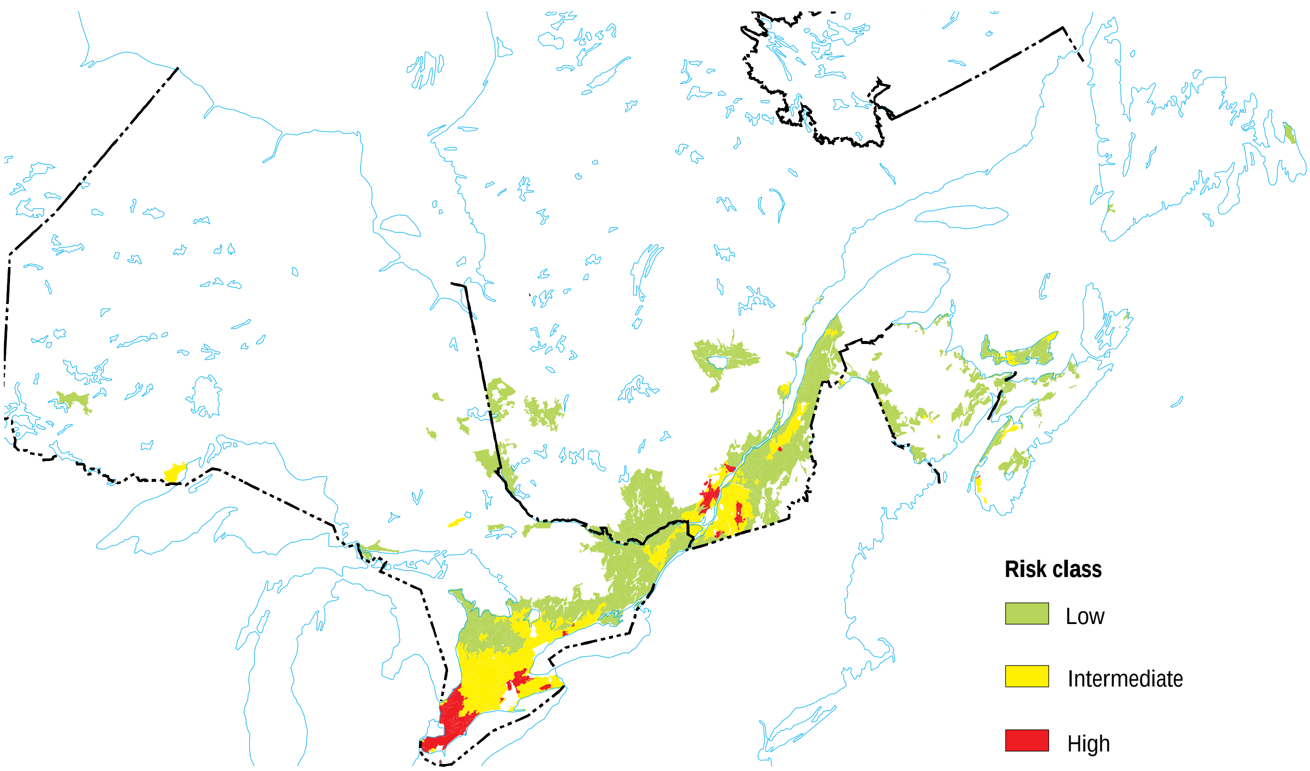
* Farmland area is the sum of all *1996 Census of Agriculture* land classes except All Other Land. Value for British Columbia is for the south coastal region only.

Interpretation

Southern Ontario and the St. Lawrence Lowlands of Quebec had the most farmland at the highest risk of water contamination by nitrogen. The areas of greatest risk correspond to those of intensive farming. Although the actual area of farmland has decreased since 1981, the area of annual crops has remained relatively constant. There have been substantial shifts in crop type, with increases in the area of crops that use high levels of nitrogen, mainly corn and soybeans. Corn requires larger additions of nitrogen than other common annual crops. Soybeans are able to fix large amounts of nitrogen to support production. In addition, the intensity of livestock production has

Figure 12-2

Risk of water contamination by nitrogen on farmland in Central and Atlantic Canada under 1996 management practices



Nitrate contamination of a British Columbia aquifer

The Abbotsford–Sumas aquifer straddles the border between British Columbia and the state of Washington. It is an unconfined sand and gravel aquifer with a water table that varies in depth from 3 to more than 20 metres. The aquifer is recharged mainly by precipitation.

The water quality issue of greatest concern for the aquifer is nitrate contamination. Groundwater nitrate concentrations exceed the Canadian water quality guideline of 10 milligrams of nitrate per litre in a large portion of the aquifer, and concentrations in individual wells have been as high as 40 mg/L. In the aquifer, the groundwater flows mainly to the south, so nitrate contamination in the Canadian portion of the aquifer affects users on the American side.

Agriculture has been identified as one of the main contributors to the nitrate contamination of the aquifer, though it is not the sole contributor. Agricultural production over the aquifer includes intensive animal production (mainly poultry, but also dairy and beef) and intensive crop production, especially raspberries. The trend over the past 30 years has been a decrease in dairy and beef operations, which have a sufficient land base on which to apply animal manure; an increase in poultry operations, which do not have an adequate local land base for manure application; and an increase in the production of raspberries, a crop with a low nitrogen requirement. The result is that nitrogen inputs from manure now exceed the capacity of the agricultural land to use that nitrogen efficiently. Steps are now being taken by producers to manage nutrients more carefully and to transport manure to other locales with lower animal populations.

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increased in this area, resulting in greater amounts of manure nitrogen to be managed. About 70% of agricultural land in the humid areas of British Columbia also had high risk values because of the growing intensification of crop and livestock production (*see* Box).

In other provinces covered by this indicator, farmland tends to be more fragmented and is of mixed quality. So, although there are areas of intensive agriculture, they are usually balanced by areas of poorer land under less demanding uses, such as pasture. Also, because of climatic limitations, the regions have not shown the same shifts to crops that produce higher levels of biomass and require larger inputs of nitrogen.

Response Options

Because the indicator was developed from generalized databases, the results should be confirmed by field testing, particularly in areas shown by the indicator to be at high risk. Research is also needed to develop methodologies and databases appropriate for assessing the risk of water contamination by nitrogen in the semi-arid regions of Canada.

In areas falling in the high risk class, measures that minimize the amount of nitrogen leaving farmland will help to reduce this risk. These measures may include growing *catch crops* (usually a lower-value crop planted in the fall after the main higher-value crop has been harvested) or using rotations that include crops that take up excess soil nitrogen. They also include many nutrient management practices, such as

- properly accounting for all major sources of nitrogen, including that added in animal manure, crop residues, and legume plowdown
- improving the estimates of crop needs
- further developing and using nitrogen tests for soil and crops, and basing nitrogen inputs on the results of such tests
- timing nitrogen application to match times of maximum crop need, and avoiding times of major leaching
- setting goals for crop yields that are both economically and environmentally sustainable.

Conclusion

The indicator applies to about 10% of Canadian farmland and provides a reasonable estimate of the risk of water contamination by nitrogen at regional and provincial levels. It is useful for making regional comparisons, showing trends over time, and targeting more detailed analysis. Although this indicator applies to the humid agricultural areas of Canada, drier areas may also be susceptible to water contamination by nitrogen, especially in areas of intensive livestock operations or intensive crop production (*see* Box on Alberta).

The trend analysis, either on its own or along with field data, may provide an early warning that areas now not at risk will become so unless appropriate management practices are put into place.

Related Indicators

This indicator may identify areas where eutrophication of surface waters is a problem, as does the Risk of Water Contamination by Phosphorus. The Risk of Water Contamination by Nitrogen increases with high levels of Residual Nitrogen. Nitrogen levels in the soil are influenced by various components of the Management of Farm Nutrient and Pesticide Inputs indicator.

Monitoring nitrogen in Alberta's farmland waters

In Alberta the agricultural industry has grown markedly in the past 25 years. Farmland area on which mineral fertilizers and pesticides are used has almost tripled. The number of cattle has grown by more than 50%, with Alberta now producing almost 40% of Canada's beef and finishing more than 65% of it.

Because agriculture occupies such a large land base in Alberta and farmers are themselves major users of water, water quality is a primary concern of the agricultural industry. Under the Canada–Alberta Environmentally Sustainable Agriculture Agreement, a 5-year study (1992–1996) was undertaken to assess the effects of primary agriculture on water quality in Alberta's agricultural areas. Water was monitored for nutrients, pesticides, and bacteria in farmstead wells and dugouts, surface waters (lakes and streams), and irrigation canals.

The major findings relating nitrogen levels in study waters to the *Canadian Water Quality Guidelines* were:

- 0.6% of 448 deep wells sampled had nitrate-plus-nitrite levels above the guideline for human drinking
- 13% of 376 shallow wells sampled had nitrate-plus-nitrite levels above the guideline for human drinking, and 0.3% of these wells exceeded the guideline for livestock drinking
- nitrate-plus-nitrite levels did not exceed the guidelines for human or livestock drinking (there are no guidelines for this combination of substances respecting aquatic life) in dugouts, streams, or irrigation canals.
- 87% of streams in areas of highly intensive farming had total nitrogen levels that exceeded the guideline for aquatic life; this figure was 65% in areas of moderately intensive farming and 32% in areas of low-intensity farming.

The source of nitrate-nitrogen in shallow wells was unclear, though research shows that excessive manure and fertilizer applications may result in widespread contamination of groundwater with nitrate. Unconfined shallow aquifers are particularly at risk.

Source: Alberta Agriculture, Food and Rural Development, 1998

13 Risk of Water Contamination by Phosphorus

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Geographic scope: Quebec
Time series: 1981, 1991, 1996

Highlights

- Phosphorus moving off farmland into surface waters can cause eutrophication; overgrowth of algae and aquatic plants; reduced oxygen levels in water; and subsequent changes in the species composition of the aquatic ecosystem. An indicator is needed to estimate to what extent phosphorus may move off farmland into surface waters under various soil and landscape conditions and agricultural management practices.

- A preliminary indicator for the Risk of Water Contamination by Phosphorus was developed. The indicator was estimated using values for the risk of phosphorus transfer, weighting these values according to seven site characteristics, then summing them to obtain an overall index. The risk was first expressed in five classes: very low, low, medium, high, and very high. However, because no land was rated at very low or very high risk, these classes were dropped and the medium risk class was subdivided into medium low, medium, and medium high. A performance objective will be defined when the indicator has been further developed.

- Indicator ratings were calculated for agricultural areas of Quebec in 1981, 1991, and 1996. Ratings were very similar between 1981 and 1996, with about 19% of farmland area at low risk, 72 to 73% at medium risk, and 8 to 10% at high risk of water contamination by phosphorus. However, this similarity masks the distinct drop in the area at low risk (13%) and the jump in the areas at medium risk (77%), especially medium high risk, in 1991.

- The approach showed some sensitivity to variations over time in the census data, particularly related to the contribution of phosphorus from manure and mineral fertilizers (e.g., the indicator estimated that the relative risk of non-point source pollution by phosphorus rose between 1981 and 1991).

- Further work on the indicator is needed to gather better index data and account for specific management practices at the farm level. This indexing approach must remain flexible to accommodate regional differences in soil characteristics and climate. Modifications must be made to refine the ratings in the methodology (e.g., some areas expected to be in the high risk class from water quality data did not rate as such with the indicator).

The Issue

Surface water in Quebec is an abundant natural resource, covering about 10% of the province. About 4500 rivers, half a million lakes, and 430 major watersheds make up this resource. The overall quality of river water has improved in the past 20 years, mainly because of better control of point-source pollution (e.g., better treatment of municipal waters and less industrial pollution). Still, long term environmental objectives have not yet been achieved, and many regions still have undesirable water quality, partly as a result of non point-source pollution by phosphorus (*see* Box on Boyer River).

Areas at risk of water contamination by phosphorus are those in which water moves freely from agricultural fields to surface waters. Regions where soil tests show high phosphorus levels and where the ability of soils to retain phosphorus is low (i.e., low soil phosphorus sorption capacities) are particularly at risk. An indicator is needed to show where the risk of such contamination by agricultural activities is of greatest concern, and how this risk is changing over time.

The Boyer watershed

Thirty years ago, the Boyer River was a prolific spawning ground for smelt. Today there is an excess of nutrients and suspended matter in the river, and the smelt are gone. The Boyer River, located near Quebec City on the south shore of the St. Lawrence River, drains a watershed of 21 700 ha. About 60% of this area is farmland, much in high density livestock production. More than half the area's 275 farms produce hogs. Excess nutrients in this watershed (the amount left in the system after crops are harvested) are estimated at 317 tonnes of phosphorus and 630 tonnes of nitrogen annually.

The poor condition of the river is of common concern for the people who live in the watershed. To do something about it, a committee, GIRB (Groupe d'Intervention pour la Restoration de la Boyer), was formed, and specific programs were designed to clean up the water and introduce resource conservation measures. With federal, provincial, and private funds, participating farmers have been building better manure storage structures, completing engineering works to stabilize river banks, managing animal watering places, and restricting animal access to the river. They have also adopted conservation farming practices that do a better job of managing crop nutrients, preventing erosion, and dealing with surplus manure.

Source: Saint-Laurent Vision 2000, 1998

The Indicator

Description

It is difficult to measure how much phosphorus reaches surface waters from farmland. The processes involved are complex, and little is known about how much phosphorus enters these waters naturally. Instead, we have adapted an indicator that rates sites based on the relative risk (compared to other sites) of phosphorus moving through them into neighbouring waters. This indicator, the Risk of Water Contamination by Phosphorus, builds on an indexing approach developed by scientists in the United States. A performance objective will be defined when the indicator has been further developed.

Method of calculation

The indicator was calculated by determining the rate at which phosphorus would move through a landscape depending on various features (*see* Box). The indicator was first expressed in five risk classes: very low, low, medium, high, and very high. However, because no land was rated at very low or very high risk, these classes were dropped and the medium risk class was subdivided into medium low, medium, and medium high to better show differences in the risk. The indicator was calculated for areas in Quebec for which data on site features were available, covering a land area of about 1.9 million hectares.

Limitations

In this application the indicator is subject to the following limitations:

- the indicator was calculated for Quebec only, because of the restricted availability of relevant data
- some data were not available (e.g., the site features *soil test phosphorus* and *degree of soil phosphorus saturation* were kept constant across the census years because data were not available; however, these values would probably have been lower in 1981 than in 1991 and 1996)
- working at the level of the *Soil Landscapes of Canada* mapping areas, many important factors related to the risk of water contamination by farm-derived phosphorus could not be included in the index (e.g., details of manure application); applying this approach at the watershed or farm level will require more detailed information

Site features

The risk of phosphorus moving from a site depends on various features of that site. Seven such features were used to calculate the Risk of Water Contamination by Phosphorus.

Two of these features are directly related to phosphorus transport: soil erosion, estimated using the Revised Universal Soil Loss Equation For Application in Canada; and *overland flow* (surface runoff) *potential*, estimated by relating the percentage of slope to runoff curve numbers.

Two site characteristics are related to the status of phosphorus in the soil: degree of soil phosphorus saturation, considered to be related to the risk of both surface and subsurface transport of P, and soil test phosphorus. Both of these were estimated from a provincial soil survey.

Three site characteristics are related to the annual phosphorus balance component: crop residue, manure, and mineral fertilizer. These features were calculated by adapting the method developed for the indicator of Risk of Water Contamination by Nitrogen.

Source: Bolinder et al., 1998

- a phosphorus-indexing approach has not been previously applied on such a large area; work is needed to refine the ratings.

Results

Figure 13-1 shows indicator ratings for mapping areas in Quebec in 1996. Most of the mapping areas with risk ratings of medium or higher were located in the St. Lawrence Lowlands and the region south of Quebec City, where agriculture is more intensive. Areas ranked at low and medium low risk were located mainly in the Laurentian region and western Quebec, as well as in the region north of Quebec City, areas where agriculture is less intensive.

Figure 13–1

Risk of water contamination by phosphorus on Quebec's farmland under 1996 management practices

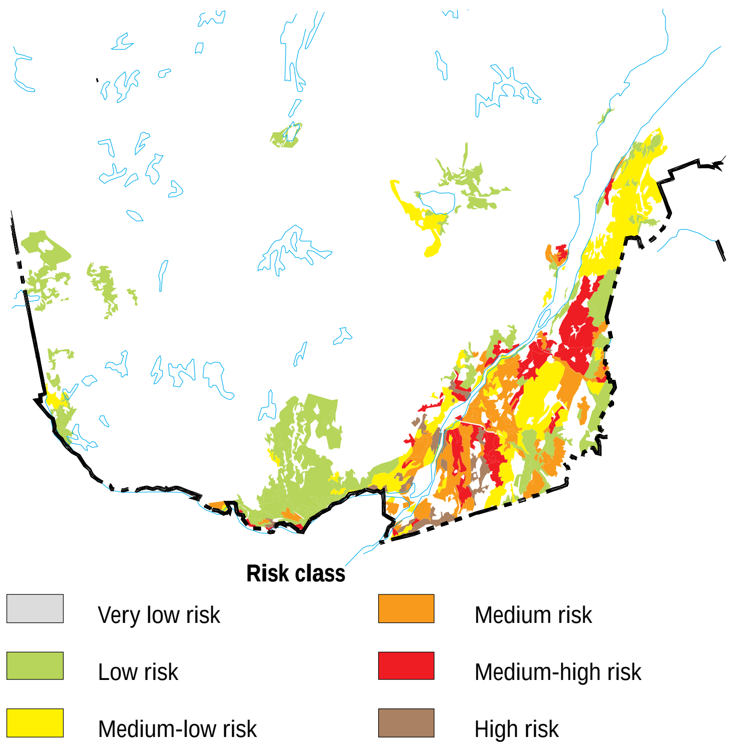


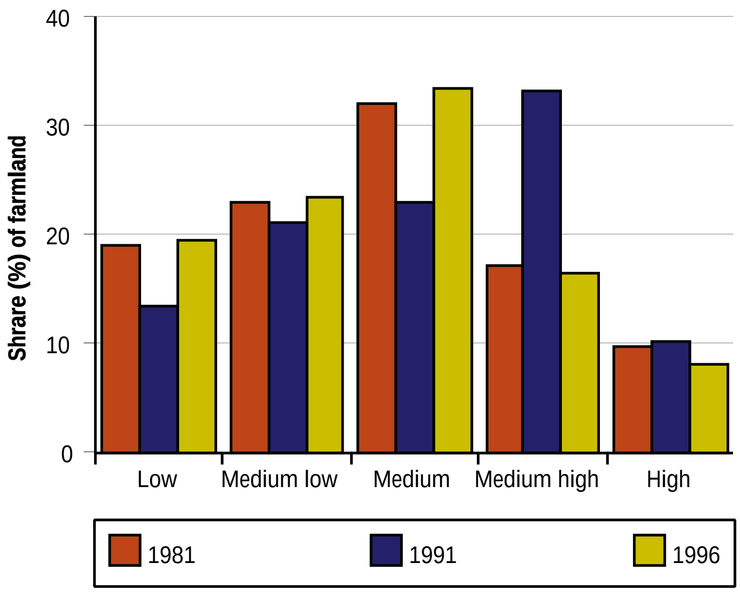
Figure 13-2 shows how risk values changed between census years. Between 1981 and 1991, the area at low risk of phosphorus movement shrank while that at medium, particularly medium high, risk grew (the area at medium high risk more than doubled during this period). By 1996, the areas at medium and high risk had returned to roughly 1981 values, and the area at low risk had grown by about 30%.

Interpretation

High phosphorus levels are often seen in areas of high density animal production, where local manure disposal may result in more phosphorus being applied to soil than is removed by harvested crops. A high degree of phosphorus saturation is also often found in soils used to grow cash crops with a high need for phosphorus, such as grain corn and soybeans (this usually means that large amounts of phosphorus fertilizer have been applied).

Figure 13–2

Changes in the risk of water contamination by phosphorus on Quebec's farmland between 1981 and 1996



Managing phosphorus on the farm

Dealing with agricultural non-point source pollution of waterways begins on the farm. Thus it is important that farmers understand the processes involved, as well as the actions needed to solve the problem. The environmental farm plans being used voluntarily by many Canadian farmers are one way to put these changes into place. A phosphorus-indexing approach with detailed information can easily be integrated into environmental farm plans.

Agronomist Jocelyn Magnan of the Club de fertilisation de la Beauce Inc., is introducing this approach to farmers in the province of Quebec when he helps to design farm plans. "The advantage with the phosphorus-indexing approach is that the farmers can easily understand the concepts involved and how it is calculated. Therefore, they can actively participate in the appropriate decisions that are required to reduce the environmental risk," says Jocelyn.

Provincial scientists in Ontario are also introducing this approach to farmers. Applying the Risk of Water Contamination by Phosphorus indicator at the farm level can identify management practices that will help to reduce the risk of phosphorus contamination of water. These practices include

- applying manure according to crop needs and the ability of the soil to retain phosphorus (i.e., phosphorus retention capacity)
- using measures to control erosion
- avoiding fall application of manure in areas of high risk.

Source: Simard et al., 1998

Total phosphorus concentrations often exceed the provincial standard (0.03 milligrams of total phosphorus per litre of water) in the Assomption, Boyer (*see* Box), Chaudière, Etchemin, Nicolet, Richelieu, St-François, and Yamaska rivers, which drain watersheds with high livestock densities. The indicator did not clearly identify all these watersheds as areas of concern, although it did identify some.

For example, mapping areas located around the Etchemin, Chaudière, and Assomption rivers showed indicator values toward the high level. Although some risk values for these areas changed over time, most of the polygons remained at medium high or high risk. The Quebec Ministry of Environment reports that, between 1988 and 1991, phosphorus levels were higher than the provincial norm 82% of the time in the Chaudière River, 97% of the time in the Etchemin River, and 100% of the time in the Assomption River.

In contrast, regions such as Abitibi and Lac Saint Jean had mapping areas mainly in the low risk class, though some medium low risk areas exist. Non point-source pollution of surface waters by phosphorus is less often observed there. These regions have a more extensive agriculture, dominated by beef and dairy cattle production, and most of the cultivated area is grassland.

Response Options

There are various ways to reduce the risk of phosphorus transfer, depending on site characteristics, cropping practices, and how much phosphorus is present at the site. For areas ranked at very low to medium risk, management options to minimize transfer of phosphorus to the surrounding environment include

- controlling erosion
- restricting animal access to surface waters
- optimizing uptake of phosphorus by crops
- managing mineral fertilizer and animal manure more effectively.

For watersheds in which soils are at high and very high risk of losing phosphorus, these management practices should be carried out along with other measures. Where soil test phosphorus is high, phosphorus additions should be limited and the balance between inputs and outputs kept as close to zero as possible. This implies that manure management strategies should be based on phosphorus rather than on nitrogen. Various codes of practice and government regulations promote this goal (*see* Box on new Quebec regulation).

Where phosphorus levels in soil are very high and the ability of the soil to retain this phosphorus is low, it is desirable to reduce the amount of phosphorus in the soil. This means that the amount of phosphorus exported by crops must be greater than the amount added to soil by manure and mineral fertilizer. Crops with a high requirement for phosphorus might also be selected (e.g., including silage corn or canola in the rotations).

Areas of intensive animal production and restricted land base would benefit from technologies that both reduce the amount or solubility of phosphorus in manure and export the manure off site (e.g., composting).

Conclusion

The Risk of Water Contamination by Phosphorus indicator highlights differences in risk levels between areas of intensive and less intensive agriculture. It also shows some sensitivity to changes over time in census data, particularly related to the contribution of phosphorus from animal manure and mineral fertilizers.

More research is needed to make sure that sites ranked in the high and very high risk classes actually and consistently transfer significantly higher amounts of phosphorus to surface waters than sites with lower risk. We caution that the indicator should only be used to identify areas at risk of phosphorus transfer. These areas should then be studied in more detail to verify the actual nature and degree of risk involved.

The sources and factors related to non point-source pollution by phosphorus may differ across the country. The indicator will have to remain flexible to take into account regional characteristics of soil and climate.

Quebec's new regulation for livestock operations

Quebec's new regulation for livestock operations, the Regulation for the Reduction of Pollution of Agricultural Origin, which came into force in July 1998, aims to protect soil and water quality through strict provisions for the timing of manure application, the application of nutrients to phosphorus-rich soils, and the separation distances between watercourses and farm activities and structures. In addition to a requirement for operating permits that is retained from previous regulations, livestock producers must prepare a nutrient management plan for the storage and application of manure, compost, and mineral fertilizers, specifying appropriate periods and amounts for application. The plan must be approved by an agronomist, a soil technologist under the supervision of an agronomist, or a producer trained for this task.

Among other requirements, producers must

- have 200 days of manure storage capacity for facilities built before 3 July 1997 and 250 days of storage capacity for facilities built after that date
- avoid manure application between 1 October and 31 March unless a nutrient management plan is in place or application practices comply with provincial guidelines
- avoid applying phosphorus fertilizer to phosphorus-rich soils beyond crop requirements and must include measures to reduce levels of soil phosphorus in the nutrient management plan.

Source: Hog Environmental Strategy Steering Committee, 1997

Related Indicators

This indicator is related to the Risk of Water Erosion, because phosphorus can be carried into surface waters by runoff from farmland. The potential for water to be contaminated by nitrogen, another crop nutrient that moves off farmland into water, is assessed by the Risk of Water Contamination by Nitrogen. The amount of phosphorus in soil is a major factor in the Risk of Water Contamination by Phosphorus, and this amount is subject to the Management of Farm Nutrient and Pesticide Inputs.

E

Agroecosystem Greenhouse Gas Emissions

E Agroecosystem Greenhouse Gas Emissions

The earth absorbs short wavelength radiation from the sun and then re-radiates it into the atmosphere at longer wavelengths. Certain gases in the atmosphere, such as water vapour, nitrous oxide, methane, carbon dioxide, and ozone, act like greenhouse windows and trap this radiation. The trapped radiation warms the earth, bringing the average surface temperature to 15°C instead of –18°C, the temperature that would occur without this trapping effect. This phenomenon, the *natural greenhouse effect*, has warmed our planet for billions of years.

Atmospheric concentrations of *greenhouse gases* and average global temperature are thought to have changed little from century to century over the last 10 000 years. During the last five decades, however, greenhouse gas concentrations have risen dramatically. As a result, these gases trap more of the outgoing terrestrial radiation, warming the atmosphere and the earth's surface in an *enhanced greenhouse effect*.

Nitrous oxide, methane, and carbon dioxide account for almost 90% of the enhanced greenhouse effect. Their concentrations have risen during the last 50 years by

- 15% for nitrous oxide
- 145% for methane
- 30% for carbon dioxide.

The Kyoto Protocol

The Kyoto Protocol to the United Nations Framework Convention on Climate Change was adopted by more than 160 nations in December 1997. The protocol is aimed at lowering overall emissions of a group of six greenhouse gases by the period 2008–2012. The three most important gases—nitrous oxide, methane, and carbon dioxide—will be measured against a base year of 1990. The three long-lived industrial gases—hydroflurocarbon, perflurocarbon, and sulfur hexafluoride—will be measured against either the 1990 or 1995 base year.

Under this international agreement, individual countries have negotiated for different levels of reduction. Switzerland will lower its emissions by 8%, as will the European Union and many central and east European states. The United States will lower its emissions by 7%, and Canada, Hungary, Japan, and Poland will lower theirs by 6%. Russia, New Zealand, and the Ukraine will stabilize their emissions, while Norway may increase its emissions by 1%; Australia, by as much as 8%; and Iceland, by 10%.

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If these concentrations continue to rise at the current rate, computer models that simulate the workings of the atmosphere predict that the average global surface air temperature will rise by about 2°C by the year 2100. Such a temperature change is expected to cause greater fluctuations in weather conditions, with severe effects on the agricultural industry and other human activities. Global warming is still being debated, but a sharp rise in global temperatures in the past decade has spotlighted humankind's contribution to climate change. Such an increase in temperature could also result in greater loss of soil carbon, which could affect the greenhouse gas budget directly.

Recognizing the threats due to climate change, many countries have recently agreed under the Kyoto Protocol to reduce their greenhouse gas emissions (*see* Box). Canada aims to reduce its emissions to 6% below the 1990 levels by the period 2008–2012. Assuming today's conditions, meeting this target will necessitate a reduction of about 140 megatonnes carbon dioxide equivalent per year. This figure corresponds to about 20% of the expected emissions in 2010. To achieve such a reduction will require a joint effort from all sectors of the Canadian economy.

14 Agricultural Greenhouse Gas Budget

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Geographic scope: National, provincial
Time series: 1981, 1986, 1991, 1996

Highlights

- Atmospheric concentrations of greenhouse gases — particularly nitrous oxide, methane, and carbon dioxide — have been increasing dramatically in the past 20 years, enhancing the greenhouse effect by which the earth's atmosphere is warmed. Uncontrolled buildup of these gases in the atmosphere may cause global warming and other climate changes.
- An indicator was developed to estimate the combined emissions of nitrous oxide, methane, and carbon dioxide as a result of agricultural activity. Emissions were estimated for nitrous oxide and methane using the Intergovernmental Panel on Climate Change methodology, and for carbon dioxide using the Century model. The performance objective is to have declining net emissions of greenhouse gases over time.
- According to the most recent estimates, total agricultural emissions of nitrous oxide, methane, and carbon dioxide (the first two expressed in carbon dioxide equivalents) in 1981, 1986, 1991, and 1996 were 83, 78, 77, and 86 megatonnes, respectively, representing about 13% of total 1996 Canadian emissions. These amounts include all sources associated with farming except food processing and transportation, and reflect an increase of about 4% between 1981 and 1996.
- Agricultural emissions of nitrous oxide in 1981, 1986, 1991, 1996 were 99, 96, 99, and 120 kilotonnes respectively, rising by 21% between 1981 and 1996. Agricultural emissions of methane were relatively constant, at 1045, 927, 949, and 1074 kilotonnes during these years. Total agricultural emissions of carbon dioxide were 30, 28, 26, and 26 megatonnes during these years, dropping by 13% between 1981 and 1996. This reduction in carbon dioxide emissions was mainly the result of adopting conservation farming practices. During this period, the increase in nitrous oxide and methane emissions was mainly the result of more-intensive farming practices and growing use of nitrogen fertilizer.
- At the provincial level, greenhouse gas emissions from Alberta increased significantly from 17 megatonnes in 1981 to 21 megatonnes in 1996. Emissions from Manitoba also increased during this period. Emissions were relatively steady in British Columbia, Saskatchewan, and the Atlantic Provinces, while those from Ontario and Quebec tended to decrease. Based on 1996 estimates, British Columbia contributed 4% to Canada's total emissions; Alberta, 34%; Saskatchewan, 19%; Manitoba, 13%; Ontario, 17%; Quebec, 11%; and the Atlantic Provinces, 2%.
- Emissions from animal manure in carbon dioxide equivalents (19 megatonnes in 1981, 20 megatonnes in 1996) and from mineral fertilizers (8 megatonnes in 1981, 12 megatonnes in 1996) generally increased throughout this period, whereas emissions from crops (16 megatonnes in 1981, 14 megatonnes in 1996) tended to decrease. Enteric fermentation has remained relatively steady in its contribution.
- Nitrous oxide release can be minimized by using methods of nitrogen application that improve plant uptake efficiency, reduce nitrous oxide release per unit of nitrogen applied, and reduce the amount of nitrogen in manure by changing the composition of livestock feed. Methane emissions can be reduced by using better methods of manure storage and feeding. Carbon dioxide emissions can be reduced by increasing soil carbon content and reducing the use of fossil fuels.

The Issue

Agriculture contributes 10 to 13% of Canada's greenhouse gas emissions. Although this is a relatively small share, reducing this contribution would help Canada meet its reduction commitment. Agriculture is also one of the sectors most likely to be affected by climate change. If change takes place gradually, agriculture may be able to adapt. But sudden change could have drastic results, such as

- changes in production patterns
- increases in crop damage
- water shortages
- new, unpredictable changes in the interactions among crops, weeds, insects, and disease.

The agricultural sector must take steps to reduce greenhouse gas emissions and to monitor its progress in doing so. To accomplish this, an accurate inventory of emissions and an understanding of the controlling factors are needed.

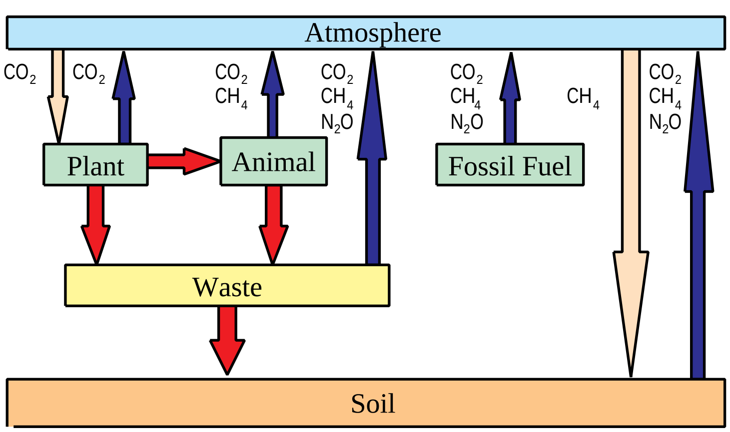
The Indicator

Description

Figure 14-1 shows the main sources and sinks of greenhouse gases associated with agroecosystems. The Agricultural Greenhouse Gas Budget indicator estimates the net exchange of nitrous oxide, methane, and carbon dioxide, with the first two gases expressed in *carbon dioxide equivalents* (*see* Box on pg. 143).

Figure 14-1

Principal sources and sinks of greenhouse gases associated with agroecosystems



The performance objective for this indicator is to have declining net emissions of greenhouse gases over time (a specific reduction target has not been established for agriculture).

Method of calculation

Nitrous oxide

We mainly followed the methodology of the Intergovernmental Panel on Climate Change (IPCC), incorporating Canadian data where possible, to estimate three categories of nitrous oxide emissions:

- direct emissions from agricultural fields
- direct emissions from animal production systems
- indirect emissions derived from nitrogen that came from agricultural systems.

Direct emissions from agricultural fields include those from

- mineral fertilizers applied to agricultural soils
- animal manure used as fertilizer
- nitrogen-fixing crops
- crop residues
- the cultivation of organic soils.

Direct emissions from animal production systems include those from animal wastes (during collection and storage) and grazing animals (direct deposit onto pastures).

Applying nitrogen fertilizers and animal manure can result in the indirect release of nitrous oxide by

- volatilization and atmospheric deposition of ammonia and various oxides of nitrogen
- nitrogen leaching and runoff.

The data used to estimate nitrogen losses in the form of ammonia and various oxides of nitrogen were derived from estimates of nitrogen fertilizer use and nitrogen from animal manure. As more measurements of nitrogen deposition become available, the emission factors will be modified to better reflect Canadian conditions.

Methane

Methane is emitted mainly from farm animals (burping and flatulence) and the *anaerobic* decomposition of their manure. We used methodology established by the IPCC to calculate these emissions. As more representative

Carbon dioxide equivalents

A gas's contribution to the greenhouse effect depends not only on its capacity to absorb and re-emit radiation, but also on its *residency time* in the atmosphere — how long it remains there in that molecular form. Gas molecules gradually break down or react with other atmospheric compounds to form new molecules with different radiative properties.

Methane has an average residency time of about 12 years; nitrous oxide, 130 years; and carbon dioxide, 200 years. Over a 20-year period, 1 kilogram of methane has 56 times greater ability to trap radiation than 1 kilogram of carbon dioxide. But, over time, some methane breaks down into carbon dioxide and water. So, over 100 years, methane has a global warming potential 21 times that of carbon dioxide. Similarly, nitrous oxide is 310 times more effective than carbon dioxide over a 100-year span.

These two figures — 21 for methane and 310 for nitrous oxide — are called *global warming potentials* and are used to weight the effectiveness of these two gases in the calculation of the greenhouse gas budget. In other words, emission values for methane and nitrous oxide are expressed as carbon dioxide equivalents.

The total carbon dioxide equivalent (measured in megatonnes) of the emissions of nitrous oxide, methane, and carbon dioxide is calculated as

$$CO_{2eq} = (N_2O \times 310) + (CH_4 \times 21) + (CO_2 \times 1).$$

The global warming potential, a tool developed mainly for policy makers, provides a simple measure to compare the potency of various greenhouse gases in carbon dioxide equivalent units. This comparison is useful when a decision must be made on which gas emissions should be reduced and what mitigation options are best. For example, a small reduction in nitrous oxide emission can be just as effective as a larger reduction in carbon dioxide emission. In this report, global warming potentials are based on a 100-year time horizon.

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data for animals in Canada become available, the emission factors will be adjusted.

Soils may act as a methane sink or as a source, depending on moisture conditions. Methane emissions from waterlogged areas were estimated by multiplying the total area of wet soils by an average emission factor based on measurements in Canada. Methane absorption by agricultural soils was estimated using an absorption value observed for agricultural land.

Carbon dioxide

Carbon dioxide emissions from soils were estimated using the Century model for carbon exchange (*see* Box in Chapter 9), which accounts for agricultural management practices, including planting, fertilizer application, tillage, grazing, and addition of organic matter. Canada's national inventory of greenhouse gases avoids overlapping estimates by attributing carbon dioxide produced from fuel consumption and the manufacture of fertilizers and machinery to the transportation and manufacturing sectors. We present estimates of agricultural greenhouse gas emissions with and without this contribution.

Limitations

The scientific study of greenhouse gases is still very new, and there is a high level of uncertainty with most estimates. Those of nitrous oxide emissions are subject to the largest error because of high spatial variability and the intermittence of emissions.

The methodology of the Intergovernmental Panel on Climate Change to calculate greenhouse gas emissions considers all agricultural systems to have the same climate, soils, crops, and management systems. More-accurate values for methane and nitrous oxide emissions are needed to reflect Canadian conditions. Calculating these values will be possible with more long term experimental observations and better models.

Figure 14-2

Greenhouse gas emissions from agroecosystems, with and without carbon dioxide emissions from on-farm fossil fuel use and indirect sources

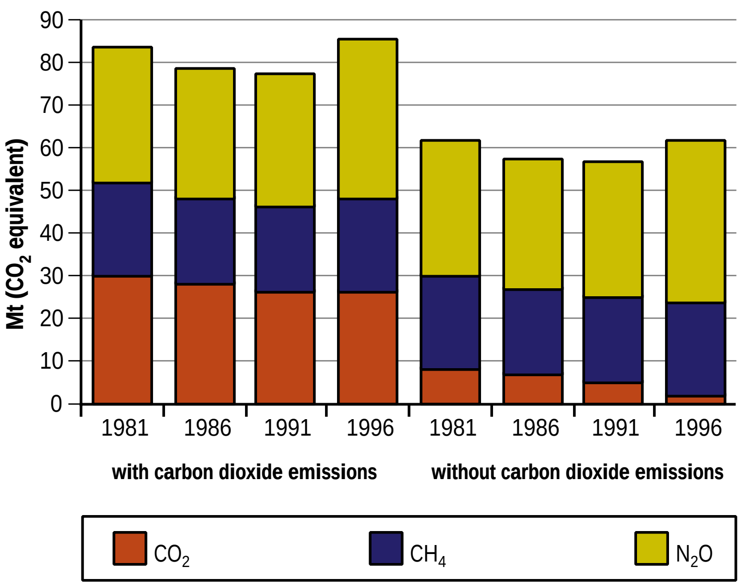


Table 14-1

Agricultural emissions of nitrous oxide

	1981	1986	1991	1996
	megatonnes of carbon dioxide equivalent			
Fertilizers	3.5	3.5	3.4	4.8
Manure	3.3	3.0	3.2	3.5
Nitrogen-fixing crops	2.3	2.8	3.0	3.9
Crop residues	4.7	4.7	4.7	5.5
Organic soils	0.1	0.1	0.1	0.1
Total soils	**13.9**	**14.1**	**14.4**	**17.8**
Animal production systems	**6.9**	**6.2**	**6.7**	**7.6**
Total indirect emissions	**9.9**	**9.5**	**9.6**	**11.8**
Total agricultural nitrous oxide emissions	**31**	**30**	**31**	**37**

Table 14-2

Agricultural emissions of methane

	1981	1986	1991	1996
	megatonnes of carbon dioxide equivalent			
Livestock	17.8	15.7	16.2	18.4
Manure	4.4	4.0	4.0	4.4
Soils	– 0.3	– 0.3	– 0.3	– 0.3
Total agricultural emissions	**22**	**19**	**20**	**23**

Results

Emissions of the three main greenhouse gases associated with agriculture are presented in carbon dioxide equivalents (Fig. 14-2) in two categories: 1) including all sources associated with farming except food processing and transportation; and 2) excluding carbon dioxide contributions from fossil fuels used on farms and other indirect sources associated with farming (specifically the manufacture of fertilizer, machinery, and pesticides; farm building construction; and electricity generation). Nitrous oxide emissions increased by 21% between 1981 and 1996 and methane emissions remained fairly constant. Carbon dioxide emissions from all sources dropped by 13%; if indirect sources are excluded, emissions dropped by 34%.

Data for all three gases are combined and presented on a provincial basis in Figure 14-3, with the Atlantic Provinces combined. Figure 14-3 presents data excluding carbon dioxide emissions from indirect sources. Alberta had the sharpest increase in total emissions during the study period. Figure 14-4 shows the contribution of major farm sources to the Canadian agricultural total of greenhouse gas emissions.

Of the total nitrous oxide emissions, direct emissions from soils account for about one-half, of which one-third is attributed to crop residues (Table 14-1). Indirect emissions, the most difficult to measure, account for about one-third of the total nitrous oxide emissions.

Table 14-2 gives a breakdown of agricultural emissions of methane. The value for soils is based on estimates of

- an emission of 12 *kilotonnes* per year
- an absorption of 24 kilotonnes per year.

Thus, Canada's agricultural soils are considered to be a net sink of methane, absorbing about 12 kilotonnes of methane each year (about 0.3 *megatonnes* in carbon dioxide equivalent).

A breakdown of agricultural emissions of carbon dioxide is given in Table 14-3. When fossil fuels used for farm equipment and stationary combustion, as well as those used for fertilizer manufacture and transportation, construction, pesticide manufacture, and electrical generation, are included, agriculture's emissions of carbon dioxide in 1996 jump from 1.8 megatonnes to 25.7 megatonnes.

Interpretation

Total agricultural emissions of nitrous oxide, methane, and carbon dioxide remained relatively steady from 1986 to 1991 but rose sharply by 1996, mainly as a result of greater emissions of nitrous oxide. Excluding indirect sources of carbon dioxide, agriculture contributes about 10% of Canada's greenhouse gas emissions. If all sources of carbon dioxide, except those from food processing and transportation, are included, agriculture's contribution is about 13%. This amount is a relatively small share, but because agriculture is intensively managed, a reduction by the agricultural sector is a viable option to help Canada meet its overall reduction goal.

The largest increase in greenhouse gas emissions in the agricultural sector was observed from 1991 to 1996 for nitrous oxide. This large increase is the result of a rise of

- 9% in crop production
- 22% in legume production
- 18% in the number of beef cattle
- 15% in the number of hogs
- 33% in the amount of nitrogen fertilizer used.

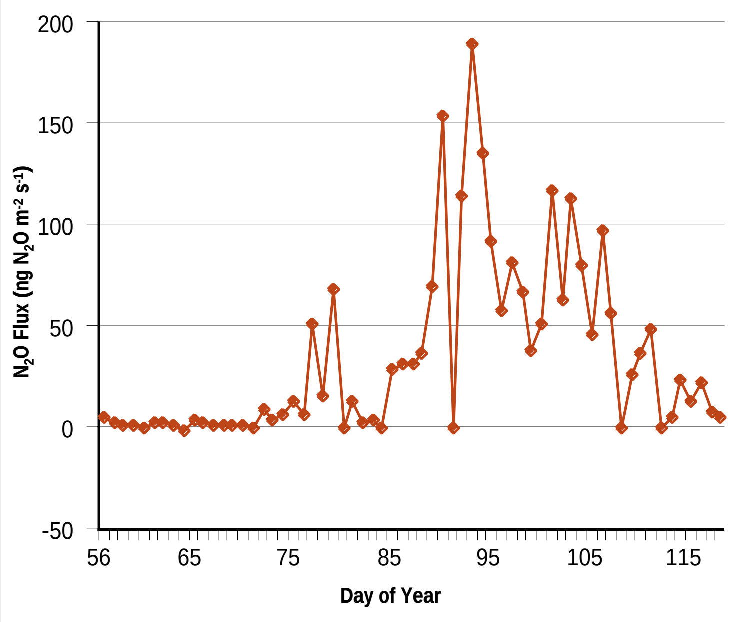
Methane emission rates used for this study correspond reasonably well to the rates determined in several Canadian studies. Methane emissions are a function of livestock population. Much progress has been made in reducing these emissions by increasing the efficiency of milk and animal production. For example, in 1951, 1.7 million cows produced 2.4 billion litres of milk, whereas in 1991, fewer than 0.9 million cows were required to produce the same amount of milk. Methane emissions from animal manure, estimated at 200 kilotonnes per year, make up 20% of the total.

Canada's agricultural soils accounted for about 7% of agricultural emissions of carbon dioxide in 1996. Agricultural soils have lost about 25% of their original carbon content since cultivation began (*see* Chapter 9). The carbon content of soils can be influenced by management practices, such as tillage systems. According to model predictions, if farmers continue to convert from conventional tillage to no-till systems at the present rate, agricultural soils will cease to be a source of carbon dioxide before 2001 and will store 0.5 to 0.7 megatonnes of carbon each year by 2010. This trend will continue only until agricultural soils have reached a new equilibrium and only if carbon-enhancing practices (such as no-till) are maintained.

A much greater share of carbon dioxide emissions comes from burning fossil fuels. Fuel use on Canadian farms releases 8 to 10 megatonnes of carbon dioxide annually. Indirect sources (notably the manufacture and transportation of

Release of nitrous oxide during snow melt

The release of nitrous oxide is sporadic, often occurring in bursts. About 50 to 75% of the annual emission of nitrous oxide in Canada occurs in early spring during the snow melt. Excess water causes *anaerobic* conditions that, coupled with adequate nitrate, available carbon, and favorable temperatures, allow for *denitrification* and the formation of nitrous oxide. Emissions of nitrous oxide are also sporadic across space because of different moisture conditions and soil nitrogen content. The release may be minimal over large areas, but high emissions are common from spots where conditions are ideal for nitrous oxide production.



Nitrous oxide emissions measured in 1996 from a soybean field in Ottawa. Bursts of nitrous oxide emissions occur just after spring thaw and following fertilizer applications.

E. Pattey, Agriculture and Agri-Food Canada

Table 14–3

Direct and indirect agricultural emissions of carbon dioxide

	1981	1986	1991	1996
	megatonnes of carbon dioxide			
Fossil fuels	9.5	7.7	8.1	9.5
Soils	7.7	7.3	5.1	1.8
Total Direct Emissions	**17.2**	**15.0**	**13.2**	**11.3**
Fertilizer manufacture, transport and application	4.4	5.5	5.1	6.6
Machinery manufacture and repair	4.7	4.3	3.9	3.7
Building construction	1.5	1.4	1.7	1.4
Pesticide manufacture	0.2	0.3	0.3	0.3
Electricity generation	1.8	1.9	2.1	2.4
Total Indirect Emissions	**12.6**	**13.4**	**13.1**	**14.4**
Total Agricultural Emissions*	**30**	**28**	**26**	**26**

*excluding food processing and transportation

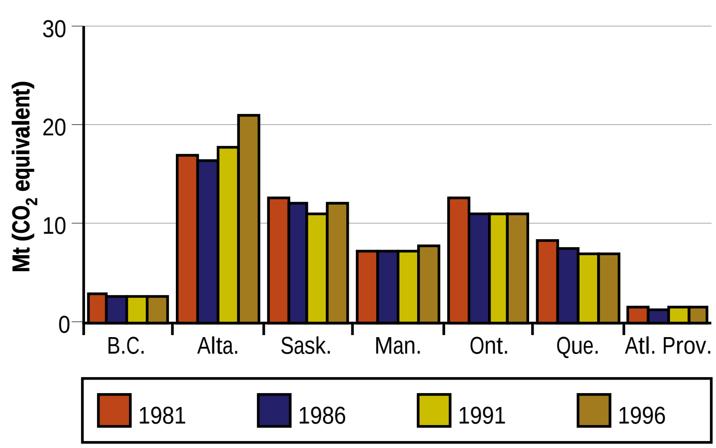
mineral fertilizer) contribute a further 14 to 16 megatonnes from fuel combustion. As fertilizer use grows, so do associated carbon dioxide emissions. Substantial amounts of carbon dioxide are also emitted during the manufacture of farm machinery, construction of buildings, and generation of electricity.

The reduction in agricultural emissions of carbon dioxide between 1981 and 1996 is mainly the result of changes in land use and management practices. These changes include

- reduction in summerfallow
- increased use of no-till farming
- inclusion of legumes or grasses in crop rotations
- improved soil management, resulting in less soil erosion
- conversion of cropland to perennial grass or trees.

Figure 14–3

Agricultural emissions of greenhouse gases, in carbon dioxide equivalents



Response Options

Nitrous oxide emissions are often increased by poor soil conditions. Improved conditions should lead to more-efficient use of nitrogen. Practices that promote such improvement include

- the use of controlled-release fertilizers
- the use of nitrification inhibitors
- improved timing of nitrogen application
- better water and manure management
- refined nitrogen content in animal feeds.

Most of the methane from manure is produced during storage. When the manure is stored as liquid or in poorly aerated piles, the lack of oxygen prevents complete decomposition to carbon dioxide, resulting in the production of methane. Thus, most of the methods to reduce methane emissions from manure involve

- slowing decomposition
- providing better aeration
- reducing storage time.

The amount of methane produced by farm animals can be reduced by improving animal feed and speeding up the passage of food during digestion by means such as

- using easily digestible feeds like grains, legumes, and silage
- harvesting forages at an earlier, more succulent growth stage
- chopping feed to increase surface area
- minimizing the use of coarse grasses and hays
- feeding concentrated supplements as required.

Agricultural emissions of carbon dioxide can be reduced by cutting down on the use of fossils fuels through practices such as

- reduced tillage
- improved irrigation scheduling

- solar drying of crops
- improved fertilizer management
- greater efficiency in farm machinery
- greater use of biofuels, such as ethanol (*see* Box).

Storing more carbon in soil is another way of reducing carbon dioxide emissions. Carbon storage can be promoted by

- growing more forages and grass
- using no-till systems
- using methods that increase yields and, in turn, crop residue input (e.g., manure application, better fertilization)
- reducing use of summerfallow
- using soil conservation practices (e.g., shelterbelts, grassed waterways)
- replanting marginal land to grass or trees.

In assessing the value of various management practices for curbing greenhouse gas emissions, it is important to look at the whole system and to account for the different global warming potential of each gas and the possible interactions between management practices (e.g., some restore carbon in soil but result in greater nitrous oxide emissions).

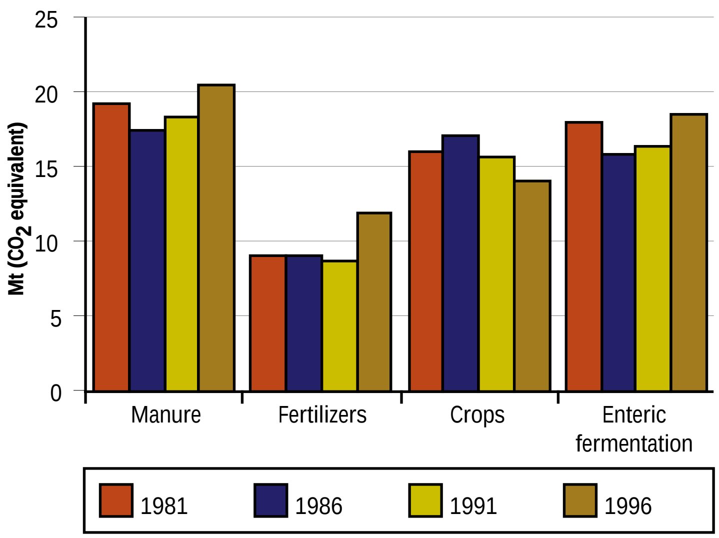
Conclusion

Canada has committed to reduce its greenhouse gas emissions to 6% below 1990 levels by 2008 to 2012. Because current emissions are already well above those in 1990, Canada may have to reduce its greenhouse gas emissions by about 20%, or the equivalent of 140 megatonnes of carbon dioxide. To achieve this reduction, all sectors of the economy will have to play a role.

Agriculture accounts for 13% of Canada's total greenhouse gas emissions from human activity if the use of fossil fuels (usually attributed to the transportation and manufacturing sectors) is considered, or 10% if not included. Total agricultural emissions have increased from 83 megatonnes of carbon dioxide equivalent in 1981 to 86 megatonnes in 1996. Because agroecosystems are intensively managed, they present many opportunities to adopt measures that reduce greenhouse gas emissions. To quantify the benefits of these

Figure 14–4

Greenhouse gas emissions from the four main agricultural sources, in carbon dioxide equivalents



Ethanol substitutes for fossil fuels

The amount of carbon dioxide generated by burning fossil fuels can be reduced by increasing the amount of plant biomass used for energy production. Biofuels, such as ethanol, can be produced from agricultural products such as corn, wheat, canola, and barley or from agricultural residues, such as wood and wood wastes. Blending 10% ethanol with gasoline can reduce emissions from transportation. Much of the carbon dioxide released from the burning of biofuels is then recaptured by new growth of vegetation. There is no net increase of carbon dioxide, as this is essentially a closed carbon cycle. In contrast, carbon dioxide released from the burning of fossil fuels represents a net increase in carbon dioxide levels, as this carbon is removed from deep inside the earth and directly added into the carbon cycle.

In Canada, about 30 million litres of ethanol are now produced annually from wheat and corn, reducing carbon dioxide emissions by about 21 kilotonnes of carbon dioxide per year. Recent developments in the ethanol industry are expected to increase Canadian production to about 350 million litres by 2000. Ethanol is most easily made from high-starch materials, but new methods make it possible to make it from fibrous matter, such as crop residues, forages, and crop wastes. In Saskatchewan it was recently estimated that about 2 megatonnes of straw and chaff are produced every year beyond that needed for animal bedding and for sustaining soils. This amount would produce about 500 million litres of ethanol, replacing about 0.4 megatonnes of carbon dioxide from fossil fuels, equivalent to 2% of the emissions from fossil fuels used in agriculture.

R.L. Desjardins, Agriculture and Agri-Food Canada measures, better methods of measuring greenhouse gas emissions are needed. More-accurate emission measurements will help in identifying the best management practices to reduce greenhouse gas emissions.

Related Indicators

The amount of Residual Nitrogen in soil is a controlling factor in the nitrous oxide component of the Agroecosystem Greenhouse Gas Budget. The extent to which management practices that limit nitrous oxide emissions are being adopted is reflected by Management of Farm Nutrient and Pesticide Inputs. Because the potential for agricultural soils to store carbon has implications for atmospheric concentrations of carbon dioxide, this indicator is also related to Soil Organic Carbon.

F

Agroecosystem Biodiversity

F Agroecosystem Biodiversity

Biological diversity, or *biodiversity*, is a term to describe the great variety of life we see around us. This variety includes the many species of plants, animals, and other organisms that inhabit the earth; the genetic variety they express and the ability to adapt to a wide range of environmental conditions that this variety allows; and the many ecosystems that abound on the earth, each with a complex array of species, individuals, communities, and interactions among them and with their physical environment.

Recognizing that the earth's biodiversity is a resource needing protection, Canada has joined with many other nations in signing the United Nations' Convention on Biological Diversity. The convention's goals are to conserve biodiversity, use its components sustainably, and equitably share the benefits gained through the use of genetic resources. Under the convention, Canada's federal, provincial, and territorial governments have worked together to develop the Canadian Biodiversity Strategy, which includes many agricultural objectives.

Agriculture benefits from biodiversity in many ways. For example,

- genetic variety is the foundation of plant and animal breeding programs
- wild species are a source of the genetic material needed to create biologically engineered crops and livestock that will perform better than existing varieties
- countless species of soil organisms are essential to the process of decomposition, the cycling of nutrients and energy, and the formation of soil
- insects and other organisms are needed as agents of biological control of crop pests
- insects serve as plant pollinators.

As well, people benefit from the presence of wildlife on agricultural land. They may enjoy viewing wildlife, or may engage in sport hunting and fishing or economic opportunities, such as ecotourism.

However, agriculture has contributed to a loss of biodiversity over the years, mainly through the alteration of natural habitats but also through effects on soil and water quality and the loss of old varieties of plants and domestic animals. To remedy this situation, many projects are under way on agricultural land in Canada to preserve and restore wetlands and riparian habitat; to protect endangered wild species, such as the swift fox, the American chestnut, and the wood poppy, and to support species recovery; to conserve endangered domestic livestock breeds and plant varieties; and to improve soil and water quality as they are affected by agriculture. These activities are helping to meet two of the agricultural goals of the Canadian Biodiversity Strategy — to maintain the agricultural resource base and to promote sustainable farming practices that are compatible with wildlife.

This section of the report presents one indicator of agroecosystem biodiversity, the availability of wildlife habitat on agricultural land (Chapter 15). Although agriculture has a history of depleting habitat, it also has the potential to restore and improve habitat through activities such as planting shelterbelts, managing woodlots, cleaning up agricultural drains, restoring wetlands and managing livestock access, and altering field management to integrate agriculture and wildlife needs. In time, this section may be expanded to include indicators that monitor key species on farmland and trends in the actual area of farmland that wildlife prefer — grasslands, woodlands and wetlands.

15 Availability of Wildlife Habitat on Farmland

P. Neave, E. Neave, T. Weins, and T. Riche

Geographic scope: National, ecozones
Time series: 1981, 1991, 1996

Highlights

- Loss and alteration of habitat is the leading cause of depletion of the earth's wildlife species, and thus of biodiversity. Conversion of natural land to agriculture has contributed to declining wildlife habitat, but agriculture also offers better habitat than some other land uses by humans, such as urban development. Wildlife on farmland offer both advantages (e.g., aesthetic appeal, hunting, fishing) and disadvantages (e.g., reduced crop yields).

- An indicator of Availability of Wildlife Habitat on Farmland was developed for the seven main ecozones in which agriculture is practised in Canada. The indicator identifies the share (%) of habitat use units associated with agricultural habitat types that have increased, decreased, or remained constant in area between 1981 and 1996. The assessment is based on habitat use by mammals, birds, reptiles, and amphibians known to occur in the agricultural areas of each ecozone. The indicator also notes changes in the distribution of agricultural habitat types during this period. A national performance objective has not yet been set, though objectives exist in specific habitat conservation programs throughout the country.

- To construct the indicator, habitat availability matrices were developed for each of the seven ecozones. These matrices specify how various wildlife species use agricultural land to meet their habitat needs (e.g., breeding, feeding, cover, staging, winter use). Each use of a habitat type by a species was recorded as one habitat use unit. Habitat use units were then summed by habitat type for each ecozone. The five habitat types assessed correspond to the five main land use categories defined in the 1996 *Census of Agriculture* (Cropland, Summerfallow, Tame or Seeded Pasture, Natural Land for Pasture, and All Other Land).

- All agricultural land has some value as wildlife habitat, but the All Other Land and Natural Land for Pasture census categories support the most habitat use units, followed by Cropland and Tame or Seeded Pasture. Summerfallow is used little as habitat by wildlife.

- The indicator shows positive trends in the availability of habitat on farmland in three ecozones. Habitat area increased for 86% of habitat use units in the Boreal Plains, 80% in the Prairies, and 73% in the Atlantic Maritime ecozones. In contrast, habitat area decreased for 74% of the habitat use units in the Mixedwood Plains and 75% in the Pacific Maritime ecozones. Habitat area remained relatively constant for 75% of habitat use units in the Boreal Shield and 79% of habitat use units in the Montane Cordillera.

- Reduced area in Summerfallow and expanded area in All Other Land and Tame or Seeded Pasture account for most increases in habitat availability between 1981 and 1996. Decreases in habitat availability are mainly the result of the expansion of Cropland through the conversion of farmland more suited as wildlife habitat, such as Natural Land for Pasture and All Other Land.

- Once additional information is gathered on how much more optimal farmland habitat is needed, if any, regional planners can set habitat goals and objectives to meet the needs of specific species groups and ecosystems.

The Issue

Each year, many of the earth's wild animal and plant species are depleted or lost to extinction, some because of natural causes and many others because of human activity. By far the main cause of wildlife loss is degradation or loss of habitat because of human encroachment through urbanization, logging, mining, agriculture, fishing, and other activities (including those that result in pollution or the introduction of exotic species).

Wildlife habitat includes all the things that a species needs to survive — food, water, cover, and home range (space). Habitat must also provide for special needs such as reproduction and dispersal. Species may use different portions of the landscape to meet their resource needs.

Their ability to meet all their needs is related to both *habitat quality* and *habitat availability* (*see* Box). If the actual area of habitat is limited, or if the habitat is of poor quality (offering limited food resources or little protection against predators), certain species will not be able to use the area to meet their needs.

Agroecosystems differ from natural ecosystems because they are managed to be more productive for human purposes. Agriculture has reduced the quantity of natural habitat, mainly through conversion of the natural landscape and changes in land use, such as drainage of wetlands and removal and fragmentation of forest cover. It can also affect the quality of wildlife habitat through various land management practices, such as tillage, fertilization, pesticide use, and intensive grazing.

Some wildlife species are able to thrive where native habitat has been replaced by agricultural habitat. Other species become restricted to the remnants of natural or semi-natural habitats remaining in the agricultural landscape. Despite the continual change of habitat in agroecosystems, agricultural lands offer more benefits to wildlife than more-developed areas, such as urban areas. These benefits include

- shelter, in the form of trees and shrubs (e.g., shelterbelts, woodlots), grass, and water
- a ready supply of food
- close proximity of natural landscapes
- less human pressure than in urban areas.

Wildlife on farmland offers many benefits to farmers and to all Canadians, including aesthetic aspects, recreational opportunities (hunting, fishing), and, in some cases, economic opportunity (e.g., ecotourism). In many cases farmers are actively managing their land to benefit wildlife. At the same time, wildlife have the potential to reduce a farm's productivity (e.g., by trampling or eating crops) and may pose a cost to the farmer.

One element of understanding how agriculture affects the environment is by assessing the availability of wildlife habitat on Canada's farmland.

Habitat availability

Wildlife species may use different parts of the landscape to meet their need for resources. Habitat availability — how well a species can meet its needs in a certain landscape — is determined by

- the abundance of the habitat type within the potential range for a species
- the current occupancy rate of the habitat type
- the patchiness of the landscape (size of, and distance between, habitat patches)
- access to, and connectance of, the habitat patches
- how the species' needs change through the seasons
- the occurrence of competitors, predators, and disease.

Natural landscapes are variable by nature, and most species use different landscape components to meet different resource needs over time. Differences in the quality of habitat patches and their position in the landscape determine the survival and distribution of a species. How these patches are connected, and how accessible they are to wildlife are also important aspects. For example, certain landscape features may act as a physical barrier or make a species vulnerable to predation.

Agroecosystems can be a mosaic of cropland, pasture, woodland, and wetland. This patchiness greatly benefits some species, such as the white-tailed deer. Other species, such as the Red-shouldered Hawk, are not as successful in patchy environments. They require large blocks of mature forest to reproduce successfully. Fragmentation of habitat blocks and the creation of additional edge can lead to greater competition, nest parasitism, and nest predation for such species.

P. Neave and E. Neave, Neave Resource Management

The Indicator

Description

To assess how agriculture generally affects habitat availability, we developed an indicator that can be assessed for each of the seven main terrestrial ecozones in which agriculture is practised. This Availability of Wildlife Habitat on Farmland indicator identifies the ways in which various wildlife species use agricultural habitat types, and then relates this use to changes in the area of these habitats. The indicator is then used to identify which habitat types in the agricultural landscape support the most wildlife use and whether these types increased, decreased, or remained constant in area between 1981 and 1996. A trend of increasing area for superior agricultural habitats is positive for this indicator. Although national objectives for this indicator have not yet been established (*see* Response Options), some objectives exist in specific habitat conservation programs throughout the country.

Method of calculation

To construct the indicator, *habitat availability matrices* were developed by ecozone for individual wildlife species associated with farmland habitat. A habitat availability matrix is a chart that relates habitat type found on agricultural land to habitat use by a wildlife species. A matrix was constructed for each bird, mammal, amphibian, and reptile known to use agricultural land and adjacent habitats in Canada to meet one or more specific habitat requirements. Species lists were developed from accepted wildlife guidebooks and expert opinion.

The vertical axis of the matrix lists agricultural habitat types. At the most general level, these correspond to the land use categories covered by the *Census of Agriculture:*

- *Cropland*
- *Summerfallow*
- *Tame or Seeded Pasture*
- *Natural Land for Pasture*
- *All Other Land*.

These broad categories were then subdivided to more precisely reflect different habitats found on agricultural land. Cropland was sub-divided into crop type (e.g., wheat, canola, corn). Natural Land for Pasture was divided into natural grassland, sagebrush/shrubs, and shrubs/woodland. All Other Land, rated the most valuable habitat type, was subdivided into buildings, shelterbelts, woodland types (e.g., plantations, woodlands with or without interior), and *wetland* types (e.g., *riparian* areas, shallow wetlands with or without extensive margins, and deep permanent ponds with or without extensive margins).

The horizontal axis of each matrix lists five main categories of habitat use:

- breeding, nesting, reproduction
- feeding, foraging
- cover, resting, roosting, basking, and loafing
- wintering
- *staging* (for birds only).

Each separate use of a habitat type by a species was recorded as one *habitat use unit* (i.e., the habitat use unit is not the number of species using a habitat, but the number of individual ways in which the habitat is used. For example Mallard feeding, Mallard nesting, and Mallard loafing in one habitat type would equal three habitat use units).

When completing the matrices, each habitat use was ranked according to how dependent a species is on a certain habitat for this use. Primary use means that a species is dependent on, or strongly prefers, a certain type of habitat (equivalent to the concept of *critical habitat*). Secondary use means that a species uses a certain habitat (e.g., to obtain food) but is not totally dependent on it. Tertiary use means that a habitat type is not needed by a species, but it might occasionally be observed there. A matrix cell was left blank if the species was not typically found in that habitat, or marked with an X if the species is known to avoid that habitat.

To summarize the data, primary and secondary habitat use entries were separately summed for the five main use categories, and then habitat use units were summed by habitat type for each ecozone. Changes in habitat area supporting these habitat use units were then analyzed to calculate the indicator. The data on habitat area were obtained from the *Census of Agriculture*.

Limitations

Because the indicator records only information about the absence or presence of certain habitat uses, it does not tell us much about habitat quality. An effort was made to factor in habitat quality by dividing three census land use types (Cropland, Natural Land for Pasture, and All Other Land) into finer categories that have different value for different species. However, the great variation in quality across the five main habitat types shows the difficulty in using census data for habitat studies. For example, All Other Land includes land unsuitable for most wildlife, such as land occupied by lanes, greenhouses, and farm buildings. Also, some farm operators may not report wetlands and woodlot area in the All Other Land category. Separating wetlands and woodlands out from the All Other Land category would prove useful in further development of this indicator.

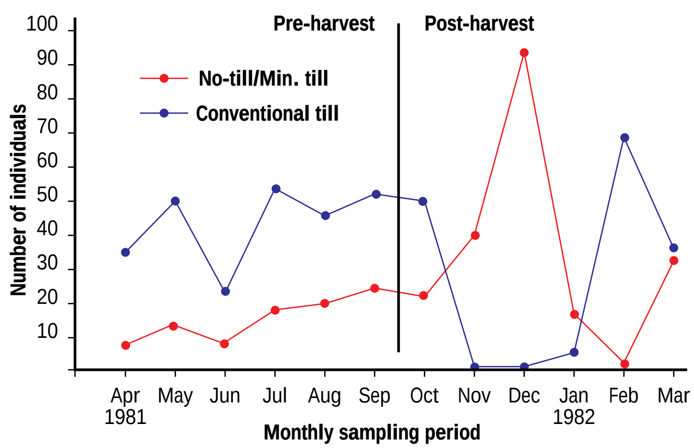
Effects of tillage on wildlife

In the past 15 years, many farmers have begun to replace conventional tillage practices with conservation tillage, including no-till. Conservation tillage makes fewer or no passes of equipment on the field and leaves more crop residue on the soil surface. Among other effects on the soil, this type of tillage

- reduces disturbance of the soil
- changes the soil's moisture regime and bulk density
- increases levels of soil organic matter.
- decreases the risk of soil erosion from wind and water.

Several studies have shown that wildlife benefits from conservation tillage. For example, invertebrate numbers have been shown to rise as a result of the protection afforded by the crop residue cover and the reduction in the mortality caused by plowing. Many species of birds become more common as their prey invertebrates grow in numbers.

Frequency of birds recorded in no-till and conventionally tilled corn



P. Neave and E. Neave, Neave Resource Management

Related to this, the indicator does not consider how successful a habitat use is. Success of use is sometimes reflected in the ranking system (e.g., for Mallard nesting, a primary ranking was used for habitats where nesting success is high and a secondary ranking for habitats with lower nesting success). This information was often available for waterfowl, but rarely for other species. Thus, even if a type of wildlife habitat increases in area, that habitat may not be of sufficient quality to support successful reproduction and maintain a population.

Using the broad land use categories does not account for biological factors that may limit a species' use of a particular habitat type. For example, a species may not use a habitat because

- one requirement is met (e.g., food), while other requirements are not (e.g., water, nest site)
- the habitat is too fragmented
- there may be behavioural barriers to use
- the preferred habitat is occupied.

Another limitation is that the indicator does not examine the effects of various land management practices. The effects on habitat use of practices such as tillage (*see* Box) and weed control practices have, however, been reported elsewhere.

Results

Table 15-1 shows the share or proportion of farmland in five different agricultural habitat types and the share of habitat use units supported by each of the five habitat types in the seven ecozones studied. Although all five habitat types are used by wildlife in all seven ecozones, Natural Land for Pasture and All Other Land support the most habitat use units across all ecozones.

After dividing Natural Land for Pasture and All Other Land into more specific habitat types, it was evident that those most important for wildlife are woodlots with and without interior, riparian areas, and shallow and deep wetlands with margins. In ecozones where these habitats are present, sagebrush/other shrub, and natural grasslands are also favoured by wildlife. Cropland and Tame or Seeded Pasture support less use by wildlife, and Summerfallow supports less than 1% of habitat use units for the wildlife species analyzed.

Table 15-1

Agricultural habitat types and associated habitat use units in 1996

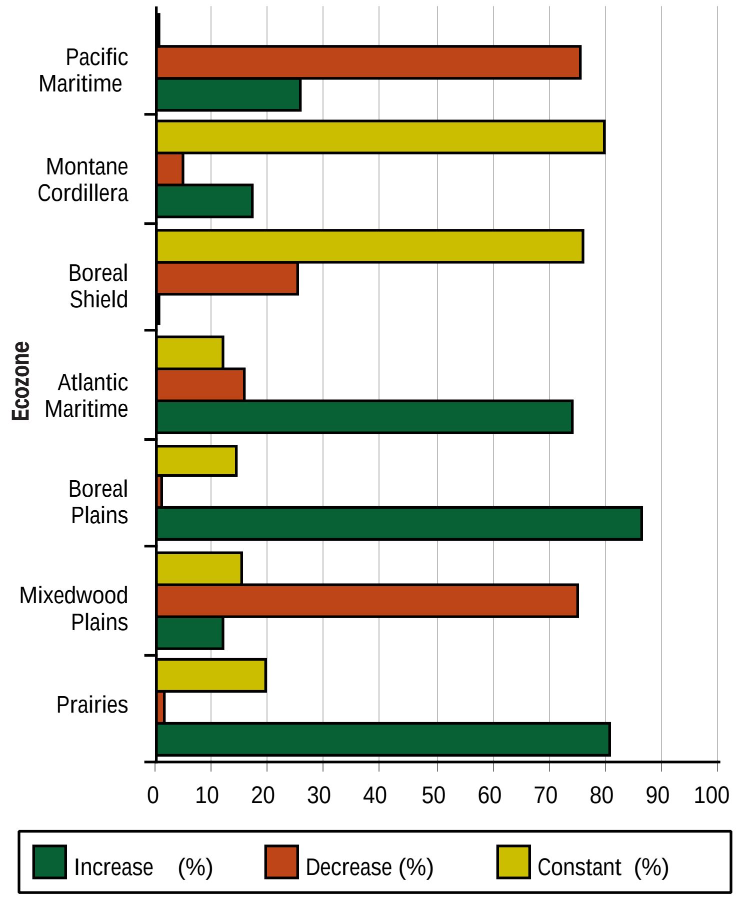
Ecozone	Total farmland area evaluated (1000 ha)	Share (%) of farmland (1) and share of total habitat use units (2) associated with various agricultural land uses: Cropland		Summerfallow		Tame or Seeded Pasture		Natural Land for Pasture		All Other Land		Total primary plus secondary habitat use units
		1	2	1	2	1	2	1	2	1	2	
Pacific Maritime	139	49	7	<1	<1	11	3	26	17	14	73	3048
Montane Cordillera	1532	16	9	<1	<1	9	3	62	17	13	70	4011
Boreal Plains	13 445	49	13	5	<1	10	3	24	14	12	69	3098
Prairies	41 853	53	17	13	<1	5	4	24	19	5	59	3865
Boreal Shield	1245	37	8	1	<1	9	3	24	14	29	75	3262
Mixedwood Plains	6294	75	11	<1	<1	6	3	10	14	9	71	3784
Atlantic Maritime	1546	40	12	<1	<1	8	3	13	12	39	73	2792

Figure 15-1 shows the share of habitat use units supported by habitat area that increased, decreased, or remained constant between 1981 and 1996. Three ecozones — the Boreal Plains, Prairies, and Atlantic Maritime — show positive trends. In the Boreal Shield and Montane Cordillera, 75 and 79% of habitat use units are associated with habitat area that remained constant. In two ecozones, the Mixedwood Plains and the Pacific Maritime, 74 and 75% of habitat use units were associated with habitat area that decreased.

Changes in the area of the five agricultural habitat types between 1981 and 1996 are given in Table 15-2. The distribution of All Other Land is shown for western (Fig. 15-2) and eastern Canada (Fig. 15-3).

Figure 15-1

Share of habitat use units for which habitat area increased, decreased, or remained constant between 1981 and 1996



Interpretation

The availability of wildlife habitat on Canadian farmland is a function of many factors, including land use. Agricultural land use has changed over the past 15 years because of changing demands in world markets and domestic policy (Table 15-2). Other factors that contribute to change in the agricultural landscape include

- crop prices
- availability of new crop varieties
- growing use of conservation farming techniques
- new technology.

Figure 15–2

Western Canadian distribution of the census land use category All Other Land in 1996

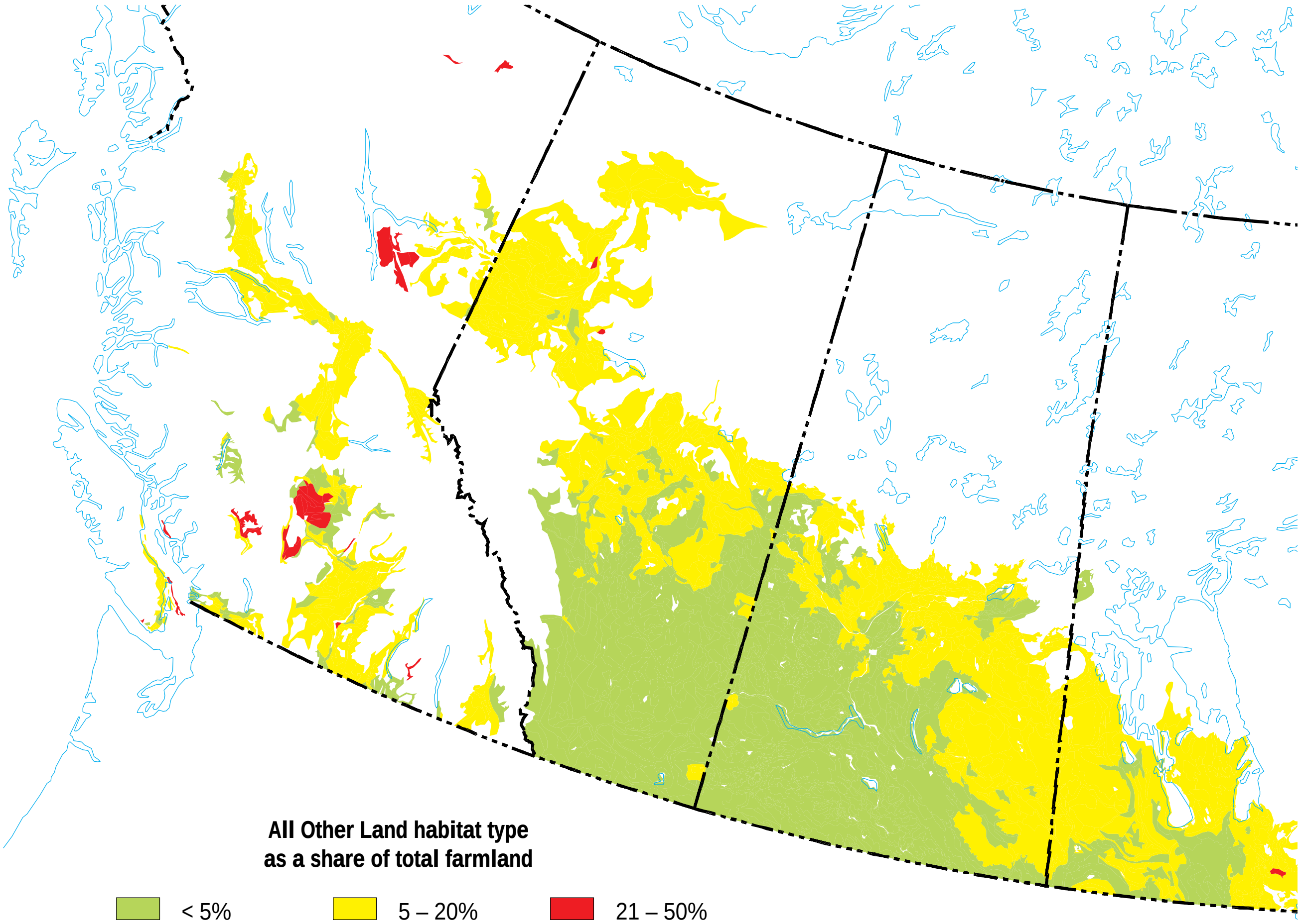


Table 15–2

Change in the areas of agricultural habitat types between 1981 and 1996

	Per cent change in area					
Ecozone	Cropland	Summerfallow	Tame or Seeded Pasture	Natural Land for Pasture*	All Other Land*	Total Farmland
Pacific Maritime	28	–	–46	6	–21	2
Montane Cordillera	constant	–	–33	7	constant	11
Boreal Plains	15	–47	41	constant	8	13
Prairies	17	–33	13	constant	16	3
Boreal Shield	–21	–	–55	–7	constant	–24
Mixedwood Plains	35	–	–50	constant	–19	10
Atlantic Maritime	constant	–	–52	–9	13	–20

* the change in the area of Natural Land for Pasture and All Other Land is calculated between 1991 and 1996 because of the change in the census definition for these land uses between 1981 and 1991.

Note: A positive number denotes a proportionate increase in area, a negative number denotes a proportionate decrease.
— signifies that this habitat type is insignificant in this ecozone.

On the whole, the availability of wildlife habitat on farmland grew between 1981 and 1996 mainly because of the expansion of Cropland as a result of reducing Summerfallow, and the expansion of All Other Land. Tame or Seeded Pasture and Natural Land for Pasture remained relatively constant, which also helped maintain habitat availability. Summerfallow is most commonly utilized in the Boreal Plains and Prairies, where the area under this practice declined by 47% and 33%, respectively, between 1981 and 1996. Land taken out of Summerfallow is usually converted to Cropland or Tame or Seeded Pasture, both of which are more suitable wildlife habitat.

In both the Pacific Maritime and Mixedwood Plains ecozones, agriculture has become more intensive in recent years. Farmland previously used for other purposes, such as woodlots or native pasture, has been brought into crop production, reducing its value as wildlife habitat. A discussion of changes in habitat by ecozone follows.

Pacific Maritime

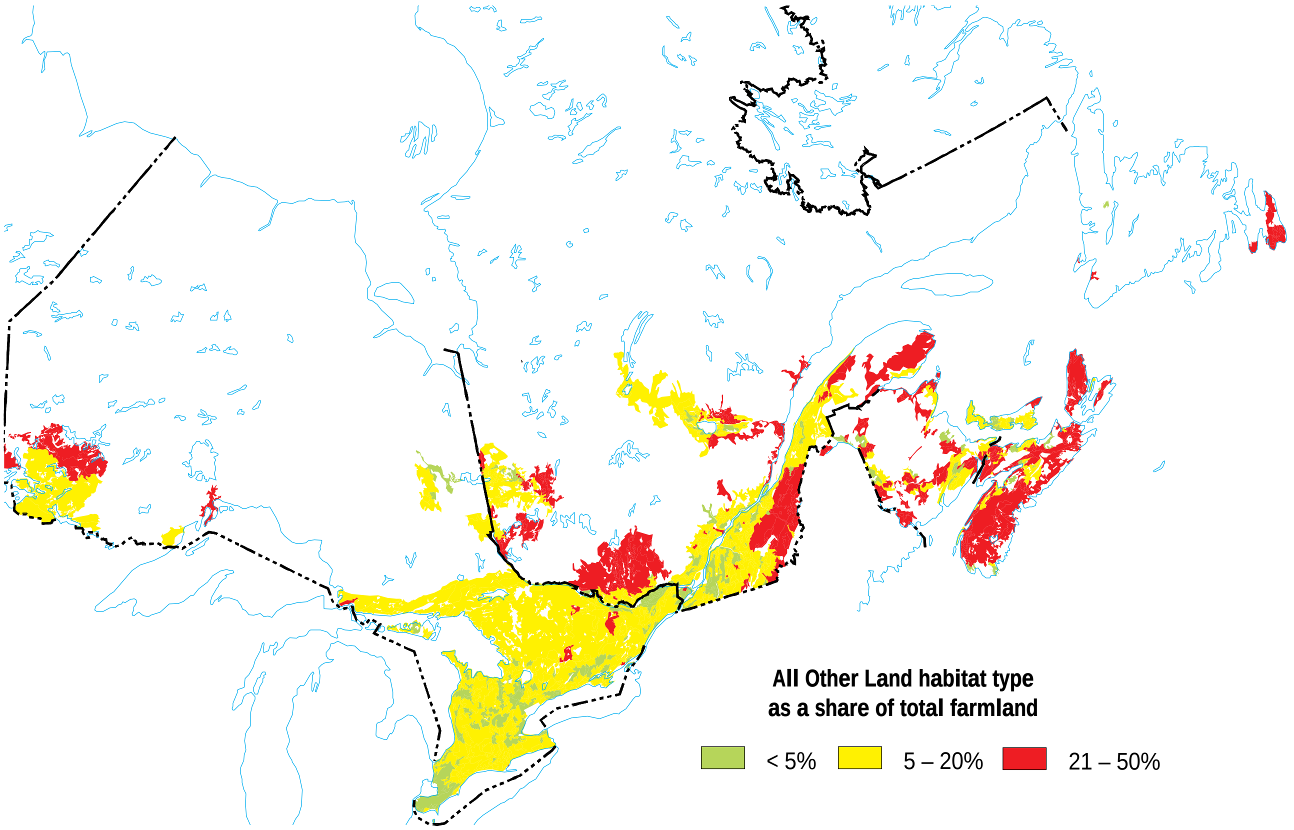
Urbanization, agriculture, and wildlife habitat are often conflicting land uses in the Georgia Basin, particularly the Lower Mainland of British Columbia. Between 1981 and 1996, the area of farmland (the sum of the area of the five census land uses, or habitat types, analyzed for this indicator) grew by 2% in this ecozone. However, Cropland grew by 28%, a negative trend for wildlife because much of this expansion came from conversion of Tame or Seeded Pasture and All Other Land, two habitat types more favourable for wildlife.

Montane Cordillera

Habitat has changed in this ecozone as a result of the reduced quality of native grassland because of fire suppression, the introduction of cattle and non-native wildlife, and drainage of wetlands. Forestry, the main industry, also strongly affects wildlife habitat in the Montane Cordillera, where the most diverse mix of ecosystems in Canada occurs.

Figure 15–3

Eastern Canadian distribution of the census land use category All Other Land in 1996



However most agricultural areas in this ecozone have a balanced distribution of the five main agricultural habitat types. Even where the most valuable agricultural habitats are limited in area, there are usually areas of forest adjacent to farmland, providing ample cover. The area of farmland grew by 11% between 1981 and 1996, while that of Cropland remained steady. The area of Natural Land for Pasture grew between 1991 and 1996, and that of All Other Land remained relatively constant (an increase of 5%).

Boreal Plains

Total farmland in this ecozone expanded by 13% between 1981 and 1996 and is having a greater effect on wildlife habitat. Logging is also a major influence on wildlife habitat.

Wildlife on intensively managed farmland in British Columbia

The Delta Farmland and Wildlife Trust was established by farmers and conservationists in 1993 to support and promote the sustainability of farmland and wildlife habitat in the lower Fraser River delta. The delta is a major stopover for birds migrating on the Pacific Flyway. It also has the highest density and diversity of waterfowl, shorebirds, and birds of prey in Canada during the winter season. The Canadian Wildlife Service and other wildlife agencies recognize that delta farmland is absolutely critical (e.g., for food, nesting, roosting) for the continued survival of the 1.5 million birds that annually use this area.

During the winter months, Wigeon, Snow Geese, and Trumpeter Swans make extensive use of planted winter cover crops (e.g., barley, winter wheat, fall rye), as well as crop residues from corn and potato fields. In 1998, the Delta Farmland and Wildlife Trust sponsored the planting of more than 1539 hectares of cover crops at a cost of $171 000. The other major field program they support is grassland set-asides. Cooperating farmers take intensively farmed fields out of production for 3 to 5 years and plant them to grass, providing habitat for small mammals, which are the main source of food for raptors (e.g., owls, hawks, and eagles). In 1998, about 243 hectares were enrolled in this program at a cost of $180 000.

The Trust has also been encouraging farmers to plant hedgerows, which provide habitat for a wide variety of songbirds, such as American Robin, Black-capped Chickadee, Savannah Sparrow, and many more. Several kilometres of hedgerows have been planted in the last couple of years. All of the programs promoted by the Delta Farmland and Wildlife Trust provide benefits to both the exceptional wildlife resource in the Fraser Valley and the agricultural community.

R.A. Bertrand, British Columbia Ministry of Agriculture and Food

The area of Cropland grew during this period, as did that of Tame or Seeded Pasture and All Other Land between 1991 and 1996, mainly as Summerfallow was reduced. Natural Land for Pasture stayed the same. Expansion of All Other Land and Tame or Seeded Pasture is deemed beneficial for wildlife, because these types support more habitat use units.

The irregular distribution of farmland in the Boreal Plains allows nonagricultural habitats, for the most part, to be readily available to wildlife. Farmland is generally mixed with the dominant forest cover types, such as

- coniferous forest (51% of the ecozone's land base)
- mixedwood forest (23%)
- deciduous forest (17%).

This mix of forest and farmland benefits most wildlife species by providing edge habitat, forest interior habitat, and proximity to both food and cover.

Prairies

Today almost 93% of the Prairies ecozone is agricultural land. All that remains of the original native vegetation is an estimated

- 1% of tall grass prairie
- 19% of mixed grass prairie
- 16% of aspen parkland.

Thus, wildlife must co-exist with agriculture, often using agricultural and neighbouring lands as habitat.

In the Prairies, the area of Cropland, Tame or Seeded Pasture, and All Other Land increased between 1981 and 1996 mainly because of the 3% expansion of total farmland (by 1.3 million hectares) and reductions in Summerfallow. Natural Land for Pasture remained the same (less than 5% change). These changes have taken place as farmers move to continuous cropping and permanent cover to improve productivity and net income and prevent soil degradation.

Most habitat use units are found in All Other Land and Natural Land for Pasture, the agricultural habitat types most beneficial for wildlife which together account for about 29% of farmland in this ecozone. As a result, most habitat use units are associated with a growing land base. Because agricultural land in the Prairies makes up about 62% of Canada's farmland and is much more extensive than in any other ecozone, this improvement is significant for some wildlife species. However, reductions in some native habitats, including prairie wetlands, continue, and agricultural conservation through land stewardship is essential to maintain these valuable resources.

Boreal Shield

The Boreal Shield Ecozone covers 18% of Canada's land area, but agriculture occupies a very small portion of the land base (less than 1%). The area of farmland decreased by 24% between 1981 and 1996. Although four out of the five agriculturals habitat types also decreased in area, All Other Land remained steady. This situation is beneficial for many wildlife species, since All Other Land supports 75% of the habitat use units. Farmland is well dispersed among forested areas of the Canadian Shield, ensuring the availability of woodland habitat next to most farmland.

Mixedwood Plains

Cropland and pasture make up a significant portion (about 55%) of this ecozone, but mixedwood and other types of forest are also regionally abundant. However, the forested area is not equally distributed, and the loss of forest habitat is particularly marked in southwestern Ontario. For example, Essex County has only 4% of its original forest remaining. In contrast, many fields and farms in eastern Ontario have been abandoned in the past 30 years, resulting in beneficial change in habitat for some species. This trend now appears to be reversing itself as select crop prices rise.

Wetlands are still abundant in eastern Ontario, but an estimated 90% of wetlands have been drained in southwestern Ontario. Much of the original Carolinian Forest found there, which supports many species typical of a more southerly climate, has been subjected to intensive agriculture. As a result, many wildlife species have declined in number and are classified as rare, threatened, or endangered.

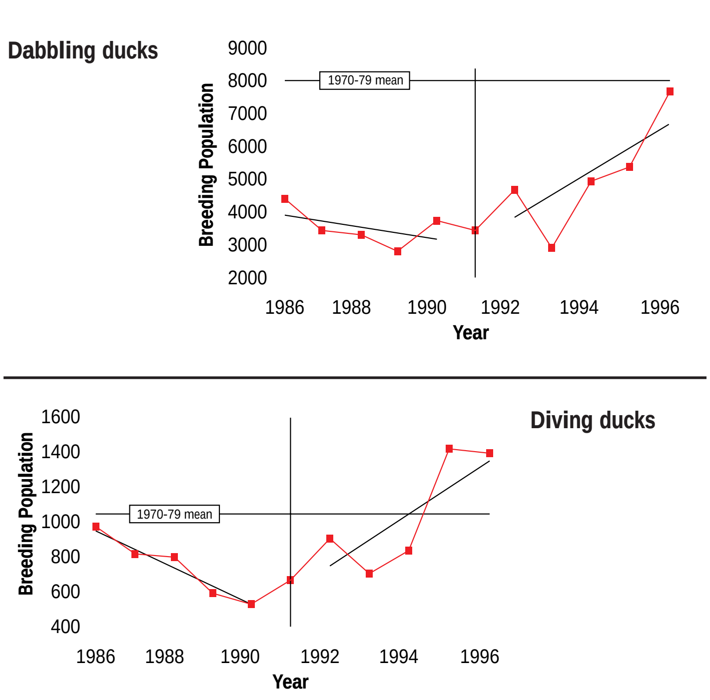
More than half of Canada's human population lives in the Mixedwood Plains, and urban areas have been encroaching on agricultural land and other wildlife habitat at a growing rate. Conservation of agricultural areas can help to maintain biodiversity in the face of urban pressures on habitat.

Waterfowl recovery

In the 1980s, waterfowl populations in North America began declining at an alarming rate. Concern for this situation led Canada, United States, and later (1994), Mexico to develop an initiative to restore continental waterfowl populations to 1970s levels by conserving the habitat for these and other wetland-dependent wildlife. The North American Waterfowl Management Plan, signed in 1986, is now the largest conservation program in the world. In Canada the plan focuses on key habitat areas for waterfowl, particularly in the Prairies, which provide breeding habitat for almost 40% of the continent's duck population. Goals of the program include the conservation and restoration of wetland and upland habitats. To achieve these goals, a landscape approach is taken and agreements made with farmers and other landowners to modify their land use and land management practices for the benefit of both their operations and wildlife. Another major component of the program is the reform of land use policy to remove the pressures to convert natural land into agricultural production.

Initially the objectives of the plan seemed too optimistic to many. But 10 years into the program, dabbling duck populations had nearly reached the 1970's average, though there was still much to be done for other species, such as the Pintail. Provincial surveys of the socioeconomic impacts of the plan show that landowners and the general public have a positive attitude toward wetland and waterfowl conservation and that communities benefit economically through jobs and greater tourism opportunities associated with the plan.

Trends in North American duck populations



B. Robinson, Environment Canada

Total farmland expanded by 10% and Cropland grew by 35% between 1981 and 1996. There were reductions in Tame or Seeded Pasture and All Other Land habitat types. The analysis shows that most habitat use units are associated with a declining area of the more valuable habitat types. Natural Land for Pasture fortunately stayed constant.

Trends in the abundance of breeding birds in two ecozones

The Breeding Bird Survey (BBS) is a large scale survey of North American birds that started in 1966. Trends in the abundance of all common bird species in the surveyed regions were recently calculated for 1966 to 1996. Survey results are presented here for the Prairies and Mixedwood Plains ecozones, where agriculture exerts a dominant pressure on wildlife habitat and wildlife species.

Prairies: BBS survey data for Saskatchewan were used as a proxy for this ecozone. Of 101 birds listed in the survey, 59 have declining numbers and 42 have growing numbers. The decline averaged over all species was small (–0.18%), but the large number of species in decline is cause for concern. Grassland species (e.g., Sprague's Pipit and Le Conte sparrow) are generally on the decline, possibly because of the decreased area in Natural Land for Pasture. Although Tame or Seeded Pasture is increasing in area, it provides a lesser-quality habitat than Natural Land for Pasture for many of the species in this guild. Wetland species increased in number in south-central and central Saskatchewan, but decreased elsewhere. The shrub/successional guild of birds is declining in southeastern Alberta and southeastern Saskatchewan, but growing in southwestern and central Saskatchewan and southern Manitoba. Woodland bird numbers are currently increasing over most of the Prairies.

Mixedwood Plains: BBS survey data for Ontario were used as a proxy for this ecozone. Of 141 birds listed in the survey that were used to construct the habitat matrices, 70 are increasing in numbers and 71 are declining. When the Canada Goose and House Finch (two species that greatly benefit from agriculture and have increased in numbers by more than 50%) are removed, the numbers have grown on average by 0.03%. Although many species are in decline, many factors apart from agriculture are likely involved. Grassland birds are generally on the decline, except for in the Frontenac Axis between Kingston and Ottawa. Wetland birds are generally growing in numbers. Shrub/successional and woodland birds are declining over about half the ecozone and increasing in the other half (including eastern Ontario, where abandoned farmland may be a factor, and the Grey–Bruce area in southwestern Ontario).

For more information on the Breeding Bird Survey, visit their website at http://www.mbr-pwrc.usgs.gov/bbs/

P. Neave and E. Neave, Neave Resource Management

Atlantic Maritime

The Atlantic Maritime ecozone contains a wide variety of habitats, including extensive mixed-wood and coniferous forests and wetlands. The influence of agriculture on habitat is much less here than in the major agricultural ecozones. Still, agriculture's occupation of the zone's most productive sites, especially river valleys, means that wildlife is affected in these areas.

Although the area in total farmland shrank by 20% between 1981 and 1996, the area in Cropland remained steady and All Other Land increased by 13%. Reversion of abandoned farms to forest may benefit some species, but the land base of this ecozone is 88% forest, so farmland may provide the variety in habitat needed to support greater biodiversity.

Response Options

The Availability of Wildlife Habitat on Farmland indicator requires reasonable habitat goals in order for us to establish performance objectives. We need a clearer idea of how much more optimal farmland habitat is needed, if any. This information is best gathered regionally, and then planners can work with landowners to

- set habitat goals that recognize the needs of targeted groups of species (*guilds*) found in that region and establish habitat thresholds below which wildlife cannot be sustained
- identify habitat and ecosystem objectives that will help meet these regional wildlife goals.

Because farmland is usually privately owned, response options usually involve the voluntary participation of landowners. Most farmers understand the value of conserving wildlife and wildlife habitat, but education and incentive programs can further this understanding and encourage the use of land management practices that favour wildlife use. These practices include

- conservation tillage systems
- delayed haying
- winter cover cropping
- rotational grazing systems
- integrated pest management
- woodlot management
- planting shelterbelts and hedgerows
- management of riparian areas
- conservation of wetlands and wetland buffers
- conservation of remaining natural (native) lands.

Conclusion

Agricultural lands offer a variety of habitats for wildlife, but some types are superior to others, especially All Other Land and Natural Land for Pasture. Farmland is not expected to expand much more in Canada, but even small expansions at the expense of natural landscapes pose a risk to wildlife locally. Agricultural habitat for wildlife is superior to the habitat offered in more developed settings, such as urban sites and roadways.

Changes in agricultural land use from less-intensive to more-intensive practices, such as bringing marginal land into crop production, create pressures on wildlife by making one or more of the habitat resources they depend on more scarce or otherwise unavailable. On the other hand, reductions in Summerfallow and conversion of marginal cropland to other uses such as Tame or Seeded Pasture will benefit wildlife. In general, from 1981 to 1996 agricultural habitat for wildlife shows positive or neutral trends for some species in all ecozones except the Pacific Maritime and Mixedwood Plains. These two regions are noted for the intensity of their agriculture.

How farmland is used is largely dictated by economics, particularly commodity prices. In good years, producers may put more land into production, including marginal land that may be best left in permanent cover and is more suited to wildlife use. The recent trend to reduce Summerfallow and to convert Cropland to permanent cover is a positive trend for wildlife, but one currently driven more by economic factors than interest in wildlife.

By and large, farmers have an interest in protecting the environment and conserving wildlife. Most recognize that agroecosystems are part of the broader environment and that farms can operate, not only to produce food, but also to serve other purposes, including provision for wildlife. Because few economic incentives currently exist to encourage farmers to conserve wildlife and their habitat, farmers must usually shoulder the cost of these activities on their own.

Stewardship programs of the Alberta Fish and Game Association

The parkland and grassland regions of central and southern Alberta are among the most intensively developed landscapes in the world. Over the last 100 years since European settlement, the combined effects of cultivation, livestock grazing, urbanization, road construction, petroleum and natural gas developments, irrigation, mining, and other human land uses have eroded away 75% of native mixed grass prairie, 90% of the northern fescue grasslands, and 95% of native parkland habitats. Of the 31 species at risk in Alberta, 24 (77%) rely on these grassland and parkland habitats.

What remains of the Alberta parkland and grassland regions is controlled mainly by landowners and will likely be subject to further degradation unless these owners are provided with incentives to retain these habitats. These incentives may be as simple as recognizing the role of private land stewardship in the conservation of our prairie and parkland wildlife, providing landowners with the resources to make their own informed land use decisions, and promoting the economic benefits of integrating wildlife habitat within an overall strategy of sustainable farming.

The Alberta Fish and Game Association, with funding support from Wildlife Habitat Canada, has developed two programs to address the wildlife conservation needs in the intensively managed grassland and parkland regions of Alberta. Since 1989, Operation Grassland Community has involved landowners in voluntary habitat protection agreements to conserve prairie habitat for the Burrowing Owl, Loggerhead Shrike, and other prairie wildlife species. Currently, 226 participants are conserving more than 20 007 hectares of prairie habitat in southern Alberta. Since 1996, the Parkland Stewardship Program has registered 63 farm families representing more than 3443 hectares of wildlife habitat on 7695 hectares of farmland. Besides their commitment to ensure the conservation of their remnant parkland habitats, more than half of participating landowners have undertaken steps to enhance their farms for wildlife by planting shelterbelts, placing nesting structures, fencing riparian areas, and developing livestock watering systems.

Both stewardship programs involve active participation by individuals, local communities, and industry. They focus on the conservation of all native habitat remnants, including wetlands, upland range, woodlots, and riparian areas, as well as incorporate landowner education and farm planning to improve wildlife habitat in the surrounding agricultural landscape.

J. Fortune, Wildlife Habitat Canada

Related Indicators

Because soil organisms and species that eat them are affected by soil quality, the Availability of Wildlife Habitat on Farmland indicator is linked to all the soil quality indicators: Risk of Water Erosion, Risk of Wind Erosion, Risk of Tillage Erosion, Soil Organic Carbon, Risk of Soil Salinization, and Risk of Soil Compaction. Many management practices that are used to control erosion, such as planting shelterbelts, also improve wildlife habitat. Keeping residues on the soil surface also improves habitat, linking this indicator to Soil Cover by Crops and Residue. Wildlife habitat can be devalued by the presence of agricultural chemicals, making a connection to Management of Farm Nutrient and Pesticide Inputs. Wildlife species dependent on wetland, riparian, or aquatic habitats will be affected by increases in the Risk of Water Contamination by Nitrogen and the Risk of Water Contamination by Phosphorus. Climate change has a tremendous potential to affect elements of agricultural habitat and thus biological diversity, linking this indicator to the Agricultural Greenhouse Gas Budget indicator.

G

Production Intensity

G Production Intensity

Agriculture has expanded and intensified production in many parts of Canada. More-intensive forms of agriculture can result in higher yields, increased productivity, and even environmental benefits (e.g., less land may be needed for agriculture than might otherwise be the case). However, intensification also increases the potential for environmental risks and impacts from agriculture. Whether or not such risks actually increase is determined in large part by the efficiency of production. The term *eco-efficiency* has been coined to capture this concept.

Eco-efficiency involves producing more-valuable products or services using fewer material and energy inputs, in turn minimizing losses to the environment and reducing pollution. Criteria for eco-efficiency include minimizing the material and energy needed to produce goods and offer services

- maximizing the use of renewable resources
- enhancing the recyclability of materials
- extending product durability
- minimizing the dispersion of toxic substances.

Agriculture uses many inputs in the production process, including capital, labour, machinery, land, water, nutrients, pesticides, and energy. Input costs are a significant proportion of overall farm operating costs. Thus, inefficient use of inputs create an economic loss for producers, and inefficient use of environmentally sensitive inputs (particularly energy, nutrients, and pesticides) can impose environmental costs on society, such as reduced water quality, excess emissions of greenhouse gases, and reduced biodiversity.

Because most inputs are priced in the marketplace, there is some incentive to use them efficiently. Considerable efforts to promote production efficiency in agriculture have been, and continue to be, made. Through research, for example, new and more-efficient production processes are developed. Information and extension programs help farmers to improve the efficiency of their operations. However, inefficient use can still result in cases in which, for example,

- the private costs of inputs are less than the full social costs of their use
- information is lacking on how much of an input to use, as well as where and when in the agricultural production cycle to use it.

The following two chapters address two aspects of production intensity and efficiency in agriculture. Chapter 16 examines the amount of residual nitrogen remaining after harvest. Chapter 17 looks at the amount of energy used in agricultural production (input) and the amount contained in products (output). Other chapters of this report also examine environmental issues related to production intensity. Chapter 5 reviews how certain farm inputs are managed on farms across Canada, and chapters 12, 13, and 14 review some environmental risks resulting from inefficient use of inputs.

16 Residual Nitrogen

K. B. MacDonald

Geographic scope: Provincial
Time series: 1981, 1991, 1996

Highlights

- Applying nitrogen in excess of crop needs reflects inefficient nutrient management, incurs unnecessary costs, and poses a threat to water quality. Movement of nitrogen into the atmosphere as ammonia and nitrous oxide contributes to poor air quality and potentially to global warming.

- An indicator was developed to estimate the difference between the amount of nitrogen (N) available to the growing crop and the amount removed in the harvested crop. This difference was called residual nitrogen. The indicator was calculated for all provinces (the Atlantic Provinces were combined) for 1981, 1991, and 1996. The performance objective is to have all Canadian farmland in classes associated with no net accumulation of nitrogen over time.

- Canadian farmland was assigned to one of four classes of residual nitrogen: Class 1: less than or equal to 20 kilograms of nitrogen per hectare (minimal), Class 2: 21–40 kg N/ha (expected in areas of intensive agriculture with low-demand crops, such as cereals), Class 3: 41–60 kg N/ha (expected in areas of intensive agriculture with high-demand crops), and Class 4: greater than 60 kg N/ha. Classes 3 and 4 may represent areas where nitrogen is accumulating and poses an environmental risk. In 1996, the Atlantic Provinces (52%) and British Columbia (70%) had the largest share of farmland in Class 1. Ontario (37%) and Quebec (28%) had the highest shares of farmland in Class 4.

- Indicator results show high levels of residual nitrogen (Class 4 in areas with high-demand crops and Class 3 in areas with low-demand crops) in areas where the trend toward cropping intensification is confirmed by other indicators. These areas include the lower Fraser Valley of British Columbia, the corridor of agricultural land from Lethbridge through Red Deer to Edmonton in Alberta; the Melfort area in northeastern Saskatchewan; the Red River Valley in Manitoba; southwestern Ontario, the area around Lake Simcoe, and the lower Ottawa Valley; the St. Lawrence Lowlands in Quebec and the region south of Quebec City; the Annapolis Valley in Nova Scotia; and the St. John River Valley in New Brunswick.

- There was a strong trend between 1981 and 1996 toward increasing levels of residual nitrogen in all provinces except British Columbia. The share of farmland showing an increase in residual nitrogen levels of at least 5 kg/ha between these 2 years ranged from 27% in British Columbia to 80% in Manitoba.

- Limitations of the data used to calculate the indicator allow only general interpretations of indicator results. The indicator appears to be useful for regional comparisons and to highlight areas where field testing should be carried out to confirm actual levels of soil nitrogen. Further development of the indicator depends on refining many data components.

The Issue

Nitrogen is an essential crop nutrient that must be managed properly to curb losses to the environment and reduce costs for farmers. Compared to other industrialized countries, Canada has a relatively low budget for agricultural nitrogen (*see* Box), but some level of residual nitrogen inevitably results from crop production. Unduly large surpluses may pose an environmental risk, particularly under humid conditions.

By its presence in manure, nitrogen forms an important link between livestock and crop production systems. Manure produced by livestock can be an asset in crop production when applied to fields as part of a full nutrient management system. On the other hand, it can be a liability if applied mainly as a means of disposal rather than a way of nutrient recycling.

By using only the amount of nitrogen needed for economically optimal crop production, farmers can

- help maintain soil quality, which supports productivity
- help control emissions of nitrous oxide, a potent greenhouse gas
- reduce the risk of water contamination
- make the best use of nitrogen from animal manure and legumes, reducing the costs of producing, purchasing, transporting, and applying mineral fertilizer
- eliminate the potential costs (e.g., fines, fees for remediation) of not complying with environmental regulations pertaining to nitrogen pollution.

An indicator is needed to assess how much nitrogen is left after harvest if nitrogen recommendations are followed, and to monitor changes in the level of residual nitrogen over time.

Nitrogen balances of OECD Countries

Among the indicators being developed by the Organization for Economic Co-operation and Development (OECD) is an agricultural nutrient balance. This indicator expresses the difference between the amount of nutrient entering agricultural systems and the amount taken up by crops. A nutrient surplus or deficit does not necessarily point to significant environmental impact. However, high and continuous surpluses of nitrogen raise the risk of environmental problems, such as water pollution and greenhouse gas emissions, and continuous deficits suggest a risk of declining soil fertility. Preliminary indicator results are presented in the table below for selected OECD countries.

The results provide a national estimate but mask considerable regional variation within countries, although the OECD intends eventually to develop the indicator to show the regional variation around the national average. Canada, for example, has one of the lowest national values of surplus nitrogen among OECD countries but, as demonstrated in this chapter, has many agricultural regions where residual nitrogen exceeds 60 kilograms per hectare per year. Other countries with more intensive agricultural production systems, such as Japan and Denmark, have much higher national levels of surplus nitrogen. OECD's analysis has revealed an overall downward trend in nitrogen surpluses across most OECD countries over the past decade. Canada is an exception to this trend. Its increase partly reflects Canadian agriculture's growing use of fertilizer to remedy historic underfertilization of soils, rising production of crops that need high inputs of nitrogen (e.g., corn), and growing numbers of livestock, particularly cattle and pigs.

Nitrogen balance for selected OECD countries

Country	Nitrogen Balance kg N/ha/yr 1985–1987	1995–1997	Percent Change
Canada	6	13	113
Denmark	154	119	–23
France	59	53	–11
Japan	145	135	–7
New Zealand	5	6	32
United States	25	31	24

Source: OECD Secretariat

The Indicator

Description

The Residual Nitrogen indicator is an estimate of the quantity of nitrogen remaining in the field after harvest. It is the difference between the amount of nitrogen that is available to the growing crop from all sources and the maximum amount removed in the harvested portion of the crop under average conditions. The crop nitrogen requirement is estimated as the amount recommended to achieve economically optimal production.

Nitrogen levels were determined from recommended rates of fertilizer application rather than for crop yields, to reflect the actual situation in which farmers must decide by an early stage of crop growth how much nitrogen to apply. Crop yield is only partly controlled by management inputs; uncontrollable growing season conditions exert a major influence. Where the levels of available nitrogen are less than or equal to crop recommendations, the ratio of nitrogen remaining to nitrogen available corresponds to standard published information and reflects the overall ability of the crop to use nitrogen. Where nitrogen is present in excess, the ratio increases.

The indicator does not itself give any insight into the environmental effects of various levels of residual nitrogen in different agricultural settings. Surplus nitrogen may pose a risk to the environment, but this risk is also sensitive to other factors, such as soil type and climatic conditions. For example, the movement of nitrogen from farmland into the broader environment is related to the movement of water. In the dry regions of interior British Columbia and the Prairies, the movement of nitrogen in water is limited, occurring mainly during storms and periods of heavy runoff. The environmental risks of having residual nitrogen in the soil are greater in humid areas of the country, such as central and eastern Canada. Thus, residual nitrogen was also used to assess the Risk of Water Contamination by Nitrogen, another indicator presented in this report.

The indicator was expressed in four classes: Class 1, less than or equal to 20 kilograms of nitrogen per hectare (minimal residual nitrogen); Class 2, 21–40 kg N/ha (expected in areas of intensive agriculture with low-demand crops, such as cereals); Class 3, 41–60 kg N/ha (expected in areas of intensive agriculture with high-demand crops, such as corn, which produce greater quantities of biomass and consequently have more nitrogen in the harvested portion as well as the residue and roots. However, in areas where agriculture is not intensive or where the requirement is low because the total biomass production is somewhat lower, this class would indicate nitrogen accumulation and possible environmental risk); and Class 4, more than 60 kg N/ha (indicating nitrogen accumulation and possible environment risk). The performance objective for the indicator is to have all Canadian farmland in classes associated with no net accumulation of nitrogen over time.

Method of calculation

The indicator was calculated by

- calculating the amount of nitrogen available from all sources (in some cases there was more nitrogen in the mapping area than would have been required according to recommendations)
- estimating the amount of nitrogen removed in the harvested portion of the crop based on a combination of recommended levels and standard tables of the portion removed in harvest
- calculating the difference between these two amounts to give a value for residual nitrogen.

The calculations included the three major agricultural sources of nitrogen: mineral fertilizer, animal manure, and legume nitrogen fixation. In the semi-arid regions, inputs also included crop residues and mineralization of soil nitrogen during periods of summerfallow. Calculations were done for 1981, 1991, and 1996 to show a trend over time and to establish the recent status of residual nitrogen. When using *Census of Agriculture* data, the category of All Other Land (which includes farmyards, woodlots, etc.) was excluded from the farmland total, because this type of land is generally not used for crop production.

Current provincial and regional nitrogen recommendations for specific crops and regions were obtained from published sources and extension specialists and used to estimate crop requirements. Published information on nitrogen distribution within the plant was used to estimate the amount of nitrogen removed in the harvested portion of the crop (actual estimates of nitrogen removed in the crop were used in calculations for the British Columbia interior, Lower Mainland, and Vancouver Island). Where the total amount of available nitrogen from all sources exceeded the levels recommended, it was assumed that none of the surplus nitrogen was removed in the crop but rather added to the amount of residual nitrogen present. No attempt was made to include the amount of nitrogen harvested by grazing animals.

Nitrogen from mineral fertilizer was estimated from national and provincial figures for nitrogen fertilizer sales. Nitrogen from animal manure was estimated using livestock numbers reported in the *Census of Agriculture* and well established values for the nitrogen content of the various types of manure. Manure from uncommon livestock (e.g., emu, llama, mink) was not included in the calculation. For British Columbia, values for nitrogen from various types of manure were changed to reflect measurements from provincial research.

We assumed that

- nitrogen in that portion of cattle manure applied to crops (some is deposited on pastures) was 60% available to crops
- all poultry and swine manure was applied to crops, and its nitrogen was 75% available
- manure nitrogen could supply up to 75% of crop requirements in the overall budget
- in British Columbia, typical rates of fertilizer nitrogen application account for the use of manure on a regional basis; there was no additional adjustment based on data from the *Census of Agriculture*.

Nitrogen from legumes was calculated using census data for the area of legumes. Annual legumes were assumed to contribute 45 kg N/ha. Legume hay was assumed to contribute 100 kg N/ha every 4 years at plowdown, for an annual contribution of 25 kg N/ha. Where summerfallow was part of the rotation, it was assumed that nitrogen mineralized during the fallow period would supply the requirements of spring wheat or other grains grown the following year.

Table 16–1

Residual nitrogen levels on Canadian farmland under 1996 management practices

Province	Farmland area* (million ha)	Share (%) of farmland in different classes of residual nitrogen			
		Class 1 ≤ 20 kg/ha	Class 2 21–40 kg/ha	Class 3 41–60 kg/ha	Class 4 > 60 kg/ha
British Columbia	1.5	70	19	3	9
Alberta	17.7	38	50	12	< 1
Saskatchewan	23.0	31	61	8	< 1
Manitoba	6.7	18	51	27	5
Ontario	4.2	26	22	15	37
Quebec	2.0	41	20	12	28
Atlantic Provinces	0.5	52	33	12	4

* Farmland area here is the sum of all *Census of Agriculture* land classes except All Other Land.

Limitations

Calculating this indicator was subject to several data limitations, including

- reliance on official recommendations for nitrogen input, which may be out of date or unavailable for new crop varieties, and do not include adjustments for factors such as cropping history and manure management
- the general nature of census data, which, for example, limits the indicator's ability to show localized areas of high nitrogen accumulation (such as those associated with intensive livestock operations) and to consider the effect of irrigation
- distortion of the quantities of nitrogen estimated from fertilizer spending in areas of speciality crops, such as fruits and vegetables (where a disproportionate amount of fertilizer costs is spent on speciality fertilizers), and where landowners make census reports in the mapping areas in which they live rather than the ones in which they farm
- discrepancies in the summation of total farmland that resulted in unreasonable estimates of residual nitrogen, making it necessary to exclude mapping areas for which the areas of cropland, summerfallow, improved pasture, unimproved pasture, and other land added up to an area greater than that reported for total farmland.

In time, better data may become available for some components of the indicator calculation. However, it is unrealistic to expect that, at a national level, all the data needed will be refined to the level of detail that would make this indicator useful for detailed interpretation. Nevertheless, the indicator is still useful for making regional comparisons and highlighting areas where field testing for nitrogen levels should be carried out. The methodology itself is a good starting point for more detailed interpretations and could be used or adapted for use in specific regions of greater concern.

Results

Estimates of residual nitrogen status are given in Table 16-1 for all the provinces (the Atlantic Provinces are combined). Most farmland (70 to 90%) in the four western provinces and Atlantic Canada fell into Classes 1 and 2. Ontario and Quebec have large agricultural areas producing high yields of crops with a high requirement for nitrogen, with the result that 40 to 52% of this area falls into Classes 3 and 4.

Table 16-2 summarizes the trends in residual nitrogen for each province between 1981 and 1996.

British Columbia is unique in that levels of residual nitrogen dropped by more than 5 kilograms per hectare on more than 50% of its farmland area between these 2 years. This result needs independent confirmation, as the calculations in British Columbia dealt with three contrasting areas — Vancouver Island and the humid lower mainland, the dry interior, and the Peace River region (which is similar to the Prairie Provinces). Alberta, Saskatchewan, and Manitoba showed a rise in residual nitrogen levels of at least 5 kg/ha on 42%, 53%, and 80% of their farmland, respectively. Levels of residual nitrogen rose by at least 5 kg/ha on a large share

Table 16–2

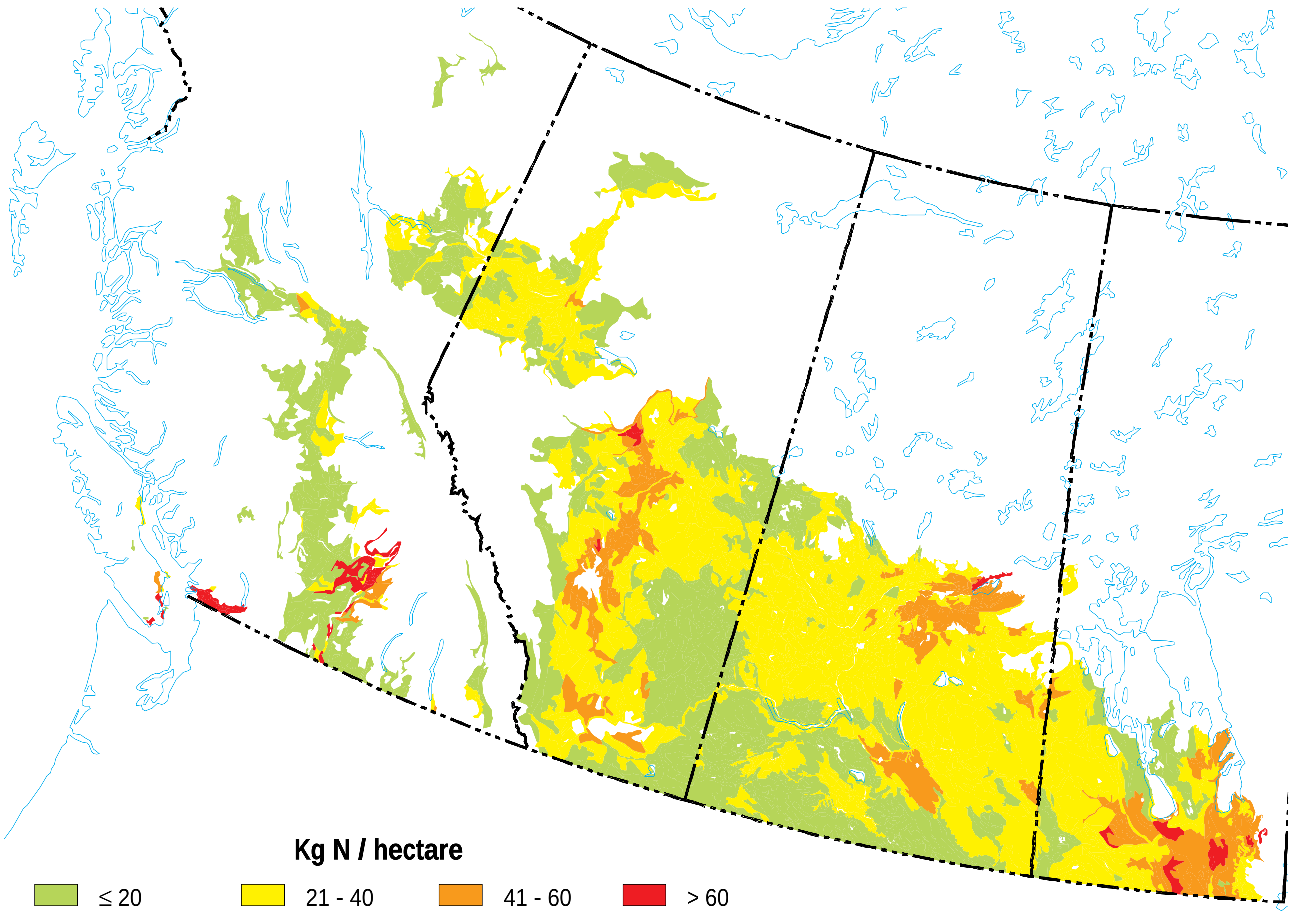
Changes in residual nitrogen levels between 1981 and 1996

Province	Farmland area* (million ha)	Share (%) of farmland for which there was a change in the level of residual nitrogen		
		Decrease of at least 5 kg/ha	No change (–5 to +5 kg/ha)	Increase of at least 5 kg/ha
British Columbia	1.5	51	22	27
Alberta	17.7	7	51	42
Saskatchewan	23.0	2	45	53
Manitoba	6.7	1	19	80
Ontario	4.2	0	31	69
Quebec	2.0	1	28	71
Atlantic Provinces	0.5	2	44	53

* Farmland area here is the sum of all 1996 *Census of Agriculture* land classes except All Other Land.

Figure 16–1

Residual nitrogen levels on farmland in western Canada under 1996 management practices



of Ontario (69%) and Quebec (71%) farmland between 1981 and 1996.

In general, the level of residual nitrogen from agricultural activities reflects the relative intensity of agriculture across the regions. Figure 16-1 shows the status of residual nitrogen in western Canada in 1996. The highest levels are found in the southwestern and south-central portions of British Columbia, the irrigation areas around Lethbridge and the region of black soils in the Red Deer and Edmonton areas in Alberta, the Melfort area in Saskatchewan, and the Red River Valley area of Manitoba.

Figure 16-2 shows the status of residual nitrogen in central and eastern Canada for 1996. In these regions higher residual nitrogen levels correspond to

- the concentration of agriculture in the southwestern part of Ontario, and around Lake Simcoe
- the St. Lawrence Lowlands of Quebec and the region south of Quebec City
- the Annapolis Valley in Nova Scotia, and the St. John River Valley in New Brunswick.

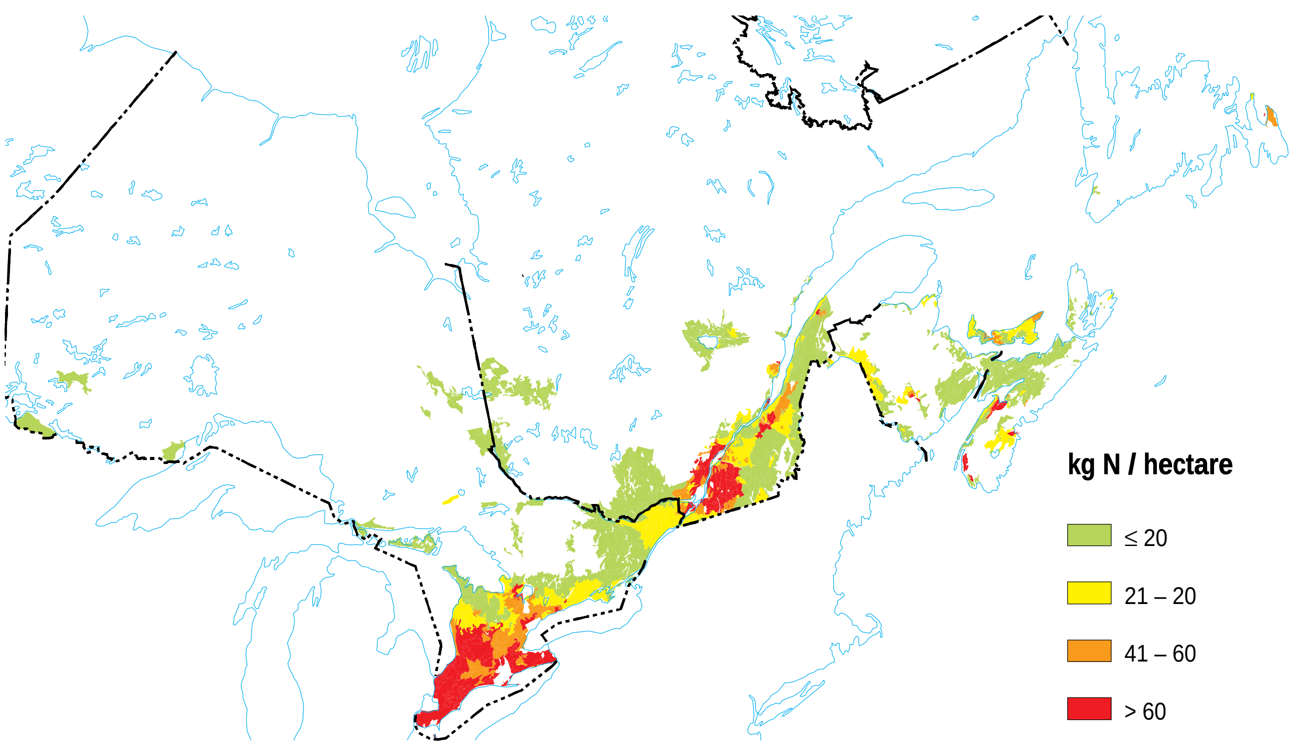
Interpretation

Lower levels of residual nitrogen were expected for the four western provinces and Atlantic Canada, where much of the farmland is in forages (important crops, but typically underfertilized). The Peace River region and the three Prairie Provinces are areas where crop production is relatively intensive, but the crops grown do not have high requirements for nitrogen. Furthermore, these areas have historically relied on the release of nitrogen from soil organic matter to provide part of the crop requirements.

The rise in the residual nitrogen levels in the Prairie Provinces between 1981 and 1996 likely reflects the increased use of mineral fertilizers to more nearly match crop requirements and reduce the risk of soil organic matter losses (*see* Box). In contrast, the large share of farmland that had an increase in residual nitrogen of at least 5 kilograms per hectare in Ontario (69%) and Quebec (71%) likely reflects the trend of increasing intensification in the most productive parts of these provinces. However, both provinces also have significant

Figure 16–2

Residual nitrogen levels on farmland in eastern Canada under 1996 management practices



A prairie perspective on residual nitrogen

As a national indicator, residual nitrogen uses the same sources of data and methods for all agricultural areas of Canada. The indicator was calculated based on the difference between the amount of nitrogen estimated to be removed in the crop and the amount added in mineral fertilizer, animal manure, and legumes. This type of data is difficult to obtain, making the calculation a very rough estimate.

In the Prairies, where most of the grain crop is exported, legumes are a relatively minor component of the crop rotation, and sources of manure are quite localized, an alternative approach has typically been taken. Nitrogen removal is calculated based on protein content, for which data are readily available for wheat and often for canola, two of the Prairies' most prominent crops. Reliable estimates of the nitrogen content of various crops are also available, and this can be used to estimate crop removal of nitrogen.

The table below shows the nitrogen removal–replacement ratios for the three Prairie Provinces for 1981, 1991, and 1996, the three census years for which the indicator was calculated. These ratios were calculated using statistics for nitrogen fertilizer consumption and the nitrogen removed in harvested portions of all crops by province. They do not include any nitrogen contributions of animal manure or estimates for nitrogen released by land under summerfallow. However, this gross estimate shows that all three Prairie Provinces remove more nitrogen in the harvested portion of crops than is added in mineral fertilizer, with the exception of Manitoba in 1996, when crop removal equaled the addition of fertilizer nitrogen.

Similarly, in the calculation of the Residual Nitrogen indicator, the removal of nitrogen in the harvested crop is substantially greater than the quantity of fertilizer nitrogen applied. However, in the overall residual nitrogen calculation, it is recognized that the portion of the crop remaining in the field (roots, straw, and chaff) contains a small amount of nitrogen. In the semi-arid conditions of the Prairies, some of this nitrogen will gradually become available to future crops. Areas of agricultural production in the two lower classes of the Residual Nitrogen indicator show where the amount of nitrogen in the harvested crop is likely to exceed the amount added in fertilizer. These areas should be examined in greater detail to identify where production practices are unsustainable because nitrogen from the breakdown of soil organic matter is being exported in the harvested crop.

In terms of soil quality, some accumulation of nitrogen is desirable due to past underfertilization of soils. It is encouraging that in recent years the fertilizer nitrogen added has been more nearly in balance with the amount removed in harvest, as shown by both approaches.

Nitrogen removal/replacement ratios for the Prairie Provinces

	Alberta	Saskatchewan	Manitoba	Prairies
1981	1.64	3.15	1.51	2.01
1991	1.71	2.87	1.11	1.87
1996	1.37	1.51	0.96	1.33

(Removal of nitrogen in crops was estimated from the harvested portion of wheat, oats, barley, rye, flax, canola, mustard, mixed grains, sunflowers, lentils, peas, canary seed, grain corn, buckwheat, tame hay, sugar beets and potatoes.)

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areas of forage production and less-intensive agriculture reflected in the area (48–60%) in Classes 1 and 2.

In western Canada, where water limits agriculture, the accumulation of residual nitrogen results in detrimental environmental effects only under certain conditions (e.g., during spring thaw). In the more humid areas of Canada where there is generally sufficient moisture for agriculture, high levels of residual nitrogen in the soil have a greater potential to contribute to declining water quality. Values for residual nitrogen in these humid areas are used as the basis for calculating another indicator presented in this report, Risk of Water Contamination by Nitrogen. The potential for nitrogen lost from farmland to contaminate water is discussed in that chapter. The following interpretation applies mainly to the semi-arid agricultural regions of Canada.

For agriculture in the semi-arid region of Canada, production is generally limited by the quantity of moisture available. Except in areas where supplemental water is available from irrigation, production is limited to extensive agriculture, with a mix of rangeland, improved pasture, hay, cereals, oilseeds. Even in the areas of intensive agriculture, production is generally limited to crops with a low demand for nitrogen, because the overall level of production is restricted by available moisture. Thus, levels of residual nitrogen are low or moderate for most of the agricultural area.

The increase in residual nitrogen between 1981 and 1996 in this region reflects the intensification of agriculture (with more area being devoted to annual crop production) and the objective to increase crop yield by adding more nitrogen fertilizer. This trend is most strongly shown in Manitoba (where 27% of cropland had 41–60 kg N/ha in 1996), followed by Alberta (12%) and Saskatchewan (8%). This result was expected, because the entire agricultural area of Manitoba is found in the Black soil zone, an area with better moisture conditions. A substantial portion of Alberta production also takes place in this zone, and Alberta also has an extensive area of irrigated land and an important livestock industry. For the parts of the semi-arid region with more favorable moisture conditions, it is not unreasonable to expect residual nitrogen levels moving into the 41–60 kg N/ha range. However, it is important to confirm that these trends do represent a gradual intensification of agricultural production rather than a nitrogen buildup resulting from localized intensive livestock operations.

For other parts of the country where moisture conditions are more favourable, levels of residual nitrogen were expected to fall into Classes 2 and 3, reflecting both the level of farming intensity in these regions and the greater production of high-yielding crops that incorporate higher levels of nitrogen into both the harvested and residual biomass. This expectation was supported by results for Ontario, Quebec, and the humid region in British Columbia's humid Lower Mainland, where there were also areas in the highest residual nitrogen class (greater than 60 kg N/ha).

Nutrient management planning

Healthy crops need more nutrients than agricultural soils can naturally provide. It is when nutrients are applied in excess of crop needs or in a manner that promotes losses to the surrounding environment that they pose an environmental risk. A good way for producers to ensure that this doesn't happen is to design and use a nutrient management plan. Producing a such a plan involves

- understanding the principles of nutrient management
- knowing soil and landscape features, soil fertility reserves, and appropriate nutrient sources
- calibrating application equipment to know how much is applied
- implementing best management practices for nutrient application, soil and water conservation, and emergency procedures (e.g., dealing with spills).

The nutrient management plan establishes a nutrient budget, determining the amount of nutrients that crops need and how these needs will be met. Soil testing provides data on existing levels of nutrients in the soil. Recommended rates of nutrient application, along with knowledge of the nutrient content of the various additional sources (e.g., animal manure, mineral fertilizer, biosolids, plowdown of legume crops) can then be used to determine the additional amount of nutrients needed to produce good yields. In this way, over-application of nutrients is avoided, and the risk of them building up in soil or being lost to the air or water is reduced. The plan also identifies ways of storing, handling, and applying nutrient sources that minimize environmental risk.

Tailor-made to the specific environmental conditions of individual farms, the nutrient management plan helps to optimize production while saving on input costs and protecting soil and water quality. And the plan is flexible, able to respond to changes in weather, soil conditions, cropping, nutrient availability, and farm resources.

Ontario Ministry of Agriculture, Food and Rural Affairs, 1998

Response Options

Areas where levels of residual nitrogen are high (Class 3 or 4 in the semi-arid regions and Class 4 in the intensive humid regions) should be examined in more detail to determine the probable cause. Soil testing can be used to confirm the results. In western Canada, soil testing plays an important role in helping farmers adjust the amount of residual nitrogen needed to achieve good yields. If high levels of residual nitrogen are borne out by soil testing, then steps should be taken to correct this situation. In particular, since about 40% of the nitrogen under the control of the farmer comes from animal manure and legume sources, extension and research related to residual nitrogen should be directed at developing environmentally sound nutrient management plans (*see* Box).

Such plans recognize that

- regular soil testing is the foundation for calculating nitrogen needs
- options for managing legume nitrogen (e.g., location and rate of incorporation) are very limited
- application of manure nitrogen is more flexible, but animal manure can be transported over limited distances and manure nitrogen is associated with other plant nutrients, such as phosphorus, that have environmental effects and must also be properly managed
- fertilizer nitrogen should be used to complement inputs of nitrogen from other sources, as it is more flexible in terms of rate, timing, and location of application.

In the more humid regions, efforts are under way to develop practical soil testing procedures to measure available nitrogen in the soil. To be effective, soils must be sampled and analyzed as close to the time of seeding and nitrogen application as possible, because nitrogen levels can change quickly with the movement of water through the soil. Better methods to account for nitrogen in animal manure and legumes are also needed.

High values for residual nitrogen across a mapping area may point to localized areas of even higher levels. These areas are usually associated with intensive livestock operations for which the land base is not large enough to properly manage the nitrogen in manure. In this situation, extension work, and possibly on-farm research, is needed to help the farmer develop alternative strategies for managing levels of nitrogen that are higher than crop requirements.

The indicator trends may identify areas of high levels of residual nitrogen that can be confirmed by soil testing. In this case, the indicator may be signaling areas of agricultural intensification where more attention should be given to adopting management practices to better manage nitrogen inputs.

If soil tests do not show the high levels of residual nitrogen estimated by the indicator, it may reflect that the recommended rates for applying nitrogen are not valid. Further research is needed to check that existing nitrogen recommendations are still valid and to develop new recommendations for new crop varieties in different agricultural regions.

An inconsistency between indicator and soil test levels of residual nitrogen might also point to inadequacies of the data. In this case the data should be corrected or the problematic mapping areas eliminated from the analysis.

Since current recommendations for nitrogen inputs in agriculture are based only on the economics of crop production, it is important to study the linkage between the economic and environmental effects of conforming to these recommendations. Only after consensus is reached on this point will it be possible to provide a full environmental interpretation of the indicator results.

Conclusion

The residual nitrogen indicator provides a reasonable indication of the status and trends in residual nitrogen derived from agricultural activities. It uses a relatively consistent calculation for crop inputs and livestock operations (averaged over mapping areas) across Canada, and therefore allows for regional comparisons.

Areas with high levels of residual nitrogen identified by the indicator are consistent with the pattern shown by other indicators of agricultural intensity, particularly those related to crop production. There is a definite trend toward increasing amounts of residual nitrogen in Canada.

The indicator is still in the preliminary stages of development, and caution should be taken when interpreting the results. The current sources of data are limited in many cases for this application. Some improvements are possible, but in other cases it would not be cost effective to compile a national data set with the level of detail needed for the analysis.

Related Indicators

Management of Farm Nutrients and Pesticides includes indicators related to the application of mineral fertilizer and animal manure, which influences levels of residual nitrogen. High levels of residual nitrogen add to the Risk of Water Contamination by Nitrogen and increase the nitrous oxide component of the Agroecosystem Greenhouse Gas Budget. They also reflect greater inputs of energy related to the production and application of mineral fertilizer, thus affecting the fertilizer component of Energy Use. Adequate fertilization of crops can help build and conserve Soil Organic Carbon.

17 Energy Use

R.J. MacGregor, R. Lindenbach, S. Weseen, and A. Lefebvre

Geographic scope: National, regional
Time series: 1981 to 1996

Highlights

- Agriculture requires energy as an input and produces products that contain energy. To meet growing world demand we must continually strive to increase output on a relatively fixed land base. This increase usually means having to use new technologies that need additional inputs, including energy. The issue is whether these new systems are sustainable.

- Two indicators were developed to estimate the amount of energy contained in agricultural inputs and the amount contained in outputs used or consumed by humans. Information on productivity for certain inputs is also provided. The preliminary performance objectives are reduced energy input and increased energy output.

- The amount of energy input into Canada's primary agricultural production grew by 8% from 1981–1985 (341 PJ) to 1992–1996 (368 PJ). Greater use of mineral fertilizers accounts for this increase. The use of diesel fuel also grew (3% annually), but this change was largely offset by a drop in the use of gasoline (–5% annually) as farmers replaced gas powered equipment with diesel powered equipment.

- Canada's total energy output in agricultural primary products grew by 13% from 1981–1985 to 1992–1996, with large contributions from major grains, animals, and other commodities. Total energy output can vary by more than 100 PJ from one year to the next, depending on grain yields.

- In the Prairies, energy input grew by 14% and energy output grew by 19% (104 PJ) between 1981–1985 and 1992– 1996. In the non-Prairie region, energy input grew by 3%, while energy output dropped by 3% (2 PJ) in the same period.

- Agricultural energy output appears to be most affected by fluctuations in climate, but also by improvements in crop varieties, farming practices and by commodity prices. The non-Prairie regions that specialize to a greater degree in livestock production and energy-intensive cropping (e.g., horticulture) show a greater energy input than output. The Prairies, with their greater emphasis on grain output (and bulk grain exports), is characterized by energy output greatly exceeding energy input.

The Issue

Agriculture, like all human activities, requires energy as an input and produces products that contain energy. Energy is used to power vehicles and farm machinery, manufacture equipment and chemicals (e.g., mineral fertilizers, pesticides), and run farm homes, among other uses. Energy leaves the agricultural system bound in commodities such as cereals, horticultural crops, livestock, and livestock products that are either consumed directly by humans or used to produce other goods (e.g., leather), or through losses to the environment.

Understanding the amount and form of energy going in and coming out of the agricultural system, along with how these are changing over time, provides some information on how the system is performing. For example, more inputs may be needed to maintain yields over time as soils become depleted. Changes in the mix of outputs produced on farms, especially greater production of livestock, would alter the amount of energy contained by outputs.

Producers want to use inputs as efficiently as possible to increase net income (i.e., through lower costs of input per unit of output). Improved efficiency also leads to better protection of the environment. If producers use less mineral fertilizer, pesticides, and other inputs, less of these inputs would be available to affect the environment. The environmental benefits of using inputs as efficiently as possible include

- conservation of non-renewable resources, such as fossil fuels
- lower emissions of greenhouse gases that contribute to global warming (e.g., nitrous oxide from mineral fertilizers)
- reduction in the risk to the local environment (e.g., water quality, wildlife habitat).

Sector growth and intensity of resource use are key aspects to interpreting this indicator. To meet growing world demand we must continually strive to increase output on a relatively fixed land base. This increase usually means having to use new technologies that need additional inputs, including energy. The issue is whether these new systems are sustainable.

Improved feed efficiency

Research has led to significant improvements in feed conversion rates. For example:

- Improved genetics and management systems allow hog producers in Manitoba to feed growers about 30% less barley than they did in the early 1970s to produce a market hog.
- Today it takes only about 7 weeks to produce a broiler, compared to 12 weeks in the 1950s. Less feed and fewer barns are needed to produce the same number of broilers today.
- The number of dairy cows in Canada continues to decline as milk yield per cow increases by 1 to 2% per year.

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The Indicator

Description

We have developed two indicators, one that estimates the total amount of energy contained in inputs (called *energy input*) and another that estimates energy contained in outputs (called *energy output*). Because direct solar energy inputs are excluded, energy input is an indicator of the quantity of non-renewable energy used by the agricultural sector. The indicators are estimated at the provincial level, with Prairie, non-Prairie, and national results reported here. Specific information on some provinces is also provided. Five-year moving averages from 1981 to 1996 are reported to smooth out significant annual fluctuations in output values.

Changes in measures of energy input and output can be short- or long-term, reflecting changes in

- technology
- government policies that affect input use or output decisions
- weather patterns that affect yields (which can lead to large fluctuations in annual energy output)
- farm management practices.

Over time all these factors affect the quantity of energy used or produced. An increase in energy input generally implies greater intensity of resource use and a higher level of risk to the environment. Growth in energy output without a significant change in the mix of agricultural products is a sign of improved productivity and efficiency. The preliminary performance objectives for these indicators are reduced energy input and increased energy output. However, real performance can be evaluated only after the cause of changes in energy are understood.

A comparison of energy inputs and outputs to evaluate energy use efficiency requires a full understanding of the complete life cycle of energy in relation to the technologies available to producers. This type of comparison may be part of the future development of these indicators.

Method of calculation

The metric unit of measure for energy used for this indicator is a petajoule (PJ). A PJ is 10 to the power of 15 joules (1 PJ = 10^{15} joules). In relation to other measures of energy, 1 calorie is equal to 4.1686 joules; 1 British Thermal Unit (BTU) equals 1054.6 joules.

The method described in *Energy Use Trends in Canadian Agriculture* was used to calculate energy input values. This method was modified to deal with a scarcity of information at the provincial level and to extend the information back to 1981.

The energy inputs assessed in this calculation are natural gas, gasoline (motor), diesel (fuel oil), electricity, NGLs (propane, butane, etc.), energy used to produce mineral fertilizers and pesticides, and energy embodied in buildings and machinery. Data for energy inputs came directly or indirectly from Statistics Canada publications and other energy reports. When data were lacking for certain years, input values were estimated using known data. For the sake of consistency with other studies, we did not include values for energy resource depletion, a factor that accounts for the extraction, refinement, and transportation of fossil fuels to the final user.

To determine energy output, information on the energy content of 34 of the most abundantly produced farm commodities was obtained from the U.S. Department of Agriculture Nutrient Database or from Agriculture and Agri-Food Canada databases. These commodities are wheat (winter and spring), durum, barley, rye, oats, canola, flaxseed, lentils, field peas, soybeans, corn (for grain), potatoes, beef, pork, milk, chicken, eggs, turkey, carrots, cauliflower, corn (fresh), cucumbers, lettuce, onions, peas, tomatoes, apples, blueberries, grapes, peaches, pears, raspberries, and strawberries. Hay and pasture were not included, because they are included in livestock production, not marketed directly.

The energy content of each commodity was multiplied by the volume of that commodity produced in each province. Production levels came from Statistics Canada reports. The total energy held in all commodities was then summed to obtain a yearly output total. To avoid double counting, the energy contained in grain was reduced to account for the amount fed to livestock.

Limitations

Calculation of the indicators was subject to the following limitations. Some data needed to calculate the indicators were lacking or out of date, or their accuracy was suspect. Attempts were made to remedy these deficiencies, but better data would improve the accuracy of the indicator. In calculating energy outputs, some minor commodities may have been neglected because data were lacking. Differences in the relationship between energy input and energy output among regions reflect the diversity of farm types and climate across Canada, not more-efficient practices in one area compared to another. Also, differences in data sources and how feed use data are handled mean that provincial estimates do not add up to national estimates. Although national estimates are more reliable, provincial estimates are also provided because they reflect changes over time.

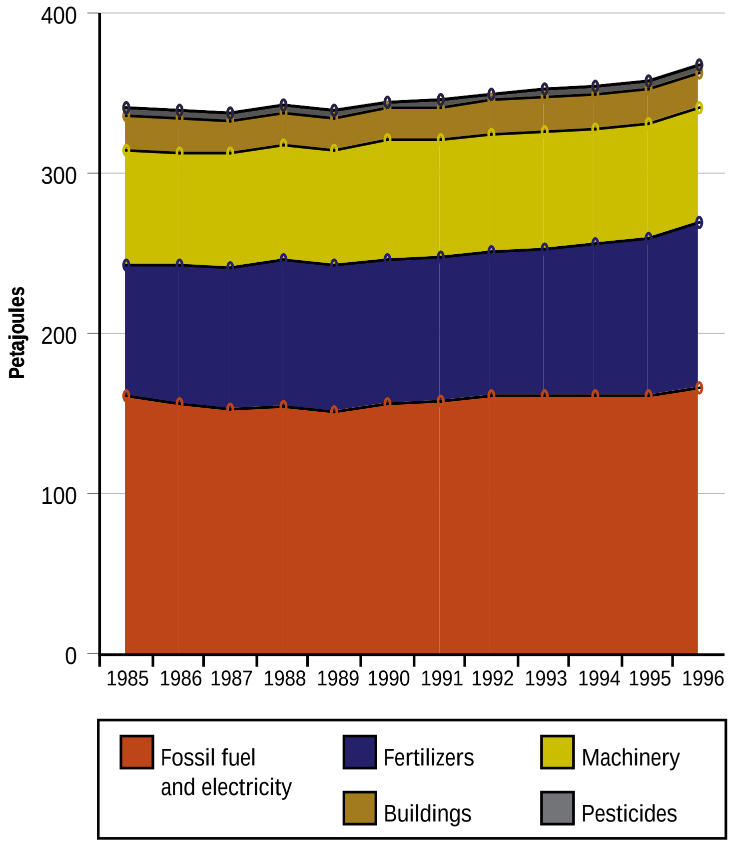
Results

Energy input

Energy input grew by 8% in Canada between 1981–1985 and 1992–1996 (Fig. 17-1). This trend results mainly from a 14% rise in energy input in the Prairies (mainly because of growing use of mineral fertilizers), compared to a 3% rise in the rest of Canada. Mineral fertilizer energy input grew by 26% (an annual growth rate of 1.4%) between 1981–1985 and 1992–1996, accounting for 26% of the national energy input during this 15-year period. Pesticide energy also increased (20%), but given its very small absolute contri-

Agricultural energy input in Canada

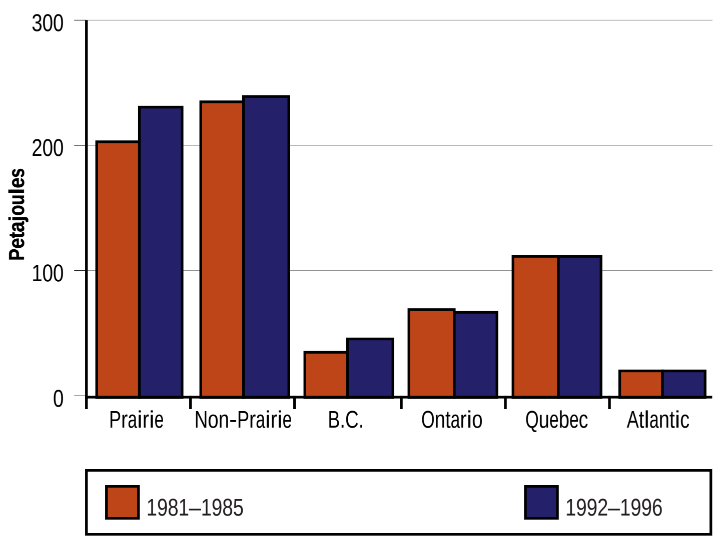
Figure 17–1



Note: Years represent 5-year moving averages. For example, 1985 represents an average of 1981 to 1985

Regional agricultural energy input

Figure 17–2



bution, the impact of this input was negligible. Total fossil fuel use increased over this period by 3%, with a significant shift away from gasoline- to diesel-powered machinery.

Regional and provincial energy use are shown in Figure 17-2. The use of livestock feed was counted as an energy input in British Columbia, Quebec, and the Atlantic Provinces, because more energy was consumed in feed than produced in major crops in these provinces. Energy input used in the Prairies grew annually at an average rate of 1%, compared to 0.1% in the rest of Canada.

The annual rate of change in energy input by province over the period 1981–1985 to 1992–1996 was

- 2.8% in British Columbia, driven mainly by an increase in imports of feed grain
- –0.2% in Alberta, where the drop in fossil fuel use exceeded the increase in mineral fertilizer use
- 1.6% in Saskatchewan, with a rise in the use of both fossil fuels and mineral fertilizers
- 2.2% in Manitoba, with a rise in the use of both fossil fuels and mineral fertilizers
- –0.4% in Ontario, with a drop in mineral fertilizer use and energy input in machinery
- –0.4% in Quebec, with a slight drop in the energy in both fossil fuels and mineral fertilizers
- –0.6% in the Atlantic Provinces, with a rise in mineral fertilizer use and the feed deficit offset by a drop in the use of fossil fuels.

Energy output

Total energy output for Canada increased by 13% between 1981–85 and 1992–96 (Fig. 17-3). Even with the smoothing effect of using 5-year moving averages, there was considerable variability nationally. As an indicator, energy output is sensitive to the yields of major crops. The annual rate of growth in energy output in major crops was about 1.2%, but when feed use (which grew at a rate of 1.6%) is netted out, the annual growth rate falls to 1%. Energy output in animals grew at a rate of 0.4%, and in other commodities at a rate of 8% (although from a very small base compared to major crops). On average, major crops (net of feed use) contributed 86% of energy output.

The Canadian situation is greatly influenced by the Prairie region, which accounts for more than 85% of Canada's total energy output. The Prairies showed a 19% increase in energy output during the study period, following an upward trend similar to the national one (Fig. 17-4). In this region energy output in major crops grew annually at a rate of 1.5%, reflecting both increasing yields (partly in response to greater use of mineral fertilizers) and expanded seeded area as the use of summerfallow declined. Feed use increased at the faster rate of 2.7%, underpinning a 1.5% increase in animal energy output. The energy output of other commodities (e.g., lentils, field peas, potatoes, and horticultural crops) expanded by almost 15% per year, but from a very small base. In 1996 other commodities still accounted for only 4% of the total energy output. Areas outside the Prairies had a slight drop (–3%) in energy output. In Ontario this drop resulted from feed use increasing faster than the energy output of major crops, which left a smaller amount of energy to export.

The annual rates of change in energy output over the period 1981–1985 to 1992–1996 were

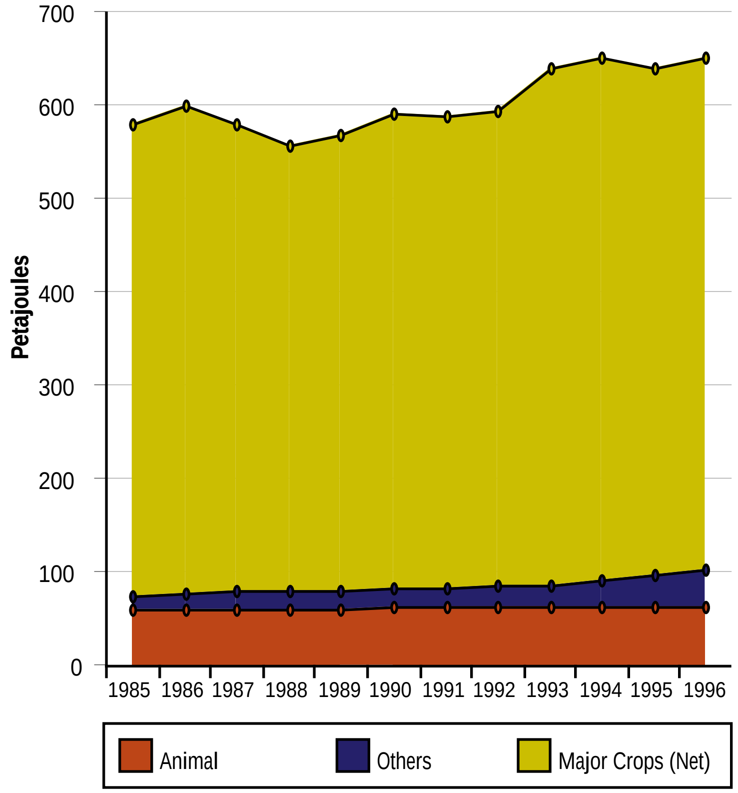
- 1.2% in British Columbia, with a rise in both animal output and feed deficit
- 1.6% in the Prairies, with a rise in all three categories of energy output
- –0.6% in Ontario, with a rise in feed use but a fairly constant energy output in animals
- 0.1% in Quebec, with a small increase in animal and other commodities energy outputs
- 1.2% in the Atlantic Provinces, with an increase in other commodities and a small increase in animal energy output.

The annual rates of changes in the energy output of selected commodities between 1981–1985 and 1992–1996 were

- beef and milk, –0.6 %
- pork, 1.3 %
- chicken, 3.6%
- wheat (including durum), 0.2%
- barley, –2.4%
- canola, 6.1%
- flax, –0.7%
- oats, 13.5%
- soybeans, 7.8%
- corn, –2%.

Figure 17–3

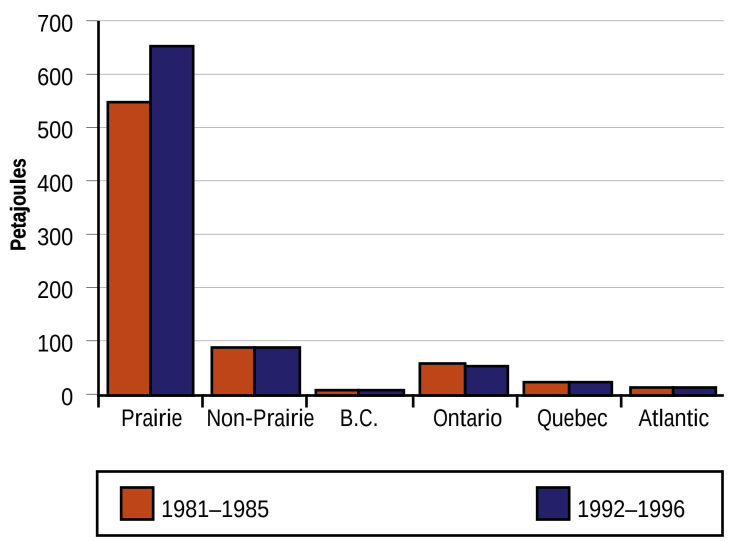
Agricultural energy output in Canada



Note: Years represent 5-year moving averages. For example, 1985 represents an average of 1981 to 1985

Figure 17–4

Regional agricultural energy output



Productivity

Productivity is one way of measuring input use efficiency. Although simple to understand, it is difficult to measure at an aggregate level. Productivity increases if the amount of output grows at a faster rate than the amount of inputs (i.e., more for less), implying that the technology or management systems are improving over time. Aggregate indices are constructed based on the value of inputs and outputs to measure change in productivity over time.

Productivity was calculated for mineral fertilizers (nitrogen, phosphorus, and potassium), pesticides, and energy (fossil fuels to power machinery and produce electricity). Indices were constructed based on expenditure and receipt data, deflated to account for price changes over time. Mineral fertilizers and pesticides were compared to crop output, and energy was compared to both crop and livestock output. Data came from an Agriculture and Agri-Food Canada productivity data base for the years 1961 to 1992. At the time of reporting, information was available up to 1992.

The estimates of productivity over the 1983–1992 period confirm the trends found above, where inputs and outputs were expressed in terms of the energy they contain. Instead of using energy as the common unit of account, the productivity indices directly compare the amount of inputs with the amount of outputs (all expressed in constant dollars). Consistent with the finding that energy output is increasing faster than energy input for mineral fertilizers, pesticides, and fossil fuels, productivity is improving at an annual rate of 1%, 2.5%, and 1.9%, respectively.

Total mineral fertilizer use on the Prairies has grown significantly, as has mineral fertilizer energy input, which almost doubled. Mineral fertilizer use efficiency increased by 2.3% annually, demonstrating the overall improvement in productivity. Up to 1980, total mineral fertilizer use in the Prairies and non-Prairie regions was roughly the same. After 1980 mineral fertilizer use in the non-Prairie region tended to level off (or drop by about 1% per year according to the energy use estimate), and there may have been some loss in productivity. This trend brought down the national use efficiency rate to 1%.

Total fossil fuel use measured in terms of constant dollars has been falling since the mid-1970s. With significant growth in outputs, overall efficiency use has improved in both Prairie and non-Prairie regions. The energy input of fossil fuels grew slowly over the 1981–1985 to 1992–1995 period.

For pesticides, the efficiency index decreased by 1.6% annually for the Prairies, more than offset by a rapid annual increase in use efficiency of 8.8% outside the Prairies. These figures point to an improvement in the national use efficiency rate of almost 2%. Both measures (quantity and energy) show a very rapid increase in use for the Prairies. However, they are not consistent for the non-Prairie region, where use in terms of quantity is dropping and energy input in pesticides is growing at an annual rate of 0.7%.

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In the Prairies there was an overall increase in the net energy output of major crops, mainly because of reduced use of summerfallow. As can be seen from the annual rates of change, energy output in wheat increased very slowly while that in barley fell, replaced by canola and oats. In eastern Canada the shift from corn to soybeans is evident. The decline in energy output in beef in eastern Canada more than offset the growth in western Canada, especially in Alberta where energy output grew by 12% between 1981–1985 and 1992–1996. Energy output in milk rose in British Columbia, but the overall reduction resulted from the declines seen in Ontario and Quebec over this period. Pork and chicken production and energy output expanded steadily.

Interpretation

Over the 1981–1985 to 1992–1996 period the energy output in major crops and other commodities in the Prairies grew faster than energy input (made up mainly of mineral fertilizer input). Higher energy output has been achieved mainly through improved yields (the result of technological change) and reduced use of summerfallow. Another way of looking at how efficiently the sector is using various inputs is to examine *input productivity*, which supports this interpretation, at least for the major inputs of mineral fertilizers and fossil fuels (*see* Box). Use of fossil fuels is increasing slowly, implying that the sector is contributing to efficient use of this non-renewable resource, with implications for greenhouse gas emissions from the sector. Greater use of mineral fertilizers is needed in the Prairies to restore soil fertility, which declines under the production of grains, oilseeds, and forage crops.

In terms of other inputs, it appears that the economic incentive to use inputs in an economically efficient manner is sufficient motivation to reduce the amount required. Energy inputs declined in all eastern regions, including mineral fertilizer use in Quebec and Ontario, probably as a result of changes in the cropping pattern (e.g., more soybeans) and greater reliance on manure. This finding demonstrates the potential that alternative production systems have to affect input use. Although the energy contained in machinery and buildings is quite large, it has remained relatively constant over this period. The change in the makeup of outputs (both crops and animals) had little overall impact on these inputs.

Grain used for feed is another important consideration. Grain and forage are the key inputs into animal production. The 1.6% increase in feed grain energy input over the 1981–1985 to 1992–1996 period exceeds the overall 1.2% increase in energy output from major crops. On average, 36% of energy output of major grains was used to feed livestock. By 1992–1996, the energy input of major grains fed to livestock was equivalent to 90% of all the other energy input. If feed efficiency can be improved, the potential for significant gains exist. Such a development has implications for the amount of inputs required to produce livestock feed, as well as for the manure and other by-products produced by livestock.

Response Options

The indicators of energy input and energy output are composed of many different components and so do not lend themselves to very specific actions. For example, the trend toward growing use of mineral fertilizers in the Prairies should be monitored to ensure that the increased level of mineral fertilizer use results in maintaining or improving productivity. Finding other management alternatives to making soils fertile would help to reduce reliance on mineral fertilizers.

Although its relative size is small, the increase in the use of pesticides is worrisome. The annual increase in energy input by almost 1%, combined with a declining productivity index on the Prairies, indicates that effort should be focussed on this issue. The effect of a change in the output mix on input use also needs study. Other commodities, along with canola and oats, grew significantly, and if pesticides play a bigger role in production of these commodities, effort should be directed at finding alternative pest management systems.

Conclusion

Over the period of study, the growth rate of energy output (1.2%) exceeded that of energy input (0.7%). The productivity indicators for mineral fertilizers, pesticides, and fossil fuels confirm continued improvements in performance by the sector. The energy contained in various inputs is a significant cost, and producers are expected to try to minimize these costs. This indicator provides support for this proposition.

Although energy use in mineral fertilizers and pesticides increased over this period in the Prairies, energy use in other inputs remained relatively constant. This was sufficient to allow strong productivity gains from improved yields and less reliance on summerfallow. Increased pesticide use on the Prairies is one area of concern, the implications of which should be evaluated through farming systems research. Another key area for improvement would be in the area of feed grain efficiency. Feed grain is the single greatest energy input into the sector, almost equal in energy terms to all other inputs combined.

Related Indicators

The Energy Use indicator is related to most other indicators presented in this report. For example, more energy will be needed to support agricultural production as soils become degraded, linking this indicator to Risk of Water Erosion, Risk of Wind Erosion, Risk of Tillage Erosion, Soil Organic Carbon, Risk of Soil Compaction, and Risk of Soil Salinization. The Management of Farm Nutrient and Pesticide Inputs will dictate to what extent mineral fertilizers and pesticides are used, affecting the amount of energy input associated with these inputs. Increasing the amount of Soil Cover by Crops and Residues may cut down on machinery and fossil fuel energy used in tillage, but more energy in herbicides may be used. Use of input energy contributes greenhouse gas emissions in the Agricultural Greenhouse Gas Budget.

H Summary

18 Regional Analysis of Environmentally Sustainable Agriculture

T. McRae and C.A.S. Smith

Geographic scope: British Columbia, Prairie Provinces, Ontario, Quebec, Atlantic Provinces
Time series: 1981, 1991, 1996

Highlights

- Primary agricultural GDP grew by about 30% between 1981 and 1996 in British Columbia, while some environmental risks declined, some remained stable, and others increased. Improvements were achieved for soils, but substantial portions of cropland remain at risk of unsustainable levels of water and tillage erosion. Agricultural habitat for most habitat use units remained stable in the central portion of the province, increased in the Peace River region, but declined in the more intensive agricultural regions of the Pacific Maritime ecozone. Greenhouse gas emissions were stable. The risk of water contamination by nitrogen increased. Some soils in the Montane Cordillera ecozone and Peace River region are under-fertilized, whereas other areas of the province under intensive horticulture and livestock production show increases in residual nitrogen. The rate of growth in agricultural energy input use in British Columbia exceeded the rate of growth in energy outputs.

- In the Prairie Provinces, strong growth (about 59%) in primary agricultural GDP between 1981 and 1996 was accompanied by notable progress in protecting soil health and to some extent in conserving agricultural wildlife habitats for most habitat use units. Environmental costs from agriculture were mainly due to greater greenhouse gas emissions. Increases in residual nitrogen had the mixed effect of conserving soil fertility, contributing to greenhouse gas (nitrous oxide) emissions and possibly increasing the risk of water contamination by nitrogen. The prairie region also showed relative improvements in energy use, as growth in agricultural energy outputs exceeded growth in energy inputs. Indicators are currently lacking for important prairie issues such as water management and the effects of irrigation and intensive livestock operations on water quality.

- Ontario achieved moderate growth in agricultural GDP (about 8%) and mixed success in reducing environmental risks between 1981 and 1996. The risk of soil degradation declined except for that associated with soil compaction, but substantial portions of cropland remain at risk of unsustainable levels of water and tillage erosion. Greenhouse gas emissions remained stable. Agricultural habitat for most habitat use units held steady in the northern agricultural area of the province but declined in the south, south-central, and southeastern regions. Levels of residual nitrogen and the risk of water contamination from nitrogen both increased considerably over much of the province. Both inputs and outputs of energy declined, the latter at a slightly higher rate.

- Quebec showed moderate growth in agricultural GDP (about 13%) and showed environmental gains in some areas and stable or worsening risks in others between 1981 and 1996. Progress is evident for soils, for which most degradation risks remained steady or declined, and most cropland is at risk of tolerable levels of soil erosion. Greenhouse gas emissions also declined. Agricultural habitat area for most habitat use units remained stable in the northern portions of the province but shrank in areas of the Mixedwood Plains ecozone where there is more intensive production. Levels of residual nitrogen and the risk of water contamination by nitrogen rose considerably over much of the province. Both the risk of water contamination by phosphorus and agricultural energy inputs and outputs remained largely unchanged.

- Agricultural GDP grew slightly (about 1%) in the Atlantic region, and environmental risks varied considerably between 1981 and 1996. Agricultural habitat area either grew or held steady for most habitat use units in the region, soil cover increased, and degradation risks were reduced for some soils. However, improvements in soil management have been modest overall, and substantial portions of cropland remain at risk of unsustainable levels of erosion. Estimated levels of residual nitrogen and the risk of water contamination from nitrogen increased considerably over much of the region. Agricultural energy output increased 17% between 1981 and 1996, whereas energy input declined by 4%.

Introduction

Previous chapters of this report focus on individual agri-environmental indicators. In this chapter we consider selected indicators and other relevant factors together on a regional basis to

- identify linkages between the indicators
- assess environmental performance in agriculture over the 1981–1996 period
- identify environmental challenges
- consider agri-environmental trends in relation to changes in economic output.

The regions considered are British Columbia, the Prairie Provinces (Alberta, Saskatchewan, and Manitoba), Ontario, Quebec, and the Atlantic Provinces (New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland and Labrador). Primary agricultural gross domestic product (GDP) is the indicator used for the economic analysis. Ideally, to meet economic and environmental objectives, GDP will increase over time and environmental risks will decrease. Such “de-coupling” can be achieved through structural changes in farming and use of more environmentally sound production practices and processes.

British Columbia

In 1996, British Columbia accounted for 3.5% of Canada’s farmland and about 7% of primary agricultural GDP. Its most important agricultural areas are the Peace River Region (in the Boreal Plains ecozone), the south central interior valleys (in the Montane Cordillera ecozone), and the Lower Mainland region (in the Pacific Maritime ecozone).

The Pacific Maritime ecozone has a mild coastal climate characterized by abundant winter precipitation. The area’s most productive agricultural soils are found in the lowlands of the Fraser Valley and southeastern Vancouver Island, where horticulture (outdoor and greenhouse production) and mixed farming predominate. The Montane Cordillera ecozone covers the southern interior areas of British Columbia, where the climate is mild and relatively dry. Agricultural activities there focus on horticulture and livestock production. The Peace River region is located in the Boreal Plains ecozone and specializes in grain and oilseed production. It resembles the northern agricultural area of the Prairie Provinces and is quite different from the rest of British Columbia. Because this region contains most of the province’s agricultural land, conditions there tend to skew provincial areal indicators toward that region.

British Columbia’s mild climate allows some of its land to be among Canada’s most agriculturally productive, and agriculture is diverse. When measured by farm cash receipts in 1997 ($1.7 billion), the key commodity groups are dairy (19.5%); poultry and eggs (19%); fruits and vegetables (18.5%); red meats (16.5%); grains and oilseeds (1.5%); and others (25%), such as mushrooms, bulbs, ornamental flowers and shrubs, and honey.

Key results for selected agri-environmental and economic indicators for British Columbia are presented in Table 18-1.

Interpretation

Environmental conditions and trends for British Columbia agriculture between 1981 and 1996 are mixed. Agricultural GDP increased strongly, and some environmental indicators show positive trends. Others show significant increases in environmental risks from agriculture.

Moderate improvements in managing soil resources have been realized. Between 1981 and 1996, indicators of soil cover (by crops and crop residues), soil organic carbon levels, and risk of tillage erosion improved overall, but tillage erosion increased in the south coastal and southern interior regions of the province. Levels of water erosion risk remained unchanged overall but increased in the Pacific Maritime and Montane Cordillera ecozones. Improvements in soil management are due in part to reduced tillage on cropland (53% of seeded area was under conservation or no-till in 1996) and reduced summerfallow in the Peace River area. Still, in 1996 almost half of British Columbia’s agricultural land base had areas at risk of unsustainable soil erosion by water and tillage, and soils continued to lose small amounts of organic carbon.

Total emissions of greenhouse gases remained stable, with no significant changes in emissions of individual gases. However, greenhouse gas emissions are relatively high in British Columbia on a per-unit area basis. Most habitat use units were supported by steady agricultural habitat

Table 18-1

Agri-environmental and economic indicators for agriculture in British Columbia

Issue	Indicator	1996 Status	1981–1996 Change
Land and Soil	Soil Cover	Good soil cover (34 bare soil days/hectare).	**Positive change:** 25% decrease in bare soil days.
	Water Erosion	44% of cropland at risk of unsustainable rates of water erosion.	**No change:** Cropland area at tolerable risk of erosion unchanged (recent improvements due to winter cover cropping in Pacific Maritime ecozone are not reflected in this result).
	Tillage Erosion	50% of cropland at risk of unsustainable rates of tillage erosion.	**Positive change:** 19% reduction in tillage erosion risk.
	Soil Carbon	Very small loss (12 kg/ha) of carbon.	**Positive change:** 40% reduction in estimated rate of soil carbon loss.
Climate Change	Greenhouse Gas Emissions	Emission of 5 million tonnes CO_2-equivalent (6% of national agricultural emissions).	**No change**
Biodiversity	Habitat on Farmland	Habitat use units by ecozone: Pacific Maritime (3048) Montane Cordillera (4011) Boreal Plains (3098).	**Negative change** in Pacific Maritime ecozone: 75% of habitat uses supported by declining habitat area. **No change** in Montane Cordillera ecozone: 80% of habitat uses supported by unchanged area. **Positive change** in Boreal Plains ecozone: 86% of habitat uses supported by increasing habitat area.
Water Quality	Risk of Water Contamination by Nitrogen (N)	94% of assessed farmland at risk of having N concentration in excess soil water near or above drinking water standard (Pacific Maritime ecozone only).	**Negative change:** 57% of assessed farmland (Pacific Maritime ecozone only) showed increasing risk of N contamination of water.
Production Intensity	Residual Nitrogen (RN)	70% of assessed farmland with negligible to low estimated RN (<20 kg/ha).	**Mixed change:** 51% of assessed farmland area showed decrease in RN of at least 5 kg/ha. RN increased in Pacific Maritime ecozone, a negative trend. RN increased and decreased in different parts of the Boreal Plains and Montane Cordillera ecozones, positive for soil health where it has increased but negative related to greenhouse gas emissions; negative where it has decreased due to underfertilization of soils.
	Energy	Energy input for 1992–1996 was 45.6 PJ, and energy output was 5.0 PJ.	**Negative change:** Increase in energy inputs (35%) exceeded increase in energy outputs (15%).
Economic Output	Agricultural GDP	About $850 million (constant 1992 $).	**Increase of about 30%.**

area in the central region of the province, increased agricultural habitat area in the Peace River region, and significantly reduced habitat area in the Pacific Maritime ecozone, where more-valuable farm wildlife habitats (such as wetlands and woodlands on farmland) were converted to other uses (such as cropland).

Estimated levels of residual nitrogen varied regionally within the province in 1996 (Fig. 16-1). Overall, only a small share (9%) of farmland showed high levels (greater than 60 kg N/ha), but these were mainly concentrated in the Lower Mainland and parts of the south-central portion of the province where concerns about

Figure 18-1

Change in the level of residual nitrogen on farmland in western Canada between 1981 and 1996

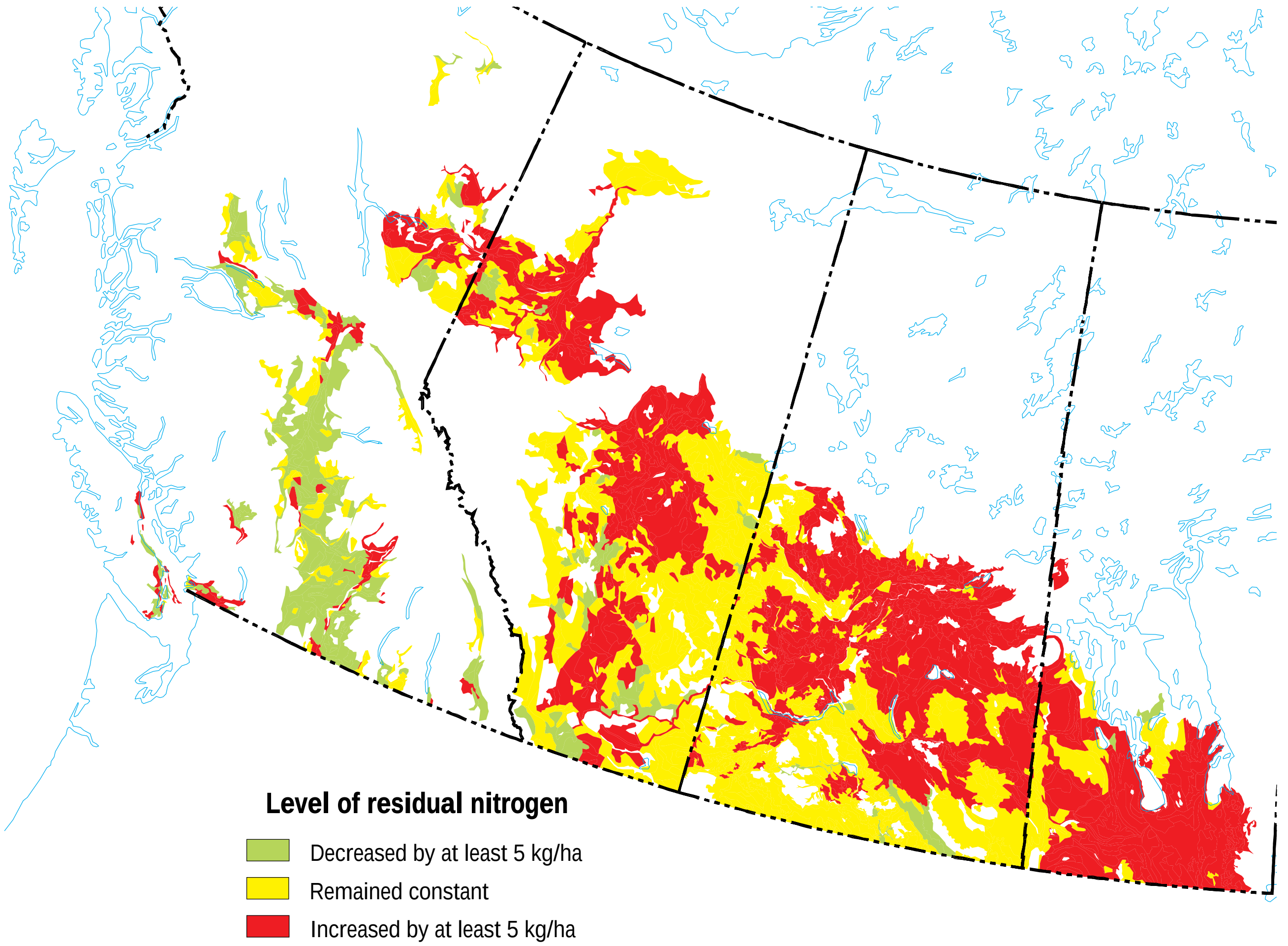
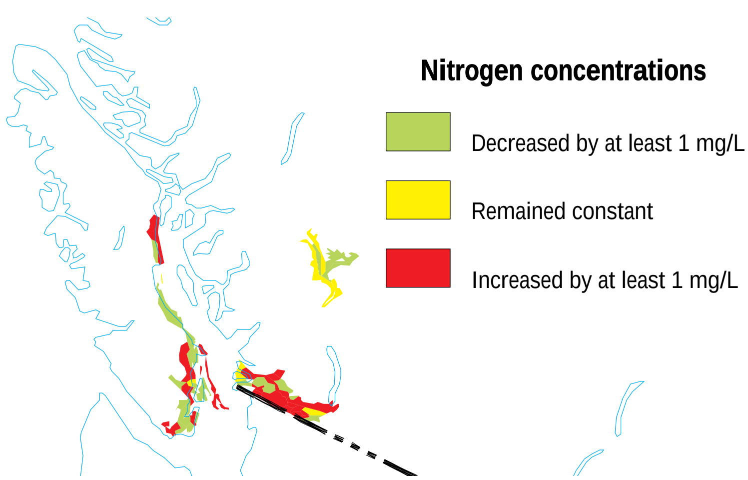


Figure 18-2

Change in the nitrogen concentration in excess water on farmland in British Columbia between 1981 and 1996



water quality predominate. The remaining agricultural areas of the province had much lower levels of residual nitrogen. Changes in residual nitrogen were also mixed (Fig. 18-1). Generally, regions with high levels also showed increases of more than 5 kg/ha between 1981 and 1996. The Peace River region also showed increases. In contrast, residual nitrogen levels decreased on most farmland in the Montane Cordillera ecozone.

The risk of water contamination by nitrogen was assessed only for the Pacific Maritime ecozone, where the nitrogen content of excess water was estimated to be near or above the drinking water standard (10 mg/L) on almost all farmland (Fig. 12-1). Between 1981 and 1996, this concentration increased by at least 1 mg N/L (10% of the drinking water standard) on almost 60% of assessed farmland, a worrisome trend. This increase occurs mainly in parts of the Fraser Valley and pockets on the east coast of Vancouver Island (Fig. 18-2).

The amount and rate of agricultural energy input use in British Columbia significantly exceeded the amount and rate of growth in energy outputs.

Challenges

The key challenges for British Columbia agriculture are to

- address concerns of surplus nitrogen and associated water contamination in the Pacific Maritime ecozone and selected areas of the Montane Cordillera ecozone. Current levels and recorded increases in residual nitrogen and the risk of water contamination are not sustainable, threatening water quality. Actions to improve nutrient management and manure storage and handling are required
- ensure adequate levels of fertilization of soils in areas of the province where cereal and oilseed production have led to soil nitrogen deficits, such as the Peace River region
- work with farmers to conserve remaining wildlife habitats in agricultural areas of the Lower Mainland region, where changes in land use have diminished the availability of useful habitats for many species
- address remaining soil quality concerns (such as soil erosion) in agricultural areas where soils remain at risk of degradation.

Prairie Provinces

In 1996, the Prairie Provinces accounted for 81.5% of Canada's total agricultural land area and about 46% of primary agricultural GDP. Most agriculture takes place in the semi-arid Prairie ecozone, but extensive and highly productive agriculture occurs in the southern portion of the cool, sub-humid parts of the Boreal Plain ecozone.

Agricultural land in the Prairie Provinces is characterized by large continuous tracts of cultivated land and sub-humid to semi-arid climate. The fine-textured soils of the region have relatively high fertility and good moisture-holding capacity, making them highly productive for crops. Much of the southern portion of the Prairie ecozone suffers from regular droughts. The Prairies are at the centre of Canada's agricultural activity, with farm receipts totalling $14.5 billion in 1997. Based on the share of total farm receipts, the major agricultural commodities are grains and oilseeds (52%), red meats (33.5%), dairy (4%), poultry and eggs (2.5%), fruits and vegetables (0.5%), and other farm commodities (7.5%). In recent years, prairie agriculture has become more diverse through the production of specialty crops (such as lentils, caraway, and mustard) and non-traditional livestock (such as elk and bison).

Key results for selected agri-environmental and economic indicators for the Prairie Provinces are presented in Table 18-2.

Interpretation

Most agri-environmental indicators show positive trends for prairie agriculture between 1981 and 1996, and agricultural GDP increased by about 59%.

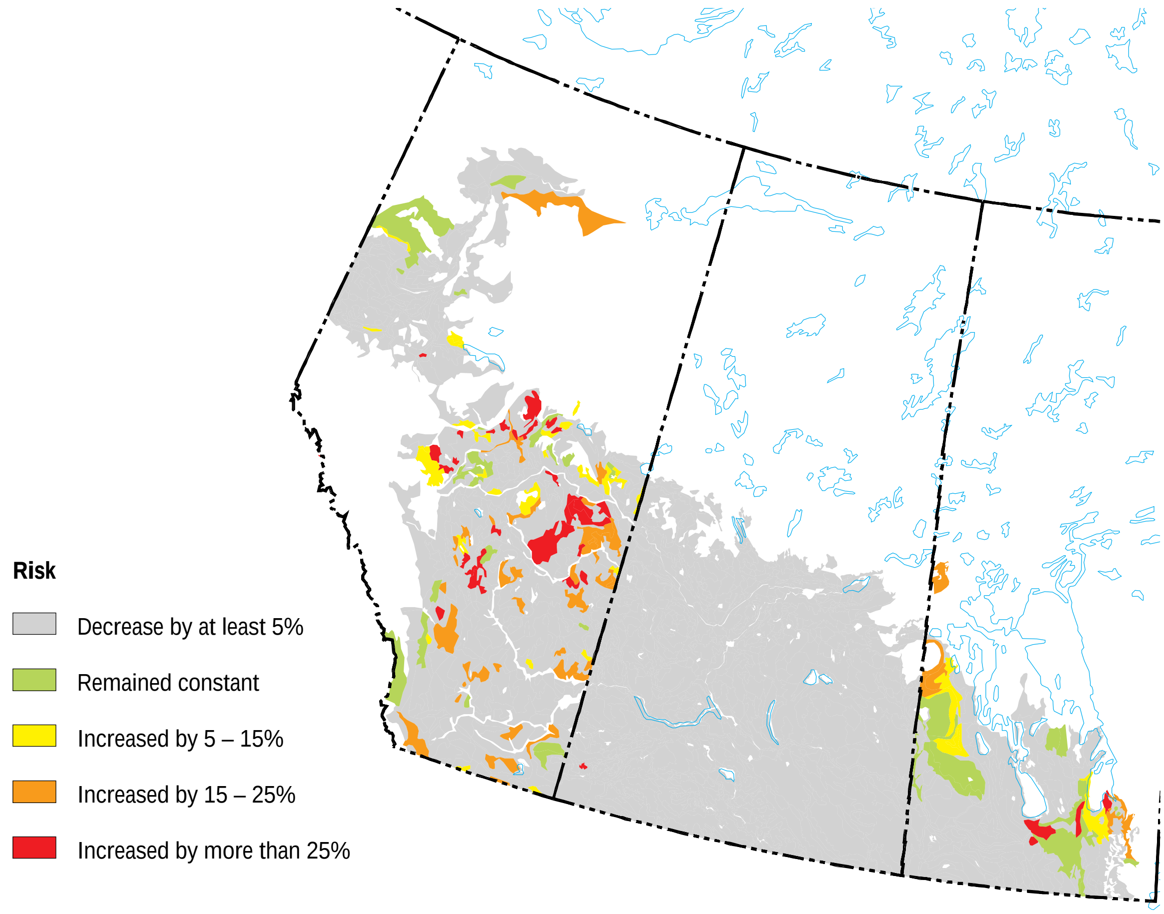
Important gains have been achieved in soil conservation. Between 1981 and 1996, soil cover increased; the risk of wind, water (Fig. 18-3), and tillage erosion dropped; and the rate of soil carbon loss declined to the point where soils in Saskatchewan are now estimated to be accumulating carbon, though at a very modest rate. These improvements are due mainly to reduced area under summerfallow, reduced tillage, and changes in the use of some marginal lands from annual crop production to forage crop production. Still, some soils remain at significant risk of degradation by erosion and salinization, indicating a need for additional conservation efforts in affected areas.

Most habitat use units were supported by an increase in agricultural habitat area. This improvement resulted from increased area under pasture and All Other Land, the agricultural land uses most used as habitat by wildlife.

Agricultural greenhouse gas emissions have increased over the Prairie Provinces as a whole, mainly because of increases in Alberta. Emissions rose for both nitrous oxide and methane due mainly to greater use of mineral fertilizers and higher livestock numbers, particularly of hogs and cattle. The exception to this trend is Saskatchewan, where emissions decreased slightly between 1981 and 1996, in part the result of significant reductions in carbon dioxide emissions from soils.

Figure 18–3

Change in the risk of water erosion on cropland in the Prairie Provinces between 1981 and 1996



Levels of residual nitrogen increased by 5 kg/ha on about half of the farmland area assessed (Fig. 18-1). Prairie soils have historically been underfertilized, so this increase is positive for soil health and productivity (because underfertilization depletes soil nutrients). The one-third of farmland area with less than 20 kg/ha of soil nitrogen remaining after harvest in 1996 (Fig. 16-1) would likely benefit from additional applications of nitrogen. However, about 13% of farmland in the Prairie Provinces was estimated to have a surplus of more than 40 kgN/ha after harvest, possibly contributing to emissions of nitrous oxide, a greenhouse gas.

For methodological reasons (see Chapter 12), the risk of water contamination from agriculture was not assessed for the Prairies. Still, the expansion of intensive livestock operations, particularly in Alberta and Manitoba, has increased this risk in certain locations (e.g., some watersheds).

The prairie region also showed relative improvements in energy use, as increases in agricultural energy outputs exceeded growth in energy inputs.

Challenges

The key challenges for agriculture in the Prairie Provinces are to

- maintain gains realized in soil conservation, particularly if cropping patterns continue to shift to crops that provide less soil residue cover, and to enhance soil conservation efforts on soils that remain at risk of degradation (including marginal lands that continue to be used for annual crop production)

Table 18–2

Agri-environmental and economic indicators for agriculture in the Prairie Provinces

Issue	Indicator	1996 Status	1981–1996 Change
Land and Soil	Soil Cover	Moderate soil cover (78 bare soil days/hectare).	**Positive change:** 21% decrease in bare soil days.
	Water Erosion	13% of cropland at risk of unsustainable erosion.	**Positive change:** Increase in cropland area at tolerable risk of erosion (8% in Alta., 26% in Sask., 1% in Man.).
	Wind Erosion	About 6% of cropland at high to severe risk of wind erosion.	**Positive change:** One-third decrease in risk of wind erosion.
	Tillage Erosion	Slightly over half of cropland at risk of unsustainable erosion.	**Positive change:** Overall reduction of 24% in risk of tillage erosion.
	Soil Carbon	Slight, variable rates of loss of soil carbon in Alta. and Man.; slight rates of gain in Sask.	**Positive change:** Overall reduction in estimated rate of soil carbon loss.
	Salinity	44% of cropland at moderate (33%) to high (11%) risk of increasing salinity.	**No change:** 3% reduction in area at high risk of increasing salinity.
Climate Change	Greenhouse Gas Emissions	Emissions of 55 million tonnes CO_2-equivalent (64% of national agricultural emissions on 82% of national farmland).	**Negative change:** 12% increase in emissions.
Biodiversity	Habitat on Farmland	Habitat use units by ecozone: Prairie (3865) Boreal Plains (3098).	**Positive change:** 86% of habitat use units in Boreal Plains and 80% in Prairie ecozone supported by increasing habitat area.
Production Intensity	Residual Nitrogen	One-third of prairie farmland with low to negligible residual nitrogen (≤20 kg/ha), remainder above that value, with 13% > 40 kg/ha.	**Mixed change:** 53% of farmland showed increase in residual nitrogen of at least 5 kg/ha. Some of this may be positive in overcoming soil nutrient depletion; overfertilization may be occurring in other areas and contributing to emissions of nitrous oxide.
	Energy Use	Energy input in 1992–1996 was 229.8 PJ, and energy output was 649.3 PJ.	**Positive change:** Increase in energy outputs (19%) exceeded increase in energy inputs (14%).
Economic Output	Agricultural GDP	About $5.4 billion (constant 1992 $).	**Increase of about 59%.**

- ensure optimal use of nutrients and land management practices so that progress in building organic carbon levels and soil fertility is maintained
- manage the environmental risks to water quality and climate (from greenhouse gas emissions) that result from ongoing growth in the livestock sector, particularly for hog and other intensive livestock operations, through proper siting of facilities and sound manure and nutrient management
- retain critical habitat for wildlife on agricultural lands, such as wetlands and riparian habitats.

Ontario

In 1996, Ontario accounted for 8.3% of the Canada's total farmland and about 25% of primary agricultural GDP. Most of Ontario's agriculture falls in the Mixedwood Plains ecozone, primarily in the Lake Erie and St. Lawrence Lowlands. Pockets of agriculture extend into the southern fringes of the Boreal Shield ecozone to the north.

Agricultural areas of the Mixedwood Plains have gentle topography, fertile soils, a warm growing season, and abundant rainfall. As a result, Ontario contains much of Canada's most productive agricultural land, yet agricultural land is lost each year to competing non-agricultural land uses in region. Agricultural areas in the Boreal Shield ecozone have a colder climate and less productive soils. Agricultural activity in this ecozone is generally restricted to livestock and forage production.

Ontario agriculture is very diversified, and 1997 farm cash receipts totalled $6.6 billion. The key commodity groups by share of total farm cash receipts are red meat (23.0%), grains and oilseeds (19.0%), dairy (18.5%), poultry and eggs (12.0%), fruits and vegetables (10.0%), and other farm commodities (17.5%). Ontario is Canada's largest producer of corn and soybeans.

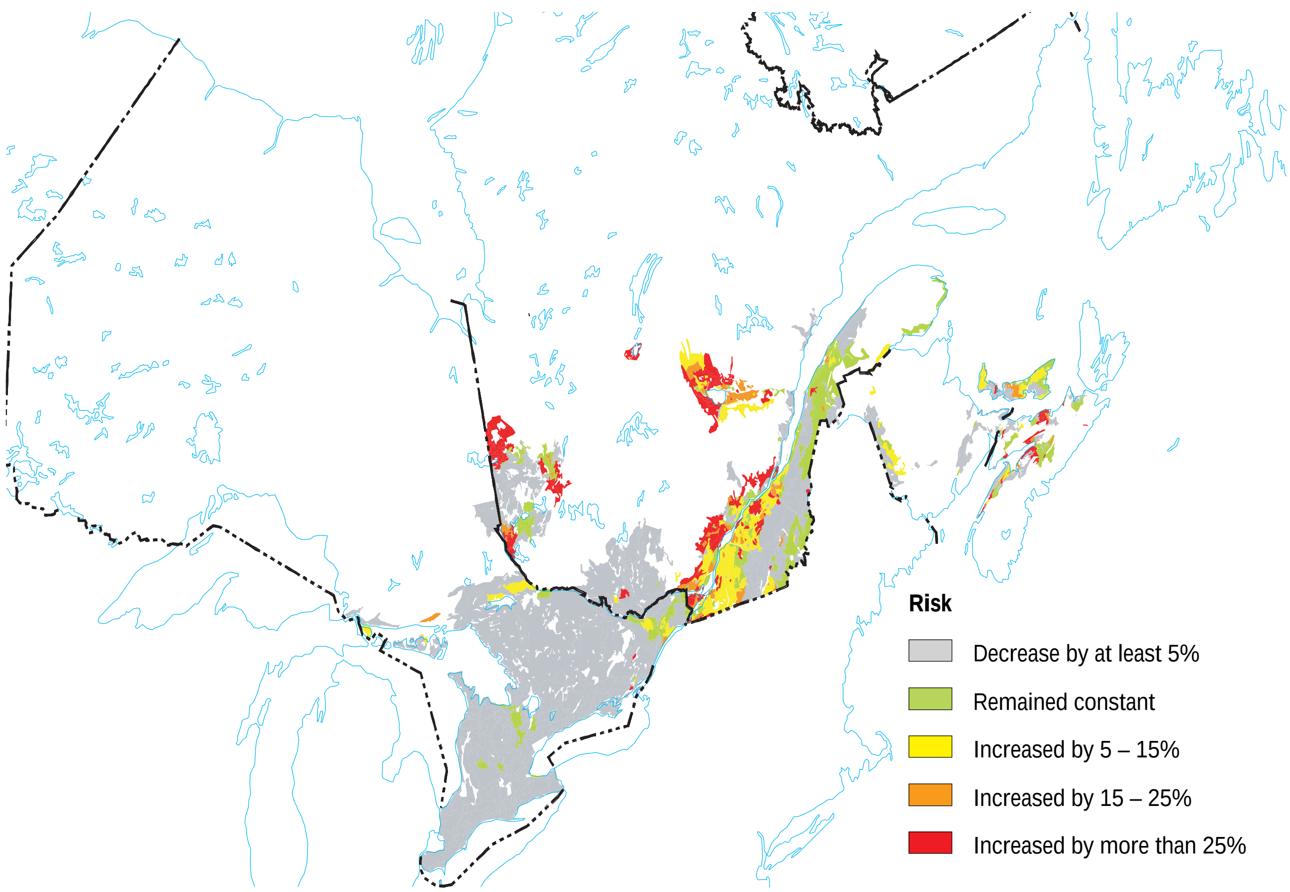
Key environmental and economic trends in Ontario between 1981 and 1996 are presented in Table 18-3.

Interpretation

Environmental conditions and trends for Ontario agriculture between 1981 and 1996 are mixed. Agricultural GDP increased by about 8%, some environmental indicators reveal slightly positive trends, and others show significant increases in environmental risks from agriculture.

Figure 18–4

Change in the risk of water erosion on cropland in Central Canada and the Maritime Provinces between 1981 and 1996



Agri-environmental and economic indicators for Ontario agriculture

Table 18-3

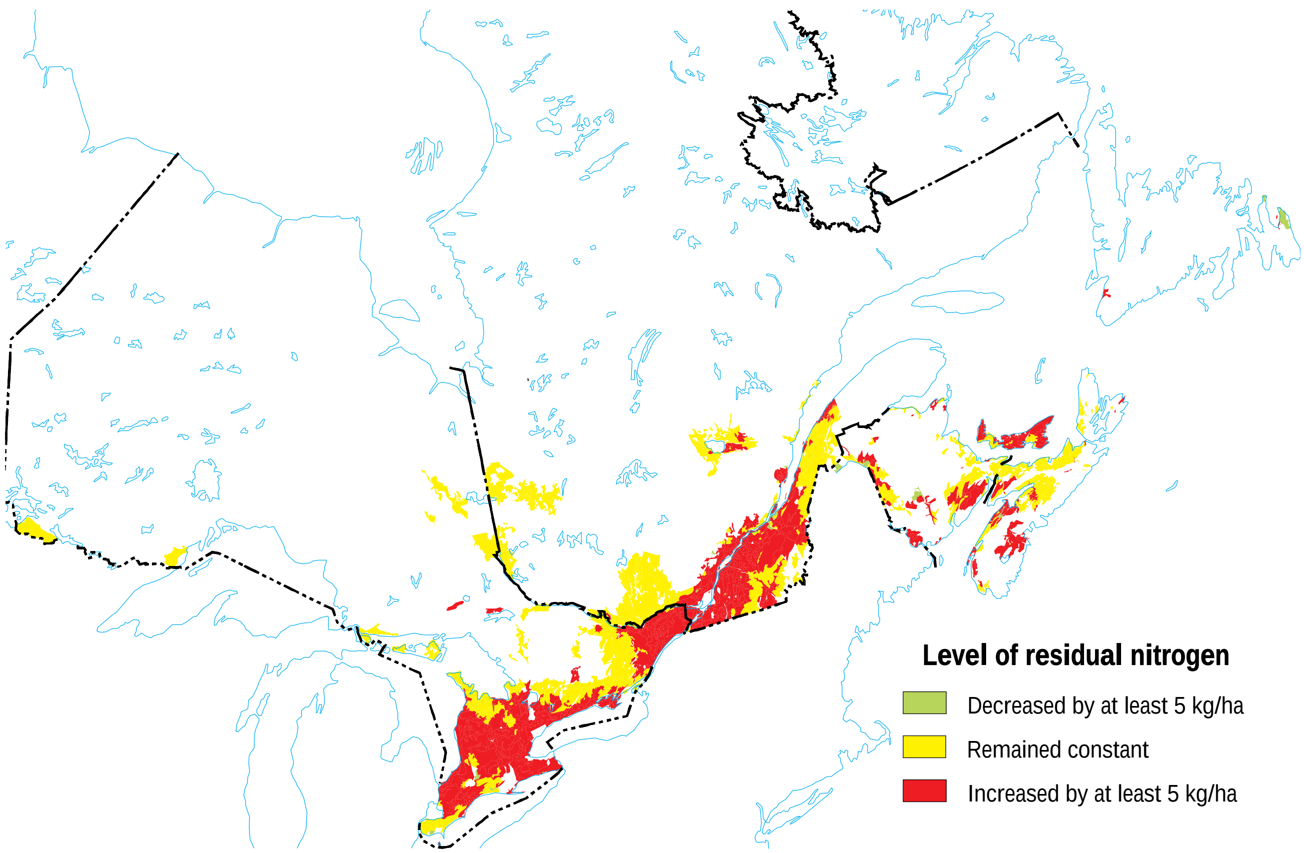
Issue	Indicator	1996 Status	1981–1996 Change
Land and Soil	Soil Cover	Moderate soil cover (96 bare soil days/hectare).	**Positive change:** 16% decrease in bare soil days.
	Water Erosion	42% of cropland at risk of unsustainable water erosion.	**Positive change:** 7% increase in cropland area at tolerable risk of erosion.
	Tillage Erosion	59% of cropland at risk of unsustainable tillage erosion.	**Positive change:** 26% reduction in risk of tillage erosion.
	Soil Carbon	Very slight rate of accumulation (3 kg/ha/yr).	**Positive change:** near equilibrium conditions.
	Soil Compaction	310 300 hectares of susceptible farmland under compaction-inducing crops.	**Negative change:** 61% increase in susceptible areas under compaction-inducing crops.
Climate Change	Greenhouse Gas Emissions	Emissions of 16 million tonnes CO_2 equivalent (19% of national agricultural emissions from 8.3% of national farmland)	**No change**
Biodiversity	Habitat on Farmland	Habitat use units by ecozone: Mixedwood Plains (3784) Boreal Shield (3262).	**Negative change** in Mixedwood Plains ecozone: 74% of habitat use units supported by declining habitat area. **Neutral change** in Boreal Shield ecozone: stable habitat area for 75% of habitat use units, decreasing area for the rest.
Water Quality	Risk of Water Contamination by Nitrogen (N)	61% of assessed farmland area at risk of having N concentration in excess water near or above drinking water standard; 39% at low risk of water contamination by nitrogen.	**Negative change:** 68% of assessed farmland area showing increase in estimated nitrogen content of excess soil water; 30% showing no change.
Production Intensity	Residual Nitrogen	37% of assessed farmland area > 60 kg N/ha.	**Negative change:** 69% of farmland area showed increase in residual nitrogen of at least 5 kg/ha.
	Energy Use	Energy input in 1992–1996 was 64.5 PJ and energy output was 48.9 PJ.	**Neutral change:** Slight decreases in both energy input (6%) and energy output (10%).
Economic Output	Agricultural GDP	About $ 2.9 billion (constant 1992 $).	**Increase of about 8%.**

Management of agricultural soils has improved overall. Soil residue cover increased, and risks of both water (Fig. 18-4) and tillage erosion dropped. Improvements in soil cover were offset to some extent by increased area under crops that provide less cover, such as soybeans. However, a substantial proportion of Ontario's cropland remains above tolerable levels of water (Fig. 6-2) and tillage erosion. The risk to soil quality has increased significantly related to soil compaction because of an increase in area under compaction-inducing crops (grain corn, root crops, and vegetable crops). Levels of soil organic carbon in 1996 were essentially at equilibrium conditions.

Emissions of greenhouse gases from Ontario agriculture were essentially stable between 1981 and 1996. Energy outputs and inputs decreased only slightly in this period.

Figure 18–5

Change in the level of residual nitrogen on farmland in eastern Canada between 1981 and 1996



The agricultural habitat area available to support most habitat use units declined significantly in the Mixedwood Plains ecozone (southern and southeastern Ontario) due to conversion of pasture area and All Other Land to cropland. Three-quarters of the habitat use units in the Boreal shield ecozone were supported by a constant agricultural habitat area, and one-quarter experienced a decline in habitat, mainly because of reduced pasture area.

Estimated levels of residual nitrogen (Fig. 18-5) and the risk of water contamination by nitrogen increased markedly overall (Fig. 18-6), especially in the southwestern and south-central portions of the province, where crop and livestock production are more intensive. In these areas, the estimated residual nitrogen frequently exceeded 60 kg/ha (Fig. 16-2), and concentrations of nitrogen in excess water from farmland were estimated at near or above the drinking water standard (Fig. 12-2). Far-eastern Ontario is potentially an area of future concern. Although nitrogen concentrations in agricultural water there are generally below the drinking water standard, residual nitrogen levels and the risk of water contamination by nitrogen rose sharply, mainly due to more intensive livestock production and expanding area under crops that require high levels of nitrogen (such as corn). In the more northern agricultural areas of the province, where agriculture is less intensive, levels of residual nitrogen and the risk of water contamination are lower and underwent little change.

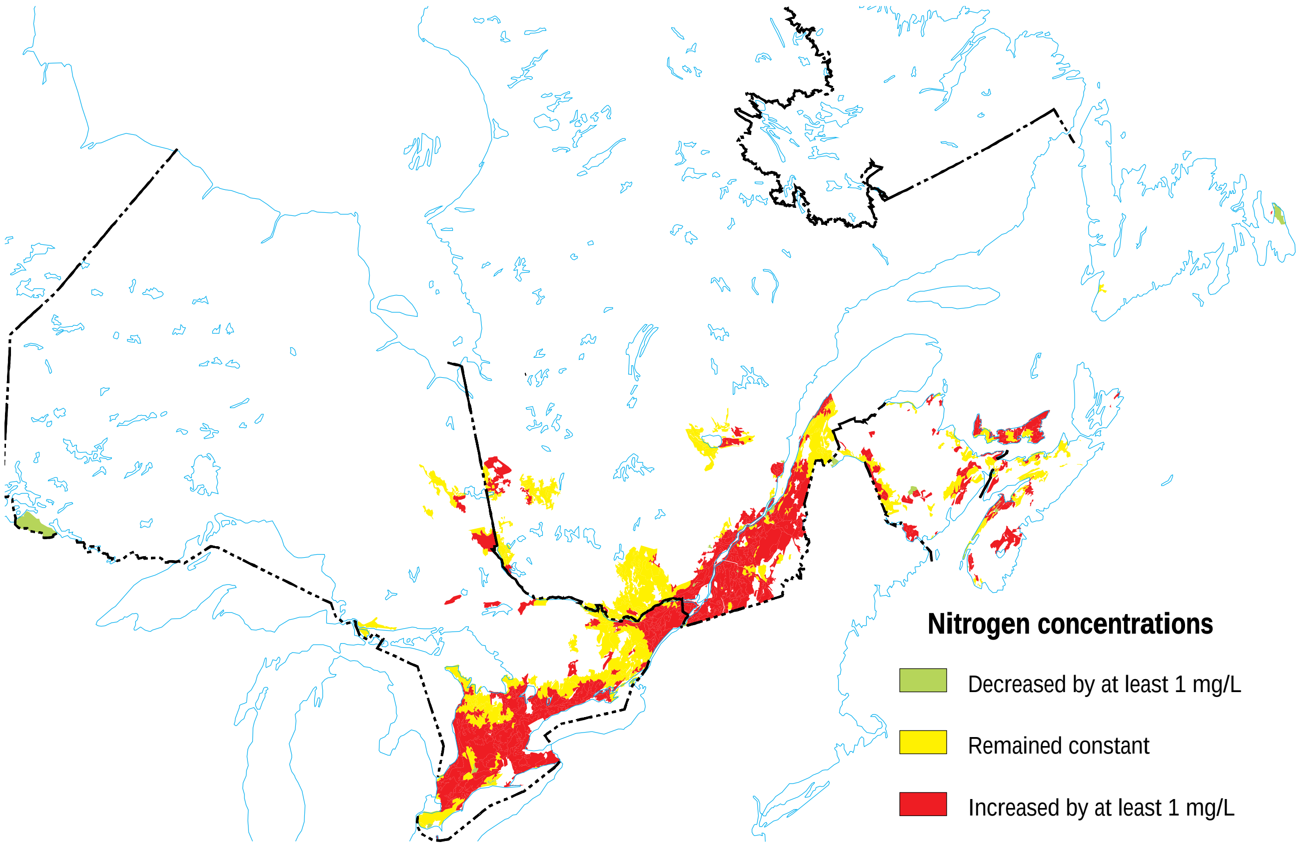
Challenges

The key challenges for Ontario agriculture are to

- improve nutrient management in areas of intensive crop or livestock production. Increases in soil nitrogen levels over much of the region are inconsistent with environmental goals for agriculture, and there is a risk that levels of nitrogen (as well as those of phosphorus, bacteria, and pesticides, which

Figure 18–6

Changes in the nitrogen concentration in excess water on farmland in Central and Atlantic Canada between 1981 and 1996



are not covered by the indicators) in agricultural water will continue to increase as agriculture expands and intensifies

- conserve key on-farm habitats for wildlife (especially remaining farm wetlands and woodlands), particularly in the southern portions of the province where cropland has expanded at the expense of more-valuable habitats on agricultural lands
- build on the progress achieved in soil conservation and target additional conservation efforts at soils that remain at risk
- manage demand for water resources in the southern regions of the province as agriculture increasingly competes for water with other sectors of the economy.

Quebec

In 1996, Quebec accounted for 5.1% of Canada's agricultural land and about 17% of primary agricultural GDP. Most of Quebec's agricultural activity occurs in the St. Lawrence Lowlands in the Mixedwood Plains ecozone. Pockets of agriculture extend into the north-central regions of the province (Boreal Shield ecozone) and eastern areas such as the Eastern Townships and Lower Saint Lawrence–Gaspé regions in the Atlantic Maritime ecozone.

Agriculture in the Quebec portion of the Mixedwood Plains is dominated by feed grains and cash crops (corn, cereals, vegetables), forage crops, and dairy and hog operations. Area under corn has expanded considerably in recent years as new varieties adapted to shorter growing seasons have been developed. Livestock and forage production predominate in the Boreal Shield and Atlantic Maritime ecozones because of the less-favourable soil and climatic conditions.

Table 18-4

Agri-environmental and economic indicators for Quebec agriculture

Issue	Indicator	1996 Status	1981–1996 Change
Land and Soil	Soil Cover	Moderate soil cover (62 bare soil days/hectare).	**No change**
	Water Erosion	88% of cropland at risk of tolerable water erosion.	**No change:** 1% increase in cropland area at risk of unsustainable water erosion.
	Tillage Erosion	75% of cropland at risk of tolerable tillage erosion.	**Positive change:** 10% reduction in risk of tillage erosion.
	Soil Carbon	Slight rates of loss of soil carbon (49 kg/ha/yr).	**Positive change:** 50% reduction in rate of soil carbon loss.
Climate Change	Greenhouse Gas Emissions	Emissions of 8 million tonnes CO_2-equivalent (9% of national agricultural emissions from 5.1% of national farmland).	**Positive change:** 27% reduction in emissions.
Biodiversity	Habitat on Farmland	Habitat use units by ecozone: Mixedwood Plains (3784) Boreal Shield (3262) Atlantic Maritime (2792).	**Negative change** in Mixedwood Plains ecozone: 74% of habitat use units supported by declining habitat area. **No change** in Boreal Shield ecozone: Stable habitat area for 75% of habitat use units; decreasing area for the rest. **Positive change** in Atlantic Maritime ecozone: 74% of habitat use units supported by increasing habitat area.
Water Quality	Risk of Water Contamination by Nitrogen (N)	58% of assessed farmland area at low risk of water contamination by nitrogen; 41% of area at risk of N levels in excess water near or above the standard.	**Negative change:** 77% of assessed farmland area shows increased risk of water contamination by nitrogen; 22% shows no change.
	Risk of Water Contamination by Phosphorus	8% of farmland area (cropland plus pasture) at high risk of water contamination by phosphorus; 73% at medium risk.	**No change:** Increase in area at medium to high risk between 1981 and 1991; return to near 1981 values by 1996.
Production Intensity	Residual Nitrogen	28% of farmland area >60 kg N/ha.	**Negative change:** 71% of farmland area shows increase in residual nitrogen of at least 5 kg/ha.
	Energy Use	Energy input in 1992–1996 was 110.0 PJ and energy output was 20.5 PJ.	**No change:** Slight decrease in energy inputs (1%) and slight increase in energy outputs (2%).
Economic Output	Agricultural GDP	About $ 2.05 billion (constant 1992 $).	**Increase of about 13%.**

Based on the share of farm cash receipts in 1997, which totalled $4.5 billion, the key commodity groups in Quebec's agriculture are red meats (31%), dairy (30.5%), poultry and eggs (12.5%), grains and oilseeds (8.5%), fruits and vegetables (7%), and other commodities (10.5%).

Key environmental and economic trends in Quebec agriculture between 1981 and 1996 are presented in Table 18-4.

Interpretation

Environmental trends for Quebec agriculture between 1981 and 1996 generally resemble those in Ontario, with some important differences in the status of soil resources. Provincial agricultural GDP increased by about 13%. Some environmental indicators showed improvements and some a negative change.

Management of agricultural soils improved slightly. Both soil cover by crops and residue and the risk of water erosion (Fig. 18-4) remained unchanged, and the risk of tillage erosion dropped by about 10%, mainly due to significant reductions in tillage. Overall in 1996, a large share (88%) of Quebec's cropland was in the tolerable risk class for soil erosion by water (Fig. 6-2), and 75% was in this class for tillage erosion. The soil compaction indicator was not calculated for Quebec, although this form of soil degradation is an important concern in that province. Although Quebec's agricultural soils are still losing soil carbon, the rate of loss has been reduced by half since 1981 and is now small.

Agricultural emissions of greenhouse gases in Quebec decreased by one-quarter between 1981 and 1996 as a result of reduced carbon dioxide emissions (from soils) and methane emissions (because of lower numbers of farm animals, except for hogs). Emissions of nitrous oxide were unchanged.

The habitat value of Quebec farmland in the Mixedwood Plains and Boreal Shield ecozones was similar to that described earlier for Ontario (because the indicator applies to all farmland in these ecozones). A small proportion of Quebec's farmland is situated in the Atlantic Maritime ecozone, where about three-quarters of habitat use units were supported by increasing agricultural habitat (Fig. 15-1).

Estimated levels of residual nitrogen and the risk of water contamination by nitrogen increased strongly on 71% and 77% of assessed farmland, respectively, in the areas of more-intensive agriculture (Figs. 18-5 and 18-6). Estimated nitrogen concentrations in excess water from farmland were near or above the drinking water standard in a much smaller area located mainly in the agricultural areas north and south of Montreal, and south of Quebec City (Fig. 12-2). As in Ontario, increases in estimated residual nitrogen and the risk of water contamination by nitrogen result mainly from the intensification of livestock production and the greater area under crops that require higher levels of nitrogen (mainly corn). Increasing levels of residual nitrogen in some areas where nitrogen concentrations in water are currently below the drinking water standard may pose a concern in the future.

Most assessed farmland area was at medium risk of water contamination by phosphorus, and 8% fell in the high risk class. Areas in these risk classes are located mainly in the St. Lawrence Lowlands and the region south of Quebec City, especially in areas of high-density livestock production (Fig. 13-1). The risk grew particularly in the Quebec, Beauce-Appalaches, and Bois-Francs agricultural regions of the province (Fig. 13-2).

Energy inputs and outputs remained virtually unchanged in Quebec agriculture between 1981 and 1996.

Challenges

The key challenges for Quebec agriculture are to

- improve nutrient management in areas of intensive livestock and crop production. Increases in residual soil nitrogen levels over much of the region are inconsistent with environmental goals for agriculture, and levels of nitrogen in water from farmland may continue to increase as agriculture expands and intensifies. Phosphorus levels in soils also require careful management
- conserve key on-farm habitats for wildlife (especially remaining farm wetlands and woodlands), particularly in the Mixedwood Plains ecozone where cropland has expanded at the expense of more valuable agricultural habitats
- ensure that soil conservation measures accompany any further increases in annual row crop production.

Atlantic Provinces

In 1996, the Atlantic Provinces accounted for 1.6% of the farmland in Canada (most of which lies in the Atlantic Maritime ecozone, with a small portion in Newfoundland and Labrador in the Boreal Shield ecozone) and about 4% of primary agricultural GDP.

Close proximity to the Atlantic Ocean creates a cool, moist, maritime climate. The growing season is shorter and cooler than in many other agricultural regions in Canada, and most agricultural activity is dispersed through valleys and coastal plains. Soils tend to be acidic, of variable texture, and associated with strong leaching. Dense subsoils that impede drainage are also common.

Table 18–5

Agri–environmental and economic indicators for agriculture in the Atlantic Provinces

Issue	Indicator	1996 Status	1981–1996 Change
Land and Soil[1]	Soil Cover	Moderate soil cover (65 bare soil days/hectare).	**Positive change:** 14% decrease in bare soil days.
	Water Erosion	40% of cropland at risk of unsustainable water erosion.	**Mixed change:** 12% increase in cropland area at tolerable risk of erosion in N.B.; 3% decrease in area at tolerable risk of erosion in N.S.; no change in P.E.I.
	Tillage Erosion	% of cropland with areas at risk of unsustainable tillage erosion: 62% for N.B.; 34% for N.S.; 51% for P.E.I.	**Positive change:** % reduction in tillage erosion risk: 8% for N.B.; 15% for N.S.; no change for P.E.I.
	Soil Carbon	Slight rate of loss (39 kg/ha/yr) of soil carbon.	**No change**
	Soil Compaction	30 000 hectares of susceptible farmland under compaction-inducing crops (76% of this area in P.E.I.).	**Mixed change:** % change in susceptible areas under compaction-inducing crops: –16% in N.B.; 47% in N.S.; 81% in P.E.I..
Climate Change	Greenhouse Gas Emissions	Emissions of 2.5 million tonnes CO_2-equivalent (3% of national agricultural emissions from 1.6% of national farmland).	**Negative change:** 14% increase in emissions.
Biodiversity	Habitat on Farmland	Habitat use units by ecozone: Atlantic Maritime (2792) Boreal Shield (3262)	**Positive change** in Atlantic Maritime ecozone: 74% of habitat use units supported by increasing habitat area. **No change** in Boreal Shield ecozone: Stable habitat area for 75% of habitat use units; decreasing area for 25% of habitat use units.
Water Quality	Risk of Water Contamination by Nitrogen (N)	82% of assessed farmland at low risk of water contamination by nitrogen; 18% at risk of having nitrogen content of excess water near or above drinking water standard.	**Negative change:** 62% of assessed farmland area shows increase in nitrogen content of excess soil water; 36% shows no change
Production Intensity	Residual Nitrogen	4% of assessed farmland with >60 kg/ha, 52% with negligible (≤20 kg/ha) residual nitrogen.	**Negative change:** 53% of assessed farmland area showed an increase in residual nitrogen of at least 5 kg/ha; 44% showed no change. Some of this may be positive in overcoming soil nutrient depletion, overfertilization may be occurring in other areas.
	Energy Use	Energy input in 1992–1996 was 18.5 PJ, and energy output was 9.0 PJ.	**Positive change:** Decrease (4%) in energy input; 17% increase in energy output.
Economic Output	Agricultural GDP	About $456 million (constant 1992 $).	**Increase of about 1%.**

[1]Results for soil compaction, water erosion, and tillage erosion indicators exclude Newfoundland and Labrador.

Agriculture is mixed, with potato, cereal, and hay production dominating land use. Livestock production is also prevalent. Farm cash receipts in 1997 totalled $999 million, distributed as dairy (22%), red meats (18.5%), poultry and eggs (17.5%), fruits and vegetables (8%), grains and oilseeds (1%), and other commodities (33%). The Atlantic region is Canada's primary source of potatoes.

Key environmental and economic trends in agriculture in the Atlantic Provinces are presented in Table 18-5.

Interpretation

Environmental trends for agriculture in the Atlantic provinces between 1981 and 1996 are mixed. Agricultural GDP increased by 1% overall, with some environmental indicators showing improvements and others a declining trend. Conditions vary considerably by province.

Prince Edward Island recorded stable or negative trends for most indicators of soil health. Soil residue cover increased slightly, the risk of soil erosion by water (Fig. 18-4) and tillage held steady, and there was a strong increase in susceptible area under compaction-inducing crops. Under 1996 conditions, an estimated 41% and 51% of cropland area was above the tolerable level of soil erosion risk by water (Fig. 6-2) and tillage, respectively.

The indicators suggest a need for additional soil conservation efforts in the Atlantic provinces. Area planted to potato crops continues to increase, and the use of reduced tillage methods remains lower than in other regions of Canada. However, the risk of water erosion is likely overestimated in some areas because some conservation measures, such as terracing and grassed waterways, are not included in the calculations. On the other hand, the risk of tillage erosion is likely underestimated because terracing structures are not considered.

Regional greenhouse gas emissions increased by 14% between 1981 and 1996, but account for only a small share (3%) of total Canadian agricultural emissions.

Agricultural land use trends have benefited wildlife overall, with about three-quarters of habitat use units supported by increasing agricultural habitat area in the Atlantic Maritime ecozone and stable habitat conditions on most land in the Boreal Shield ecozone. Improvements result from an increase in the area of All Other Land (Fig. 15-3).

Estimated levels of residual nitrogen remained unchanged on just under one-half of assessed farmland area, the remaining showing an increase of at least 5 kg/ha, including most of Prince Edward Island and parts of New Brunswick and Nova Scotia (Fig. 18-5). Similarly, the estimated concentration of nitrogen in excess water from farmland was well below the drinking water standard on about 80% of the assessed area; however, 62% of this area recorded an increase in the nitrogen content of water by at least 1 mg N/l (Fig. 18-6), indicating possible concerns in the future. Areas with nitrogen concentrations in excess water at or above the drinking water standard in 1996 are shown in Fig. 12-2. Increases result mainly from general increases in fertilizer use and increased area under crops that require higher levels of nitrogen (mainly potatoes) .

Agricultural energy output increased considerably between 1981 and 1996 due to greater output of a wide range of commodities, whereas energy inputs declined slightly.

Challenges

The key challenges for agriculture in the Atlantic Provinces are to

- ensure that soil conservation measures accompany any further increases in annual row crop production, especially of potatoes. Agricultural sustainability on Prince Edward Island is threatened by soil erosion, and efforts to address this concern are needed. Additional soil conservation measures are also required in areas of New Brunswick and Nova Scotia at risk of unsustainable levels of water erosion
- improve nutrient management in areas of intensive livestock and crop production. Within Nova Scotia's Annapolis Valley, estimated concentrations of nitrogen in excess water are greater than the drinking water standard, and increases in nitrogen concentration in excess water have been estimated for many agricultural regions of all three provinces.

Conclusion

Integrated regional analysis of environmental and economic indicators reveals considerable differences in agri-environmental conditions, trends, and farming systems across Canada. Growth in agricultural GDP has been accompanied by

- general improvement in the management of soils
- steady or increasing agricultural habitat available to support most wildlife habitat uses in all ecozones save for the Pacific Maritime and Mixedwood Plains
- increased environmental costs related to increases in residual nitrogen, greenhouse gas emissions, and risk of water contamination by nitrogen.

No major agricultural region of the country is without some indicators showing negative trends.

The prairie region is a semi-arid area largely characterized by extensive crop production (cultivation of cereals, oilseeds, and pasture) and both extensive and intensive livestock production. Together the indicators suggest that considerable progress toward environmental sustainability has been achieved in this region. Reductions in tillage, summerfallow, and use of marginal land have led to gains in soil conservation and soil quality. Changes in land use have also benefited wildlife overall. However, emissions of greenhouse gases have risen, some soils remain at risk of degradation, and water quality may be at risk locally because of greater use of fertilizers and more-intensive animal production. Further intensification of crop and livestock production will increase the environmental risks unless steps are taken to manage such risks.

Climatic, geographic, and agricultural conditions are markedly different in the other (non-prairie) agricultural regions of Canada, where more-favourable climates permit more-intensive forms of agriculture. These regions are characterized by the cultivation of more-valuable crops (such as corn, potatoes, vegetables, and soybeans), and higher levels of inputs. Dairy, hog, poultry, and beef operations are also prevalent. This more-intensive form of agriculture in an environment where water supplies are abundant increases the potential for agriculture to have adverse environmental effects.

The indicators suggest that in south and central British Columbia, Ontario, Quebec, and the Maritimes, improvements in conserving soils have been realized, although work remains to be done. Land use changes in parts of British Columbia and central Canada have adversely affected wildlife habitat. Negative trends are evident in estimated residual nitrogen concentrations and in the risk of water contamination from nitrogen in most humid regions of the country.

19 Conclusions

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Highlights

- Canadian agriculture has made considerable progress in conserving the natural resource base that supports production, although some soils remain at risk of unsustainable levels of degradation. Factors that have contributed to improvements include investments in research and the development and use of new, economically viable farming technologies and soil conservation practices.

- With regard to agriculture's compatibility with natural systems, performance is mixed. In some areas, several environmental risks have increased, and environmental conditions have worsened. The main factor responsible has been an intensification of agriculture across much of the country resulting from structural changes in farming and increased market demand for some products.

- The findings of this study suggest a need for ongoing efforts by policy makers, producers, researchers, analysts, educators, and the public to achieve a more environmentally sustainable agriculture industry. Ways in which agri-environmental indicators can be used to support actions are identified and discussed.

- The agri-environmental indicator study identified key limitations in the national capacity to assess the environmental sustainability of agriculture. To enhance our analytical capacity, additional research is needed to further understand agriculture–environment interactions and processes, and to address data limitations and gaps.

Introduction

Canadian agriculture is diverse and highly managed, and makes a significant contribution to our nation. Historically, agriculture helped settle the country and it continues to provide abundant, affordable food for Canadians, as well as benefits related to economic and rural development. However, the sector has not been immune to developments elsewhere in society and is increasingly driven by forces over which it has little control.

Prominent among these forces are technological changes, changes in markets and commodity prices, and the need to enhance productivity and competitiveness. These changes have led to structural changes on farms, such as more concentrated and intensive production. Questions and concerns about the environmental implications of agriculture have arisen as a result. In this chapter, we provide an overview of the main findings and conclusions that emerge from this report, along with their implications.

Environmental sustainability of agriculture

Chapter 2 of this report introduced two criteria against which to judge the environmental sustainability of agriculture:

- how well agriculture conserves natural resources that support agricultural production
- how compatible agricultural systems are with natural systems and processes.

Table 19-1 provides an overview of key conclusions about the environmental sustainability of agriculture by section or chapter of this report.

With regard to natural resource conservation, the indicators point to a continuation of the trends first reported in Agriculture and Agri-Food Canada's 1995 report *The Health of Our Soils—Toward Sustainable Agriculture in Canada*. Substantial and continued progress is evident, as soil management has improved overall and most soil degradation risks have been reduced.

It is evident that Canadian agriculture has responded positively to concerns raised in the 1980s about declining soil quality. For example,

- governments have invested in soil research and extension services
- programs have been established that have removed some marginal lands from annual crop production
- producers have formed voluntary associations to promote soil conservation
- new, economically viable technologies (such as no-till seeders and improved land management practices) have been developed and used to better manage soil resources.

However, soil conservation must remain an important part of the sector's overall efforts to address environmental challenges. Progress has been uneven across the country, and soils in most areas of intensive agriculture remain at unsustainable levels of degradation risk. Intensification of cropping has offset gains realized from the adoption of conservation practices in some areas.

With regard to agriculture's compatibility with natural systems, performance is mixed. Environmental risks have increased in some areas, and environmental conditions have sometimes worsened. The main factor responsible has been an intensification of agricultural production in many regions where climatic, agronomic, and economic conditions have permitted it. These changes have resulted in increased inputs of nitrogen and other nutrients per unit of land area, leading in turn to greater risk of declining water quality and growth in emissions of greenhouse gases.

Changes in land use since 1981 have increased the area of the most valuable wildlife habitats on Canada's agricultural land, except in southwestern British Columbia, southern Ontario, and southern Quebec. Here, habitat availability has declined mainly because of regional reductions in the area of agricultural land and the expansion of cropland at the expense of more-valuable agricultural wildlife habitats.

On balance, risks to the environment from agriculture have been reduced in some areas and have grown in others. The implications of these findings for decision makers are discussed later in this chapter.

Table 19–1

Key findings for agriculture's environmental performance

Chapter or Section	**Findings** (1981–1996, except where noted otherwise)
Driving forces	Globalization and changes in technology, population growth, and market demand have often intensified agricultural production, sometimes with environmental consequences. At the same time, social preferences have evolved to demand a more environmentally sound agriculture. Potential environmental risks will continue to increase as intensification continues, requiring management responses from industry, governments, and consumers.
Farm management	Management of agricultural soils has improved overall. Overall, sound fertilizer and pest management practices are in use, although there is room for improvement. Manure is the nutrient source most needing improved management (above based on 1995 data only).
Soil quality	Soil degradation risks have been reduced overall. Additional effort is required to conserve soils remaining at risk of unsustainable levels of degradation.
Water quality	The risk of water contamination from nitrogen has increased overall in most humid areas (the risks were not assessed on the Prairies, but these have likely increased due to intensive livestock operations).
Greenhouse gas emissions	There was a small overall increase in emissions, with most increases occurring from 1991 to 1996. Carbon dioxide emissions decreased, nitrous oxide emissions increased, and methane emissions remained stable.
Agricultural wildlife habitat	Agricultural lands are used extensively by wildlife for their habitat needs. Most habitat uses were supported by an increasing agricultural habitat area, except in southwestern B.C. and southern Quebec and Ontario, where most habitat uses were supported by a shrinking agricultural habitat area.
Production intensity	Levels of residual nitrogen per hectare increased in all agricultural regions except B.C. (where some regional increases were evident). Increases on the Prairies are beneficial to soils in production systems with a net nitrogen deficit. Relative gains were realized nationally and on the prairies, as growth in agricultural energy output exceeded growth in agricultural energy input. In the non-prairie region, overall energy inputs increased, whereas overall energy outputs dropped.

National capacity for environmental analysis of agriculture

This study has made extensive use of available data, expertise, research capacity, and models. In doing so, we have learned much about our national capacity to do environmental analysis in agriculture. The findings, summarized below, have implications for biophysical and economic research, as well as future efforts to collect indicator data.

The usefulness and application of the indicators is limited to broad-scale assessments, as the national scope of this study has required the aggregation of data over large areas. This treatment has resulted in the loss of information about point sources of pollution (such as poorly managed intensive livestock operations), which are important to the overall picture of how agriculture is performing with respect to the environment.

Most indicator results are subject to some level of uncertainty, mainly because of an imperfect understanding of ecosystem processes and agriculture–environment relationships, but also because of limitations in data. This uncertainty is greater for topics for which research is relatively new, such as that on nitrous oxide emissions from soils.

Through this study we have pushed the limits of available data. Limitations are evident regarding the

- spatial detail, locational accuracy, and coverage of census, soil, and other data
- difficulty in assigning an economic value to agri-environmental assets and services
- infrequent assessments because of the 5-year cycle of the *Census of Agriculture*
- incompleteness or lack of data for the following key areas: species abundance and diversity in agricultural areas; amount and location of critical agricultural habitats (such as wetlands and woodlands); farm management of water, nutrients, and pesticides; concentrations of agricultural contaminants in water; and quantities of pesticide inputs used in agriculture.

The factors listed above have also affected the scope of issues covered in this study. Areas not covered or only partially covered include the assessment of

- water quality, which in this report does not examine the risks related to intensive livestock operations, agriculture in the semi-arid agricultural areas, and contamination by sediment, pesticides, pathogens, and phosphorus (for provinces other than Quebec)
- water management, such as irrigation efficiency
- regional environmental risks from agricultural pesticide use, such as risks to ecosystem health and biodiversity
- aspects of biodiversity other than agricultural wildlife habitats, such as species and genetic diversity in agriculture.

Neither does this report express indicator results in economic terms, which would facilitate comparison of environmental changes with changes in other aspects of agriculture, such as the value of production.

In summary, to improve the accuracy and scope of our capacity to assess the environmental sustainability of agriculture, additional work is needed to further understand agriculture–environment interactions and processes, and to address data limitations and gaps.

Using agri-environmental indicators for environmentally sustainable agriculture

This report presents information on agriculture's relationship with the environment. The results have implications for all people and agencies concerned with the health of both the environment and Canada's agricultural industry, including government policy makers and analysts, farmers and farm leaders, researchers, educators, and the broader public. Below, we review and comment on how agri-environmental indicators can be used by these groups as a guide to promote environmentally sustainable agriculture.

Policy makers

Agricultural policy makers today face an important challenge—achieving an optimal balance among social, economic, and environmental goals in order to maximize the net social benefits from agriculture. Agricultural production policies must be assessed not only for their economic and social impacts, but also for their environmental implications. Policy development and reform are already moving in this direction, and this thrust must continue.

Agri-environmental indicators can be used to

- help quantify the linkages between the economic and environmental effects of existing and proposed policies
- provide important feedback on whether environmental conditions warrant adjustments in existing policies or new policy initiatives
- inform policy makers about environmental scenarios or outcomes that may result from expected or potential developments in markets, policies, technologies, and other factors (*see* Box).

A key policy challenge concerns the signals coming from the economic framework within which agriculture operates. To the extent that environmental inputs (such as water) or environmentally sensitive inputs (such as fertilizers) used in agriculture are underpriced, inefficient levels of use and environmental impact may result. Similarly, the market generally rewards farmers only for the economic

Environmental forecasting: a new tool for policy design

The driving forces shaping today's world will also influence societal outcomes in the future. Although the future cannot be predicted with certainty, scenarios can be developed using assumptions about how current and alternative factors might affect the future. If policy makers possessed information on possible outcomes, they would be better placed to take actions today to avoid adverse outcomes and thus ensure a more sustainable future. For example, economists regularly issue forecasts about the future state of the economy. In response, economic policy levers, such as the interest rate, are manipulated in an attempt to shape future economic conditions.

In general, policy makers have not had the benefit of forward-looking environmental information to guide policy design. This situation is beginning to change as more sophisticated analytical tools and models, such as environmental indicators, are brought into use. The need for such information is growing as environmental policy goals are set into the future. One example of such goals is the greenhouse gas reduction targets agreed to by countries through the Kyoto Protocol.

If an environmental indicator is sensitive to economic and social factors, such information can be used to project possible directions of the indicator in the future. Many of the agri-environmental indicators included in this report have been designed with this in mind and are beginning to be used in this way. The Agricultural Greenhouse Gas Budget indicator reported in Chapter 14 provides one example. This indicator was constructed using information about animal populations, crop production, management practices, fertilizer and fossil fuel use, and other agricultural factors that influence net emissions. To determine how agricultural emissions might evolve in the future, this indicator was projected to 2010 using data from Agriculture and Agri-Food Canada's Medium Term Baseline (which predicts future levels of agricultural prices and output). The potential to reduce emissions was estimated based on the adoption of farming practices that affect emissions, such as use of forages, livestock feeding strategies, levels of tillage, grazing strategies, fertilizer use, manure handling systems, use of summerfallow, and agro-forestry.

Selected results of this work are presented below. Under the Kyoto Protocol, Canada has committed to reducing its emissions average over the 2008–2012 period to 6% below the 1990 level. To achieve this goal:

- Agricultural emissions would have to decrease by about 17% below the emission levels projected to 2010 for a business-as-usual scenario, based on how greenhouse gases are currently counted (an 8% reduction would be required if soil carbon sinks are included).
- Agricultural emissions would have to decrease by about 30% below the emissions levels projected for a high export–growth scenario for agriculture (another sectoral objective), without soil sinks.
- Increasing area under no-till to 50% of prairie cropland, reducing summerfallow from 5 to 3 million hectares, improving management of grazing land, and planting additional shelterbelts would come close to meeting the Kyoto requirement, but only if carbon sequestration in soils, currently excluded from the Kyoto Protocol, is counted internationally. If soil carbon sinks remain outside of the Protocol, the measures described above would actually lead to a small increase in emissions associated with the business-as-usual scenario.

This type of information is being used to help identify which strategies would be most effective in reducing emissions from agriculture. This effort is part of a larger national process underway to devise strategies through which Canada can meet its Kyoto commitment.

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commodities they produce. They have less economic incentive to provide public (non-market) goods and services, including environmental services such as wildlife habitat, potentially leading to an undersupply. Until prices are more closely aligned with true costs, and markets and incentives are created that encourage the optimal provision of environmental goods and services by agriculture, environmental problems will likely persist.

It is encouraging to see that over the past 15 years a variety of policy responses have been put into place to improve agriculture's environmental performance, from the local to the international levels. The challenge is to select and apply the most effective combination of instruments to achieve desired outcomes in agriculture. The indicators suggest that the environmental risks inherent to agricultural production will increase as output expands. Agricultural and environmental policy must be flexible and forward-looking, so that producers are provided with the tools, information, and incentives they need to bring environmental considerations into their farm operations.

Farmers and farm leaders

Farmers have a large stake in the environmental health of their industry. Environmentally sound farm practices can contribute to agriculture's economic health and a healthy rural environment. The sector has made considerable progress in raising awareness about the environmental aspects of agriculture among the farm population and in adopting new processes, methods, and tools that enhance both productivity and environmental management on farms.

Although the indicators presented are not reported at the farm level, they do have implications for how farmers manage their operations. The nature of the specific practices and risks on farms varies by location and type of farm operation, but overall, the indicators suggest that improvements are required in the areas of

- management of manure and other farm inputs
- efficiency of nutrient use
- protection of water quality
- conservation of wildlife habitat on farms
- control of greenhouse gas emissions
- maintenance of soil quality.

At the farm level, indicators can also be used to consider multiple aspects of environmental farm management and to help with on-farm environmental assessments. A promising development is the move toward whole-farm management, supported by environmental farm plans and farm conservation clubs. Whole-farm management provides an opportunity for farmers to view and manage their operations not only as food production systems, but also as systems that require careful management of environmental inputs and produce environmental benefits to society, such as a pleasing landscape and wildlife habitat.

Farmers and farm leaders can use the indicators to further increase awareness about industry's environmental achievements, as well as about challenges that remain. The indicators can also facilitate and inform discussions among industry, governments, and the public about agri-environmental issues. More complete coverage of issues would improve the indicators' usefulness for such purposes.

The industry is also increasingly active in both delivering environmental programs and funding environmental research in agriculture. Indicators can be used to identify priority issues requiring attention and to strategically target programs and other initiatives at areas and resources at greatest environmental risk.

Researchers and analysts

The research and analytical community has a key role to play in helping agriculture to become more environmentally sustainable. Agri-environmental indicators could be useful in

- establishing priorities for research
- identifying knowledge gaps about agro-ecosystem processes
- pointing to areas for which new data are required to refine model output, or validation of existing process models is needed
- serving as technology transfer tools to advise policy makers and farmers.

The challenges facing agricultural research and the directions that are needed are summarized in four general areas:

1. To make agriculture increasingly productive and efficient in resource use, which includes
    - research to increase production efficiencies and enhance nutrient use efficiency for plants; to improve plant resistance to climatic stress, disease, and insects; and to boost livestock productivity
    - the design of implements to allow the use of reduced tillage operations for a wider range of crops and to increase the efficiency of cultivation, seeding, and harvesting operations and the precision of nutrient applications
    - the placement of these new tools within new farm production systems (e.g., new crop rotations, crop uses, and interfaces with animal production systems and the surrounding environment)

- the design of flexibility into farm production systems, along with the ability to deal with growing variability in weather conditions and longer-term climatic changes in order to lessen the risk of reduced yields and the uncertainty of economic return for farmers.

2. To better control biological processes internally within agricultural ecosystems (e.g., through the use of bio-controls) to reduce reliance on external non-biological inputs, through
    - continued research on better ways to manage pests that will ultimately reduce, and in some cases eliminate, the use of pesticides in many crops
    - additional research into pest thresholds, integrated pest management (IPM) technology, and new chemistry to replace some of the older, less IPM-compatible pesticide products.

3. To better close nutrient cycles within agricultural ecosystems and thus curb nutrient leakage to the surrounding environment and the resulting pollution, through
    - engineering and management research into such things as better systems to handle and store manure, enable animals to better utilize feed, and reduce methane production by farm animals
    - options to reduce on-farm fossil fuel energy consumption and resultant atmospheric emissions of carbon dioxide
    - development and transfer of tools and information for precise and timely application of plant nutrients (principally nitrogen and phosphorus) to farmland to reduce losses to the surrounding environment.

4. To provide timely, relevant, and readily accessible information to support and evaluate environmental decisions by stakeholders and policy makers, by
    - generating accessible, reliable, timely, and relevant information about agricultural interactions with the environment
    - improving risk assessment of new technologies and practices, so that their environmental benefits and costs are understood and considered
    - within governments, maintaining the capacity to develop and improve indicators of environmental sustainability for agriculture, as well as to address the analytical limitations and data gaps identified earlier in this chapter.

The public

The public has an interest in environmentally sound production methods which contribute to food safety, reduce the environmental impacts of agriculture felt beyond the farm gate, and provide environmental benefits to society.

Agri-environmental indicators provide a general report card that can help interested individuals

- track the environmental performance of Canadian agriculture
- become better informed about the opportunities and constraints facing producers
- support public programs (such as agricultural research and conservation programs) that promote environmentally sustainable agriculture
- support agriculture's efforts to improve the environment by purchasing environmental outputs produced by agriculture where markets exist (e.g., by participating in agrotourism)
- make informed food-purchasing decisions
- identify areas where they might apply public pressure to motivate further improvements.

Educators can use the indicators as tools to better inform agricultural students and tomorrow's farmers about interactions between agriculture and the environment.

The future

Trade-offs may sometimes exist in the short term between environmental, social, and economic goals in agriculture. However, over the longer term sound environmental and resource management is fully compatible with other objectives of sustainable agriculture.

Environmental improvement in agriculture is a continuous process best achieved through collaboration and partnerships among all parties directly or indirectly involved. It is our hope that the information presented in this report contributes to the understanding and dialogue that must underpin such cooperative work in the future.

Glossary

Agri-environmental indicator Measure of a key environmental condition, risk, or change resulting from agriculture, or of management practices used by producers.

Agroecosystem Ecosystem under agricultural management; an open, dynamic system connected to other ecosystems through the transfer of energy and materials.

Agrotourism Tourism related to the enjoyment of agricultural land; a type of **ecotourism**.

All Other Land *Census of Agriculture* category of agricultural land use denoting land occupied by farm buildings, barnyards, gardens, greenhouses, mushroom houses, idle land, woodlots, sugar bushes, tree windbreaks, bogs, marshes, sloughs, etc.

Anaerobic Without oxygen or at a low concentration of oxygen.

Anhydrous ammonia Liquid form of mineral nitrogen fertilizer.

Banding Method by which dry mineral fertilizer is applied in a band along a seeded row in cropland, as opposed to **broadcast** application.

Bare-soil day Day or day equivalent (e.g., two half-days) when soil is not covered by crop canopy or residue and is thus exposed to the elements.

Biodiversity *See* **biological diversity**.

Biological diversity (*also* **biodiversity**) Variety of species and ecosystems on the earth and the ecological processes of which they are part; includes three components: ecosystem diversity, species diversity, and genetic diversity.

Biomass Total mass of a species or group of species per unit of space or of all the species in a community.

Biophysical Pertaining to the biological and physical features of an environment.

Biotechnology Within agriculture, refers to the science and methods of genetic engineering to produce new varieties of crops or livestock with superior features.

Black soils Grassland soil type occurring on the Canadian Prairies, characterized by a very dark surface, a brownish B horizon, and usually a calcareous C horizon.

Broadcast Method of fertilizer application by which fertilizer is regularly scattered on the soil surface.

Brown soils Grassland soil type occurring on the semi-arid Canadian prairies, characterized by a brown surface, lighter brown B horizon, and usually a calcareous C horizon.

Bulk density Mass of dry soil per unit of bulk volume before drying to a constant mass.

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.

Carbon dioxide equivalent 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 sequestration Biochemical process by which atmospheric carbon is absorbed by living organisms, including trees, soil microrganisms, and crops; storage of carbon in soil, with the potential to reduce atmospheric carbon dioxide levels.

Catch crop Usually a lower-value crop that is planted either between rows of a main crop or in the fall after the main higher-value crop has been harvested, to take up excess nutrients, such as nitrogen, from the soil.

Census of Agriculture National agriculture census that records information on farm structure and economics, crops and land use, and livestock; taken every 5 years.

Cereal Relating to grain or the plants that produce grain, such as wheat, barley, rye, and oats.

Chem-fallow Control of weeds on summerfallow land using herbicides instead of tillage.

Climate change All of the changes that global climate may undergo as a result of the **enhanced greenhouse effect**, including **global warming** and changes in the amount and pattern of precipitation.

Compost Organic residues, often with soil added, that have been piled, mixed, moistened, and allowed to decompose; used as a soil amendment.

Compaction Natural or human process by which soil is compressed, resulting in greater bulk density.

Conservation tillage Any tillage sequence the object of which is to minimize or reduce loss of soil and water; operationally, a tillage or tillage-and-planting combination that leaves a 30% or greater cover of crop residue on the surface.

Contour cultivation Cultivation with the contour of the land, rather than up- and downslope.

Conventional tillage Primary and secondary tillage operations normally performed in preparing a seedbed, usually resulting in less than 30% cover of crop residues on the soil surface after completion of the tillage sequence.

Critical habitat Habitat that is essential for the maintenance and long term survival of a wildlife species.

Crop diversification Expansion of the variety of crops grown to improve farm economics.

Crop residue Plant material remaining after harvesting, including leaves, stalks, roots.

Cropland *Census of Agriculture* category of agricultural land use denoting the total area on which field crops, fruits, vegetables, nursery products, and sod are grown.

Dark Brown soils Grassland soil type occurring on the Canadian prairies, characterized by a dark brown surface, a lighter brownish B horizon, and usually a calcareous C horizon.

Dark Gray soils Transitional soil of the parkland zone on the Canadian prairies, characterized by a dark gray surface, a brownish B horizon, and usually a calcareous C horizon.

Deep ripping (*also* **subsoiling**) Primary tillage operation that manipulates soil to a greater depth than normal plowing; accomplished with a heavy-duty chisel plow that shatters soil.

Degree of soil phosphorus saturation Percentage of the potential phosphorus retention sites on soil particles already occupied by phosphorus.

Direct seeding Seeding directly into the undisturbed soil surface, without tilling the soil first.

Driving force Societal influences (e.g., market signals, government policy, production technologies) or farming factors (e.g., production strategies, production practices, inputs, practices) that shape the environmental effects of agriculture.

Driving Force–Outcome–Response Framework Conceptual framework for assessing environmental sustainability that identifies driving forces that influence agricultural activities, outcomes of these activities, and responses by society to shape and ensure desirable outcomes.

Ecodistrict Detailed mapping unit in Canada’s ecological classification system, two or more of which comprise an ecoregion.

Eco-efficiency A process where more abundant or valuable products or services are produced using relatively fewer material and energy inputs, in turn minimizing losses to the environment and reducing pollution.

Ecoregion Mapping unit in Canada’s ecological classification system, two or more of which comprise an ecozone.

Ecotourism Type of tourism promoting the natural environment and its ecological features.

Ecozone Largest mapping unit in Canada's ecological classification system; agriculture is carried out in seven of Canada's 15 ecozones.

Empirical Based on observational (qualitative) or experimental (quantitative) data.

Energy input Non-renewable energy (i.e., not including sunlight) that is put into agricultural systems, for example to power vehicles and farm machinery, manufacture equipment and chemicals (e.g., fertilizer, pesticides), and run farm homes.

Energy output Energy embodied in the products of agriculture that are used or consumed by humans.

Enhanced greenhouse effect Effect of the build-up of greenhouse gases in the atmosphere, resulting in more of the earth's radiations being trapped and potentially leading to **global warming**.

Environmental farm plan Plan outlining environmental concerns on an individual farm, as well as steps to address these concerns; voluntarily prepared and carried out by the farmer.

Environmentally sustainable agriculture Agriculture that can be carried on indefinitely without significantly harming the environment.

Evapotranspiration Movement of water into the atmosphere by evaporation from the soil and transpiration from plants.

Farm conservation club Voluntary association of farmers with a shared interest in improving environmental management on their farms.

Forage Grass or legume crop harvested to feed to livestock; may be stored dry as hay or under moist conditions as silage, or plowed into the soil as **green manure**.

Genetic engineering Manipulation of the genetic material of an organism to produce desired traits.

Global warming Predicted rise in global temperatures under elevated levels of atmospheric greenhouse gases.

Global warming potential Measure of the ability of a greenhouse gas to trap radiation and thus contribute to **global warming**.

Grassed waterway Grassed strip of land that serves as a channel for surface runoff; a method of controlling erosion.

Gray soils Luvisolic soils, characterized by a light-coloured surface, a brownish B horizon, and usually a calcareous C horizon.

Green manure Any plant material plowed into the soil while it is still green to serve as a natural fertilizer.

Groundwater Subsurface water, the upper surface of which forms the water table in geological materials such as soils, sand and gravel formations, and bedrock formations.

Guild Set of species that share a common habitat, use the same resources, or use resources in the same manner, thus having similar ecological niches or lifeforms.

Habitat availability How accessible and useable a habitat is to a species, depending on factors such as the abundance of the habitat type within the species' range; current level of occupancy; landscape patchiness; seasonal changes in species' needs; and occurrence of competitors, predators, and disease.

Habitat availability matrix Chart that relates habitat type found on agricultural land to habitat use by a wildlife species.

Habitat quality Fitness of a habitat to provide for the needs of a species.

Habitat use unit Each separate use of a habitat type by a species.

Inherent erodibility A soil's natural tendency to erode because of its physical nature or the landscape condition, such as slope, on which it occurs.

Injection Method by which liquid or gaseous fertilizer is injected through tubes below the soil surface; typically used to apply liquid manure and anhydrous ammonia.

Input Something put into, or added to, a farming system, such as energy, pesticides, or nutrients.

Input productivity Incremental yield or economic return in response to system inputs.

Integrated pest management Control of pests using a combination of techniques such as crop rotations, cultivation, and biological and chemical pest controls.

Intensive livestock production Concentrated production of a large number of animals on a small land base, usually including specialized structures for housing, feeding, and rearing animals.

Interseeding *See* **intercropping**.

Intensive row cropping Crop production method with high levels of inputs (e.g., fuel, fertilizer, labour) and thus usually associated with high levels of production per unit of area; applies to crops grown in widely spaced rows that may be cultivated between the rows for weed control, are hilled, or both, including potatoes, tobacco, vegetables, beans (white, green, pinto, etc.), sugar beets, and corn.

Intercropping (*also* **interseeding)** Seeding a secondary crop along with the primary crop to provide enhanced soil cover, nutrients, pest control, or other production benefits.

Kilotonne One thousand tonnes, or one million kilograms (about 2.2 million pounds).

Landscape erodibility Degree to which a landscape can be eroded because of its natural features, such as soil and topographic conditions; term is also applied to erosion by tillage, through the process of **tillage erosion**.

Megatonne One million tonnes, or one billion kilograms (about 2.2 billion pounds).

Mineral fertilizer Commercial formulation of crop nutrients, such as nitrogen, phosphorus, and potassium, in an inorganic form, including ammonium phosphate, potassium chloride, and calcium nitrate.

Mineralization In biological systems, the release of nutrients through the decomposition of organic matter; often used to describe the microbial conversion of organically bound nutrients into ionic forms suitable for plant uptake.

Native ecosystem Ecosystem in its natural state, unaltered by human activity.

Native vegetation Community of plants in native ecosystems.

Natural Land for Pasture *Census of Agriculture* category of agricultural land use denoting uncleared or uncultivated land used for pasture.

Nitrate Soluble form of nitrogen that is a common source of nitrogen for plants; naturally present in groundwater and surface water but sometimes elevated to pollution levels by agricultural activity.

Nitrogen Key crop nutrient and water pollutant in soluble forms such as **nitrate**; also forms **nitrous oxide**.

Nitrous oxide Potent greenhouse gas.

No-till system (*also* **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; sometimes practised in combination with **subsoiling** to facilitate seeding and early root growth, leaving the surface residue virtually undisturbed except for a small slot in the path of the shank of the subsoiler.

Nutrient Substance required by an organism for proper growth and development; key crop nutrients are nitrogen, phosphorus, and potassium.

Oilseed Crop from whose seeds oil is produced (e.g., canola, flax, sunflower).

Pedotransfer function Equation used to estimate the value of one soil property based on the values of other related properties (e.g., soil bulk density can be estimated if the soil texture and organic carbon content are known).

Pesticide Chemical that kills or controls pests; includes herbicide, insecticide, fungicide, nematocide, rodenticide, and miticide.

Pheromone Biochemical substance produced by an organism to stimulate a behavioural or physiological response by an individual of the same species.

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.

Phosphorus Key crop nutrient and potential water pollutant, especially of surface waters.

Plow pan Compacted zone of soil 20 to 40 cm below the surface that sometimes develops immediately below the plow layer in cultivated soil.

Polygon Irregularly shaped delineation on a map; used in the context of mapping units in the *Soil Landscapes of Canada* map series, superimposed on *Census of Agriculture* enumeration area maps to align physical data on soils and landscapes with information on agricultural management practices.

Potassium Key crop nutrient.

Precision farming Farm management at a level that allows inputs to be tailored to variable conditions across short distances in a single field.

Pulse Legumes that provide edible seeds, such as beans, peas, and lentils.

Residency time Time that a component is present in a system (e.g., the time a greenhouse gas is present in the atmosphere).

Residue anchoring Mechanically fixing straw or other plant residues in an upright or partially upright position in the field after harvest to protect the soil.

Residue management Keeping a certain portion of crop residue on the soil surface to help prevent soil degradation; associated with **conservation tillage**.

Respiration In plants, the function of giving off oxygen as a by-product of photosynthesis.

Riparian Related to the land bordering a stream or other body of water.

Risk indicator Indicator that estimates the potential for some form of resource degradation by considering relevant contributing factors

Rotational grazing Livestock management involving the movement of animals from one pasture to another in a systematic way.

Row crop *See* **intensive row cropping**.

Runoff Water running over the soil surface as a result of precipitation or snowmelt.

Saline Containing salts.

Salinization Process by which soil becomes more **saline**.

Sedimentation Deposition of eroded soil in surface waters such as streams and lakes.

Soil cover Vegetation, including crops, and crop residues on the surface of the soil.

Soil degradation Process(es) by which soil declines in quality and is thus made less fit for a specific purpose, such as crop production.

Soil Landscapes of Canada 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 quality Fitness of a soil to support an intended use, such as crop growth.

Soil structure Physical properties of a soil relating to the arrangement and stability of soil particles and pores.

Soil test Analysis of a soil sample to measure key properties in crop production, such as pH, nutrient levels, and organic carbon content.

Soil test phosphorus Amount of phosphorus extracted by a common laboratory procedure for the purpose of making fertilizer recommendations.

Staging Birds congregating to rest, usually during migration.

State indicator Indicator that expresses an actual resource condition, usually based on direct field measurements.

Straw mulching Covering soil with a layer of straw to prevent erosion.

Subsoiling (*also* **deep ripping**) Breaking up of compact subsoils without inverting them, using a special knife-like plough that is pulled through the soil usually at depths of 30 to 60 cm and spacings of 60 to 150 cm; used to improve water movement and root penetration.

Summerfallow *Census of Agriculture* category of agricultural land use and general term denoting cropland that is not cropped for at least 1 year but is managed by cultivating or spraying.

Sustainable agriculture Form of agriculture that can be practised indefinitely in a manner that is consistent with social, economic and environmental goals.

Tame or Seeded 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.

Terracing Steplike surface that breaks the continuity of a slope.

Teragram One billion kilograms.

Tillage erosion Soil erosion caused by tillage implements and aided by gravity.

Tillage erosivity Propensity of a tillage operation, or a sequence of operations, to erode soil through the process of tillage erosion; a function of the design and operation of the tillage implement and the suitability of the tractor–implement match.

Tolerable risk Level of resource degradation that does not exceed the rate of natural restorative processes or is acceptable and sustainable because of factors that mitigate this risk; a level of risk that society accepts.

Trade liberalization Process whereby trade in goods and services among nations is enhanced through more-open markets and the reduction or elimination of trade barriers such as tariffs.

Turbidity Measure of water clarity; degree to which water is cloudy because of suspended sediments.

Volatilization Change to gaseous form.

Water deficit Insufficient supply of soil water for crop production.

Water surplus More soil water than is needed for crop production.

Wetlands Areas of land inundated by surface water or groundwater; under the Canadian Wetland Classification System, denoted in five classes: bogs, fens, marshes, swamps, open waters.

Wildlife habitat Parts of an environment on which an organism depends to carry out its life processes.

Wind erosion Removal of surface soil by wind.

Winter cover crop Crop grown during the winter months to curb soil erosion by winter rains and snowmelt.

Zero tillage *See* **no-till system**.

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