Trends in residual soil nitrogen for agricultural land in Canada, 1981-2006

C.F. Drury, J.Y. Yang and R. De Jong[1]

Canadian Biodiversity: Ecosystem Status and Trends 2010
Technical Thematic Report No. 15
Published by the Canadian Councils of Resource Ministers

[1] All authors are with Agriculture and Agri-Food Canada

Library and Archives Canada Cataloguing in Publication

Trends in residual soil nitrogen for agricultural land in Canada, 1981-2006.

Issued also in French under title:
Tendances de l'azote résiduel dans le sol pour les terres agricoles du Canada, de 1981 à 2006.
Electronic monograph in PDF format.
ISBN 978-1-100-19925-2
Cat. no.: En14-43/15-2011E-PDF

This report should be cited as:
Drury, C.F., Yang, J.Y. and De Jong, R. 2011. Trends in residual soil nitrogen for agricultural land in Canada, 1981-2006. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No. 15. Canadian Councils of Resource Ministers. Ottawa, ON. iii + 16 p.
http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-1

PREFACE

The Canadian Councils of Resource Ministers developed a Biodiversity Outcomes Framework[1] in 2006 to focus conservation and restoration actions under the *Canadian Biodiversity Strategy*.[2] *Canadian Biodiversity: Ecosystem Status and Trends 2010*[3] was a first report under this framework. It assesses progress towards the framework's goal of "Healthy and Diverse Ecosystems" and the two desired conservation outcomes: i) productive, resilient, diverse ecosystems with the capacity to recover and adapt; and ii) damaged ecosystems restored.

The 22 recurring key findings that are presented in *Canadian Biodiversity: Ecosystem Status and Trends 2010* emerged from synthesis and analysis of technical reports prepared as part of this project. Over 500 experts participated in the writing and review of these foundation documents. This report, *Trends in residual soil nitrogen for agricultural land in Canada, 1981-2006*, is one of several reports prepared on the status and trends of national cross-cutting themes. It has been prepared and reviewed by experts in the field of study and reflects the views of its authors.

Acknowledgements

We would like to express our appreciation to Dr. E.C. Huffman and Dr. Xueming Yang for providing N coefficient data. We are also very grateful to the National Agri-Environmental Health Analysis and Reporting Program (NAHARP) for funding this research. Finally, we'd like to thank the reviewers of this report.

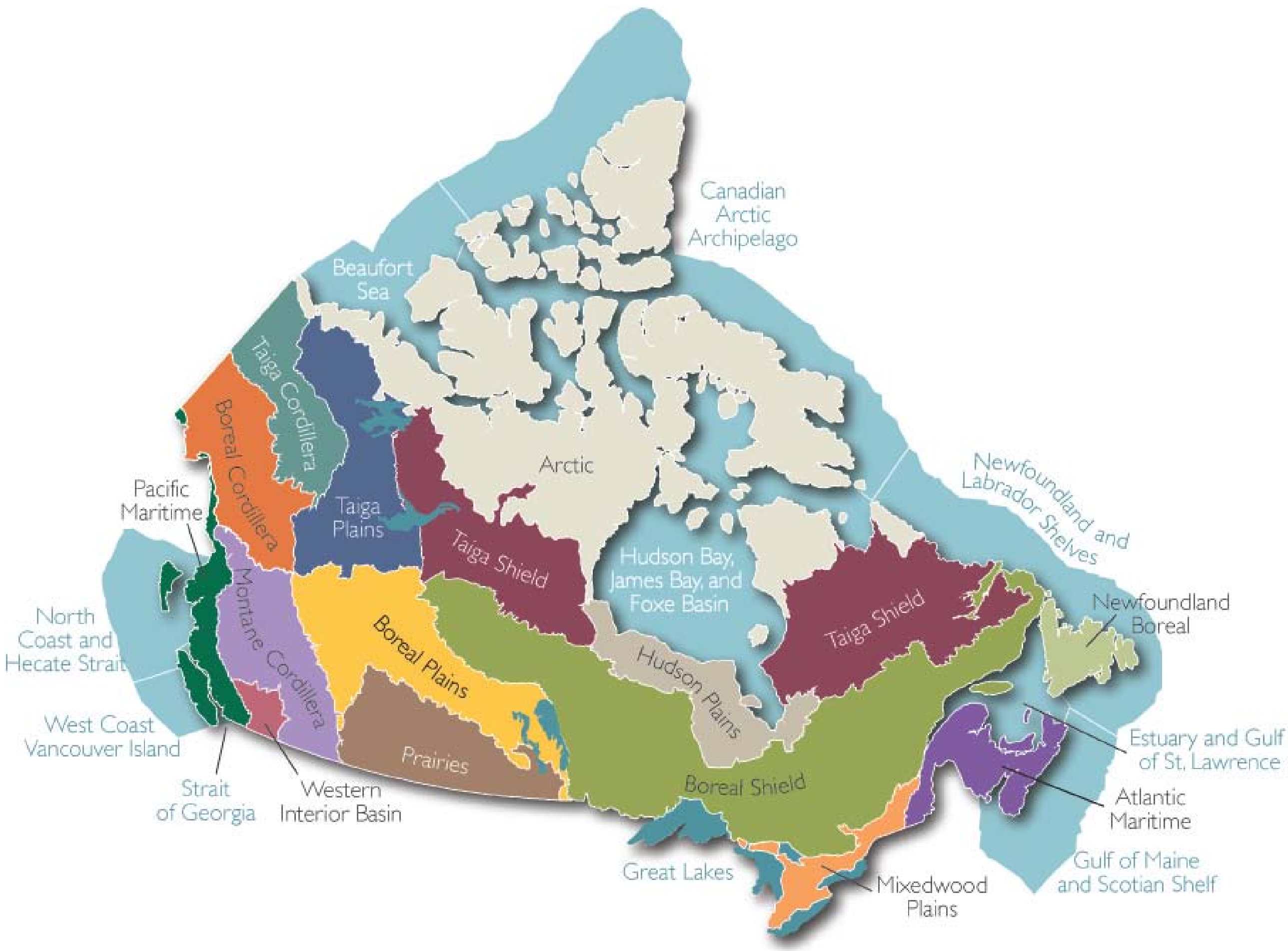
[1] Environment Canada. 2006. Biodiversity outcomes framework for Canada. Canadian Councils of Resource Ministers. Ottawa, ON. 8 p. http://www.biodivcanada.ca/default.asp?lang=En&n=F14D37B9-1

[2] Federal-Provincial-Territorial Biodiversity Working Group. 1995. Canadian biodiversity strategy: Canada's response to the Convention on Biological Diversity. Environment Canada, Biodiversity Convention Office. Ottawa, ON. 86 p. http://www.biodivcanada.ca/default.asp?lang=En&n=560ED58E-1

[3] Federal, Provincial and Territorial Governments of Canada. 2010. Canadian biodiversity: ecosystem status and trends 2010. Canadian Councils of Resource Ministers. Ottawa, ON. vi + 142 p. http://www.biodivcanada.ca/default.asp?lang=En&n=83A35E06-1

Ecological Classification System – Ecozones+

A slightly modified version of the Terrestrial Ecozones of Canada, described in the *National Ecological Framework for Canada*,[4] provided the ecosystem-based units for all reports related to this project. Modifications from the original framework include: adjustments to terrestrial boundaries to reflect improvements from ground-truthing exercises; the combination of three Arctic ecozones into one; the use of two ecoprovinces – Western Interior Basin and Newfoundland Boreal; the addition of nine marine ecosystem-based units; and, the addition of the Great Lakes as a unit. This modified classification system is referred to as "ecozones+" throughout these reports to avoid confusion with the more familiar "ecozones" of the original framework.[5]



[4] Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch. Ottawa/Hull, ON. 125 p. Report and national map at 1:7 500 000 scale.

[5] Rankin, R., Austin, M. and Rice, J. 2011. Ecological classification system for the ecosystem status and trends report. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No. 1. Canadian Councils of Resource Ministers. Ottawa, ON. http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-1

Table of Contents

List of Figures

List of Tables

AGRI-ENVIRONMENTAL INDICATORS

As part of the National Agri-Environmental Health Analysis and Reporting Program, Agriculture and Agri-Food Canada has developed a suite of science-based agri-environmental indicators. These were first reported in 2000 (for 1981 to 1996), updated in 2005 (for 1981 to 2001), and most recently reported in 2010 (for 1981 to 2006) (Eilers et al., 2010). Three of these indicators are presented by ecozone+ as part of the Technical Thematic Report Series for *Canadian Biodiversity: Ecosystem Status and Trends 2010*. They are soil erosion on cropland (McConkey et al., 2011), wildlife habitat capacity (Javorek and Grant, 2011), and this report on residual soil nitrogen.

All three of these agri-environmental indicators use data from the Canadian Census of Agriculture database. This database categorizes the agricultural landscape into four main cover types: Cropland, Pasture (broken down into Improved and Unimproved Pasture), Summerfallow, and All Other Land (All Other Land includes, for example, barnyards, woodlots, lanes, windbreaks, marshes, and bogs) (Huffman et al., 2006; Statistics Canada, 2008). The soil erosion and residual soil nitrogen Technical Thematic Reports focus on the agricultural land in production and therefore only use the first three cover types in their calculations (Unimproved Pasture is not included in the soil erosion analysis). Javorek and Grant (2011), on the other hand, include the All Other Land cover type when reporting on wildlife habitat capacity on agricultural land. The definition of "Cropland" in the soil erosion report differs from that used by the Canadian Census of Agriculture in that it includes the Census of Agriculture categories of Cropland, Improved Pasture, and Summerfallow when referring to "Cropland". For these reasons, numbers presented for the total amount of agricultural land or Cropland or proportions of different cover types for an ecozone+ or region may differ slightly between the three agricultural reports prepared as part of the Technical Thematic Report Series for *Canadian Biodiversity: Ecosystem Status and Trends 2010*. Additional discrepancies may exist due to the methodology used to maintain anonymity of the data (see Eilers et al., 2010 for more information).

INTRODUCTION

The Residual Soil Nitrogen (RSN) Indicator is an estimate of the amount of inorganic nitrogen that remains in the soil per hectare after crops are harvested (Drury et al., 2010). Most of the inorganic nitrogen remaining in the soil after harvest is in the form of nitrate (NO_3^-) but it can also include ammonium and trace amounts of nitrite. High RSN levels can occur when crop yields are lower than expected or when fields receive more fertilizer or manure than needed for crop production. Yield reduction leading to high RSN levels can occur as a result of many factors, including, adverse climatic conditions (for example, insufficient or excess precipitation, or early or late frost), disease, insects, or from poor soil quality (for example, compact soils, poor aeration, or degraded structure). The RSN present in the soil after harvest can leach out of the crop root zone, particularly in humid areas where precipitation is typically greater than evaporation. High levels of nitrate in excess of the National Agri-Environmental Standards Initiative recommended Ideal Performance Standards of 4.7 mg nitrogen per litre (N/L) for freshwater can be harmful to the environment (Guy, 2008; Guy, 2009) and nitrate levels in both surface and groundwater in excess of the drinking water guidelines can be harmful to livestock and humans when this water is used for potable consumption (Chambers, 2001). Further, in wet soil conditions, nitrate is subject to denitrification loss which reduces nitrate to nitric oxide (NO), nitrous oxide (N_2O) and dinitrogen (N_2) (Drury et al., 1992). Although NO and N_2O emissions have a negative impact on air quality, these gaseous losses reduce the amount of residual nitrate in the soil which can potentially be leached out of the root zone and can therefore reduce risk to water contamination. In regions where leaching and denitrification losses are low, RSN may remain in the root zone and can be available to the subsequent crop. Therefore, estimating RSN in soils is useful to identify the agronomic regions that are at medium to very high risk of accumulating nitrate in the fall which may leach into the groundwater or be denitrified and impact air quality. It is also useful to track the changes in RSN levels in the soil over time in order to observe whether the risk of nitrate accumulation in soils is increasing, decreasing, or remaining steady. In regions with elevated RSN levels, management practices can be adopted to reduce the amount of RSN in the soil which can be both economically and environmentally beneficial.

Nitrate concentrations in water have been found to affect biodiversity. The short term freshwater exposure limits (49 mg N/L or 218 mg NO_3^-/L) for Canada were based on LC_{50} values for the nitrate concentrations which were toxic to a range of invertebratess (such as, caddisfly and water flea), fish species (such as, channel catfish, lake whitefish, bluegill, rainbow trout, and chinook salmon), as well as amphibians (such as, Pacific tree frog and African clawed frog) (Guy, 2008). The long term exposure limits to nitrate in freshwater were also obtained based on LC_{10} values and maximum acceptable toxicant concentration values for a range of fish, amphibians and invertebrates and the recommended National Agri-Environmental Standards Initiative Ideal Performance Standard was established at 4.7 mg N/L or 21 mg NO_3^-/L (Guy, 2009). Nitrate concentrations of 6.25 and 25 mg N/L were reported to have sublethal effects on embryo development rates as well as the fry body size of lake trout and lake whitefish (Mcgurk et al., 2006). These concentrations can be in the range of concentrations of tile drainage water being released from agricultural land (Drury et al., 2009; Drury et al., 2010). High concentrations of nitrate, ammonia, and/or phosphate have also been implicated in the formation of algal blooms (Chambers et al., 2001).

RESIDUAL SOIL NITROGEN INDICATOR

The annual RSN values presented in this report were determined with a Canadian Agricultural Nitrogen Budget model (CANB v3.0) which estimates all of the nitrogen inputs (nitrogen fertilizer addition, manure addition, legume nitrogen fixation, and atmospheric deposition) and outputs (crop removal, ammonia volatilization, and denitrification) and then calculates the difference between the nitrogen inputs and nitrogen outputs (Yang et al., 2007; Yang et al., 2011). The RSN Indicator provides an estimate of the amount of "unused" nitrogen that remains in the soil at the end of the cropping season. The RSN values were calculated on a soil landscape of Canada (SLC) polygon basis and these values were then scaled up to an ecozone+ and national level to give an estimate of RSN per hectare (agricultural land area weighted average). The SLC polygons are mapping units which range in size from 10,000 ha to 1 million ha and contain soils with similar properties, landscape attributes, as well as climate (Lefebvre et al., 2005).

Census of Agriculture data (farm area, livestock types and numbers, and crop types and areas), fertilizer sales, crop yield and climatic data, and soil landscape information (such as, soil types and slopes) were the primary data sources used in the model (Bourque and Koroluk, 2003; Beaulieu, 2004; Agriculture and Agri-Food Canada and Statistics Canada, 2008). Published coefficients were also used to estimate both inputs and outputs from agricultural soils (ASABE, 2005). For example, manure production was based on the number and type of livestock raised in the region (for example, dairy, hog). However, it was also necessary to estimate manure nitrogen losses via ammonia volatilization and denitrification based on manure form (solid versus liquid), storage system (six liquid manure and seven solid manure storage systems), as well as application time and method (four application periods and three incorporation methods). Hence, the estimated manure nitrogen input is the amount of manure nitrogen that was applied to agricultural land after volatilization losses, denitrification losses, and storage losses were taken into account. The mineralization of organic nitrogen from manure and legume crop residues was estimated for the current year, as well as for the 2nd and 3rd years after application.

Risk classes based on the RSN level present in the soil at the end of the growing season (very low risk 0 to 9.9 kg N/ha; low risk 10 to 19.9 kg N/ha; moderate risk 20 to 29.9 kg N/ha; high risk 30 to 39.9 kg N/ha; and very high risk >40 kg N/ha) were assigned to farmland (Drury et al., 2010). The area of land in each risk class was mapped for the agricultural ecozones+ in Canada (Figure 1).

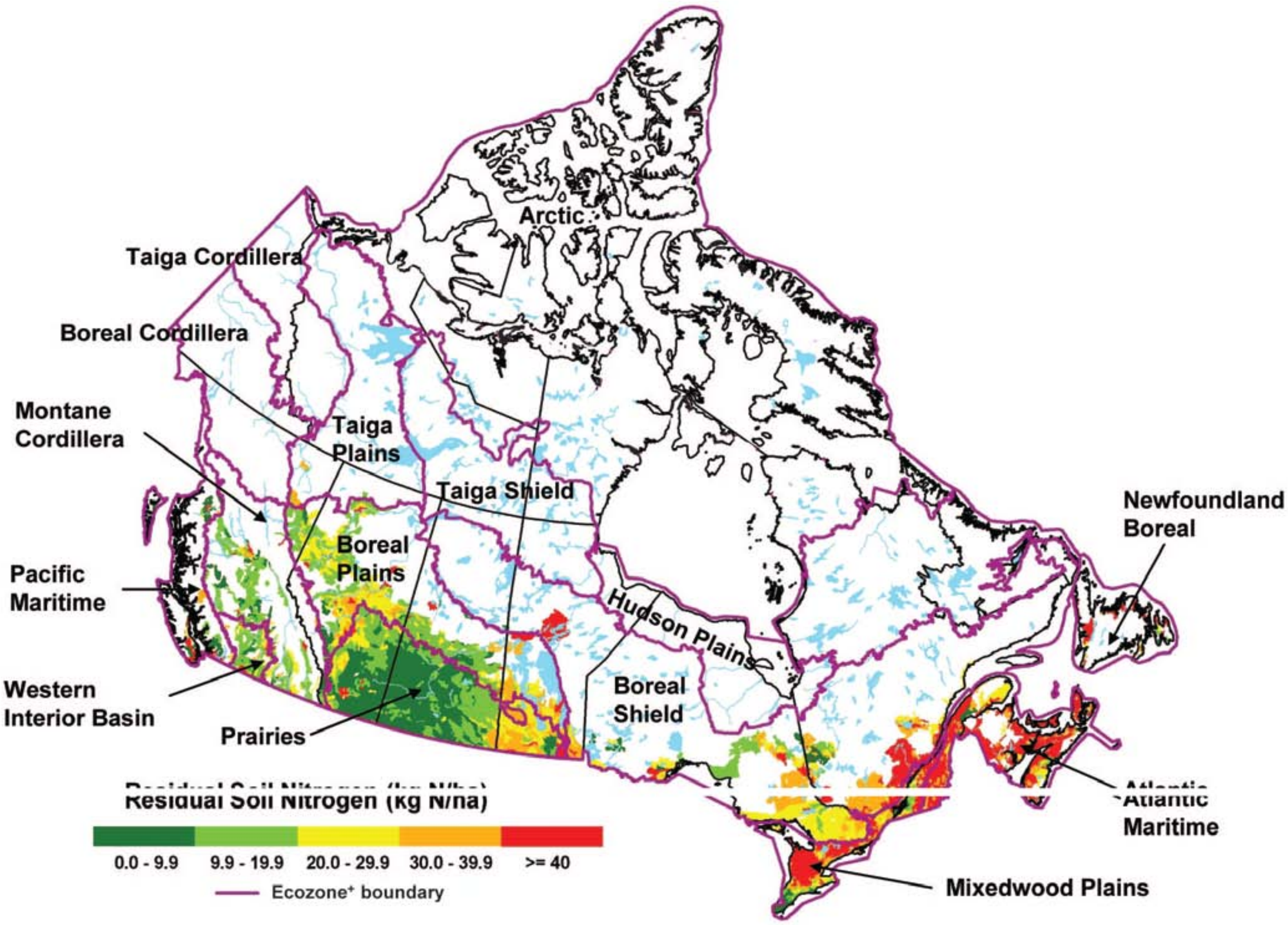


Figure 1. Residual soil nitrogen (RSN) risk classes for agricultural land in Canada, 2006.

Model limitations

The resolution of the RSN model is the SLC polygon scale. Although the amount of fertilizer and manure nitrogen that is applied to soils can be estimated for each SLC polygon based on fertilizer sales and on the livestock type and numbers, we do not know the proportion of each nitrogen source that is applied to a particular crop in the polygon. Thus assumptions had to be made to reconcile crop nitrogen requirements with the amount of fertilizer nitrogen sold and manure produced in any given polygon (Huffman et al., 2008; Yang et al., 2011).

Most of the crop yield data was based on 60 Canadian agricultural regions, while other crop yields, such as for alfalfa and pasture, are based on provincial data. However, it would be preferable to have yield estimates based on each SLC polygon instead of the larger Canadian agricultural regions. Additional information concerning the assumptions used in the model for ammonia volatilization, denitrification gas partitioning, and others was reported by Yang et al. (2007).

Management practices such as conservation tillage, cover crops, and conversion from annual to perennial crops may have increased soil organic matter levels in some regions which could have tied up RSN as soil organic nitrogen. Conversely, soil organic nitrogen levels may decline in soils where land in perennial crops was converted to annual crops and/or when changes in management practices resulted in reduced crop yields and carbon inputs (for example, shift from mixed livestock farms to cash crop farms). We were unable to account for changes in soil organic matter levels across regions and over time in this model. Hence soil organic matter levels were assumed to be at steady state.

RESULTS

National perspective

The RSN levels varied across Canadian farmland in 2006 from the very low risk class (0 to 9.9 kg N/ha) to high risk class (>40 kg N/ha) (Figure 1). The agricultural land in the Prairies Ecozone+ was split primarily between the very low risk and low risk classes. The inputs are somewhat limited as a result of the lower yield potential in this dryland environment. Agricultural land in the Boreal Plains Ecozone+ presents a medium to very high risk areas in both central Alberta and the eastern regions of this ecozone+ (central Manitoba). The southern areas of both the Pacific Maritime and Western Interior Basin ecozones+ were generally in the very high risk class with RSN levels exceeding 40 kg N/ha. The Montane Cordillera Ecozone+ has both low and medium risks area in southwest areas of British Columbia but agricultural land in central British Columbia was primarily in the low risk class. The Boreal Shield Ecozone+ covers a wide geographic area and the RSN risk class is generally in the very high risk class in central Manitoba and the regions north of the St. Lawrence lowlands. The south central regions in the Boreal Shield are characterized as having soils in the medium to high risk classes. For the Mixedwood Plains Ecozone+ the RSN ranges from very low and low risk classes in southwestern Ontario to medium to very high risk classes in the north and eastern portions of the ecozone+. The agricultural land in the Atlantic Maritime Ecozone+ was primarily in the very high risk class, although areas of northern New Brunswick and southwestern Prince Edward Island had polygons in the medium risk class. The agricultural land in the mid-western and northern regions of the Newfoundland Boreal Ecozone+ was in the very high risk class whereas the southeastern areas ranged from very low to the high risk class.

There were 61.4 million ha of agricultural land[6] in Canada distributed amongst 3,285 SLC polygons in 2006 (Table 1). The nitrogen inputs increased steadily from 42.7 kg N/ha in 1981 to 66.9 kg N/ha in 2006 (Table 2). In 1981, the nitrogen inputs from fertilizer (15.2 kg N/ha) and from nitrogen fixation from legumes (15.9 kg N/ha) were quite similar and both were greater

[6] Agricultural land, as discussed in this report, does not include the "All Other Land" category from the Census of Agriculture. See the Agri-environmental indicators section on page 1 of this report for an overview of the land included in the analysis for each of the three ESTR Technical Thematic Reports on agri-environmental indicators.

than the nitrogen input from manure (8.9 kg N/ha) (Table 3). Nitrogen inputs for all three sources increased over time and in 2006 the N input to soils was 25.1, 28.3, and 10.8 kg N/ha respectively (Table 3). Nitrogen outputs also increased across Canada over time from 33.4 kg N/ha in 1981 to 49.1 kg N/ha in 2006 primarily as a result of increased crop yields (Table 2). The net result was that the RSN levels also increased from 9.3 kg N/ha in 1981 to a maximum of 25.0 kg N/ha in 2001 followed by a decrease to 17.8 kg N/ha in 2006. The 2001 drought in many areas of Canada contributed to lower yields and nitrogen uptake values which left more nitrogen in the soil after harvest. Producers add fertilizer and manure based on the expectation of an average or above average growing season and expectation of average to above average yields.

Table 1. The agricultural land area and number of Soil Landscape of Canada polygons in Canada by ecozones+, 2006.

Ecozone+	**Number of SLC polygons**	**Agricultural land area (thousands of ha)**
Pacific Maritime	108	203
Western Interior Basin	104	593*
Montane Cordillera	200	1,163
Taiga Plains	5	9
Boreal Plains	605	12,053
Prairies	985	39,945
Boreal Shield	251	920
Mixedwood Plains	469	5,338
Atlantic Maritime	514	1,130
Newfoundland Boreal	44	21
Canada	**3,285**	**61,375**

* The agricultural land area reported here for the Western Interior Basin is greater than that reported in the ESTR wildlife habitat capacity report (Javorek and Grant, 2011). This discrepancy can be attributed to the methodology used to maintain the anonymity of the data. See the Agri-environmental indicators section on page 1.

Table 2. Nitrogen input, output, and residual soil nitrogen (RSN) for Canadian ecozones[+] that contain agricultural land, 1981 to 2006.

Ecozone[+]	Nitrogen input (kg N/ha)						Nitrogen output (kg N/ha)						RSN (kg N/ha)					
	1981	**1986**	**1991**	**1996**	**2001**	**2006**	**1981**	**1986**	**1991**	**1996**	**2001**	**2006**	**1981**	**1986**	**1991**	**1996**	**2001**	**2006**
Pacific Maritime	93.0	106	97.2	99.7	110	103	50.6	52.6	53.2	49.8	46.7	46.0	42.4	53.4	44.0	49.9	63.3	57.0
Western Interior Basin	59.7	55.3	50.7	51.7	56.6	41.8	39.1	34.6	32.7	31.4	32.0	25.4	20.6	20.7	18.0	20.3	24.6	16.4
Montane Cordillera	52.9	51.3	50.4	49.6	51.4	44.8	39.5	36.9	37.1	33.0	31.2	29.0	13.4	14.4	13.3	16.6	20.2	15.8
Taiga Plains	27.0	38.2	31.2	40.9	53.9	56.8	23.8	31.7	28.4	32.5	37.2	35.6	3.2	6.5	2.8	8.4	16.7	21.2
Boreal Plains	40.8	46.4	50.8	62.0	69.7	69.3	32.7	38.1	40.3	43.4	43.3	47.2	8.1	8.3	10.5	18.6	26.4	22.1
Prairies	27.6	32.7	32.9	44.1	50.6	52.5	24.3	29.2	27.8	35.1	32.6	40.7	3.3	3.5	5.1	9.0	18.0	11.8
Boreal Shield	82.4	95.1	91.8	98.6	109	107	62.6	73.1	62.4	70.1	65.6	74.0	19.8	22.0	29.4	28.5	43.4	33.0
Mixedwood Plains	123	139	138	143	149	153	80.1	87.0	90.2	96.0	86.2	112	42.9	52.0	47.8	47.0	62.8	41.0
Atlantic Maritime	95.8	110	108	122	132	137	68.1	78.0	64.6	81.9	73.4	81.4	27.7	32.0	43.4	40.1	58.6	55.6
Newfoundland Boreal	50.7	83.5	72.7	115	106	102	30.6	42.3	40.6	67.3	52.1	48.4	20.1	41.2	32.1	47.7	53.9	53.6
Canada	**42.7**	**48.0**	**48.5**	**59.1**	**65.7**	**66.9**	**33.4**	**38.0**	**37.2**	**43.6**	**40.7**	**49.1**	**9.3**	**10.0**	**11.3**	**15.5**	**25.0**	**17.8**

Table 3. Nitrogen input from manure, fertilizer, and nitrogen fixation by leguminous crops for Canadian ecozones[+] that contain agricultural land, 1981 to 2006.

Ecozone[+]	Manure nitrogen input* (kg N/ha)						Fertilizer nitrogen input (kg N/ha)						Legume nitrogen fixation** (kg N/ha)					
	1981	**1986**	**1991**	**1996**	**2001**	**2006**	**1981**	**1986**	**1991**	**1996**	**2001**	**2006**	**1981**	**1986**	**1991**	**1996**	**2001**	**2006**
Pacific Maritime	49.2	54.2	52.5	52.8	54.9	56.1	17.2	26.2	18.0	21.1	26.6	18.1	24.6	23.3	24.8	23.9	26.5	26.4
Western Interior Basin	17.8	15.2	16.3	17.1	16.7	13.5	12.0	10.7	7.3	8.7	10.4	4.7	27.9	27.5	25.2	23.9	27.4	21.7
Montane Cordillera	15.1	13.7	14.4	15.0	13.6	11.7	8.7	9.7	7.2	7.7	9.3	6.6	27.1	25.9	26.8	25.0	26.5	24.5
Taiga Plains	4.0	6.7	5.5	6.9	8.4	8.5	8.9	15.1	11.2	12.1	16.1	11.0	12.1	14.4	12.5	20.0	27.4	35.3
Boreal Plains	6.7	6.5	7.5	9.2	9.8	10.2	15.1	19.2	18.8	26.0	26.2	25.8	16.8	18.6	22.4	24.7	31.6	31.1
Prairies	5.1	4.7	5.4	6.7	7.3	7.8	11.4	15.9	15.2	23.5	23.6	23.0	8.9	9.9	10.2	11.8	17.6	19.6
Boreal Shield	19.2	20.8	20.6	20.8	20.7	20.3	15.5	20.8	21.7	20.8	23.5	21.3	41.6	47.5	43.5	51.0	59.3	59.8
Mixedwood Plains	28.5	28.2	27.3	27.1	26.7	26.6	40.2	50.0	44.2	43.2	44.1	43.7	47.4	53.2	59.7	65.2	71.1	76.0
Atlantic Maritime	30.3	32.2	32.1	32.0	31.7	32.9	21.7	28.3	31.3	31.9	35.6	36.4	39.6	45.3	40.0	54.3	60.3	63.9
Newfoundland Boreal	23.8	42.4	32.0	45.1	40.9	34.5	11.3	18.3	17.5	21.7	19.9	28.1	13.6	20.9	21.2	46.3	43.3	37.7
Canada	**8.9**	**8.3**	**8.8**	**10.1**	**10.5**	**10.8**	**15.2**	**19.8**	**18.7**	**25.5**	**25.8**	**25.1**	**15.9**	**17.2**	**18.4**	**20.9**	**26.8**	**28.3**

* Manure nitrogen input represents the net amount of mineral nitrogen applied to the soil or released from the mineralization of organic nitrogen over three years

** Legume nitrogen fixation represents the biologically fixed nitrogen from legume residues that become available in the soil in the first year after plowing as well as the N mineralized from legume residues incorporated into the soil in the previous years.

When both land area and RSN estimates were considered on a national basis, there were about 565,000 tonnes of inorganic nitrogen remaining in Canadian soils following harvest in 1981. This increased 2.7 fold to 1.52 million tonnes in 2001. It then decreased to 1.06 million tonnes in 2006 primarily as a result of increased nitrogen outputs compared to nitrogen inputs, reflecting higher crop yields during the latter 5-year period. Nevertheless, the 2006 levels of inorganic nitrogen remaining in Canadian soils were still about twice as high as the 1981 levels. This model does not account for changes in soil organic matter. If soil organic matter were to have increased, then some of this RSN may have been immobilized and converted to soil organic nitrogen.

The risk of loss of RSN (especially nitrate) to the environment is a function of the amount, timing, and nature (rain versus snow) of precipitation in the particular region as well as the antecedent soil moisture contents. Humid regions such as those found in central and eastern Canada as well as coastal British Columbia would be at a greater risk of nitrate loss than the drier regions such as the Canadian prairies (Prairies and Boreal Plains ecozones+).

Ecozone+ results

There are ten ecozones+ that have more than 5% of their land area in agricultural production in any one SLC polygon. They are: Pacific Maritime, Western Interior Basin, Montane Cordillera, Taiga Plains, Boreal Plains, Prairies, Boreal Shield, Mixedwood Plains, Atlantic Maritime, and Newfoundland Boreal. These will be referred to as "agricultural ecozones+". The RSN Indicator was estimated for these ten ecozones+ from 1981 to 2006.

Pacific Maritime Ecozone+

There were 203,000 ha of agricultural land distributed amongst 108 SLC polygons in the Pacific Maritime Ecozone+ in 2006 (Table 1). The Pacific Maritime contains only 0.33% of the agricultural land in Canada and most of this is located along the coastal areas of southern British Columbia (Figure 1). The nitrogen inputs increased from 93.0 to 110 kg N/ha from 1981 to 2001, followed by a decrease to 103 kg N/ha in 2006 (Table 2). Manure is the greatest nitrogen source in this ecozone+ with inputs increasing from 49.2 kg N/ha in 1981 to a maximum of 56.1 kg N/ha in 2006 (Table 3). In 2006, the nitrogen inputs from legume fixation (26.4 kg N/ha) and fertilizer addition (18.1 kg N/ha) were each less than half of the input from manure (56.1 kg N/ha). The nitrogen outputs fluctuated between 46.0 and 53.2 kg N/ha over the six census years with the variation primarily due to fluctuating yields and crop nitrogen removal, although changes in crop type may also have contributed to the variation. The RSN values also varied over time with the lowest value of 42.4 kg N/ha in 1981 and the maximum of 63.3 kg N/ha in 2001. The 2001 RSN maximum in the Pacific Maritime Ecozone+ was greater than the RSN values for all other ecozones+ and across all six census years. The high RSN level in 2001 was due to a combination of increasing inputs from manure (from 49.2 kg N/ha in 1981 to 54.9 kg N/ha in 2001), fertilizer (from 17.2 kg N/ha in 1981 to 26.6 kg N/ha in 2001), and legume nitrogen fixation (from 24.6 kg N/ha in 1981 to 26.5 kg N/ha in 2001), while the crop outputs decreased from 50.6 kg N/ha in 1981 to 46.7 kg N/ha in 2001. The decrease in crop outputs was due to a combination of factors including changes in crop areas and decreasing hay yields. Pasture land area decreased from 64% in 1981 to 55% in 2001, while increases in acreage occurred for alfalfa (3% increase), forage crops (2% increase), fruits and vegetable crops (2% increase,) and cereal crops (1% increase).

Western Interior Basin Ecozone+

The Western Interior Basin Ecozone+ is the smallest (Figure 1) of the agricultural ecozones+; however, there is more agricultural land in this ecozone+ (593,000 ha) than the Pacific Maritime (203,000 ha), Taiga Plains (9,000 ha), and Newfoundland Boreal (21,000 ha) (Table 1). The agricultural land in the Western Interior Basin Ecozone+ is located in 104 SLC polygons. The nitrogen inputs generally decreased over time from 59.7 kg N/ha in 1981 to 41.8 kg N/ha in 2006 (Table 2), although higher nitrogen inputs were observed in 2001 (56.6 kg N/ha) compared to the earlier (1996) or later (2006) census years. The decrease in nitrogen inputs from 2001 to 2006 was due to a combination of decreasing livestock numbers and manure (nitrogen inputs from livestock decreased from 16.7 to 13.5 kg N/ha), decreasing fertilizer nitrogen inputs (from 10.4 to 4.7 kg N/ha), and decreasing nitrogen fixation by legumes (from 27.4 to 21.7 kg N/ha) (Table 3). The nitrogen outputs also decreased over time from 39.1 kg N/ha in 1981 to 25.4 kg N/ha in 2006. This decrease was due to several factors including changing crop acreages and decreasing hay yields. The area of unimproved pasture increased from 60 to 79% while the area of improved pasture decreased from 18 to 5%. Crop yields and nitrogen output were higher for improved pasture compared to unimproved pasture. The net result was that the Western Interior Basin Ecozone+ was the only agricultural ecozone+ where the RSN in agricultural land decreased over time (from 20.6 kg N/ha in 1981 to 16.4 kg N/ha in 2006).

Montane Cordillera Ecozone+

There were 200 SLC polygons representing 1.163 million ha of agricultural land (1.9% of agricultural land in Canada) in the Montane Cordillera Ecozone+ in 2006 (Table 1). Most of the agricultural land in this ecozone+ is located in British Columbia and southwestern Alberta. The nitrogen inputs remained fairly constant from 1981 to 2001 with a range from 49.6 to 52.9 kg N/ha however there was a substantial decrease in nitrogen input from 51.4 kg N/ha in 2001 to 44.8 kg N/ha in 2006 (Table 2). This decrease was due to a combination of decreased manure inputs (from 13.6 to 11.7 kg N/ha), decreased fertilizer additions (from 9.3 to 6.6 kg N/ha), as well as a decreased legume crop acreage and nitrogen fixation (from 26.5 kg N/ha to 24.5 kg N/ha) (Table 3). The level of nitrogen inputs was similar to that observed for the Western Interior Basin. The nitrogen outputs generally decreased over the 25 years from 39.5 to 29.0 kg N/ha which is in contrast to the trends observed in all other agricultural ecozones+ except for the Western Interior Basin and the Pacific Maritime. The decreased nitrogen outputs were due to an increase in unimproved pasture area (62% in 1981 to 71% in 2006) as well as a decrease in both improved pasture (from 14% in 1981 to 10% in 2006) and forage crop area (from 12% in 1981 to 7% in 2006). The net effect of the changes in nitrogen inputs and outputs were generally increasing RSN values from 13.4 kg N/ha in 1981 to a maximum of 20.2 kg N/ha in 2001 followed by a decrease to 15.8 kg N/ha in 2006.

Taiga Plains Ecozone⁺

The Taiga Plains Ecozone⁺ contained the smallest agricultural area (9,000 ha) and the fewest number of SLC polygons (5) of all agricultural ecozones⁺ in Canada in 2006 (Table 1). The agricultural polygons are located strictly in the northern portions of British Columbia and Alberta (Figure 1). In 1981, both the nitrogen input (27 kg N/ha) and the nitrogen output (23.8 kg N/ha) were very low and the difference between the two (that is, the RSN) was only 3.2 kg N/ha (Table 2). The nitrogen input doubled over a 25-year period and was 56.8 kg N/ha by 2006 whereas the nitrogen output increased by about 50% over the 25 years to 35.6 kg N/ha. Hence there was about a seven fold increase in RSN to 21.2 kg N/ha by 2006 as N outputs increased at a lower rate than N inputs. These data indicate that too little nitrogen was applied to the crops in 1981 but with the two-fold increase in nitrogen addition over 25 years, only about 40% was removed in the harvested portion of the crop. Nevertheless, the 2006 RSN values (21.2 kg N/ha) in the Taiga Plains were similar to those in the Boreal Plains (22.1 kg N/ha) and considerably lower than agricultural ecozones⁺ in eastern Canada (33.0 to 55.6 kg N/ha).

Boreal Plains Ecozone⁺

The Boreal Plains Ecozone⁺ contained the second largest area of agricultural land in Canada in 2006 (19.6%) at 12.053 million ha found in 605 SLC polygons (Table 1). The nitrogen inputs steadily increased over time with 40.8 kg N/ha in 1981 to 69.3 kg N/ha in 2006 (Table 2). In 1981, both fertilizer nitrogen (15.1 kg N/ha) and legume nitrogen fixation (16.8 kg N/ha) were greater sources of nitrogen than applied manure (6.7 kg N/ha) (Table 3). Over the 25-year period, all three nitrogen sources increased primarily as a result of increasing legume acreage and livestock numbers, with the largest increases with nitrogen fixation to 31.1 kg N/ha which was about three times greater than the nitrogen input from manure (10.2 kg N/ha) and about 20% greater than nitrogen fertilizer (25.8 kg N/ha) in 2006. The nitrogen outputs also increased from 32.7 to 47.2 kg N/ha over the 25-year period. The RSN values were very low in 1981 at 8.1 kg N/ha and they increased over three-fold to a maximum of 26.4 kg N/ha in 2001, followed by a slight decrease to 22.1 kg N/ha in 2006.

Prairies Ecozone⁺

The Prairies Ecozone⁺ contained the largest amount of agricultural land at 39.945 million ha which was 65% of the agricultural land in Canada (Table 1). The nitrogen inputs were on average lower than all other ecozones⁺ with 27.6 kg N/ha in 1981 and increasing to 52.5 kg N/ha in 2006 (Table 2). The major nitrogen input in 2006 was fertilizer nitrogen (23.0 kg N/ha) followed by legume nitrogen fixation (19.6 kg N/ha) with manure being the lowest of these sources at 7.8 kg N/ha. The nitrogen outputs steadily increased over the 25 years from a low of 24.3 kg N/ha in 1981 to a maximum of 40.7 kg N/ha in 2006. These increases were due to a combination of increased crop yields as well as decreased areas of summer fallow. However, in 2001, the nitrogen output (32.6 kg N/ha) was lower than either 1996 (35.1 kg N/ha) or 2006 (40.7 kg N/ha) as a result of the widespread drought. Yearly variations in precipitation contribute to the variability in nitrogen output and therefore RSN. The nitrogen outputs increased at a lower rate than the nitrogen inputs and the RSN increased from a low of 3.3 kg N/ha in 1981 to a high of 18.0 kg N/ha in 2001, and then decreased to 11.8 kg N/ha by 2006. Nevertheless, the Prairies Ecozone+ had the lowest RSN of all agricultural ecozones+ in 2006 (Table 2).

Boreal Shield Ecozone+

The Boreal Shield Ecozone+ is the largest terrestial ecozone+ (Figure 1); however, it contains a relatively small amount of agricultural land at 920,000 ha (about 1.5% of agricultural land in Canada) distributed amongst 251 SLC polygons (Table 1). The nitrogen inputs were 82.4 kg N/ha in 1981, increasing to 109 kg N/ha in 2001, and then declining slightly to 107 kg N/ha in 2006 (Table 2). The majority of the nitrogen inputs in 2006 were from legume crops (59.8 kg N/ha) followed by fertilizer (21.3 kg N/ha) and manure (20.3 kg N/ha) (Table 3). It should be noted that manure nitrogen inputs remained fairly constant from 1981 to 2006 whereas both fertilizer and legume inputs increased by 37 and 44%, respectively. The increase in N_2 fixation was due to the increasing acreage of legume crops over the 25-year period. The nitrogen outputs increased from 62.6 to 74.0 kg N/ha from 1981 to 2006. The RSN increased more than two-fold from a low of 19.8 kg N/ha in 1981 to a maximum of 43.4 kg N/ha in 2001 followed by a decrease to 33.0 kg N/ha in 2006.

Mixedwood Plains Ecozone+

The Mixedwood Plains Ecozone+ contained 5.338 million ha of agricultural land distributed amongst 469 SLC polygons in 2006 (Table 1). The agricultural productivity of this area is very high as a result of warmer temperatures resulting from the moderating influence of the Great Lakes, particularly for southwestern Ontario, as well as higher precipitation rates. As a result, the nitrogen inputs are the greatest among all ecozones+ (Table 2). The yield potential of this region is achieved as long as there are sufficient nutrients such as inorganic nitrogen available to meet the crop requirements. Since most of the nutrients in the harvested crop are removed every year, additional nutrient inputs are required to ensure that they do not become limiting to crop growth. In 1981, it was estimated that 123 kg N/ha was added to agricultural land and the nitrogen inputs steadily increased to 153 kg N/ha in 2006. Nitrogen outputs primarily in crop yields and nitrogen uptake were also the greatest across all ecozones+ with an estimated output of 80.1 kg N/ha in 1981 which increased to a maximum of 112 kg N/ha in 2006. It should be noted that 2001 output was considerably lower than the outputs in 1996 and 2006 as this was primarily due to a drought in 2001 which reduced crop yields and nitrogen uptake. The RSN values were very high with 42.9 kg N/ha remaining in the soil in 1981 and 41.0 kg N/ha remaining in the soil after harvest in 2006. The RSN reached a maximum of 62.8 kg N/ha in 2001, the drought year. RSN levels in the Mixedwood Plains were similar to those in the Pacific Maritime with the exception of 2006 where the RSN in the Mixedwood Plains (41.0 kg N/ha) were considerably lower than those in the Pacific Maritime (57.0 kg N/ha). Legume nitrogen fixation was the dominant nitrogen source for the Mixedwood Plains and the nitrogen input from fixation increased from 47.4 kg N/ha in 1981 to 76.0 kg N/ha by 2006 as a result of increased acreages of legume crops such as soybean. The nitrogen input from fertilizer remained fairly constant over the 25 years with a range of 40.2 to 50 kg N/ha. Manure additions slightly decreased over 25 years from 28.5 kg N/ha in 1981 to a low of 26.6 kg N/ha in 2006 as a result of declining livestock numbers and manure production.

Atlantic Maritime Ecozone+

The Atlantic Maritime Ecozone+ had a comparatively small agricultural land area (1.13 million ha) distributed amongst 514 SLC polygons in 2006 (Table 1). The nitrogen inputs were the second highest of all agricultural ecozones+ on a per hectare basis (Table 2). Nitrogen inputs increased from 95.8 kg N/ha in 1981 to a maximum of 137 kg N/ha in 2006. The inputs from legume nitrogen fixation were greater than from either manure or fertilizer addition with 39.6 kg N/ha added through fixation in 1981, which increased to 63.9 kg N/ha by 2006 as a result of increased legume acreage (Table 3). Manure nitrogen inputs remained fairly constant over the 25 years ranging from 30.3 kg N/ha in 1981 to 32.9 kg N/ha in 2006. Fertilizer nitrogen inputs increased steadily from 21.7 kg N/ha in 1981 to a maximum of 36.4 kg N/ha in 2006. There was quite a bit of fluctuation in nitrogen outputs over this period probably due to variations in crop yield and nitrogen uptake. Nitrogen output ranged from a low of 64.6 kg N/ha in 1991 to a high of 81.9 kg N/ha in 1996. The RSN in the Atlantic Maritime increased from 27.7 kg N/ha in 1981 to a maximum of 58.6 kg N/ha in 2001 followed by a slight decrease to 55.6 kg N/ha in 2006. In 2006, the Atlantic Maritime had the second highest RSN value of all agricultural ecozones+; second only to the Pacific Maritime at 57.0 kg N/ha.

Newfoundland Boreal Ecozone+

The Newfoundland Boreal Ecozone+ contained the second smallest area of agricultural land (21,000 ha distributed into 44 SLC polygons) of the agricultural ecozones+ in 2006 (Table 1). The nitrogen inputs increased by about 2.3 times over fifteen years (from 50.7 kg N/ha in 1981 to 115 kg N/ha in 1996) and then gradually decreased to 102 kg N/ha in 2006, which was twice the 1981 level (Table 2). Manure nitrogen was the greatest source of nitrogen in 1981 at 23.8 kg N/ha compared to 11.3 kg N/ha for fertilizer and 13.6 kg N/ha for legume nitrogen fixation; however by 2006, legume fixation (37.7 kg N/ha) and manure addition (34.5 kg N/ha) contributed similar amount of nitrogen to agricultural land with fertilizer being the lowest of these three sources at 28.1 kg N/ha (Table 3). The nitrogen outputs increased from 30.6 kg N/ha in 1981 to a maximum of 67.3 kg N/ha in 1996 and then decreased to 48.4 kg N/ha in 2006. The increase in nitrogen outputs from 1981 to 2006 was due primarily to changes in crop areas. For example, unimproved pasture area decreased from 65% in 1981 to 46% in 2006, while forage crop areas increased from 12 to 23%, alfalfa increased from 1 to 6%, and cereal crop areas increased from 2 to 5%. The RSN levels generally increased over time from a low of 20.1 kg N/ha in 1981 to a maximum of 53.9 kg N/ha in 2001 which levelled off to 53.6 kg N/ha in 2006.

Changes in the RSN risk classes from 1981 to 2006

The RSN levels in 2006 were compared to the levels in 1981 (Figure 2). The land areas where RSN risk class decreased (that is, had lower RSN levels) were found in central British Columbia, southern Ontario, and southern Quebec. Most of the land in the Prairies Ecozone+ located in Saskatchewan and Alberta remained in the same risk class, however the eastern regions of the Prairies (Manitoba) increased RSN values by at least one risk class. Increases in risk class were also observed for the southeastern portion of the Boreal Shield, as well as the Atlantic Maritime The central portion of the Mixedwood Plains was found to have RSN values that remained in the same class over the 25-year period.

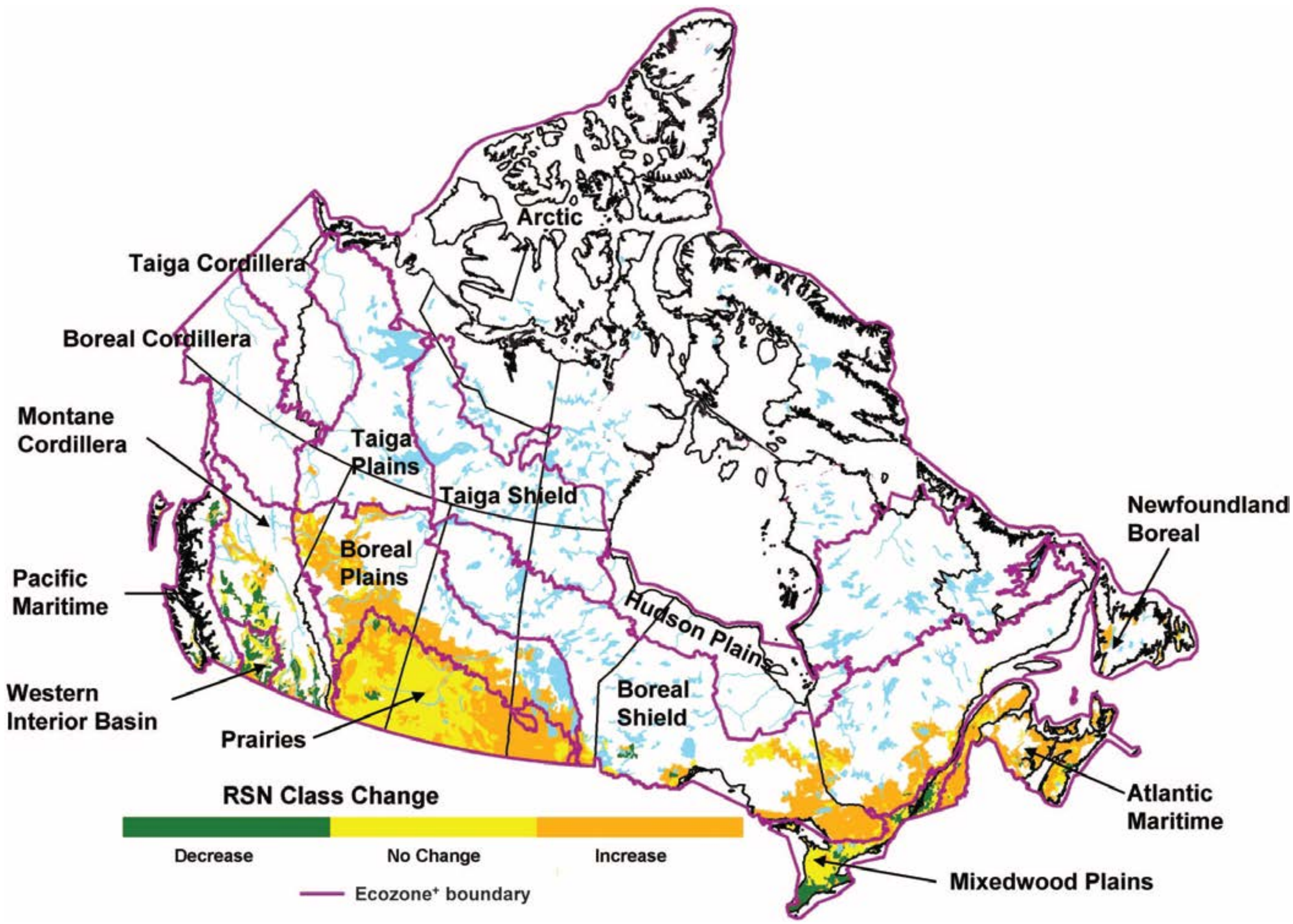


Figure 2. Agricultural land in Canada for which RSN changed by at least one risk class from 1981 to 2006.

In summary, the RSN levels were in the very low and low risk classes for most of the Prairies Ecozone+ but high and very high RSN levels occurred in Manitoba, the central portion of the Mixedwood Plains Ecozone+, and the Atlantic Maritime Ecozone+ (Figure 1). RSN should be measured in these high risk areas, and if the *in situ* measurements correspond to model estimates, then management practices should be implemented which would reduce the risk of exporting RSN to waterways.

References

Agriculture and Agri-Food Canada and Statistics Canada. 2008. Customized tabulations. Census of Agriculture, CGC Base 1996, 2001, 2006. Ottawa, ON.

ASABE. 2005. Manure production and characteristics. ASABE Standards 2006: ASAE D384.2. American Society of Agriculture and Biological Engineers. St. Joseph, MI. 727 p.

Beaulieu, M.S. 2004. Manure management in Canada. Farm Environmental Management in Canada. Vol. 1 No. 2. Edited by Koroluk, R. Statistics Canada. Ottawa, ON. 52 p.

Bourque, L. and Koroluk, R. 2003. Manure storage in Canada. Farm Environmental Management in Canada. Vol. 1 No. 1. Edited by Vani, R. Statistics Canada. Ottawa, ON. 46 p.

Chambers, K. 2001. Assessing the feasibility of applying the co-operative model to First Nations community based development initiatives: a case study of the Xaxl'ep and a native plant nursery. Occasional Paper No. 1. BC Institute for Co-operative Studies. Victoria, BC.

Chambers, P.A., Guy, M., Roberts, E.S., Charlton, M.N., Kent, R., Gagnon, C., Grove, G. and Foster, N. 2001. Nutrients and their impact on the Canadian environment. Agriculture and Agri-Food Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada and Natural Resources Canada. 241 p.

Drury, C.F., McKenney, D.J. and Findlay, W.I. 1992. Nitric oxide and nitrous oxide production from soil: water and oxygen effects. Soil Science Society of America Journal 56:766-770.

Drury, C.F., Tan, C.S., Reynolds, W.D., Welacky, T.W., Oloya, T.O. and Gaynor, J.D. 2009. Managing tile drainage, subirrigation and nitrogen fertilization to reduce nitrate loss and enhance crop yields. Journal of Environmental Quality 38:1193-1204.

Drury, C.F., Yang, J., De Jong, R., Huffman, T., Yang, X., Reid, K. and Campbell, C.A. 2010. Residual soil nitrogen. *In* Environmental Sustainability of Canadian Agriculture. Agri-Environmental Indicator Report Series. Report No. 3. Edited by Eilers, W., Mackay, R., Graham, L. and Lefebvre, A. Agriculture and Agri-Food Canada. Ottawa, ON. Chapter 12. pp. 74-80.

Eilers, W., Mackay, R., Graham, L. and Lefebvre, A. (eds). 2010. Environmental sustainability of Canadian agriculture. Agri-Environmental Indicator Report Series. Report No. 3. Agriculture and Agri-Food Canada. Ottawa, ON. 235 p.

Guy, M. 2008. Ideal performance standards for the nitrate ion. National Agri-Environmental Standards Initiative. Report No. 4-54. Environment Canada. Gatineau, QC. 73 p.

Guy, M. 2009. Ideal performance standards to prevent nitrate toxicity. National Agri-Environmental Standards Initiative Synthesis Report No. 12. Environment Canada. Gatineau, QC. 27 p.

Huffman, E.C., Yang, J.Y., Drury, C.F., De Jong, R., Yang, X.M. and Liu, Y.C. 2008. Estimation of Canadian manure and fertilizer nitrogen application rates at the crop and soil-landscape polygon level. Canadian Journal of Soil Science 88:619-627.

Huffman, T., Ogston, R., Fisette, T., Daneshfar, B., Gasser, P.Y., White, L., Maloley, M. and Chenier, R. 2006. Canadian agricultural land-use and land management data for Kyoto reporting. Canadian Journal of Soil Science 86:431-439.

Javorek, S.K. and Grant, M.C. 2011. Trends in wildlife habitat capacity on agricultural land in Canada, 1986-2006. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No. 14. Canadian Councils of Resource Ministers. Ottawa, ON. vi + 46 p. http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-0.

Lefebvre, A., Eilers, W. and Chunn, B.(eds). 2005. Environmental sustainability of Canadian agriculture. Agri-Environmental Indicator Report Series. Report No. 2. Agriculture and Agri-Food Canada. Ottawa, ON. 220 p.

McConkey, B.G., Lobb, D.A., Li, S., Black, J.M.W. and Krug, P.M. 2011. Soil erosion on cropland: introduction and trends for Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No. 16. Canadian Council of Resource Ministers. Ottawa, ON. iv + 22 p. http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-0.

Mcgurk, M.D., Landry, F., Tang, A. and Hanks, C.C. 2006. Acute and chronic toxicity of nitrate to early life stages of lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonus clupeaformis*). Environmental Toxicology and Chemistry 25:2187-2196.

Statistics Canada. 2008. 2006 census of agriculture [online]. Government of Canada. http://www.statcan.gc.ca/ca-ra2006/index-eng.htm (accessed 8 August, 2008).

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

Yang, J.Y., Huffman, E.C., Drury, C.F., Yang, X.M. and De Jong, R. 2011. Estimating the impact of manure nitrogen losses on total nitrogen application on agricultural land in Canada. Canadian Journal of Soil Science 91:107-122.