AGRI-ENVIRONMENTAL INDICATOR PROJECT

Agriculture and Agri-Food Canada

REPORT NO. 20

AGROECOSYSTEM GREENHOUSE GAS BALANCE INDICATOR: NITROUS OXIDE COMPONENT

Technical Report: Estimates of Nitrous Oxide Emmisions from Agroecosystems in Canada for 1986 and 1991 Using the the Revised 1996 IPCC/OECD Methodology

C.A. Monteverde, R.L. Desjardins and E. Pattey

Agriculture & Agri-Food Canada, Research Branch

JUNE 1997

PREFACE

The Agri-Envrionmental Indicator (AEI) Project of Agriculture and Agri-Food Canada (AAFC) was initiated in 1993 in response to recommendations made by several agencies, organizations and special studies. The overall objective of the project is to develop and provide information to help integrate environmental considerations into decision-making processes of the agri-food sector.
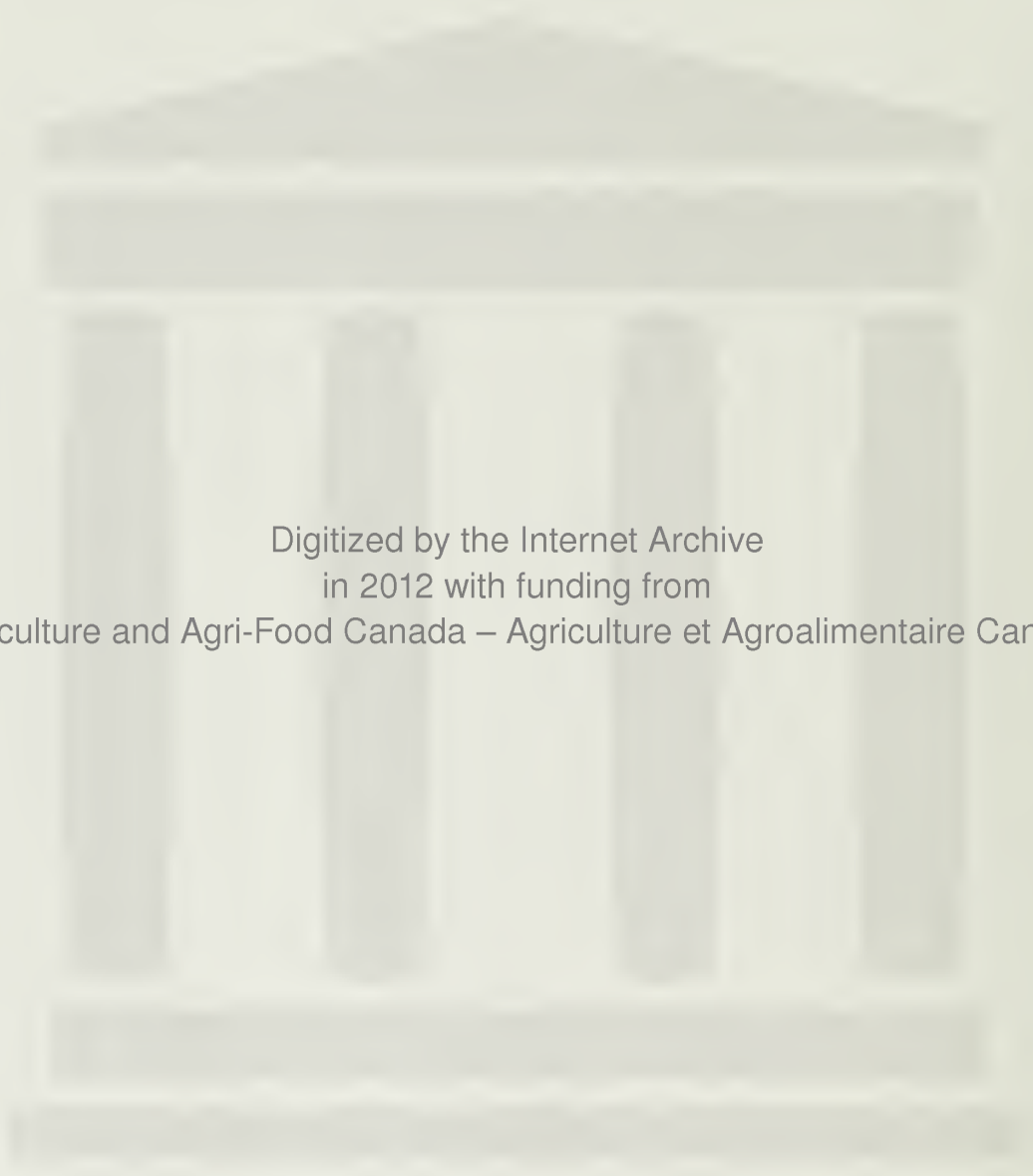
The project aims to develop a core set of regionally-sensitive national indicators that build on and enhance the information base currently available on environmental conditions and trends related to primary agriculture in Canada. The nitrous oxide component of the Agroecosystem Greenhouse Gas Balance indicator is an important part of the agri-environmental indicator set. Indicators are also being developed for other aspects of agricultural greenhouse gases and in relation to issues of water quality, agroecosystem biodiversity, farm resource management, soil quality and agricultural production efficiency.

Research results in the form of discussion papers, scientific articles and progress reports are released as they become available. A comprehensive report is planned for fiscal year 1998-1999 which will include data from the 1996 Statistics Canada Census of Agriculture.

Comments and questions on this paper should be addressed to:

Dr. Raymond Desjardins
Eastern Cereal and Oilseed Research Centre
Research Branch, Agriculture and Agri-Food Canada
Central Experimental Farm, Building No. 74
Ottawa, Ontario
K1A 0C6

Telephone: (613) 759-1522
Facsimile: (613) 966-0646
E-mail: Desjardins@em.agr.ca

Table of Contents

Abstract

Nitrous oxide (N_2O) emissions from agroecosystems in Canada were estimated on a provincial and national basis using the 1996 IPCC/OECD methodology and the Census of Agriculture data for 1986 and 1991. Total N_2O emissions were 93.4 Gg N_2O in 1986 and 92.7 Gg N_2O in 1991. Using a 100 year time horizon, this is equivalent to 26774.7 and 26594.9 Gg of CO_2.

Agricultural components of total emissions are direct and indirect emissions from soils, animals and emissions from other agricultural sources. Direct N_2O emissions from agricultural soils contributed 49.06 Gg N_2O in 1986 and 48.24 Gg N_2O in 1991. Crop residues and nitrogen fertilizers were the principle sources of these emissions, contributing approximately 37% and 31% in 1986 and 1991, respectively. The principle sources of indirect N_2O emissions were from atmospheric deposition of NH_3 and NO_x, leaching and runoff which contributed 27.10 Gg N_2O and 26.39 Gg N_2O in 1986 and 1991, respectively. Grazing animals contributed about 10.21 Gg N_2O in 1986 and 11.16 Gg N_2O in 1991. Other N_2O emissions considered in the IPCC/OECD methodology were from animal waste during storage and from human sewage. Together, these contributed about 7 Gg N_2O.

Although there are still considerable uncertainties in the emission factors used in these calculations, these results demonstrate that agricultural practices are an important source of N_2O emissions.

1.0 Introduction

Presently, the atmospheric concentration of N_2O is about 312 ppbv and its rate of increase is approximately 0.5% (IPCC, 1996). Its long atmospheric lifetime and unique absorption bands give N_2O a large global warming potential (GWP). According to the IPCC (1996), a molecule of N_2O is about 310 times more effective in its GWP, on a 100 year basis, than a molecule of CO_2. The increase of atmospheric N_2O is particularly important as it also contributes to the destruction of stratospheric ozone.

There are many small sources of N_2O, both natural and anthropogenic, which are difficult to quantify. Therefore, the current N_2O budget is very poorly understood. The sources (14 Tg-N/yr) exceed the sinks (10 Tg-N/yr) by 40% (Keller and Reiners, 1994). The main anthropogenic sources are from agriculture and various industrial processes such as the production of adipic acid and nitric acid (IPCC 1996).

Globally, agriculture contributes about 70% of anthropogenic N_2O emissions (Mosier, 1993). Nitrogen fertilizers with mineral nitrogen sources, animal manure and nitrogen derived from N-fixation (leguminous crops) all contribute to N_2O emissions produced from the soil (Duxbury *et al.*, 1993). Processes such as manure applications and the incorporation of crops or crop residues into the soil may significantly affect the production of N_2O. Other N_2O sources come from biomass burning, fossil fuel combustion, nitrification and denitrification, most of which are difficult to quantify (Batjes and Bridges, 1992).

This report estimates N_2O emissions from Canada's agricultural industry based on the 1996 Revised IPCC/OECD Guidelines for Nitrous Oxide inventory methodology and the 1986/1991 Census of Agriculture data.

2.0 Methodology

The IPCC methodology for estimating the N_2O emissions from agriculture is broken down into three main areas: (a) direct emissions from agricultural soils; (b) direct emissions from animal production systems, and; (c) indirect emissions from agricultural systems. These groups may be subdivided into their main N_2O contributors (Figure 1):
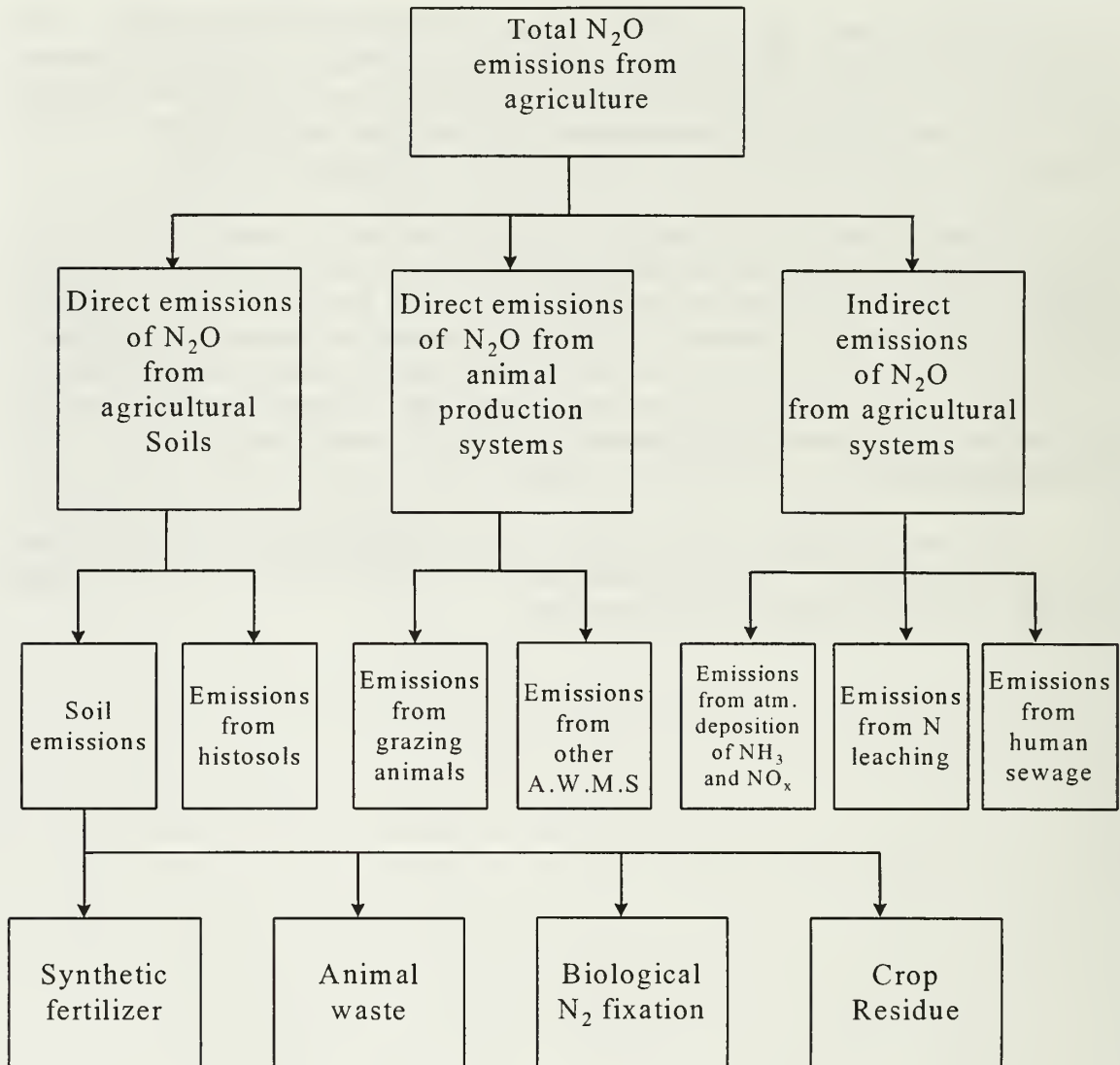
Figure 1. Schematic of the main sources considered for calculation of N_2O emissions

2.1. Direct N_2O Emissions from Agricultural Soils

2.1.1 N_2O Emissions from Synthetic N Fertilizers (F_{SN})

The use of commercial nitrogen fertilizers has increased significantly in the past decade. This increase in nitrogen in the soil is producing significant N_2O emissions (Bouwman, 1990; Eichner 1990). Several types of nitrogen fertilization are commercially available which include anhydrous ammonia, urea,

ammonium nitrate, ammonium sulfate, and nitrogen solutions. The total nitrogen content from these fertilizers ranges from approximately 20 to 82%. In addition to nitrogen fertilizers, several types of ammoniated phosphates are also available which contain 10 to 18% total N (Walsh, 1973).

2.1.1.1 Data Sources

The estimates of synthetic fertilizer N inputs to agricultural soils were obtained from the Canadian Fertilizer Consumption, Shipment and Trade publications (Asselstine and Girard, 1992; Spearin and O'Connor, 1991). The fertilizer consumption figures are subject to uncertainty because they may not correspond exactly to on-farm consumption in a specific province. There is also some inter-provincial and possibly international movement of fertilizer between retailers and farms.

Between 1970 and 1985, in some agricultural areas in Canada, the amount of fertilizer applied has increased thirty-fold (Statistics Canada, 1991). The largest percentages of fertilizer applications are found in Alberta, Saskatchewan, Manitoba and Ontario.

The default factors used to calculate emissions due to nitrogen fertilizer were obtained from Bouwman (1996). These factors are based on published measurements of N_2O emissions from fertilized and unfertilized soils, and from the IPCC/OECD emission factors (1996b) (Table 1). An emission factor of 0.1 NH_3-N + NO_x-N/kg of synthetic fertilizer is used to account for the loss from ammonia volatilization and emission of nitric oxide through nitrification after fertilization.

Table 1. Percentage of N fertilizer evolved as N_2O for various fertilizer types

Fertilizer Type	%
1. Anhydrous Ammonia	1.6[1]
2. Ammonium Nitrate	0.3[1]
3. Ammonium Sulfate (salts of Ammonium)	0.1[1]
4. Urea	0.3[1]
5. Calcium Nitrate	0.2[1]
6. Phosphate	1.25[2]

[1]Bouwman, 1996.
[2]IPCC/OECD, 1996b.

2.1.1.2 Calculations

Nitrous oxide emissions from nitrogen fertilizers are estimated using the total nitrogen fertilizer consumption. It is calculated excluding the 10% NH_3 and NO_x emissions estimated to be lost to the atmosphere during the application.

Equation 1:

$$N_2O_{(fertilizers)} = \Sigma \text{ N Fertilizer Consumption (kg N/yr)} * 0.9 * EF_{(fert.\ type)} * 10^{-6}$$

where: $EF_{(fert.\ type)}$ = Emission factor by fertilizer type;
10^{-6} = conversion from kg to Gg;
$N_2O_{(fertilizers)}$ = Gg N_2O-N/yr.

2.1.2 N_2O Emissions from Animal Wastes (F_{AW})

Manure contains significant amounts of C and N, and when applied to soils, contributes to the release of N_2O (Angers and N'Dayegamiye, 1991; Collins *et al.* 1992; Lessard *et al.* 1993). Its nutrient content can vary greatly, depending on the type and size of animal, the amount and type of feed, the collection system and the management between the production and application (Eck and Stewart, 1996). It is therefore difficult to accurately estimate the magnitude of this source of N_2O.

2.1.2.1 Data Sources

Ontario, Quebec, Manitoba and Alberta have the largest livestock populations in the country. These populations are usually categorized into the following groups: dairy cattle, non-dairy cattle, swine, sheep, and poultry.

It is difficult to estimate N in animal feed and excreta, the NH_3 losses, and the annual amounts of excreta per animal type and size. Therefore, only a rough estimate can be determined based on animal population and agricultural practices. The manure used as a fertilizer is corrected for NH_3 volatilization and NO_x emissions. This is assumed to be approximately 20% of nitrogen applied (IPCC/OECD,1996b). The default factor used for nitrogen excretion is based on a study conducted by Culley and Barnett (1984) and the emission factors are based on the IPCC/OECD (1996b) data as shown in Table 2.

Table 2. N content in manure from various animal types and manure N produced in pasture and paddock as well as respective emission factors

Animal	N content (kg N/animal/yr)[1]	Emission Factor EF[2]	% Manure N produced in Pasture and Paddock[3]	Emission Factor
				EF3[4]
1. Dairy cow	63	0.0125	0	0.02
2. Non-Dairy cow	39	0.0125	84	0.02
3. Swine	14	0.0125	0	0.02
4. Poultry	0.6	0.0125	1	0.02
5. Sheep	6.0	0.0125	88	0.02

[1] Culley and Barnett, 1984.
[2] IPCC/OECD, 1996b; Table 4-18.
[3] IPCC/OECD, 1996b; Table 4-7; Safley et. al., 1992.
[4] IPCC/OECD, 1996b; Table 4-8; Safley et. al, 1992.

2.1.2.2 Calculations

Based on the livestock population and the nitrogen excretion factors from the IPCC/OECD (1996b), N_2O emissions can then be calculated:

Equation 2:

$$N \text{ Excretion}_{(animal\ type)} = N_{(NEX)} = \Sigma \text{ Manure Production}_{(animal\ type)} * N \text{ content}_{(animal\ type)}$$

Equation 3:

$$\text{Total N }_{(NEX)} = \Sigma N \text{ Excretion}_{(animal\ type)}$$

Equation 4:

$$N_2O_{(animal\ wastes)} = (\text{Total N Excretion} - \text{Manure N }_{(during\ grazing)})*(1 - Frac_{(GASM)}) * 0.0125 * 10^{-6}$$

where: $Frac_{(GASM)}$ = fraction of livestock N excretion volatilized as NH_3 and NO_X (kg NH_3 and NO_X-N/kg N excreted); 0.2 (IPCC/OECD, 1996b, Table 4-17); $N_2O_{(animal\ wastes)}$ = Gg N_2O-N/yr.

The above data must also be evaluated for each province so that the animal wastes used to fertilize crops and those deposited on the pasture while the animals are grazing are not counted twice. This is done by subtracting the amount of nitrogen excreted by grazing animals from the total nitrogen excreted by animals.

2.1.3 N_2O Emissions from N fixing Crops (F_{BN})

Legumes, such as alfalfa, clover and soybeans are capable of converting atmospheric nitrogen into a usable form for the plant. This is achieved through a symbiotic relationship with the N-fixing *Rhizobia* bacteria located in their roots. N_2O emissions can therefore be produced even when the crops receive little or no additional nitrogen fertilization (Bouwman, 1996).

2.1.3.1 Data Sources

Canada produced a total of about 17.5 million metric tonnes of leguminous crops in 1986, while in 1991 the production was approximately 18.5 million metric tonnes. These values are probably underestimated because they only include the production of peas, soybeans, beans, lentils and alfalfa. The N_2O emissions from these N-fixing crops is calculated by multiplying the area of land used, by the mean crop yield. This value, multiplied by the %N in the specific crop, gives the amount of nitrogen available. The amount of nitrogen available is then multiplied by an emission factor to give the amount of N_2O emitted.

The production data of N-fixing crops by province were obtained from Statistics Canada (1992). The emission factor of 1.25% kg N_2O-N/kg N was used to calculate N_2O emissions (IPCC/OECD, 1996b).

2.1.3.2 Calculations

N_2O emissions from N-fixing crops are calculated by assuming that the dry biomass production of pulses and soybeans is about twice the mass of edible crop (FAO, 1990b). A default factor of 0.03 kg N/kg of dry biomass is used to convert from units of kg dry biomass/yr to kg N/yr in crops. The moisture content of the crops is assumed to be 15%.

Equation 5:

$$N_2O_{(N\text{-fixing crops})} = 2 * [\text{Total Seed Yield}_{(kg\ dry\ biomass)} * (\text{N-content/kg of dry biomass})] * 0.0125 * 10^{-6}$$

where: N-content/kg of dry biomass = 0.03 kg N/kg dry biomass;

$$N_2O_{(N\text{-fixing crops})} = Gg\ N_2O\text{-N/yr.}$$

2.1.4 N_2O Emissions from Crop Residues (F_{CR})

Nitrous oxide is also emitted as a result of crop residue decomposition in the field. There is only a limited amount of information regarding re-utilization of nitrogen from crop residues to agricultural fields and the amount of nitrogen converted to N_2O.

2.1.4.1 Data Sources

Almost 85% of Canada's cropland can be found in Manitoba, Saskatchewan and Alberta (Statistics Canada, 1992), with the overall area of farmland in Canada remaining fairly constant. Alberta, which had 20.8 million ha of cropland in 1991, reported the largest increase in farm land in 1986 of 156,000 ha (Statistics Canada, 1992). The principal agricultural crops cultivated in Canada include wheat, canola, oats, barley, rye, mixed grains, flaxseed, corn, buckwheat, tame hay, sugar beets and leguminous crops.

The distribution of agricultural crops were obtained from Statistics Canada, by province, using the 1986/1991 crop production data. An emission factor of 1.25% (IPCC/OECD, 1996b) is used to calculate the N_2O emissions (kg N_2O-N/kg N).

2.1.4.2 Calculations

Nitrous oxide emissions from crop residues are estimated by assuming that crop production is about twice the mass of the edible crop (FAO, 1990b). A default factor of 0.015 kg N/kg of dry biomass is used to convert units of kg dry biomass/yr to kg N/yr .

In Canada, it is assumed that 30% of the crop residues remains on the field (Blevins and Frye, 1993).

Equation 6:

$$N_2O_{(crop\ residues)} = 2*[\text{Total Crop Production} * Frac_{(NCRO)} + \text{Total Seed Yield}_{(pulses\ \&\ soybeans)} * Frac_{(NCRBF)}] * (1- Frac_{(R)}) * (1- Frac_{(BURN)}) * 0.0125 * 10^{-6}$$

where: $Frac_{(NCRO)}$ = fraction of N in non-N-fixing crops (kg N/kg of dry biomass); Table 3;

$Frac_{(NCRBF)}$ = fraction of nitrogen in N-fixing crops (kg N/kg of dry biomass); Table 3;

$Frac_{(R)}$ = fraction of crop residue that is removed from the field as crop(kg N/kg of dry biomass); Table 3;

$Frac_{(BURN)}$ = fraction of crop residue that is burned rather than left on field; Table 3;

$N_2O_{(crop\ residues)}$ = Gg N_2O-N/yr.

Table 3. Default values for N-fixing crops and crop residues

$Frac_{NCRO}$	0.015 kg N/kg of dry biomass
$Frac_{NCRBF}$	0.03 kg N/kg of dry biomass
$Frac_R$	0.70 kg N/kg crop-N
$Frac_{BURN}$	0.25 in developing countries & 0 in developed countries

Source: IPCC/OECD, 1996b; Table 4-17.

2.1.5 N_2O Emissions from Histosols

Nitrous oxide is also emitted as a result of the cultivation of organic soils (histosols), which have an abundant nitrogen-rich organic matter throughout their soil profile. They are often wet, with a high water table, and provide a good environment for denitrification.

2.1.5.1 Data Sources

Estimates of the quantity and distribution of organic soils are uncertain. Levesque (1982) estimated that the total area of cultivated soils is about 15,400 ha, approximately 0.02% of the total agricultural land found in Canada.

2.1.5.2. Calculations

Nitrous oxide emissions from histosols are calculated as the product of the total area of cultivated organic soils and the emission factor for direct soil emissions.

Equation 7:

$N_2O_{(histosols)}$ = Area of cultivated organic soils * IPCC Def. Factor$_{(temperate\ regions)}$ * 10^{-6}

where: IPCC Def. Factor$_{(temperate\ regions)}$ = 5.0 kg N_2O-N /ha/yr ;
$N_2O_{(histosols)}$ = Gg N_2O-N/yr.

2.1.6 Total Direct N₂O Emissions from Agricultural Soils

The total direct N_2O emissions from agricultural soils is the sum of the following agricultural sources:

Equation 8:

Direct N_2O $_{(Gg\ N2O/yr)}$ = {$N_2O_{(fertilizers)}$ + $N_2O_{(crop\ residues)}$ + $N_2O_{(N\text{-}fixing\ crops)}$ + $N_2O_{(animal\ wastes)}$ + $N_2O_{(histosols)}$} * 44/28

2.2. Direct Soil Emissions of N₂O from Animals

There are two possible sources of N_2O emissions from animals: a) dung and urine deposited from grazing animals and; b) animal wastes during storage and treatment. The only sources considered in this section are the emissions from pastures and paddocks.

2.2.1 N₂O Emissions from Grazing Animals

Nitrogen in the dung and urine of grazing animals results in N_2O emissions. According to Flessa *et al.* (1995), nutrient cycling in pasture is highly influenced by grazing animals such as non-dairy cattle. It is estimated that 84% of the consumed nitrogen is returned in animal excreta.

2.2.1.1 Data Sources

Estimates of the total nitrogen content in manure from various types of livestock are based on a study conducted by Culley and Barnett (1984). Their values are considerably lower than those given by the IPCC. Table 2 presents the default factors used in this study.

2.2.1.2 Calculations

Estimates of N_2O emissions from grazing animals are calculated using the following equations:

Equation 9:

$$N2O_{(animals)} = N2O_{(AWMS)} = \Sigma_{(T)} \ [N_{(T)} * N_{(NEX)} * AWMS_{(T)} * EF3_{(AWMS)} \ ]$$

Equation 10:

$$N2O_{(AWMS)} = [N_{(T=1)} * N_{(NEX=1)} * AWMS_{(T=1)} * EF3_{(AWMS)} + \ldots. + \ (N_{(T=Max)} *$$
$$N_{(NEX=Max)} * AWMS_{(T=Max)} * EF3_{\ (AWMS)})]* 10^{-6} * 44/28$$

where: T = type of animal category;
$N_{(T)}$ = no. of animals of type T;
$N_{(NEX)}$ = N excretion of animals of type T (kg N/animal/yr); (IPCC/OECD,1996b; Table 4-6);
$AWMS_{(T)}$=fraction of $N_{(NEX)}$ from pastures and paddocks for animals of type T;
$EF3_{\ (AWMS)}$ = 0.02; Table 2;
$N2O_{(AWMS)}$ = Gg $N2O$.

2.3. Indirect N₂O Emissions from Nitrogen Sources in Agriculture

The application of nitrogen fertilizers and animal manures can result in the indirect release of N_2O by: (a) volatilization and atmospheric deposition of NH_3 and NO_x (mainly from N fertilizer); (b) nitrogen leaching and runoff; and (c) municipal sewage which will be included in section 2.5.2.

2.3.1 Indirect Emissions from Atmospheric Deposition of NH₃ and NO$_x$.

Atmospheric deposition of NH_3 and NO_x originating from fertilizer applications and from animal manure applications are the only sources taken into consideration in the calculations of the indirect emissions.

2.3.1.1 Data Sources

The data used to estimate the N losses in the form of NH_3 and NO_x are based upon the estimated nitrogen fertilizer use ($N_{(FERT)}$) and nitrogen from animal manure ($N_{(NEX)}$). Default values of 0.1 kg N/yr for fertilizer and 0.2 kg N/yr for animal manure account for NH_3 and NO_x volatilization. An emission factor of 0.01 kg of N_2O-N per kg NH_3-N and NO_x-N emitted is used to calculate the N_2O emissions (IPCC/OECD, 1996b).

2.3.2. Indirect N_2O Emissions from N Leaching

Leaching and runoff are significant mechanisms by which N_2O is lost from the soil. Nitrogen from fertilizers and animal manures can enter the groundwater through this process, be denitrified, and become a source of N_2O downstream.

2.3.2.1 Data Sources

The following inventory includes data that were used for the estimation of N_2O emissions from atmospheric deposition. The total nitrogen excretion from animal manures ($N_{(NEX)}$) includes the manure produced during grazing. The IPCC/OECD default factor of 0.3 kg N/kg N fertilizer or manure N, is used as the fraction of the fertilizer or manure lost to leaching and surface runoff. This value is also used to calculate N_2O-N emissions. An emission factor of 0.025 kg N_2O-N/kg of nitrogen leaching/runoff is used.

2.3.2.2 Calculations

Equation 11:

$$N_2O_{(indirect)} = (N_2O_{(G)} + N_2O_{(L)}) * 44/28$$

$$N_2O_{(G)} = N_{(FERT)} * Frac_{(GASF)} + N_{(NEx)} * Frac_{(GASM)} * EF_4 * 10^{-6}$$

$$N_2O_{(L)} = (N_{(FERT)} + N_{(NEX)}) * Frac_{(LEACH)} * EF_5 * 10^{-6}$$

where: $Frac_{(LEACH)}$ = Fraction of nitrogen input to soils that is lost through leaching and runoff (kg N of N applied) (IPCC/OECD,1996b;Table 4-17);

$N_2O_{(G)}$ = N_2O emissions due to atmospheric deposition of NH_3 and NO_X (kg N/yr.);

$N_2O_{(L)}$ = N_2O emissions due to nitrogen leaching and runoff (kg N/yr);

EF_4 = 0.01 kg N_2O-N/kg NH_3-N & NO_X-N deposited (IPCC/OECD, 1996b; Table 4-18);

EF_5 = 0.025 kg N_2O-N/kg N from leaching and runoff (IPCC/OECD, 1996b; Table 4-18);

$N_2O_{(indirect)}$ = Gg N_2O.

2.4 Total N_2O Emissions from Agricultural Soils

The total N_2O emissions from agricultural soils are the sum of the direct emissions from agricultural soils, the emissions from grazing animals, and the indirect emissions associated with atmospheric N deposition and N leaching.

2.5 Other Sources of N$_2$O Emissions

2.5.1 N$_2$O Emissions during Manure Storage

Nitrous oxide is often emitted during the storage of animal manure when the nitrogen is either nitrified or denitrified. The amount of N$_2$O emitted is dependent on the type of system and the duration of storage. The emissions include those from anaerobic lagoons (AL), liquid systems (LS), solid storage and drylot (SSD) and other systems (OS).

2.5.1.1 Data Sources

The data used to estimate emissions from animal manure was used in the calculation of N$_2$O emissions from AWMS. The IPCC/OECD (1996b) and Culley and Barnett (1984) emission factors (Table 4) are based on estimates of animal distribution and management systems for each animal type.   The majority of the emission factors are based on a very limited amount of information (IPCC/OECD, 1996a).

2.5.1.2 Calculations

Nitrous oxide emissions from other animal management systems can be estimated using the following equations:

Equation 12:

$$N_2O_{(AWMS)} = \Sigma_{(T)} \, [N_{(T)} * N_{(NEX)} * AWMS_{(T)}] * EF_{3(AWMS)} * 10^{-6} * 44/28$$

where: $N_{(T)}$ = no. of animals of type T;
$N_{(NEX)}$=N excretion of animals of type T (kg N/animal/yr); (IPCC/OECD,1996b;Table 4-6);
$AWMS_{(T)}$ = Fraction of $N_{(NEX)}$ that is managed in different for animals of type T (IPCC/OECD, 1996b; Table 4-7);
EF_3=Emission factor (IPCC/OECD,1996b; Table 4-8);
$N_{(NEX)(AWMS)}$ = Nitrogen excretion per Animal Waste Mgt. System (kg/yr).

Table 4. Default values for N excretion per head per animal type

Animal	N content (kg/animal/yr)[1]	% Manure N produced in AWMS[2]				Emission Factor EF3[3]			
		AL	LS	SSD	OS	AL	LS	SSD	OS
1. Dairy cow	63	10	23	23	7	0.001	0.001	0.02	0.005
2. Non-Dairy cow	39	0	1	14	1	0.001	0.001	0.02	0.005
3. Swine	14	25	50	18	6	0.001	0.001	0.02	0.005
4. Poultry	0.6	5	4	0	90	0.001	0.001	0.02	0.005
5. Sheep	6.0	0	0	2	10	0.001	0.001	0.02	0.005

[1] *Culley and Barnett, 1984.*
[2] *IPCC/OECD, 1996b; Table 4-7.*
[3] *IPCC/OECD, 1996b; Table 4-8; Safley et. al, 1992.*

2.5.2 Nitrous Oxide Emissions from Municipal Sewage Treatment

Human sewage can either be treated or processed before it is discharged into rivers or estuaries. The sludge can also be directly applied to the soil without any prior treatment.

2.5.2.1 Data Source

It is assumed that nitrogen constitutes approximately 16% by weight of human protein intake. The emission rates for sewage treatment and land disposal of human sewage are assumed to be small. This is based on the low emission rates of N_2O reported for operating wastewater facilities (Hemond and Duran, 1989; Czepiel *et al.,* 1995), and the lack of information of N_2O production from land disposal of human sewage. It is also assumed that minimal removal of sewage nitrogen occurs during land disposal and sewage treatment, and that all sewage nitrogen enters rivers and/or estuaries (IPCC/OECD, 1996b). Nitrous oxide emissions in rivers and estuaries due to nitrification and denitrification are estimated to be 0.01 kg N_2O-N/kg N sewage.

2.5.2.2 Calculations

Nitrous oxide emissions from sewage are calculated by using the following equation:

Equation 13:

$$Gg\ N_2O_{(s)} = NR_{(people)} * Protein * Frac_{(NPR)} * EF_6\ x\ 10^{-6} * 44/28$$

where: $N_2O_{(s)}$ = N_2O emissions from human sewage (kg N_2O-N/yr);
Protein = Annual per capita protein intake (kg/person/yr);
$NR_{(people)}$ = Number of people;
EF_6 = Emission factor (default 0.01 (0.002-0.12) kg N_2O-N/kg sewage-N produced; (IPCC/OECD, 1996b; Table 4-18);
$Frac_{(NPR)}$ = Fraction of nitrogen in protein (default= 0.16 kg N/kg protein) (IPCC/OECD, 1996b;Table 4-19).

3.0 Results and Discussion

This section presents estimates of N_2O emissions from agroecosystems in Canada for the years 1986 and 1991. The following sources considered were: (a) the direct emissions from agricultural soils; (b) the direct emissions from grazing animals; (c) the indirect emissions induced by agricultural practices (i.e. mineral nitrogen application and livestock production) and; (d) other sources, such as the direct emissions from AWMS and the indirect emissions from municipal sewage treatment.

3.1 Estimates of Direct N_2O Emissions from Agricultural Soils

The direct N_2O emissions from the different agricultural sources for 1986 and 1991 are summarized in Tables 5 and 6.

Table 5. Magnitude of the sources of the direct N_2O emissions from agricultural soils in 1986

Province	A F_{SN} (Gg N/yr)	B F_{AW} (Gg N/yr)	C F_{CR} (Gg N/yr)	D F_{BN} (Gg N/yr)	E $F_{histosols}$ (Gg N/ha/yr)	F Total Emissions (Gg N/yr)	G Total Direct Emissions (Gg) G=F [44/28]
Atlantic Provinces		0.20	0.14	0.03	0.0013	0.37	0.59
Quebec	0.55	1.17	1.06	0.39	0.0355	3.20	5.03
Ontario	1.62	1.29	2.56	2.07	0.0325	7.57	11.90
Manitoba	2.04	0.33	1.27	0.56	0.0015	4.20	6.60
Saskatchewan	2.57	0.29	3.08	1.55	-	7.50	11.78
Alberta	2.75	0.63	2.70	0.73	-	6.80	10.69
B.Columbia	0.23	0.21	0.28	0.15	0.0062	0.88	1.38
CANADA	**9.75**	**4.12**	**11.25**	**6.02**	**0.077**	**31.22**	**49.06**
%Contribution	31%	13%	37%	19.0%	0.2%		

Table 6. Magnitude of the sources of the direct N_2O emissions from agricultural soils in 1991

Province	A F_{SN} (Gg N/yr)	B F_{AW} (Gg N/yr)	C F_{CR} (Gg N/yr)	D F_{BN} (Gg N/yr)	E $F_{histosols}$ (Gg N/ha/yr)	F Total Emissions (Gg N/yr)	G Total Direct Emissions (Gg) G=F[44/28]
Atlantic Provinces		0.18	0.11	0.04	0.00125	0.33	0.52
Quebec	0.50	1.05	0.81	0.36	0.0355	2.76	4.86
Ontario	1.60	1.22	2.40	2.35	0.0325	7.40	11.57
Manitoba	2.40	0.35	1.36	1.01	0.0015	5.10	8.01
Saskatchewan	1.70	0.34	2.96	1.15	-	6.15	9.66
Alberta	2.80	0.74	2.87	1.64	-	8.95	12.65
B.Columbia	0.09	0.21	0.28	0.15	0.0625	0.74	1.16
CANADA	**8.95**	**4.09**	**10.92**	**6.66**	**0.077**	**30.70**	**48.24**
%Contribution	29%	13%	36%	22%	0.2%		

Estimated emissions from fertilizer application (F_{SN}) were generally higher in 1986 compared to 1991. This corresponds to a slight decrease in fertilizer use in 1991. Only Manitoba and Alberta were the exceptions to this trend, showing an increase in emissions from 1986 to 1991. Alberta contributed the highest N_2O emissions from fertilizer applications (2.75 and 2.80 Gg N_2O-N/yr), followed by Saskatchewan (2.57 and 1.70 Gg N_2O-N/yr). The Atlantic Provinces showed the lowest total emissions in 1991 with 0.33 Gg N_2O-N/yr. Several studies have shown that N_2O is emitted with the addition of N fertilizer and that the emissions can vary with each type (Bremner and Blackmer, 1978; Bouwman, 1996). However, Byrnes *et. al.* (1990) suggest that soil properties are more important than the amount of fertilizer applied. The total N_2O emissions from fertilizer applications are estimated at 9.75 Gg N_2O-N (15.32 kt N_2O) in 1986 and 8.95 Gg N_2O-N (14.06 kt N_2O) in 1991.

Ontario had the highest N_2O emissions (1.29 and 1.22 Gg N_2O-N/yr) from animal manure (F_{AW}), followed by Quebec (1.17 and 1.05 Gg N_2O-N/yr). The smallest contribution was from the Atlantic provinces (0.20 and 0.18 Gg N_2O-N/yr).

These values correspond to the various agricultural activities found throughout Canada. For example, Ontario and Quebec in 1991 accounted for more than 70% of the dairy industry (Statistics Canada, 1991). Alberta had lower N_2O emissions from animal manure because most of the N_2O emitted from manure is accounted for in the direct N_2O emission by grazing animals.

Nitrous oxide emissions from nitrogen fixing crops (F_{BN}) ranged from 0.03 to 2.07 Gg N_2O-N/yr in 1986 and from 0.04 to 2.35 Gg N_2O-N/yr in 1991. The N_2O emissions for this type of crops were estimated to be 6.02 Gg N_2O-N/yr and 6.66 Gg N_2O-N/yr for 1986 and 1991, respectively, with the highest emissions from Ontario, Saskatchewan and Alberta.

A difference in crop production between 1986 and 1991 resulted in the decrease in emissions from crop residues (F_{CR}). Provinces that were exceptions to this trend are Alberta and Manitoba, who showed a significantly higher crop production in 1991. The difference in N_2O emissions from 1986 and 1991 is most likely related to interannual variations in the climate.

Histosols ($F_{histosols}$) contributed minimally to N_2O emissions with a total of only approximately 0.08 Gg N_2O-N/yr in both 1986 and 1991. This represents only 0.2% of the total direct emissions produced from agricultural soils.

Among the five direct emission sources from agricultural soils, crop residues were the most important source of the direct N_2O emissions (about 36% and 37% of total N_2O emissions were released from crop residues in 1986 and 1991, respectively). Synthetic fertilizers accounted for approximately 31% and 29% of total emissions produced from agricultural soils in respective years. The total direct N_2O emissions released in Canada were ~ 31.22 Gg N_2O-N/yr or ~ 49.06 Gg in 1986 and ~ 30.70 Gg N_2O-N/yr or ~ 48.24 Gg in 1991. Overall, Ontario had the highest emissions (11.90 Gg N_2O) in 1986 and Alberta had slightly higher emissions (12.65 Gg N_2O) in 1991 (Tables 7 and 8).

3.2 Estimates of the Direct N_2O Emissions from Grazing Animals

The summary of the results for direct N_2O emissions from grazing animals is presented in Table 7. Grazing animals in Canada emitted 10.21 Gg N_2O and 11.16 Gg N_2O for the years 1986 and 1991, respectively. Alberta emitted the most of any province, contributing 3.76 Gg N_2O (1986) and 4.69 Gg N_2O (1991).

Table 7. Total N$_2$O emissions from grazing animals by province in 1986 and 1991

Province	A Nitrogen Excretion (N$_{(NEX)}$) (kg N/yr) [1]		B Emission Factor for AWMS (EF3)[2] (kg N$_2$O-N/kg N) Default values[2]	C N$_2$O Emissions from Grazing Animals (Gg) C = (A x B) [44/28] x 10^{-6}	
	1986	1991		1986	1991
Atlantic Provinces	7,645,483.8	7,572,733.8	0.02	0.24	0.24
Quebec	23,526,663.6	22,776,278.7	0.02	0.74	0.72
Ontario	56,682,946.2	53,333,501.7	0.02	1.78	1.68
Manitoba	33,344,288.3	33,095,419.2	0.02	1.05	1.04
Saskatchewan	64,888,680.0	71,566,230.2	0.02	2.04	2.25
Alberta	119,560,028.0	149,142,425.0	0.02	3.76	4.69
B. C.	19,207,895.4	17,489,713.3	0.02	0.60	0.55
CANADA	**324,855,985.3**	**354,976,301.9**	0.02	**10.21**	**11.16**

[1] *Based from Statistics Canada, 1993.*
[2] *IPCC/OECD, 1996b; Table 4-8.*

3.3 Estimates of the Indirect N$_2$O Emissions

Tables 8 and 9 indicate the total indirect N$_2$O emissions from atmospheric deposition of NH$_3$ and NO$_x$ for 1986 and 1991. Alberta produced the highest emissions, mainly due to the higher manure and N fertilization use in this area. Ontario and Saskatchewan also had high emissions in 1986 and 1991. A total estimated amount of 2.68 Gg N$_2$O-N/yr and 2.65 Gg N$_2$O-N/yr were emitted in Canada for 1986 and 1991, respectively.

Table 8. Indirect N$_2$O emissions from atmospheric deposition of NH$_3$ and NO$_x$ in 1986

	A Synthetic fertilizer N $_{(fert)}$[1] (kg N/yr)	B Fraction of Syn. Fert. N Applied that Volatilizes [2] Frac$_{(GASFS)}$ (kg N/kg N)	C Amt. Of Syn. N Applied to Soil that Volatilizes (kg N/kg N)	D Total N Excretion by livestock N$_{(NEX)}$ [3] (kg N/yr)	E Fraction of Total Manure N Excreted that Volatilizes Frac$_{(GASM)}$ (Kg N/Kg N)	F Total N Excreted by livestock that Volatilizes (kg N/kg N)	G Emission Factor EF$_4$	H N$_2$O Emissions (Gg N$_2$O-N/yr)
Province		Default Values (Table 4-A)	C=(A x B)		Default Values [4] (Table 4-17)	F=(D x E)	Default Values [5] (Table 4-18)	H=(C+F) xGg x 10^{-6}
Atlantic Prov.				27,799,299.6	0.2	5,559,859.92	0.01	0.06
Quebec	89,443,000	0.10	8,944,300	140,752,959.8	0.2	28,150,591.96	0.01	0.37
Ontario	219,446,000	0.10	21,944,600	185,561,727.8	0.2	37,112,345.56	0.01	0.59
Manitoba	235,960,000	0.10	23,596,000	66,837,533.4	0.2	13,367,506.68	0.01	0.37
Saskatchewan	317,600,000	0.10	31,760,000	93,879,614.2	0.2	18,775,922.84	0.01	0.51
Alberta	308,908,000	0.10	30,890,800	182,179,889.6	0.2	36,435,977.92	0.01	0.67
B. C.	33,537,000	0.10	3,353,700	39,957,643.4	0.2	7,991,528.68	0.01	0.11
CANADA	**1,204,894,000**	**0.10**	**120,489,400**	**736,968,667.8**	0.2	**147,393,733.6**	0.01	**2.68**

[1] *Spearin and O'Connor, 1991.*
[2] *IPCC/OECD, 1996a; (Table 4-A).*
[3] *Based from Statistics Canada, 1993.*
[4] *IPCC/OECD, 1996b; (Table 4-17).*
[5] *IPCCOECD, 1996b; (Table 4-18).*

Table 9. Indirect N₂O emissions from atmospheric deposition of NH₃ and NOₓ in 1991

Province	A $N_{(fert)}$[1] (kg N/yr)	B Frac$_{(GASFS)}$ (kg N/kg N) Default Values (Table 4-A)	C Amt. Of Syn. N Applied to Soil that Volatilizes (kg N/kg N) C=(A x B)	D Total N Excretion by livestock $N_{(NEX)}$[3] (kg N/yr)	E Frac$_{(GASM)}$ (Kg N/Kg N) Default Values[4] (Table 4-17)	F Total N Excreted by livestock that Volatilizes (kg N/kg N) F=(D x E)	G Emission Factor EF_4 Default Values[5] (Table 4-18)	H N₂O Emissions (Gg N₂O-N/yr) H=(C+F) xGg x 10⁻⁶
Atlantic Prov.				25,850,074.2	0.2	5,170,014.8	0.01	0.05
Quebec	91,760,000	0.10	9,176,000	128,130,397.8	0.2	25,626,079.6	0.01	0.35
Ontario	174,860,000	0.10	17,486,000	175,319,186.0	0.2	35,063,837.2	0.01	0.53
Manitoba	254,903,000	0.10	25,490,300	67,880,745.5	0.2	13,576,149.1	0.01	0.39
Saskatchewan	226,396,000	0.10	22,639,600	105,669,484.1	0.2	21,133,896.8	0.01	0.44
Alberta	328,301,000	0.10	32,830,100	222,642,739.7	0.2	44,528,547.9	0.01	0.77
B. C.	21,791,000	0.10	2,179,100	38,759,582.9	0.2	7,751,916.6	0.01	0.10
CANADA	1,121,273,000	0.10	112,127,300	764,252,210.3	0.2	152,850,442.1	0.01	2.65

[1] Spearin and O'Connor, 1991.
[2] IPCC/OECD,1996a; (Table 4-A).
[3] Based from Statistics Canada, 1993.
[4] IPCC/OECD,1996b; (Table 4-17).
[5] IPCC/OECD,1996b; (Table 4-18).

Tables 10 and 11 summarize the N₂O emissions from N leaching and runoff (columns I-M). Canada contributed a total of 14.56 Gg N₂O-N/yr and 14.14 Gg N₂O-N/yr from N leaching and runoff in 1986 and 1991, respectively. The highest indirect emissions from N leaching and runoff were from the province Alberta. Total indirect N₂O emissions for 1986 (27.10 Gg N₂O) are slightly higher compared to the emissions for 1991 (26.39 Gg N₂O). This is consistent with the estimates from nitrogen fertilizers and nitrogen from animal manures.

Table 10. Indirect N₂O emissions from N leaching in 1986

Province	I Synthetic Fertilizer Used, $N_{(fert)}$[1] (kg N/yr)	J Livestock N Excretion $N_{(NEX)}$[2] (kg N/yr)	K Frac$_{(LEACH)}$[3] (kg N/kg N) Default Values (Table 4-17)	L Emission Factor[4] EF_5 Default Values (Table 4-18)	M N₂O Emissions From Leaching (Gg N₂O-N/yr) M=(I+J)xKxLx 10⁻⁶	N Total Indirect N₂O Emissions (Gg N₂O/yr) N=(H+M)[44/28]
Atlantic Prov.		27,799,299.6	0.3	0.025	0.21	0.42
Quebec	89,443,000	140,752,959.8	0.3	0.025	1.73	3.30
Ontario	219,446,000	185,561,727.8	0.3	0.025	3.04	5.70
Manitoba	235,960,000	66,837,533.4	0.3	0.025	2.27	4.15
Saskatchewan	317,600,000	93,879,614.2	0.3	0.025	3.09	5.64
Alberta	308,908,000	182,179,889.6	0.3	0.025	3.68	6.85
B. C.	33,537,000	39,957,643.4	0.3	0.025	0.55	1.04
CANADA	1,204,894,000	736,968,667.8	0.3	0.025	14.56	27.10

[1] Spearin and O'Connor, 1991.
[2] Based from Statistics Canada, 1993.
[3] IPCC/OECD, 1996b; (Table 4-17).
[4] IPCC/OECD, 1996b; (Table 4-18).

Table 11. Indirect N$_2$O emissions from N leaching in 1991

	I	J	K	L	M	N
	Synthetic Fertilizer Used, N$_{(fert)}$[1] (kg N/yr)	Livestock N Excretion N$_{(NEX)}$[2] (kg N/yr)	Fraction of N that Leaches Frac$_{(LEACH)}$[3] (kg N/kg N)	Emission Factor[4] EF$_5$	N$_2$O Emissions From Leaching (Gg N$_2$O-N/yr)	Total Indirect N$_2$O Emissions (Gg N$_2$O/yr)
Province			Default Values (Table 4-17)	Default Values (Table 4-18)	M=(I+J)xKxL x10^{-4}	N=(H+M)[44/28]
Atlantic Prov.		25,850,074.2	0.3	0.025	0.19	0.38
Quebec	91,760,000	128,130,397.8	0.3	0.025	1.65	3.14
Ontario	174,860,000	175,319,186.0	0.3	0.025	2.63	4.95
Manitoba	254,903,000	67,880,745.5	0.3	0.025	2.42	4.42
Saskatchewan	226,396,000	105,669,484.1	0.3	0.025	2.49	4.60
Alberta	328,301,000	222,642,739.7	0.3	0.025	4.13	7.71
B. C.	21,791,000	38,759,582.9	0.3	0.025	0.45	0.87
CANADA	1,121,273,000	764,252,210.3	0.3	0.025	14.14	26.39

[1] *Spearin and O'Connor, 1991.*
[2] *Based from Statistics Canada, 1993.*
[3] *IPCC/OECD, 1996b; (Table 4-17).*
[4] *IPCCOECD, 1996b; (Table 4-18).*

3.4 Estimates of Total N$_2$O Emissions from Agricultural Soils

The estimated total N$_2$O emissions from agricultural soils are summarized in Table 12. The most significant emissions were from the direct emissions from soils, which contain more than half of total emissions. Nitrous oxide emissions from agricultural soils contributed a total of ~ 86.37 Gg N$_2$O in 1986 and ~ 85.79 Gg N$_2$O in 1991. Alberta contributed most to the total N$_2$O emissions from agricultural soils followed by Ontario and Saskatchewan.

Table 12. Total N$_2$O emissions from agricultural soils by province in 1986 and 1991

Province	A Direct Emissions from soils (Gg)		B Direct Emissions from Grazing Animals (Gg)		C Indirect Emissions NH$_3$ & NO$_x$; Leaching (Gg)		D Total N$_2$O Emissions (Gg) D=A+B+C	
	1986	1991	1986	1991	1986	1991	1986	1991
Atlantic Provinces	0.59	0.52	0.24	0.24	0.42	0.38	1.25	1.14
Quebec	4.18	4.34	0.74	0.72	3.30	3.14	8.22	8.20
Ontario	11.90	11.57	1.78	1.68	5.70	4.95	19.38	18.20
Manitoba	6.60	7.76	1.05	1.04	4.15	4.42	11.8	13.20
Saskatchewan	11.78	9.66	2.04	2.25	5.64	4.60	19.46	16.50
Alberta	10.69	12.62	3.76	4.69	6.85	7.71	21.3	25.02
B. C.	1.38	1.15	0.60	0.55	1.04	0.87	3.02	2.57
CANADA	49.06	48.24	10.21	11.16	27.10	26.39	86.37	85.79

The total N$_2$O emissions occurring in eastern and western Canada are shown in Figures 2a and b. The emissions are given Gg of N$_2$O at the scale of the Soil Landscape of Canada (SLC) polygon level. These are stratified into major soil zones and textural classes.

The relative changes in N$_2$O emissions on a provincial basis for 1986 to 1991 are shown in Figure 3. These values depend of the amount and type of agriculture
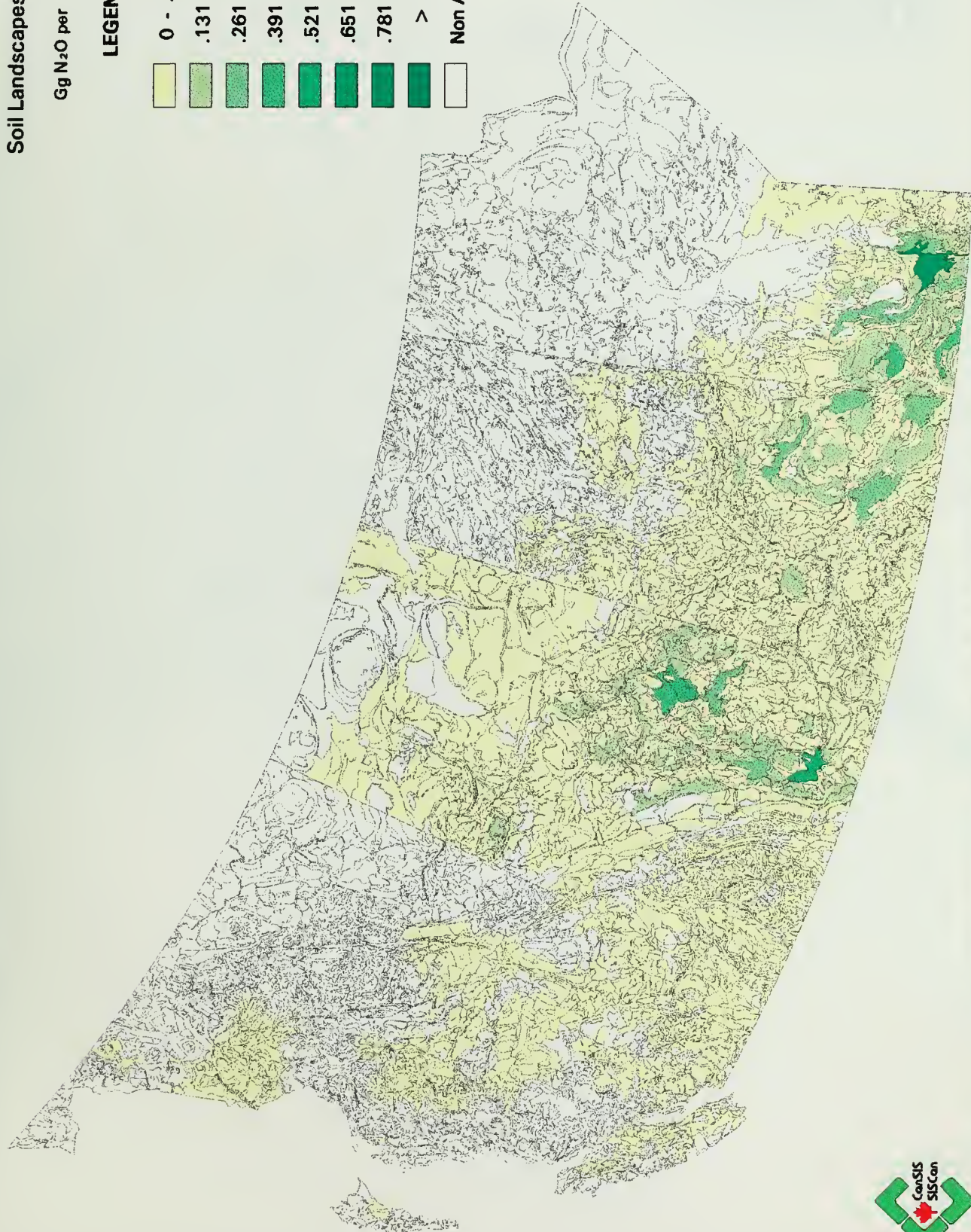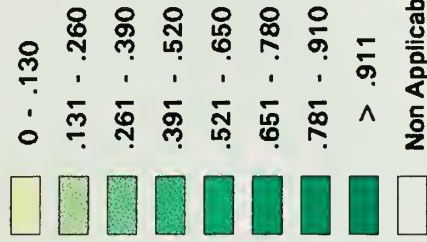
WESTERN CANADA

TOTAL N₂O

Soil Landscapes of Canada

Gg N₂O per polygon

LEGEND

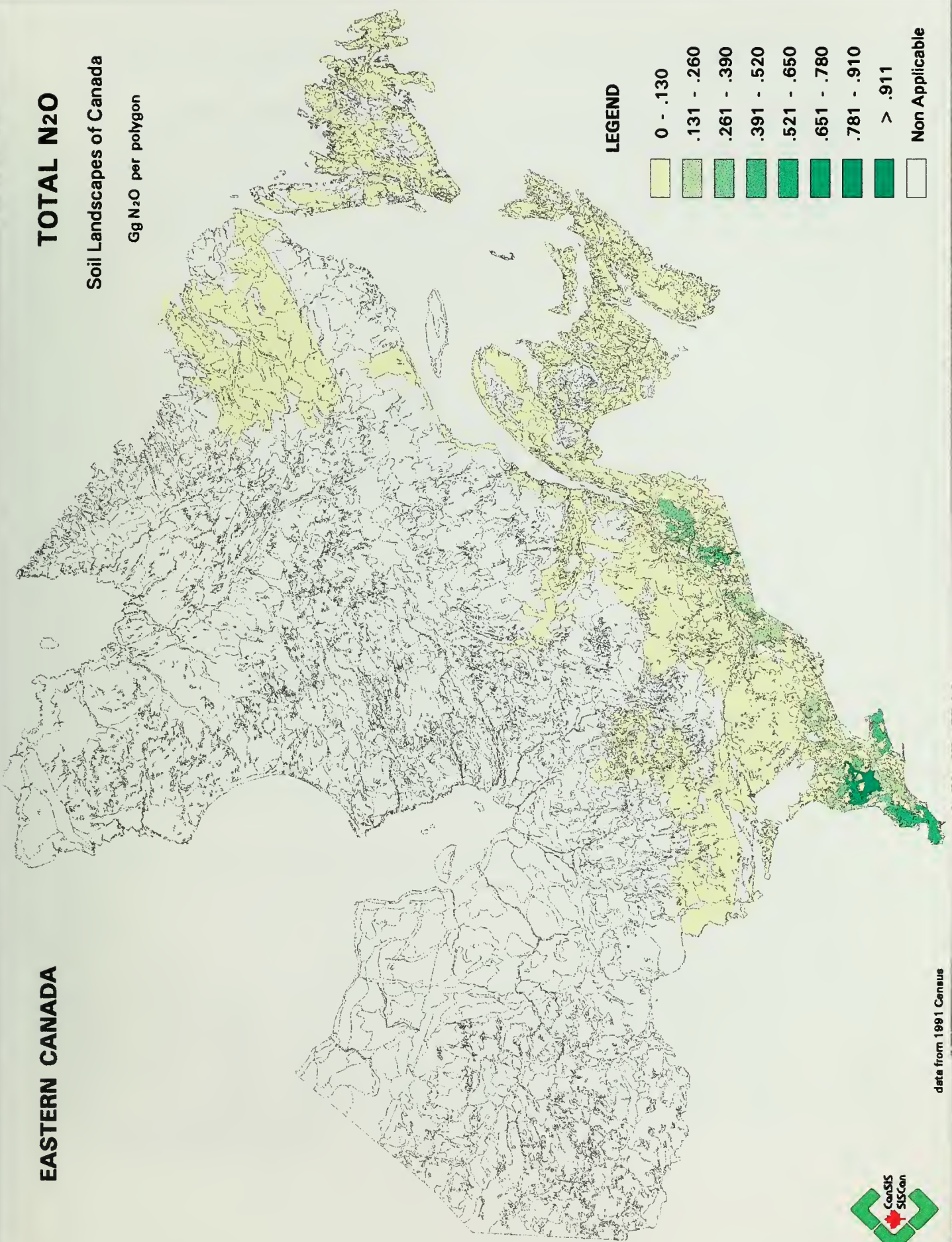|	
	0 - .130
	.131 - .260
	.261 - .390
	.391 - .520
	.521 - .650
	.651 - .780
	.781 - .910
	> .911
	Non Applicable

data from 1991 Census

CanSIS
SISCan

EASTERN CANADA

TOTAL N2O

Soil Landscapes of Canada

Gg N2O per polygon

LEGEND

	0 - .130
	.131 - .260
	.261 - .390
	.391 - .520
	.521 - .650
	.651 - .780
	.781 - .910
	> .911
	Non Applicable

data from 1991 Census

CanSIS
SISCan

practiced in each of the provinces. Ontario, Saskatchewan and Alberta have the highest N$_2$O emissions, but they also have the largest agricultural regions.

The only increases in total N$_2$O emissions from agricultural soils between 1986 and 1991 were in Manitoba and Alberta. This is perhaps because these provinces were the only two to increase fertilizer applications (F_{SN}) between 1986 and 1991 (Tables 5 and 6). The largest decrease in total emissions from soils was in Saskatchewan. This is largely due to a decrease in most sources contributing to direct N$_2$O emissions from agricultural soils (also Tables 5 and 6).
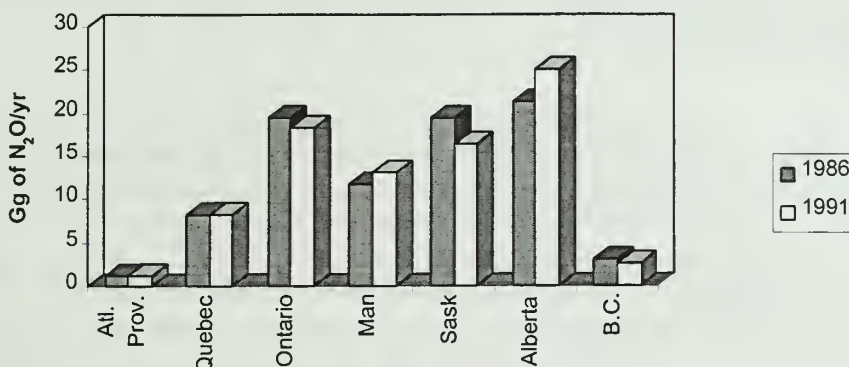
Figure 3. Total N$_2$O emissions from agricultural soils by province in 1986 and 1991

3.5 Estimates of N$_2$O Emissions from other Sources

Tables 13 and 14 present the N$_2$O emissions from the different animal waste management systems (AWMS). About 4.32 Gg and 4.43 Gg of N$_2$O in 1986 and 1991 respectively, were emitted from this source. The highest contributions were from Ontario (1.18 Gg N$_2$O) in 1986 and Alberta (1.12 Gg N$_2$O) in 1991.

Table 13. Total N$_2$O emissions from animal waste management systems by province in 1986

Province	A Nitrogen Excretion N$_{(NEX)\ (AWMS)}$ (kg N/yr) [1]				B Emission Factor for AWMS (EF3)[2] (Kg N$_2$O-N/kg N)				C Annual N$_2$O Emissions (Gg)
	AL	LS	SSD	OS	AL	LS	SSD	OS	C = (A x B) x [44/28] x 10^{-6}
Atlantic Prov.	1,262.3	4,977.6	81,464.0	27,242.2	0.001	0.001	0.02	0.005	0.18
Quebec	6,436.9	35,572.0	481,364.7	94,230.6	0.001	0.001	0.02	0.005	0.97
Ontario	6,515.2	36,501.9	571,220.6	134,200.6	0.001	0.001	0.02	0.005	1.18
Manitoba	912.5	10,265.8	197,879.9	27,228.6	0.001	0.001	0.02	0.005	0.37
Saskatchewan	783.5	6,628.6	270,469.2	18,939.5	0.001	0.001	0.02	0.005	0.47
Alberta	2,045.7	15,519.8	527,862.8	42,956.9	0.001	0.001	0.02	0.005	0.92
B. C.	1,247.5	3,811.5	107,789.3	34,424.5	0.001	0.001	0.02	0.005	0.23
CANADA	19,203.5	113,277.2	2,238,050.5	379,222.9	0.001	0.001	0.02	0.005	4.32

[1] *Based from Statistics Canada, 1993.*
[2] *IPCC/OECD, 1996b; Table 4-8.*

Table 14. Total N$_2$O emissions from animal waste management systems by province in 1991

Province	A Nitrogen Excretion N$_{(NEX) (AWMS)}$ (kg N/yr)[1]				B Emission Factor for AWMS (EF3)[2] (kg N$_2$O-N/kg N)				C Annual N$_2$O Emissions (Gg)
	AL	LS	SSD	OS	AL	LS	SSD	OS	C = (A x B) x [44/28] x 10^{-6}
Atlantic Prov.	1,197.4	4,207.8	74,862.9	26,183.6	0.001	0.001	0.02	0.005	0.17
Quebec	6,001.1	30,925.2	432,024.5	560,558.4	0.001	0.001	0.02	0.005	0.88
Ontario	6,498.9	33,562.8	532,541.3	708,383.2	0.001	0.001	0.02	0.005	1.11
Manitoba	1,010.4	10,732.5	201,594.2	241,573.7	0.001	0.001	0.02	0.005	0.38
Saskatchewan	1,171.1	7,989.6	308,989.3	338,165.0	0.001	0.001	0.02	0.005	0.53
Alberta	2,948.7	17,266.6	648,217.5	715,140.1	0.001	0.001	0.02	0.005	1.12
B. C.	1,407.8	3,583.2	101,272.7	145,762.2	0.001	0.001	0.02	0.005	0.23
CANADA	**20,235.4**	**108,267.7**	**2,299,502.5**	**2,816,034.4**	0.001	0.001	0.02	0.005	**4.43**

[1] Based from Statistics Canada,1993.
[2] IPCC/OECD, 1996b; Table 4-8.

Table 15 shows the N$_2$O contribution from human sewage. This is a minor source and the emissions are directly related to population density.

Table 15. N$_2$O emissions from human sewage by province in 1986 and 1991

Province	A Total Population[1]		B Annual per capita Protein Consumption (kg/person/yr)	C Fraction of nitrogen in protein (kg N/kg of protein)[2]	D Default Emission Factor for Indirect Emissions kg N O-N/kg sewage-N produced[3] EF$_6$	E Total Nitrous Oxide Emissions (Gg) E=A*B*C*D*10^{-10} * (44/28)	
	1986	1991	37.23	0.16	0.01	1986	1991
Atlantic Prov.	2,277,613	2,322,349	37.23	0.16	0.01	0.21	0.22
Quebec	6,532,461	6,896,000	37.23	0.16	0.01	0.61	0.65
Ontario	9,101,694	10,085,000	37.23	0.16	0.01	0.85	0.94
Manitoba	1,063,016	1,092,000	37.23	0.16	0.01	0.10	0.10
Saskatchewan	1,009,613	989,000	37.23	0.16	0.01	0.09	0.09
Alberta	2,365,825	2,546,000	37.23	0.16	0.01	0.22	0.24
B. C.	3,282,061	3,282,000	37.23	0.16	0.01	0.31	0.31
CANADA	**25,309,331**	**27,297,000**	37.23	0.16	0.01	**2.37**	**2.56**

[1] Estimated from 1991 Population; Statistics Canada Cat. No. 93-304.
[2] IPCC/OECD, 1996a; Table 4-24.
[3] IPCC/OECD, 1996b; Table 4-18.

3.6 Estimates of Total N2O Emission from Agriculture

A summary of the N$_2$O emissions from various agricultural sources and the total agricultural N$_2$O emissions for Canada is shown in Figure 4, for the years 1986 and 1991.
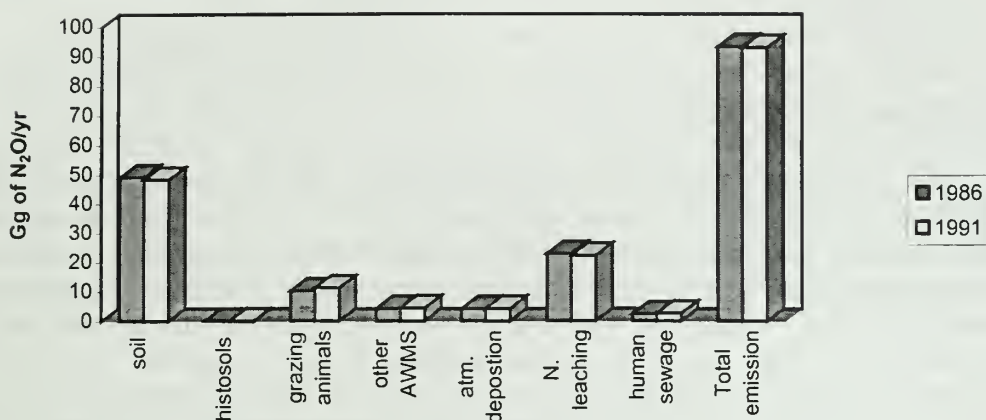
Figure 4. Total N$_2$O emissions for Canada in 1986 and 1991

Total N$_2$O emissions in Canada decreased between 1986 and 1991, from 86.37 and 85.79 Gg (Table 12). The largest contributors were (in descending order of magnitude) from direct emissions from agricultural soils, N leaching and grazing animals. Out of these, only N$_2$O emissions from grazing animals increased between 1986 and 1991.

The total national N$_2$O emissions can be expressed in CO$_2$ equivalency (using the 100 year GWP Time Horizon) as 26774.7 Gg CO2 equivalent in 1986 and 26594.9 Gg CO$_2$ equivalent in 1991.

4.0 Summary and Conclusion

This report presents an estimate of the N$_2$O emissions from agricultural sources in Canada, using the 1996 Revised IPCC/OECD methodologies for 1986 and 1991. The direct emissions from agricultural soils represent about half of the total emissions. This corresponds to 49.06 Gg N$_2$O in 1986 and 48.24 Gg N$_2$O in 1991. Crop residues (37%) and N fertilizers (31%) were the most important sources of direct emissions. The relative importance of N$_2$O emissions among the five direct sources is: crop residues, N fertilizers, animal wastes, biological nitrogen-fixing crops, and histosols. The estimated emissions from grazing animals accounted for 10.21 Gg N$_2$O and 11.16 Gg N$_2$O in 1986 and 1991, respectively. Higher emissions were found in Alberta where the largest concentration of grazing cattle is found. Emissions from animal wastes during storage were about 4.32 Gg N$_2$O and 4.43 Gg N$_2$O in 1986 and 1991 respectively. Emissions from human sewage were about 2.37 Gg N$_2$O (1986) and 2.56 Gg N$_2$O (1991).

Overall, N$_2$O emissions were higher in Alberta, Ontario and Saskatchewan. These are proportional to the level of agricultural activity found in these provinces. Agricultural soils in Canada contributed a total of ~ 86.37 Gg N$_2$O in 1986 and ~ 85.79 Gg N$_2$O in 1991.

The results calculated in this report do not take into account any N_2O emissions produced from fossil fuel consumed on the farm. Liu (1995) estimated that about 2 Gg of N_2O was emitted in 1986 and 1991 from this source.

5.0 Future Undertakings

It is well recognized that the methodology used in this report still has many limitations. Although the results provide a good indication of the magnitude of emissions from the various agricultural sources, this report does not take into account environmental conditions that might have considerable influence on the interannual variations of N_2O emissions. As well, the emission factors are still highly uncertain because of the high degree of spatial variation of N_2O emissions. Results from the inventory will soon be compared to model results obtained using the DNDC model recently developed by Li *et al.* (1994). Field measurements using enclosures and tunable diode are presently being collected. These studies should provide emission factors that are more representative of conditions across Canada.

List of Figures

Lists of Tables

References

Angers, D.A., and A. N'Dayegamiye. 1991. Effects of manure application on carbon, nitrogen and carbohydrate contents of a silt loam and its particle-size fractions. *Biol. Fert. Soils.* **11**:79-82.

Asselstine, A., and L. Girard. 1992. Canadian fertilizer consumption, shipments and trade, 1990/1991. Farm Development Policy Directorate. Farm input markets unit, Agriculture Canada.

Batjes, N.H., and E.M. Bridges. 1992. World environment of soil emissions. International Soil Reference and Information Centre, Wageniger, Germany, p. 204.

Blevins, R.L., and W.W. Frye. 1993. Conservation tillage in soil management. *Adv. Agron.* **51**:33-78.

Bouwman, A.F. 1990. Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. *In* A.F. Bouwman (ed.), Soils and greenhouse effect. John Wiley and Sons, N.Y., p. 61-127.

Bouwman, A.F. 1996. Direct emission of nitrous oxide from agricultural soils. Nutrient cycling of agroecosystems. Kluwer Academic Publishers, **46**:53-70.

Bremmer, J.M. and A.M. Blackmer. 1978. Nitrous Oxide: Emission from soils during nitrification of fertilizer nitrogen. *Science* **199**:295-296.

Byrnes, B.H., C.B. Chritianson, L.S. Holt and E.R. Austin. 1990. Nitrous Oxide emissions from the nitrification of nitrogen fertilizer. p. 489-495. *In* A.F. Bouwman (ed.), Soils and greenhouse effect: the present status and future trends concerning the effects of soils and their cover on the fluxes of greenhouse gases, the surface energy balance and the water balance. John Wiley and Sons, Chester, England.

Collins, H.P., P.E. Rasmussen, & C.L. Douglas Jr. 1992. Crop rotation and residue management effects on soil carbon and microbial dynamics. *Soil Sc. Soc. Am. J.* **56**:783-788.

Culley, J.L.B., and G.M. Barnett. 1984. Land Disposal of Manure in the Province of Quebec. *Canadian Journal of Soil Science.* **64**:75-86.

Czepiel, P., P. Crill, and R. Harriss. 1995. Nitrous oxide emissions from municipal wastewater treatment. *Environ. Sci. Technol.* **29**:2352-2356.

Duxbury, J.M., L.A. Harper and A. R. Mosier. 1993. Contribution of agroecosystems to global climate change. p. 1-18. *In* L.A. Harper, A. R. Mosier, J.M. Duxbury and D.E. Rolston (eds.) Agricultural ecosystem effects on trace gases and global climate change. *Amer. Soc. Agron.* Publication No 55.

Eck, H.V., and B.A. Stewart. 1996. Manure: soil amendments and environmental quality. Agriculture and environment series.

Eichner, M.J. 1990. N_2O emissions from fertilized soil: summary of available data. *J. Environ. Qual.* **19**:272-280.

FAO. 1990b. FAO statistics series No. 94. Food and Agricultural Organization of the United Nations. Production Yearbook, Rome, Italy.

Flessa, H., P. Dorch, and F. Beese. 1995. Nitrous oxide emissions from cattle excretion, pasture land: a global inventory.

Hemond, H.F., and A.P. Duran. 1989. Fluxes of N_2O at the sediment - water and water-atmosphere boundaries of a nitrogen-rich river. *Wat. Resour. Res.* **25**:839-846.

IPPC.1996. The science of climate change: summary for policymakers. Technical summary of the working group 1 report, p.1-56.

IPCC/OECD. 1996a. Guidelines for national greenhouse gas inventories. Reference manual. Chapter 4: agriculture.

IPCC/OECD. 1996b. Guidelines for national greenhouse gas inventories. Workbook. Module 4: agriculture.

Keller, M., and W.A. Reiners. 1994. Soil-atmosphere change of nitrous oxide, nitric oxide, and methane under secondary succession of pasture to forest in the Atlantic lowlands of Costa Rica. *Global Biogeochem. Cyc.* **8**:399-409.

Lessard, R., P. Rochette, E.G Gregorich, E. Pattey and R.L Desjardins. 1993. Increases in N_2O fluxes resulting from manure amendments on a maize soil. Centre for Land and Biological Resources Research, Agriculture and Agri-Food Canada, Research Branch, Ottawa.

Levesque, M. 1982. Overview of the Agricultural Peatlands in Canada. A Symposium on Peat and Peatlands, 12-15 September.

Li, C., S.E. Frolking, R.C. Harriss, and R.E. Terry. 1994. Modeling nitrous oxide emissions from agriculture. *Chemosphere,* **28**:1401-1415.

Liu, J. 1995. Preliminary estimate of the greenhouse gas balance for agroecosystems in Canada in 1991. Internal report of Agriculture and Agri-Food Canada, p.1-21.

Mosier, A. R. 1993. Nitrous oxide emission from agricultural soils. *In*: Methane and nitrous oxide, methods in national emissions inventories and options for control. Proceedings of the International IPCC workshop, National Institute of Public Health and Environmental Protection, The Netherlands, 3-5 Februrary, p 273-285.

Safley, L.M., M.E. Casada, J.W. Woodbury, and K.F. Roos. 1992. Global methane emissions from livestock and poultry manure. US Environmental Protection Agency, Global Change Division, Washington, D.C., February 1992. EPA/400/1091/048.

Spearin, M., and K. O'Connor. 1991. Canadian Fertilizer Consumption, Shipments and Trade, 1989/1990. Farm Development Policy Directorate, Input industries and markets section, Agriculture Canada.

Statistics Canada. 1994. Canadian agriculture at a glance. Statistics Canada Cat. No. 96-301.

Statistics Canada. 1993. Livestock and animal products section: Livestock statistics. Statistics Canada Cat. No. 23-603E.

Statistics Canada . 1992. Agricultural profile of Canada part 1. Statistics Canada Cat. No. 93-350.

Statistics Canada. 1991. Human activity and the environment 1991. Statistics Canada Cat. No. 11-509E Occasional.

Walsh, L.M. 1973. Soil and applied nitrogen,. Ext. fact sheet. 2519, University of Winconsin, Madison.