AGRI-ENVIRONMENTAL INDICATOR PROJECT

Agriculture and Agri-Food Canada

REPORT NO. 21

AGROECOSYSTEM GREENHOUSE GAS BALANCE INDICATOR: METHANE COMPONENT

Technical Report: Net Methane Emissions from Agroecosystems in Canada for the Years 1986 and 1991

R.L. Desjardins, Agriculture and Agri-Food Canada
S.P. Mathur, Consultant

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 methane 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

Methane emissions from agroecosystems in Canada were estimated for 1986 and 1991. The principle source of CH_4 was from livestock production. According to these estimates, farm animals produced about 639 kt of CH_4 during 1986 and 681 kt of CH_4 during 1991. An additional 203 and 209 kt of CH_4 were also emitted from animal manures in 1986 and 1991, respectively. The regional magnitude of these sources is presented in kg CH_4/km^2 for both eastern and western Canada. Agricultural soils, which can either be a source or a sink of CH_4 depending on the soil moisture conditions, were estimated to emit about 12 kt CH_4/yr and absorb 7 kt CH_4/yr. Burning of fossil fuels on farms produced about 1 kt CH_4/yr. Overall, the net CH_4 emissions from agroecosystems during 1986 and 1991 were estimated to be 848 kt and 896 kt, respectively. For a 100 year time horizon, the total CH_4 emissions during 1986 and 1991 were equivalent to 17.8 and 18.8 million tonnes of CO_2, respectively.

1.0 Introduction

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) gases are all natural components of the atmosphere that trap heat radiated from Earth. This process is referred to as the greenhouse effect. Under natural emissions and removal processes, the concentration of these gases should be relatively constant. However, in the last century, human-induced activities have significantly altered the atmospheric concentration of these gases.

Since 1750, the atmospheric concentration of CO_2 has increased by 30%, N_2O by 15% and CH_4 by 145% (IPCC, 1996). The sharp rise of CH_4 is of particular concern because on a kg for kg basis, CH_4 is considerably more potent as a greenhouse gas than CO_2. This is due to the type of radiation trapped by CH_4, and its important role in atmospheric chemistry. Methane is estimated to be responsible for 15-18% of present global warming, second only to CO_2 whose contribution is estimated at 55-60%. However, the concentration of CH_4 is increasing at a higher annual rate (0.6%) than that of CO_2 (0.4%). With this rate of increase and its many indirect effects, CH_4 is predicted to become even more important in its potential for global warming.

Human activities are responsible for 64% of the total annual emissions of CH_4 (Duxbury *et al.*, 1993), while only 3% of the CO_2 emissions are anthropogenic. On a global basis, agriculture contributes 26% to the anthropogenic emissions of CO_2, which are produced mainly from fossil fuels, while it is responsible for 65% of the anthropogenic CH_4 emissions. Of these, approximately one-quarter have been estimated to originate from livestock operations.

It is predicted that a reduction of anthropogenic CH_4 emissions by 10% would stop the rise in the atmospheric level of CH_4. Since CH_4 has a relatively short atmospheric lifetime (about 11 years), a reduction in CH_4 emissions would help mitigate global warming relatively quickly (Williams, 1994). By contrast, reductions of 50 to 100% would be necessary to prevent increases in other greenhouse gases with longer atmospheric lifetimes.

Presently, there are an estimated 4850 Tg (1 Tg = 10^{12} g) of CH_4 in the atmosphere, corresponding to a concentration of 1721 ppbv. Sources contribute an estimated 535 Tg per year, whereas sinks account for the removal of an estimated 560 Tg per year (Prather *et al.*, 1996). This implies that either there are unknown or underestimated sources, or overestimated sinks, which must be better defined if the estimated yearly increase of 37 Tg in the atmosphere is to be explained.

This report presents an estimate of the 1986 and 1991 net CH_4 emissions from agroecosystems in Canada. Its focus is on the CH_4 emissions from farm animals and their manure, but the exchange of CH_4 with respect to agricultural soils is also discussed.

2.0 Methane from Animals

On a global scale, enteric fermentation by ruminants accounts for the input of an estimated 80 Tg of CH_4 into the atmosphere per year (Watson *et al.*, 1992), of which domestic cattle contribute about 85%. The primary products of fermentation in the rumen are volatile fatty acids, propionic and butyric, as well as CO_2 and CH_4. Volatile fatty acids (VFAs) are the major sources of energy for ruminant animals, but they have the inescapable consequence of generating CH_4 (McAllister *et al.*, 1997). Methane production can be decreased by promoting a shift in the rumen toward propionic acid generation. However, the production of VFAs cannot be completely eliminated without compromising the animal's capacity to convert forages and grains to meat and milk.

Factors that influence ruminal CH_4 production include the type of feed, level of feed intake and the variation of feed. For example, the CH_4 yield from ruminal fermentation of legume forage tends to be lower than the yield from grass forage. Generally, it was found that when the feed intake was increased, the percentage of dietary energy lost as CH_4 decreased (Johnson and Johnson, 1995). The addition of ionophores may also decrease CH_4 loss. Ionophores are compounds that facilitate the transport of ions across a lipid membrane by making the membrane more permeable. Ionophores, such as monensin, reduce feed intake by 5-6%, and thus decrease CH_4 losses. However, these effects are short-lived and are likely to be related to the reduction in feed intake rather than to any effects on biomethanogenesis (Johnson *et al.*, 1994). All properties of the forage that decrease the rate of digestion or prolong the residence time of feed within the rumen, generally increase the CH_4 produced per unit of forage digested.

Other factors that affect the rate of CH_4 production include ambient temperature and the digesta passage rate. McAllister *et al.* (1997) observed a decrease of 20% in the CH_4 production of adult sheep when the ambient temperature was lowered from 33 C to 8 C. Unlike temperature, an inverse relationship exists between CH_4 production and digesta passage rates. Methane emissions decreased 29% when the fractional passage rate of particulate matter was increased 63% in steers (McAllister *et al.*, 1997).

Methane emitted by exhalations and eructations from animals is difficult to measure because it varies between individual cows, and according to the type of feed. Enzymes, inhibitors and antibiotics also affect CH_4 generation. The CH_4 emission per head per year depends on the breeds and lines of cattle, the live weight, the rate of weight gain, the level of exercise and age of the animal. These factors must all be taken into account in order to obtain an accurate estimation of the CH_4 produced from farm animals.

2.1 The Empirical UK - OECD Approach

A working group within the Organization for Economic Co-operation and Development (OECD) developed broad guidelines to estimate greenhouse gas emissions for large groups of animals (IPCC/OECD, 1994). Based on these guidelines, CH_4 emissions from cattle in the U.K. were estimated to be 64.3 kg CH_4/hd/yr. As can be observed from Table 1, the emission rate for cattle is very dependent on the proportion of the various types of cattle.

2.2 The Detailed Level U.S. - OECD Approach

The U.S. EPA (1994) employed a version of the draft Tier 2 methodology recommended by the IPCC to arrive at a rate of CH_4 emission for cattle of 53.3 kg CH_4/hd/yr (IPCC/OECD, 1994). This value was obtained using a mechanistic model of ruminal digestion and animal production that was applied to thirty-two different diets and nine different cattle types. The cattle types represented different weights, ages, feeding systems and management systems that occur typically in the U.S.

2.3 The Canadian Approach

Methane emissions from animals in Canada, for 1986 and 1991, were calculated using the livestock inventory data from Statistics Canada (1993), and are shown on a provincial basis in Tables 2 and 3. The estimated CH_4 emission rates from livestock used to calculate the CH_4 emissions are shown in Table 1. Based on recent studies in Canada, these numbers might be slightly underestimated, but the actual emissions are most likely within the range of errors that the measurements have reported.

Table 1. Estimated CH_4 emission rates from farm animals in Canada for 1986 and 1991

Animals	Emission rates (kg/hd/yr)	
Dairy Cattle	91.2	
Beef Cattle	57.3	
Slaughter Cattle	43.0	
Calves	29.1	
Total Cattle	52.4 (1986)	51.2 (1991)
Hogs	1.6	
Poultry	0.005	
Sheep and Lambs	7.0	

Table 2. Methane emissions from various farm animal types by province in 1986

Provinces	Dairy Cattle		Non-Dairy Cattle		Hogs		Poultry		Sheep/Lambs		Total Livestock	
	Pop. [1] (10^3)	CH_4 (kt/yr)	Pop. [1] (10^3)	CH_4 (kt/yr)	Pop. [1] (10^3)	CH_4 (kt/yr)	Pop. [1] (10^3)	CH_4 (kt/yr)	Pop. [1] (10^3)	CH_4 (kt/yr)	Pop. [1] (10^3)	CH_4 (kt/yr)
Atl. Prov.	125.8	11.5	220.9	9.4	373.0	0.6	7280.9	0.04	61.2	0.4	7840.9	21.9
Quebec	830.0	75.7	676.0	27.2	2927.0	4.7	20503.4	0.10	112.5	0.8	24372.9	108.5
Ontario	723.0	65.9	1661.0	69.8	3172.0	5.1	32008.2	0.16	205.5	1.4	36108.7	142.4
Manitoba	94.5	8.6	996.5	44.2	1089.0	1.7	6298.1	0.03	22.6	0.2	7504.2	54.7
Sask.	73.5	6.7	1962.5	87.9	608.0	1.0	3769.7	0.02	53.0	0.4	4504.1	96.0
Alberta	175.0	16.0	3571.0	159.5	1508.0	2.4	8852.4	0.04	183.6	1.3	10719.0	179.2
B.C.	113.0	10.3	564.5	25.0	214.3	0.3	9229.5	0.05	56.5	0.4	9613.3	36.1
Canada	2134.8	194.7	9652.4	423.0	9891.3	15.8	87942.2	0.44	694.9	4.9	100663.2	638.8

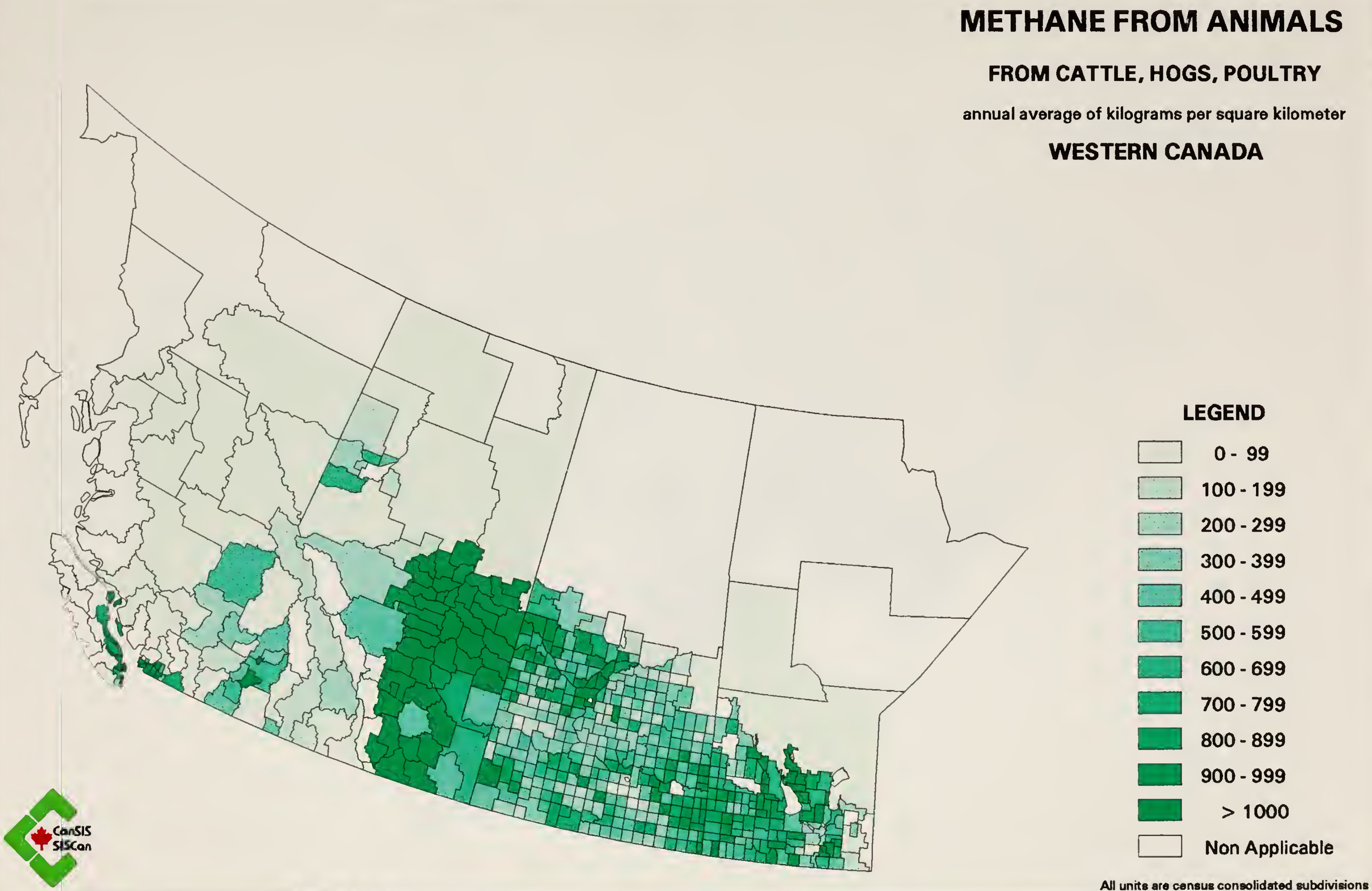
[1] Statistics Canada, 1993;

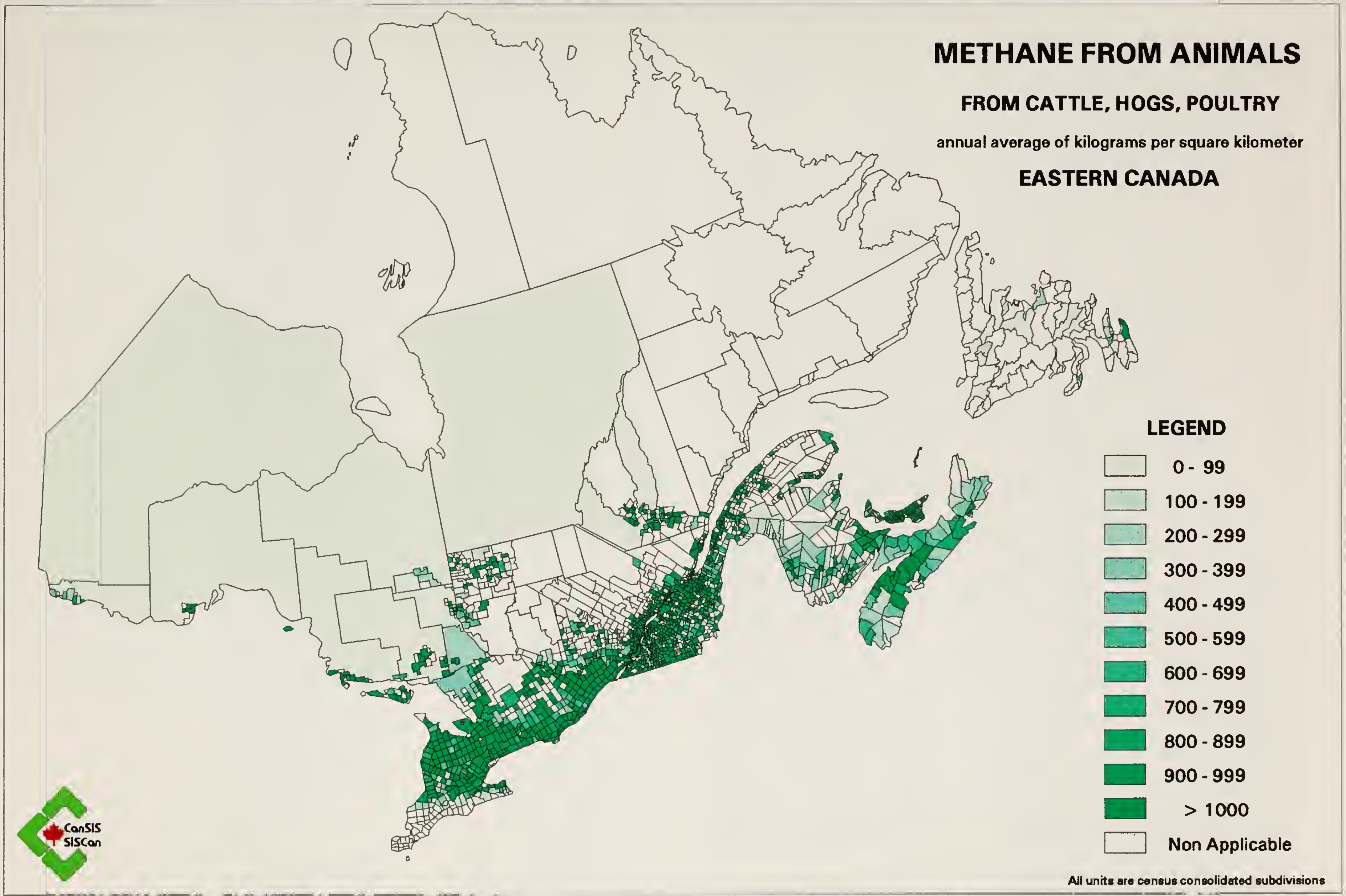
Table 3. Methane emissions from various farm animal types by province in 1991

Provinces	Dairy Cattle		Non-Dairy Cattle		Hogs		Poultry		Sheep/Lambs		Total Livestock	
	Pop.[1] (10^3)	CH_4 (kt/yr)	Pop.[1] (10^3)	CH_4 (kt/yr)	Pop.[1] (10^3)	CH_4 (kt/yr)	Pop.[1] (10^3)	CH_4 (kt/yr)	Pop.[1] (10^3)	CH_4 (kt/yr)	Pop.[1] (10^3)	CH_4 (kt/yr)
Atl. Prov.	110.1	10.0	226.8	9.7	335.5	0.5	7884.3	0.04	61.2	0.4	8610.5	20.7
Quebec	744.0	67.9	694.0	28.2	2997.5	4.8	23386.3	0.12	112.5	0.8	27936.8	101.8
Ontario	671.0	61.2	1604.0	68.1	2960.0	4.7	37632.2	0.19	205.5	1.8	43117.2	136.0
Manitoba	80.0	7.3	1015.0	45.3	1310.0	2.1	7172.7	0.04	22.6	0.2	9612.7	54.9
Sask.	62.0	5.7	2217.0	99.7	843.0	1.3	3969.4	0.02	53.0	0.6	7183.4	107.3
Alberta	152.0	13.9	4519.0	201.9	1760.0	2.8	9664.2	0.05	183.6	`2.1	16394.2	220.7
B.C.	111.0	10.1	637.0	28.3	238.5	0.4	12253.2	0.06	56.5	0.5	13312.7	39.4
Canada	1930.1	176.1	10912.8	481.2	10444.5	16.6	101962.2	0.52	694.9	6.4	126167.4	680.8

[1] Statistics Canada, 1993;

Figure 1a shows the CH_4 emitted in kg CH_4/km^2 by cattle, hogs and poultry in western Canada during 1991. The highest emissions were in the province of Alberta. The prairie provinces accounted for more than half the cattle in Canada that year (Dyer, 1995). Figure 1b shows the CH_4 emitted by cattle, hogs and poultry in eastern Canada during 1991, with the highest emissions in southern Ontario and Quebec.


METHANE FROM ANIMALS
FROM CATTLE, HOGS, POULTRY
annual average of kilograms per square kilometer
WESTERN CANADA
LEGEND
0 - 99
100 - 199
200 - 299
300 - 399
400 - 499
500 - 599
600 - 699
700 - 799
800 - 899
900 - 999
> 1000
Non Applicable
All units are census consolidated subdivisions
CanSIS
SISCan


METHANE FROM ANIMALS
FROM CATTLE, HOGS, POULTRY
annual average of kilograms per square kilometer
EASTERN CANADA
LEGEND
0 - 99
100 - 199
200 - 299
300 - 399
400 - 499
500 - 599
600 - 699
700 - 799
800 - 899
900 - 999
> 1000
Non Applicable
All units are census consolidated subdivisions
CanSIS
SISCan

Several studies have been carried out in Canada in recent years to quantify CH_4 emissions from animals. A 120-head dairy barn, located near Ottawa, Canada, was modified and effectively transformed into a large laboratory in which CH_4 production from cows was monitored on a continuous basis for about three years. This approach kept the animals in their accustomed environment, eliminating the stress associated with placement in special respiratory chambers. Over a three year period the mean 24-hr CH_4 emission per cow was 561± 72 L CH_4 d^{-1} cow^{-1}. This is equivalent to 137 ± 18 kg CH_4/hd/yr (Kinsman *et al.*, 1995). This value is considerably larger than the value of 91.2 used by other groups (Table 1). Similar numbers to those obtained by Kinsman *et al.* (1995) have been obtained by Schuepp *et al.* (1997) during July and August 1996, by measuring concentration profiles of CH_4 and SF_6 downwind of a dairy barn housing lactating cows and a feedlot/paddock housing dry holstein heifers.

Other techniques have been developed to measure CH_4 production for free ranging animals, notably the simultaneous release of SF_6 in the rumen of the animal (Johnson *et al.,* 1994; McCaughey *et al.,* 1997). The eructed gases are collected at the mouth of the steer into an evacuated flask which is hung around the neck of the animal during an 8- to 24-hour period, and subsequently analysed for CH_4 and SF_6. Methane emissions were estimated at an average of 270 L CH_4 d^{-1} $animal^{-1}$ (66 kg/hd/yr) under Canadian conditions for an average 400 kg steer (McCaughey *et al.,* 1997). It is estimated that an additional 10% of CH_4 is released by the animal through flatulence.

3.0 Methane from Animal Wastes

The IPCC (1990) Working Group III report has underlined the potential importance of CH_4 emissions from animal wastes, suggesting that under anaerobic waste management systems "uncontrolled" CH_4 emissions from cattle wastes might be of similar magnitude as CH_4 emissions from livestock digestive processes. The potential for CH_4 generation from manure depends on its moisture and the bioavailable carbon content, which in turn is dependent on the type of animal and the nature of its feed.

The CH_4 production factors for Canada, calculated in units of kg CH_4/kg volatile solids (VS), are shown in Table 4. These numbers are based on: (a) standard types of storage and management; (b) the maximum theoretical convertibility of organic carbon in the wastes to CH_4, and; (c) the actual amount of organic matter in the wastes voided by each animal type. Methane production factors were combined with the population of the various animal types to obtain the emission estimates given in Tables 5 and 6.

Table 4. Factors used in the calculation of CH_4 emissions from farm animal manures for 1986 and 1991

Animals	Typical Live Animal Mass[1] (kg)	kg Manure per day / 1000 kg Live Animal Mass [2]	% Volatile Solids[2] (VS)	CH_4 Production Factor [3] (kg CH_4/kg VS)
Bulls	720	58	7.2	0.011
Dairy Cattle	610	86	10.0	0.019
Beef Cattle	500	58	7.2	0.011
Dairy Heifers	360	86	10.0	0.019
Beef Heifers	415	58	7.2	0.011
Heifers for Slaughter	360	58	7.2	0.011
Steers	415	58	7.2	0.011
Calves	180	58	7.2	0.011
Boars and Sows	181	84	8.5	0.043
All Other Hogs	46	84	8.5	0.044
Sheep and Lambs	27	40	9.2	0.019
Chickens	1.15	68	14	0.024

[1] *Taiganides and Stroshine, 1971.*
[2] *U.S. E.P.A, 1994 (Table C-14).*
[3] *Jaques, 1992 (Table 25).*

Table 5. Methane emissions from various farm animal manures in 1986

	Cattle		Hogs		Sheep/ Lambs		Poultry		Total Livestock	
Province	manure (10^3 kt)	CH_4/yr (kt)	manure (10^3 kt)	CH_4/yr (kt)	manure (10^3 kt)	CH_4/yr (kt)	manure (10^3 kt)	CH_4/yr (kt)	manure (10^3 kt)	CH_4/yr (kt)
Atl. Prov	3.72	5.27	0.69	2.57	0.02	0.04	0.21	0.70	4.64	8.58
Quebec	18.40	29.92	5.33	19.81	0.04	0.08	0.59	1.97	24.36	51.78
Ontario	24.10	32.23	5.96	22.10	0.08	0.14	0.91	3.07	31.05	57.54
Manitoba	9.23	9.06	2.02	7.52	0.01	0.02	0.18	0.60	11.44	17.20
Sask.	16.43	14.39	1.16	4.29	0.02	0.04	0.11	0.36	17.72	19.08
Alberta	30.75	27.63	2.83	10.51	0.07	0.13	0.25	0.85	33.90	39.12
B.C.	6.18	6.97	0.40	1.47	0.02	0.04	0.26	0.89	6.86	9.37
Canada	108.81	125.47	18.39	68.26	0.26	0.48	2.51	8.43	129.97	202.67

Table 6. Methane emissions from various farm animal manures in 1991

	Cattle		Hogs		Sheep/Lambs		Poultry		Total Livestock	
Province	manure (10^3 kt)	CH_4/yr (kt)	manure (10^3 kt)	CH_4/yr (kt)	manure (10^3 kt)	CH_4/yr (kt)	manure (10^3 kt)	CH_4/yr (kt)	manure (10^3 kt)	CH_4/yr (kt)
Atl. Prov	3.56	4.81	0.62	2.31	0.02	0.04	0.23	0.76	4.43	7.92
Quebec	17.14	27.36	5.48	20.35	0.05	0.08	0.67	2.24	23.34	50.03
Ontario	22.93	30.42	5.52	20.49	0.10	0.17	1.07	3.61	29.62	54.69
Manitoba	9.12	8.71	2.45	9.09	0.01	0.02	0.28	0.69	11.86	18.51
Sask.	18.21	15.59	1.56	5.80	0.04	0.06	0.11	0.38	19.92	21.83
Alberta	37.65	32.64	3.31	12.29	0.12	0.21	0.28	0.93	41.36	46.07
B.C.	6.70	7.35	0.45	1.66	0.03	0.05	0.35	1.18	7.53	10.24
Canada	115.31	126.88	19.39	71.99	0.37	0.63	2.99	9.79	138.06	209.29

Many factors enter into the interpretation of these data. For example, Casada and Safely (1990) assumed that cold temperatures reduce CH_4 generation from manure by about 20%. However, it must be realized that in cold climates, such as Canada, the storage time is longer than the storage periods in warmer climates. This is because of reduced opportunity for spreading the waste on non-frozen land without a standing crop more than a few inches high. Since it is possible that the stockpiles of manure may warm up to mesophillic temperature (even in the winter), methanogenesis may occur even at these lower temperatures.

Figures 2a and 2b show the CH_4 emitted from cattle, hog and poultry manure for western and eastern Canada in terms of annual averages of kg CH_4/km^2. In 1991, the Prairie provinces were responsible for the production of half of all Canadian manure. However, most of eastern Canada experienced higher manure production per hectare of farmland than western Canada (Dyer, 1995)(Tables 5 and 6). More than 95% of all CH_4 emissions from manure were produced from hogs and cattle.

Manure management is known to affect CH_4 and other greenhouse gas emissions. In a recent study, Pattey *et al.* (1997) showed that manure stored as slurry from dairy and beef cattle produced the highest CH_4 emissions. When dairy cattle manure was composted, the CH_4 emissions from stockpiled manure were reduced at least six-fold. Composting beef manure resulted in even lower CH_4 emissions. Of the total direct contribution of CH_4 from dairy cattle manure, approximately 65% was from slurry, 31% from stockpiled manure and less than 4% from compost. The direct contribution of CH_4 produced from beef manure was slightly different. Over a three month period, the direct CH_4 contribution from slurry was 76%, and after five months it increased to 83%. The direct contribution of CH_4 from stockpiled manure was 16% and less then 1% from compost (Table 7). Before making recommendations based on these emissions, the emissions of other greenhouse gases such as N_2O and CO_2 must also be considered (Monteverde *et al.*, 1997).

Table 7. Methane emissions from manure stored under different conditions

Storage type	CH_4 from Beef Cattle Manure[1]	CH_4 from Dairy Cattle Manure[1]
Compost	0.005	0.038
Stockpile	0.097	0.247
Slurry (3 months)	0.332	0.524
Slurry (5 months)	0.519	

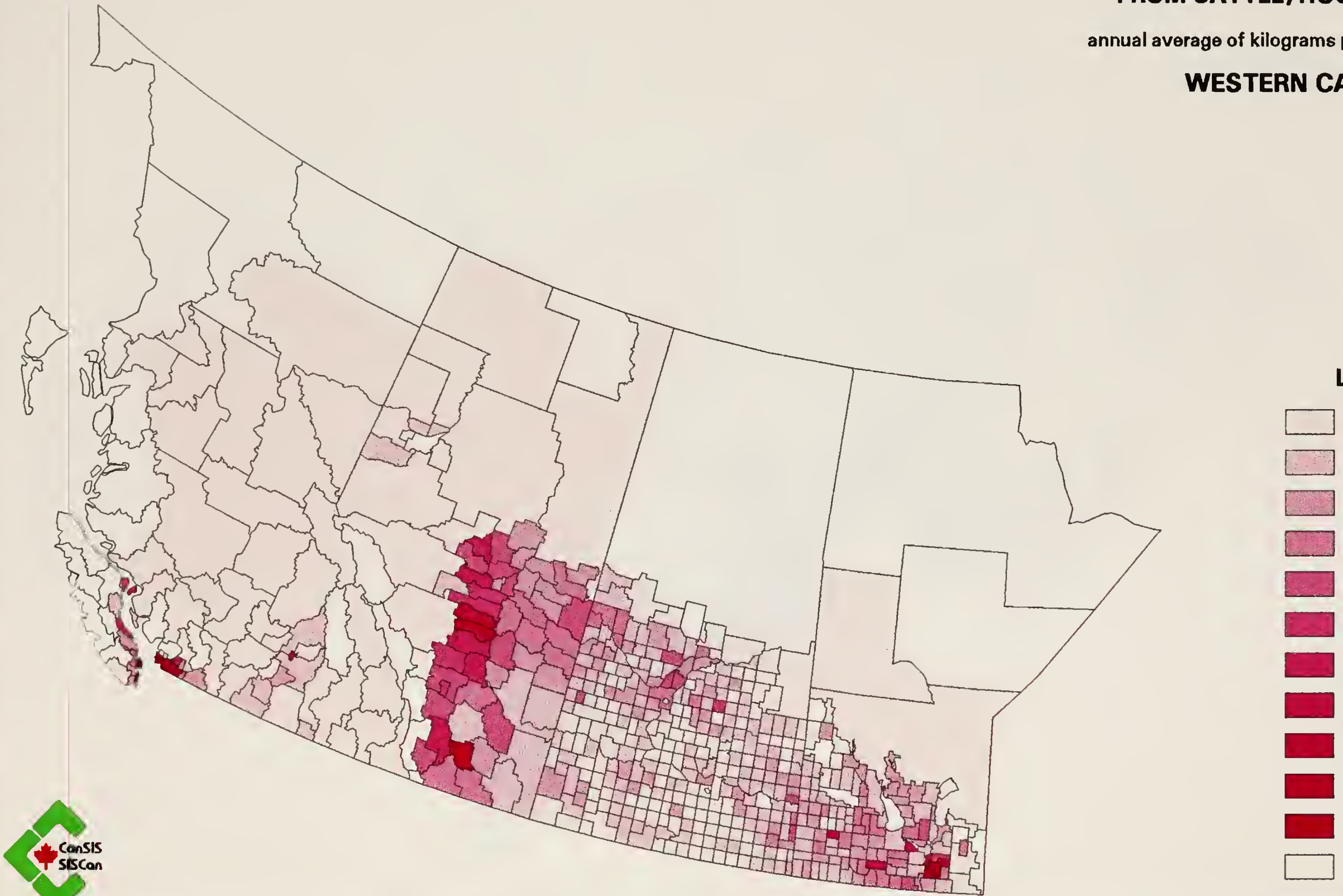
** data expressed in kg of CO_2 equivalent per mass of initial dry manure for a 20 year time horizon.*
[1] Pattey et al., 1997.

METHANE FROM MANURES

FROM CATTLE, HOGS, POULTRY

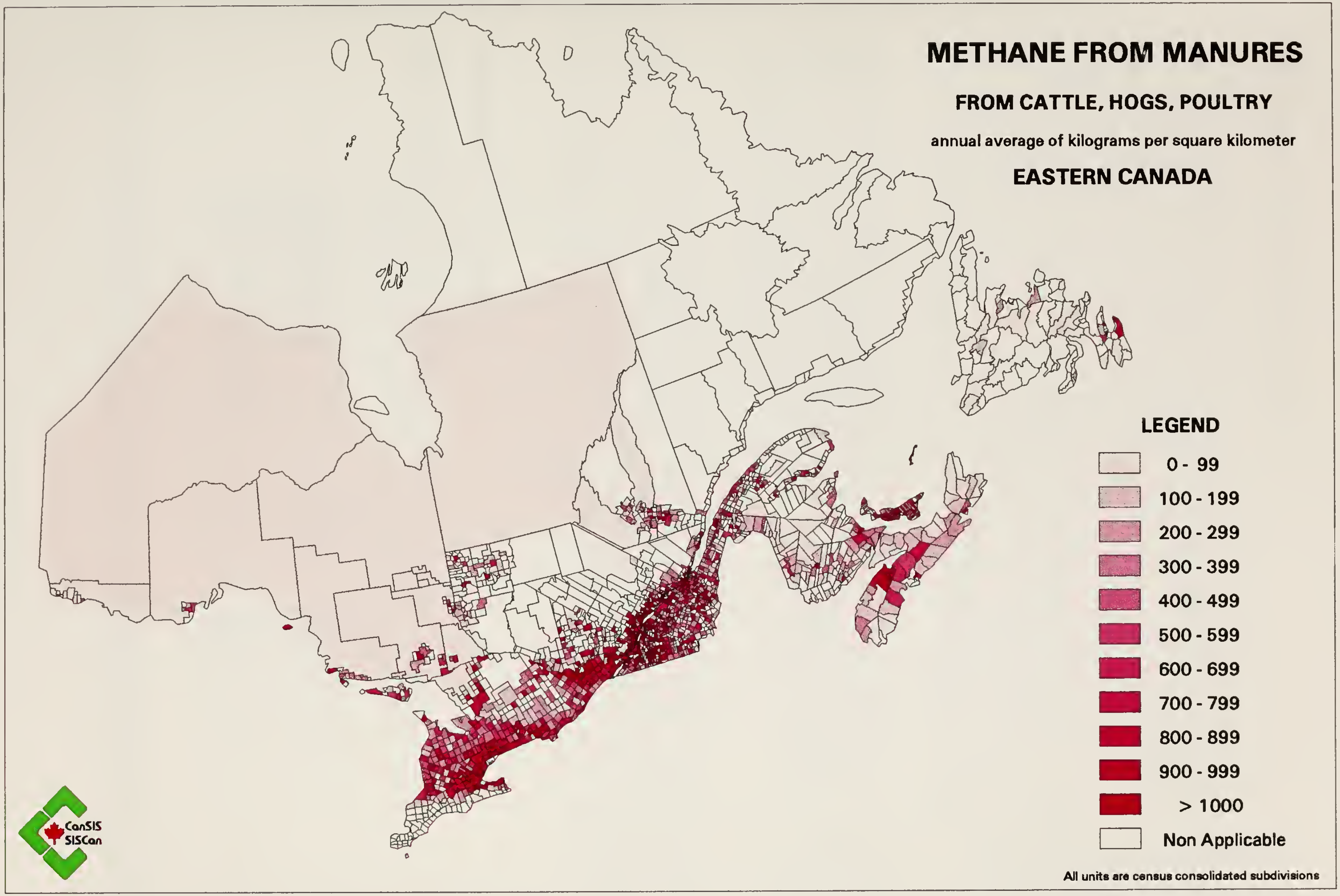
annual average of kilograms per square kilometer

WESTERN CANADA



All units are census consolidated subdivisions

CanSIS SISCan


METHANE FROM MANURES
FROM CATTLE, HOGS, POULTRY
annual average of kilograms per square kilometer
EASTERN CANADA
LEGEND
0 - 99
100 - 199
200 - 299
300 - 399
400 - 499
500 - 599
600 - 699
700 - 799
800 - 899
900 - 999
> 1000
Non Applicable
All units are census consolidated subdivisions
CanSIS
SISCan

4.0 Methane from Agricultural Soils

The oxidation of atmospheric CH_4 by well-drained soils accounts for approximately 10% of the global CH_4 sink. Whether a soil acts as a source or a sink for CH_4 depends on the relative rates of methanogenic and methanotropic activity. Methane emission occurs from soils when the activity of methanogens dominates, while CH_4 consumption is prominent when methanotrophic activity dominates. The ability of soil to consume or produce CH_4 depends on the land use and the type of soil. Soils can consume CH_4 at rates ranging from a few to a fraction of 1 mg m^{-2} d^{-1}. Although there is little information available on waterlogged areas in agroecosystems, a well-drained soil that normally acts as a sink could become a source of CH_4 when it becomes saturated (Topp and Pattey, 1997). The CH_4 emissions from soil were estimated to be 12 kt CH_4/yr using an emission rate of 1 g CH_4/m^2/yr for wet areas (Liu, 1995).

Numerous studies have shown that the application of nitrogenous fertilizers to soils frequently inhibits CH_4 oxidation (Mosier, 1993). Ammonia acts as a competitive inhibitor of the enzyme which oxidizes CH_4 to CO_2 (Bedard and Knowles, 1989). It is also predicted that the nitrite produced by methanotrophic nitrification is toxic to microorganisms, possibly because it inhibits the last enzyme in the CH_4 oxidation pathway (King and Schnell, 1994).

Cultivated soils are not an important source or sink of CH_4. However, dried, uncultivated soils and pastures may absorb CH_4 (Williams, 1994). The area of non-improved cropland in 1986 was about 22.5 million ha and in 1991 it was 22.3 million ha (Dumanski *et al.*, 1994). Assuming an estimated uptake rate of 2.5×10^{-4} g CH_4/m^2/day and a dry season of four months, the CH_4 uptake of the soils was then calculated to be about 7 kt for both 1986 and 1991 (Liu, 1995).

5.0 Summary and Conclusion

Table 8. Summary of CH_4 emissions from agroecosystems in Canada

Source	1986 (kt)	1991 (kt)
Livestock	639	681
Animal Manures	203	209
Soils	5	5
Fossil Fuel Combustion	1	1
Total	848	896

This report presents an estimate of CH_4 emissions from agroecosystems in Canada for 1986 and 1991 (Table 8). The CH_4 production from livestock was estimated to be 639 kt and 681 kt in 1986 and 1991, respectively. The contributions from cattle, hogs, sheep and poultry to these values were, respectively, about 617.7, 15.8, 4.9 and 0.4 kt in 1986 and 657.3, 16.6, 6.4 and 0.5 kt in 1991. The CH_4 estimated to have been produced from livestock manure in 1986 and 1991 was 203 kt and 209 kt, respectively. The approximate contributions from cattle, hogs, sheep/lambs and poultry were 125.5, 68.3, 0.5, 8.4 kt in 1986 and 126.9, 72.0, 0.6, 9.8 kt in 1991. Soil may act as both source and sink of CH_4. The CH_4 emitted from soils in Canada was estimated to be 12 kt, and the CH_4 uptake of soils was 7 kt in both years. Fossil fuel combustion on farms has been estimated to produce about 1 kt of CH_4 per year. The net annual contributions per year, resulting from these estimates, are 848 kt CH_4 for 1986 and 896 kt CH_4 for 1991. When interpreting these figures on greenhouse gas contributions from livestock operations, the compensating effects of CO_2 through carbon storage in grasslands should also be considered. This factor is not considered in this report, but increased carbon storage in soils has recently been documented by Smith *et al.* (1995). Future work on agricultural greenhouse gases will integrate all factors into a net greenhouse gas budget.

LIST OF TABLES

LIST OF FIGURES

Acknowledgments

The authors would like to thank the following in various phases of the work; Barry Grace, the Agriculture and Agri-Food manager of the Program on Energy Research and Development (PERD) for financial support; Dan Sabourin and Brian Monette for creating the maps; Richard Riznek, Corinne Merrill, Michelle Buckley and Ward Smith for assisting in the preparation of the report.

References

Bernard, C, and R. Knowles. 1989. Physiology, biochemistry and specific inhibitors of CH_4, NH_4^+ and CO oxidation by methanotrophs and nitrifiers. *Microbiol. Rev.* **53**:68-84.

Casada, M.E., and L.M. Safely, 1990. Global methane emissions from livestock and poultry manure. U.S. Environmental Protection Agency. CX-816200-01-0.

Dumanski J., L.J. Gregorich, V. Kirkwood, M.A. Cann, J.L.B. Culley, and D.R. Coote. 1994. The status of land management practices on agricultural land in Canada. Centre for Land and Biological Resource Research, Agriculture and Agri-Food Canada, Technical Bulletin 1994-3E, Ottawa, Canada.

Duxbury, J.M., L.A. Harper, and A.R. Mosier. 1993. Contributions 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 ecosystems effects on trace gases and global climate change. ASA Special publication. No.55. ASA, CSSA, SSSA, Madison, WI.

Dyer, J.A. 1995. Agri-environmental indicators for an environmental report card on Canadian livestock densities and manure production with some Canada-USA comparisons. pp. 58. Centre for Land and Biological Resources Research, Research Branch, Agriculture & Agri-Food Canada, Ottawa.

IPCC. 1996. Climate change 1995: the science of climate change. pp. 56. Houghton, J.T., L.G. Mecrofilho, B.A. Callander, N. Harris, A. Katterby, and K. Maskell (eds). Cambridge University Press, Cambridge.

IPCC/OECD. 1994. IPCC guidelines for national greenhouse gas inventories. 1-3 vol. Reporting instructions, workbook, and draft manual. Paris, France.

IPCC. 1990. Methane emissions and opportunities: workshop results of Intergovernmental Panel on Climate Change. Coordinated by the Japan Environment Agency and U.S. EPA, office of air and radiation. 1 vol., Washington, D.C.

Jaques, A.P. 1992. Canada's greenhouse gas emissions: estimates for 1990. pp. 78. Report EPS 5/AP/4. Environmental Protection, Conservation and Protection Branch, Environment Canada, Ottawa.

Johnson K., M. Huyler, H. Westberg H., B. Lamb, and P. Zimmerman. 1994. Measurement of methane emissions from livestock using SF_6 tracer technique. *Environ. Sci. Technol.* **28**:359-362.

Johnson, K.A, and D.E. Johnson, 1995. Methane emissions from cattle. *J. Anim. Sci.* **73**:2483-2492.

King, G.M and S. Schnell, 1994. Effect of increasing atmospheric methane concentration on ammonium inhibition of soil methane consumption. *Nature* **370**:282-284.

Kinsman, R., F.D Sauer, H.A. Jackson and M.S. Wolynetz. 1995. Measurements of methane emissions from dairy cows in full lactation monitored over a six-month period. *J. Dairy Sci.* **78**:2760-2766.

Liu, J. 1995. A preliminary estimate of net CH_4 emissions from Canada's agroecosystems in 1986 and 1991. pp.7. Internal report, Agriculture and Agri-Food Canada, Ottawa.

McAllister, T.A., E.K. Okine, G.W. Mathison, and K.-J. Cheng. 1997. Dietary, environmental and microbiological aspects of methane production in ruminants. In press.

McCaughey W.P., K. Wittenberge and D. Corrigan. 1997. Methane production by cattle on pasture. Proceedings of workshop on greenhouse gas research in agriculture, Agriculture and Agri-Food Canada, Sainte-Foy, Quebec, 12-14 March.

Monteverde, C.A., R.L. Desjardins, E. Pattey. 1997. Estimates of nitrous oxide emissions from agroecosystems in Canada for 1986 and 1991 using the revised 1996 IPCC/OCED methodology. Agri-environmental indicator project. Agriculture and Agri-Food Canada, report No. 20.

Mosier A.R. 1993. Nitrous oxide emissions from agricultural soils. p.273-285. 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 February.

Pattey, E., R.L Desjardins, P. Rochette, E.G. Gregorich, M. Edwards and S.P. Mathur. 1997. Emissions of greenhouse gases from manure under contrasting storage conditions. Proceedings of Workshop on Greenhouse Gas Research in Agriculture, Agriculture and Agri-Food Canada, Sainte-Foy, Quebec, 12-14 March.

Prather, M, R. Derwent, D. Ehnalt, P. Fraser, E Sanhueza, and X. Zhou. 1996. Radiative forcing of climate change: other trace gases and atmospheric chemistry. p. 86-103. *In* J.T Houghton, L.G. Meirofilho, B.A. Callander, N. Harris, A. Katterby, and K. Maskell (eds.), Climate change 1995: The science of climate change. Contribution of Working Group 1 to the Second Assessment Report of the IPCC. Cambridge University Press, Cambridge.

Schuepp, P. H., S.K. Kaharabata, and L.A. Wittebol. 1997. Observations and modelling of methane emissions from agricultural livestock operations. Interim report, Agriculture Canada 1996-1997, contract file No. 01E86-6-0807/001/SS.

Smith, W.N., P. Rochette, C. Monreal, R.L Desjardins, E. Pattey, and A. Jaques. 1995. Agroecosystems greenhouse gas balance indicator: carbon dioxide component. pp.26. Agri-environmental indicator project. Agriculture and Agri-Food Canada, report No. 13.

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

Taiganides, E.P, and R.L Stroshine. 1971. Impact of farm animals production and processing on the total environment. p. 95-98. Livestock and waste management and pollution abatement proceedings.

Topp, E. and E. Pattey. 1997. Soils as sources and sinks for atmospheric methane. In press.

U.S. - EPA. 1994. Inventory of U.S. greenhouse gas emissions and sinks. 1990-1993.

Williams, A. (ed.). 1994. Methane emissions. Watt Committee on Energy. Report No.28, London, UK.

Watson, R.T., L.G. Meirofilho, E. Sanhueza, A. Janetos. 1992. Greenhouse gases: sources and sinks. p. 24-46. *In* J.T. Houghton, B.A. Callender, S.K. Varney (eds.), Climate change 1992: the supplementary report to the IPCC scientific assessment. Cambridge University Press, Cambridge.

DATE DUE

MAR 0 4 2003			
APR AVR 1 7 2003			
GAYLORD			PRINTED IN U S A