AGRICULTURE AND AGRI-FOOD
CLIMATE CHANGE
FOUNDATION PAPER

Agriculture and Agri-Food Climate Change Table
Spring 1999

PREFACE

The purpose of this document was to provide the Agriculture and Agri-Food Climate Change Issue Table with background information on climate change issues and agriculture. The document reflects available knowledge and literature at the time of writing.

It has been based on work already completed, with a heavy dependence initially on the draft and subsequently the final version of the Health Of Our Air document recently released by the Research Branch of Agriculture & Agri-Food Canada. The major contribution of the Health Of Our Air document to the preparation of the Foundation Paper needs to be fully acknowledged. Without the work undertaken by the Health Of Our Air team, it would have been extremely difficult to produce a Foundation Paper within the tight time frames of the project.

Sources of information ranged from original references, to quoted references in other papers and to personal communications and opinions. To the extent possible, references have been included in the report where they could be verified. Where the original source has not been referenced, it has not been possible to verify the original source document. In some cases the information cited may have been based on an author's informed opinion rather than the result of actual research.

As the Agriculture Table on Climate Change examines a number of these greenhouse gas issues, this will inevitably lead to a need to revise certain issues raised in this foundation paper. Some issues have not been addressed at all in this initial version and others will need to be revisited after the Agriculture Table has had the opportunity to more fully scrutinize the issue. At the very least, it needs to be recognized that this Foundation Paper was a compendium of issues identified at the beginning of the Agriculture Table deliberations. .

That is why this Foundation Paper is reflective of a work in progress. It represents the beginning of the process but not the end. To ensure that the Foundation Paper is viewed in the proper context, it would be necessary to also review subsequent documents prepared for the Agriculture Table. In particular, the Options Paper to be produced as a result of Agriculture Table deliberations would also need to be reviewed. This is because the Options Paper will reflect the conclusions of the Agriculture Table at the end of its' deliberations.

Executive Summary

Agricultural activities that contribute directly to emissions of greenhouse gases (GHG) include: enteric fermentation in domestic livestock, livestock manure management, agricultural soil activities, and agricultural residue burning. Irrigation and tillage practices may also generate anthropogenic (human-induced) greenhouse gas emissions.

In 1996, agricultural activities were responsible for emissions of 61 Mt (million tonnes) of CO_2, or approximately 9.5% of total Canadian GHG -emissions. Methane (CH_4) and nitrous oxide (N_2O) are the primary greenhouse gases emitted by agricultural activities at 38% and 61% respectively. Methane emissions from enteric fermentation and manure management represent about 38% of total CH_4 emissions from anthropogenic activities, respectively. Beef and dairy cattle are the largest emitters of methane. Agricultural soil management activities such as fertilizer application and other cropping practices were the largest source of nitrous oxide emissions, accounting for approximately 48% of total Canadian N_2O emissions.

Warming potential (radiative forcing) of a gas depends on both its capacity to absorb and re-emit radiation and how long the effect lasts. CH_4 and N_20 have 21 and 310 times the warming potential of CO_2, respectively (IPCC 1996). CH_4 HAS an average lifetime of about 12 years, N_2O 130 years, and CO_2 200 years.

Total emissions of CO_2 from Canadian agricultural activity are the sum of net soil C loss, emissions from direct use of fossil fuel, and emissions from indirect uses of fossil fuel. Estimates from 1996 are that agricultural activity released about 28 Mt of CO_2 (8 Mt C) into the atmosphere. Projections to 2010 suggest total emissions will not change appreciably from those in 1996. Emissions from soils are predicted to decline and become negative but emissions from indirect sources may increase, offsetting these benefits. These estimates assume a ‘business-as-usual’ scenario.

Though present in the atmosphere at very low concentrations that rate of increase of CH_4 which had been 1.1% has now dropped to about 0.6% per year. Globally, agriculture is a very prominent source of CH_4, accounting for about two thirds of human induced emissions. Most of the methane emitted from agriculture is produced by the microbial breakdown of plant material. Virtually all of the CH_4 emission on Canadian farms is from livestock. According to current estimates, about 1Mt of CH_4 was emitted from Canadian farms in 1996. Of this, about 80% came directly from livestock, the remainder from livestock manure. If livestock numbers increase as predictd, there may be further increases in CH_4 emissions unless new methods are adopted that reduce emissions per animal.

Nitrous oxide (N_2O) occurs naturally in the atmosphere at very low concentrations (about 300 ppbv), but the concentration is now increasing at a rate of about 0.3% per year. Much of this increase comes from agriculture, which accounts for up to 70% of the N_2O emissions from human activity. N_2O poses two threats: As a very potent greenhouse gas with a long lifetime in the atmosphere (about 130 years and N_2O released in the atmosphere is eventually converted to nitric oxide (NO), a gas that breaks down ozone (O_3). Higher N_2O levels, therefore, not only contribute to the greenhouse effect, but may also increase indirectly the intensity of UV radiation. Most of the N_2O from agriculture is produced in the soil.

Nitrous oxide emissions from Canadian farms can only be roughly estimated due to limited understanding of N_2O formation and release. Estimates rely on equations, from the IPCC (1996) that are based on three sources: direct emissions from soils, direct emissions from livestock production, and indirect emissions from farms. Based on this calculation, direct emissions of N_2O from agricultural soils in Canada in 1996 were estimated to be 0.057 Mt N_2O. When averaged over the area of cultivated land in Canada, this equates to about 1 kg N_2O-N per ha per year. The estimated emission rates, however, vary widely among regions.

Direct emissions from livestock were calculated by estimating the amount of N in manure, and assuming that a specified portion of that N was emitted as N_2O. According to this approach, direct emissions from livestock were estimated to be 0.024 Mt of N_2O in 1996. Indirect emissions were calculated from estimates of atmospheric N (e.g., NH_3) deposited on the soil, N leached from farm fields, and ~~a~~ production of human sewage. According to these calculations, leached N is the most important, accounting for more than 80% of the roughly 0.038 Mt of N_2O released from indirect sources in 1996. Based on the IPCC approach, total emissions of N_2O from agriculture in Canada in 1996 were about 0.120 Mt N_2O. Direct emissions from soils accounted for about half. According to current estimates, N_2O emissions have increased steadily since 1981, increasing by 21% from 1991 to 1996. Much of the increase resulted from higher N inputs as fertilizers and animal manure. With expected future increases in livestock numbers and higher crop yields, N_2O emissions may climb further unless improvements are made in N management.

The carbon © cycle is central to farming systems. Methods to reduce CO_2 rely mainly on managing that cycle more efficiently: re-cycling as much organic C as possible, minimizing disruption of soil, optimizing use of the sun's energy, and relying less on energy from outside. Because they promote efficiency, many of these methods also help sustain land resources, and may even be profitable. As a result, practices such as conservation tillage and in particular no-till are being adopted for reasons quite apart from their benefits to atmospheric CO_2 . For example, most farms in Canada now use less tillage than a generation ago, and an increasing proportion now use no-tillage practices. Similarly, the area of land devoted to summer fallow has fallen from about 11 million ha in 1971 to about 6 million ha in 1996. The use of these and other C-conserving practices will likely continue to increase in coming decades.

Methods that reduce CH_4 production on farms focus on feeding practices. Specific feeding practices that reduce emissions from these animals have been identified. Many of these practices are already practical , being used and economical. When used together, they can lower loss of energy through CH_4 release from about 5 to 8% of the gross feed energy to as low as 2 or 3%. Because feeding efficiency is increased, these practices also often have economic benefits.

Most of the CH_4 from manure is produced during storage. When the manure is stored as liquid or in poorly-aerated piles, lack of oxygen prevents complete decomposition to CO_2 (a preferable route since it has a lower warming potential), resulting in the release of CH_4. Most of the methods of reducing emission involve slowing decomposition rate, providing better aeration, or reducing the duration of storage. These methods can reduce, to some extent, the CH_4 emission from animal manure. Because of high livestock densities in some areas, and the high cost of handling and transportation, manure management still remains a challenge, and new ways to reduce emissions are needed.

Reducing N_2O emitted from farmland is achieved when excess NO_3^- in soil undergoes denitrification, either on farmland or after it is leached away. Preventing build-up of NO_3^- or avoiding soil conditions that favour denitrification can reduce emissions. Some N_2O is also emitted during the conversion of NH_4^+ to NO_3^- (nitrification). Overall, the best way to reduce N_2O losses is to manage the N cycle more efficiently, thereby avoiding the buildup of excessive NH_4^+ or NO_3^- . Fertilizers account for about 9% of production costs on farms, and any method that reduces N losses has economic benefits.

Potential impacts of climate change on agriculture will be reflected most directly through the response of crops, livestock, soils, weeds, and insects and diseases to the elements of climate to which they are most sensitive. One of a number of to examine possible effects of climate change on agriculture, the Canada Country Study, examined the impacts of climate change on various regions in Canada under the scenario that over the next century a further warming of 1° to 3.5 ° C will occur.

To date however, few studies have fully accounted for future changes in climate variability, water availability, and the many ways by which farmers might respond to the changing climate. These factors may be as important as the direct effect of the change in climate itself. If appropriate adaptation strategies are identified and implemented in a timely fashion, the overall vulnerability of the region may be reduced. However, uncertainties exist about the feasibility of implementation and efficacy of technological adaptation.

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1. Profile of Sector's GHG Emissions

1.1 Agriculture and Agri-food Sector

Based on Agriculture and Agri-Food Canada data, the Canadian agri-food system provides over 80% of the food and beverage products consumed by 30.3 million Canadians. Food expenditures represented only 13.6% of total consumer disposable income, one of the lowest food costs in the world. In 1997, agriculture, one of the largest resource based sectors, produced $28.2 billion in revenue for Canadian farmers, who in turn paid $14.4 billion to farm input suppliers for inputs of energy, seed and feed. Agricultural exports, valued at $12.5 billion in 1997, were 2 times as large as agricultural imports. This contributed positively to Canada's net trade balance. (AAFC, 1998a)

Food and beverage processing industries, combined, represent the second largest manufacturing sector in GDP terms and shipped agri-food products worth $52.3 billion. $9.8 billion of processed agri-food products were exported. Imported processed agri-food products, some of which were further processed in Canada, amounted to $9.6 billion in 1997. (AAFC, 1998a)

1.1.1 Agri-food System Contribution to Economic Growth

In general, the rate of economic growth for the total agri-food system has lagged behind the economy as a whole. However, in the 1990s, the rate of growth in the agri-food system has surpassed the total economy (1.7% versus 1.5%). Following declines in percentage share of total Canadian GDP through the 1980s, the agri-food system share now stands at 8.6% in 1997. It has been at this level for most of the 1990s. (AAFC, 1998a)

The agriculture and food & beverage sectors' combined share of total Canadian GDP, which does not include the distribution and food service components, declined from an average of 5.6% in the 1970s to a 4.6% share during the 1980s. In 1997, the share of total GDP stood at 4.3%. The distribution and food & beverage service sectors' combined share of GDP has varied between 4.5% & 4.0% since the early 1980s, and stood at 4.2% in 1997. (AAFC, 1998a)

1.1.2 Agriculture and Food & Beverage Sectors Provincial Economies

From a sector perspective, in absolute terms, Ontario and Quebec contributed the greatest amount to national agriculture and food & beverage GDP because much of the food and beverage processing sector is located in these provinces. From a provincial perspective, in relative terms, agriculture and food & beverage GDP is most important to the economies of Saskatchewan and Prince Edward Island.

1.1.3 Agri-food System Employment 1997

The Agri-food system provided 1.8 million jobs in 1997, accounting for 13.3% of total national employment. Agriculture sector employment has been declining over the last few decades, but recent data shows the rate of decline is slowing. Productivity is improving, as these industries rationalize to become more competitive. The food and beverage sector employment varies with the business cycle, and has recently increased. Employment growth continues in the Distribution and Food Service sectors. This reflects the long term economy wide trend toward service and tertiary industry employment growth. (AAFC, 1998a)

1.1.4 Value of Trade

Agriculture and food & beverage trade with the world as a whole has grown consistently during the 1990s. The U.S. remains our largest trading partner, accounting for 50% of total Canadian agri-food export value and providing 59% of Canadian agri-food imports. Since 1990, Canada has been a net exporter of agri-food products to the U.S.. Trade with the rest of the world exhibits a somewhat different pattern. Although exports continued to grow, the relative growth in imports has been faster, resulting in a slight decline in the net trade balance in 1997. (AAFC, 1998a)

1.1.5 Trade by Degree of Processing 1997

Bulk commodities and intermediate processed agri-food goods still account for a higher share of export value than consumer oriented products. Total exports reached $22.3 billion in 1997. A target of 4% of world agri-food exports by the year 2005 has recently been adopted by the agriculture & agri-food sector. Reaching this target depends on maintaining the growth in value-added exports. An additional focus on value added products could result in additional greenhouse gas emissions. (AAFC, 1998a)

1.1.6 Trade Balance by Degree of Processing

Canada has a positive net trade balance in bulk commodities and intermediate products. Bulk commodities continue to dominate net trade figures and are relatively stable between $3 and $5 billion annually. Intermediate products have shown a steady increase in net trade balance from $1.3 billion in 1990 to about $3.2 billion in 1997. Consumer oriented products have a consistently negative trade balance which has varied between $2 and $3 billion since 1990. (AAFC, 1998a)

1.1.7 Structure of Agriculture Sector, Farm Size and Number

Larger farms represent an increasing share of all farms based on gross farm receipts. Farm numbers have been declining over time, reflecting increased farm productivity. However, according to the 1996 Census of Agriculture, the inter-census decline in the number of working farms is the lowest since 1941. The number of large farms (>$100,000 in gross farm sales) increased 11% from 1991 to 1996, while the number of smaller farms declined 6%. The result, large farms now represent 30% of total farms, up from 27% in 1991. Larger more modern farms have a greater potential to reduce greenhouse gas emissions for any given level of output. (AAFC, 1998a)

1.1.8 Structure of Agriculture Sector, Area Farmed & Herd Size

Total land in farms has remained more or less constant since 1971. Average land holdings per farm increased 2% to 611 acres between 1991 and 1996. In 1971, land in crops represented 41% of total farm land; in 1996, it has risen to 51%. For summer fallow area, the share in 1971 was 16%; in 1991, the share has fallen to 9%. This reflects improved land management and farming techniques. The 1996 Census confirms the strengthening of the red meats industries. Both pigs and beef cow numbers are the highest they have been for the past 25 years. (AAFC, 1998a)

1.1.9 Structure of Agriculture Sector, Commodity Groups

The red meats industries surpassed grains and oilseeds as the largest farm cash receipts generator during the decade ending in 1996; however, in 1997, grains & oilseeds farm cash receipts exceeded those of red meat farms. Significant expansion of the western Canadian livestock industry, especially swine, is expected over the medium term. If this happens, the red meat farms will again become the largest commodity sector.

Grains and oilseeds continue to dominate Canadian commodity exports, as wheat remains by far the largest export product. Canola has gained strength in recent years, based primarily on increased export demand.

The growth of fruit & vegetables and other farm commodities points to greater diversification in Canadian agriculture production.

1.1.10 Structure of Agriculture Sector, Farm Financial Situation

Canadian farmers have gained financial strength through the 1990s. The average net worth of Canadian farms rose between 1995 and 1997 to $646,426 per farm (AAFC, 1999). In 1995, the average net worth for small farms was $327,479; the average for large farms was $941,907. Average net worth rose more for large farms (by 31%) than for small farms (19%) primarily because of larger increases in land values. (AAFC, 1998a)

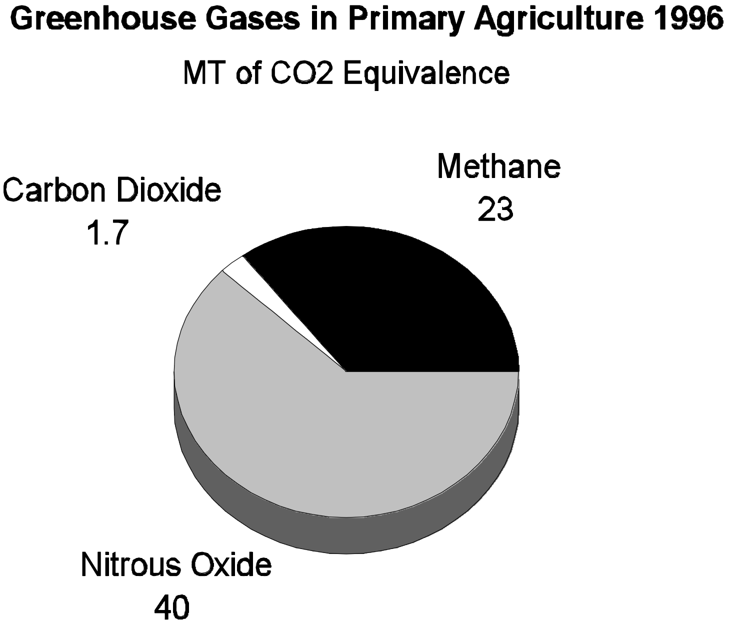
1.1.11 Performance of Agriculture Sector, Farm Incomes

Net cash income is defined as total cash market receipts plus program payments less operating expenses after rebates. It represents the money available to farmers to pay their living costs, upgrade their operations, and provide for savings and outside investments. Net cash income has been relatively stable for most of the 1990s. Although lower commodity prices are forecasted for 1997 to 1999 period, the Net Income Stabilization Account program will soften the decline in net cash farm income for most commodity sectors.

1.2 Introduction of Greenhouse Gases and Agriculture

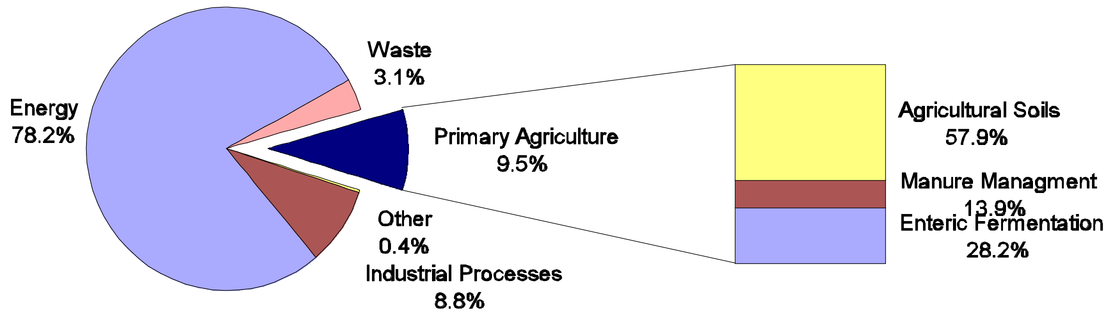
Agricultural activities contribute directly to emissions of greenhouse gases through a variety of processes. The Agricultural sector includes the following sources: enteric fermentation in domestic livestock, livestock manure management, agricultural soil activities, and agricultural residue burning. Several other agricultural activities, such as irrigation and tillage practices, may also generate anthropogenic (human-induced) greenhouse gas emissions; however, the impacts of these practices are too uncertain to estimate emissions.

In 1996, agricultural activities were responsible for emissions of 64 Mt (million tonnes) of CO_2, or approximately 9.5% of total Canadian greenhouse gas emissions (Environment Canada, 1998). Methane (CH_4) and nitrous oxide (N_2O) were the primary greenhouse gases emitted by agricultural activities at 36% and 61% respectively (Environment Canada, 1998). Methane emissions from enteric fermentation and manure management represent about 22% and 5% of total CH_4 emissions from anthropogenic activities, respectively (Environment Canada, 1998). Of all domestic animal types, beef and dairy cattle are by far the largest emitters of methane. Agricultural soil management activities such as fertilizer application and other cropping practices were the largest source of nitrous oxide emissions, accounting for approximately 49% of total Canadian N_2O emission (Environment Canada, 1998). Manure management and agricultural residue burning are smaller sources of N_2O emissions.



Source: Canada's 1996 Greenhouse Gas Emission Summary (Draft)

Agriculture's Contribution to Canada's Greenhouse Gas Emissions



Source: Canada’s 1996 Greenhouse Gas Emission Summary (Draft)

1.3 Global Warming Potential

The potential contribution of radiative forcing of the various greenhouse gases differ dramatically. Accurately calculating the amount of radiative forcing attributable to given levels of emissions of these gases, over some future time horizon, requires a complex and time-consuming task of calculating and integrating changes in atmospheric composition over the period. For policy purposes, the need is for an index that translates the level of emissions of various gases into a common measure in order to compare the radiative forcing effects without directly calculating the changes in atmospheric concentrations. This information can be used to calculate the cost effectiveness of alternative reductions, e.g., to compare reductions in CO_2 emissions with reductions in CH_4 emissions.

A number of approaches, called Global Warming Potential (GWP) indices, have been developed in recent years. These indices account for the direct effects of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other gases. They also estimate indirect effects on radiative forcing due to emissions of gases which are not themselves greenhouse gases, but lead to chemical reactions that create or alter greenhouse gases. The concept of global warming potential, which was developed by the Intergovernmental Panel on Climate Change (IPCC), compares the potency of various greenhouses (e.g., compares the effect of reducing CO_2 emissions relative to another greenhouse gas for a specific time horizon).

The heat-trapping potential of a gas depends on both its capacity to absorb and re-emit radiation and how long the effect lasts. Gas molecules gradually dissociate or react with other atmospheric compounds to form new molecules, with different radiative properties. For example, CH_4 has an average lifetime of about 12 years, N_2O 130 years, and CO_2 200 years. Over a 100 year period, $CH_{4,}$ has a global warming potential of 21 times that of CO_2. As time proceeds, some of the CH_4 molecules are broken down into CO_2 and H_2O. Global warming potentials can be expressed in 20, 100 and 500 year time horizons. To keep consistent with IPCC guidelines, this paper uses the 100 year global warming potentials as illustrated in the table below.

GWP’s are used to convert greenhouse gases to a CO_2-equivalent basis so that the relative magnitudes of different greenhouse gases can be readily compared. The GWP will be an important concept for countries in determining the relative importance of each of the major emissions sources and in developing appropriate mitigation strategies.

Current GWP estimates for the three greenhouse gases have been calculated and their 100 year global warming potentials are the following:

Global Warming Potential (per unit mass of gas)
(Current Estimates Based on 1996 IPCC Guidelines)

Greenhouse Gas	**GWP (100 years)**
Carbon Dioxide	1
Methane	21
Nitrous Oxide	310

1.4 Carbon Dioxide

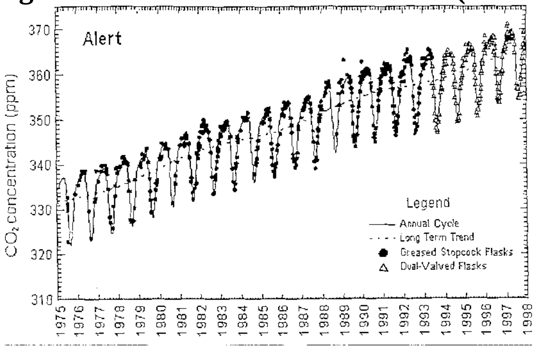
1.4.1 The Global Carbon Cycle

There are about 40,000,000 Mt (million tonnes) of C in global circulation (Janzen et al., 1998). Most of this is in the oceans but large pools also occur in soils, vegetation, and the atmosphere. Of these three pools, the atmosphere is the most active. The CO_2 in the air is continually being removed by plants through photosynthesis and by absorption into the oceans. At the same time, however, CO_2 in the air is being replenished by release from plants, soils, and oceans. Thus, though C is always cycling, the atmospheric CO_2 concentration was constant from year to year. Analysis of air bubbles trapped in old glaciers and shells buried in ocean sediments reveals that the atmospheric concentration of CO_2 has been the same (about 270 ppmv) for about 10,000 years.

That changed with the advent of the industrial revolution. Since then, the demand for energy has resulted in the ever-increasing extraction of fossil fuels from deep reserves and its conversion to atmospheric CO_2. This process, in effect, withdraws C from an inactive C pool, and emits it into the atmosphere as CO_2. Other activities have also favoured increases in atmospheric CO_2: removal of forests has resulted in the conversion of vegetative C to CO_2, and the cultivation of previously undisturbed soils has resulted in the conversion of soil C to CO_2. Because of these disturbances, the emissions of CO_2 into the atmosphere now exceed the withdrawals, resulting in the gradual buildup of CO_2.

In 1995, fossil fuel combustion alone released 23,500 Mt of CO_2 into the atmosphere (Janzen et al., 1998). The natural C cycle can absorb some of this increased CO_2 emission: some is absorbed by oceans, some by increased photosynthesis in plants. Nevertheless, the total amount of CO_2 in the atmosphere is still increasing by about 11,700 Mt CO_2 every year (Janzen et al., 1998). These increases are readily apparent in monthly measurements of atmospheric CO_2 at Alert, NWT which, despite seasonal variations reflecting plant growth, show a clear, undeniable upward trend. This trend is typical of other areas as well.

Monthly Average Carbon Dioxide Concentrations (1975-1998), Alert, NWT



Source: Environment Canada

1.4.2 Carbon Cycles in Agricultural Ecosystems

The carbon cycle in cropped land is quite simple, at least in principle. Carbon dioxide is absorbed from the atmosphere by plant leaves, and transformed, via photosynthesis, into C-containing compounds such as sugars, carbohydrates, cellulose, and lignin. Some of this material is used by the plant, a portion is removed during harvest (e.g., in grain), and the rest is returned to the soil. This residue, including roots, becomes part of the soil organic matter. Microorganisms in the soil, in turn, decompose the soil organic matter, releasing CO_2 into the atmosphere and closing the loop. This cycle is essentially the same in all cropping systems, but rates vary depending on climate, soil and crop type.

Where present, livestock add another component to the carbon cycle. Instead of being exported, much of the harvested plant material is fed to animals or used as bedding. A portion of this C is released by the animals to the atmosphere as CO_2 and CH_4, a portion is removed as animal products, but much is returned to the soil as manure. Consequently, livestock-based systems often retain higher proportions of C on the farms.

In systems that have remained largely unchanged for several decades, the amount of C entering the soil as plant residues is usually balanced by the amount of C converted to CO_2 by microbial activity. Consequently, though C is continually added to the soil, the amount of C stored in the soil may not change measurably over the long term.

1.4.3 Management Effects on C Cycle

A change in the way land is managed can disrupt the C cycle, changing the amount of C stored. Perhaps the most drastic example of this was the initial cultivation of soils for farming. This event, which happened on many Canadian farmlands more than a century ago, resulted in high losses of soil C: many soils lost about 25% of the C originally present in the C-rich surface layer, releasing a lot of CO_2 into the atmosphere. There are several reasons for this loss. First, farming involves the harvest of C from the fields and the removal of this C means less input of new C. C content is related directly to the quantity of crop residues returned to the land and inversely to the N deficit in the soil. Several studies have shown that there is a strong positive correlation between soil organic nitrogen and the quantity of crop residue returned, and a strong negative correlation with apparent N deficit. As well, cultivation and growing annual crops often speed up the conversion of soil C to CO_2 by soil microbes. After soils have been cultivated for a few decades, however, losses of C usually slow down or cease entirely, and the level of soil C is again stable.

The impact of the initial cultivation of the C cycle is largely past. Today we are interested more in how current practices or future modifications might affect the C cycle. By choosing the crops, tillage practices, fertilizer treatments, and other options, farmers can alter the C cycle, thereby increasing the amount of C stored in the system.

1.4.4 Measuring Management Effects on C Cycle

How do we determine the impact of farming practices on the C cycle? One way is to measure all of the flows in the C cycle in a farm field (e.g., using isotope carbon fractions). By subtracting the amounts of C leaving the field from the amounts entering, we can calculate the net change in C. Such measurements are very helpful in describing how management affects the C cycle, but they are very time-consuming and are used only at selected research sites.

Another way is to measure the net exchange of CO_2 between vegetation and the atmosphere above it. Using sensors placed on towers, the transfer of CO_2 above the crop is measured continuously for months or even years, allowing calculation of CO_2 exchange over an entire field. The exchange of CO_2 from whole regions can be measured using aircraft equipped with CO_2 sensors. By measuring the difference in CO_2 concentration between upward and downward moving air, spatial differences in CO_2 exchange over large areas at a given time can be estimated. This approach, using towers, aircraft, and other variations, provides an average of net CO_2 emissions from larger areas, thereby overcoming the natural variations that occur across a field. Its main disadvantage is the specialized instrumentation and the difficulty of integrating over long time periods.

A third method, the one most widely used, is to measure the change in the amount of stored C after a number of years. In farm fields (as opposed to forests), virtually all of the C is stored in the soil organic matter. By measuring the amount of soil C once, and then again several years later, it is possible to tell whether the field has gained or lost C under a certain management. A common variation on this approach is to measure the change under one treatment relative to another. For example, if we are interested in the effect of tillage on C storage, we can maintain two systems side by side - one tilled, the other not - and then measure the increase in stored C in the untilled plot by comparing it to that in the tilled plot. But measuring changes in soil C is not easy. Any increase may be small (say 3 tonnes/ha) compared to the amount initially there (say, 60 tonnes/ha). This problem is further complicated by the natural variability of C in the field, which is often much greater than the difference we are looking for. Accurate measurement of soil C change, therefore, requires very careful sampling and analysis. Some researchers have focussed on specific forms of soil C or on atomic markers (isotopes) to measure soil C changes more precisely. Hence, by using measurements from specific locations, models can be verified, and their predictions for large areas can be accepted with some confidence.

To estimate the effects of management on the C cycle over large regions, we have to rely on models. These models may be very simple equations or highly complex computer programs that take into account many variables like weather, soil type, and farming practices to predict C processes on the farm. Whatever their complexity, these models need to be checked against actual measurements to ensure they are reliable.

1.4.5 Estimates of CO_2 Emissions in Canada

The net emissions of CO_2 from Canadian agriculture can be calculated by estimating the annual change in stored C and adding CO_2 release from fossil fuel. Most of the C stored in agroecosystems occurs in soil, so the change in storage can be estimated from the gain or loss of soil C. The following table shows estimated CO_2 emissions from Canadian crop production from direct and indirect sources.

Estimated CO_2 Emissions from Canadian Agriculture from Direct and Indirect Sources (Mt)*

	1991	**1996**
Direct Emissions		
Soils	5.1	1.7*
Fuel used on farm	8.1	9.5
Total Direct Emissions	***13.2***	***11.2***
Indirect Uses of Fossil Fuel		
Fertilizer manufacture, transport & application	5.1	6.6
Machinery manufacture & repair	4.8	4.8
Building construction (steel & cement manufacture)	2.3	2.2
Pesticide manufacture	0.3	0.3
Electricity generation	2.1	2.4
Total Indirect Emissions of Fossil Fuel	***14.6***	***16.3***
Total Emissions Attributable to Agriculture	**27.8**	**27.5**

* As per 1996 IPCC Guidelines, only direct emissions from soils will fall under Agriculture, the other sources will fall under Energy and Transport.

Source:Janzen et al., 1998; E. Coxworth et al., 1995

1.4.6 Estimate of Soil C Change

Estimating soil C change for all of the agricultural area of Canada is difficult, because of the variability of soil properties and management practices across the country. Because measuring the change directly would require enormous effort, our estimates rely on mathematical models. The site-specific model CENTURY makes use of simplified relationships of the soil-plant-climate interactions to describe the dynamics of soil carbon and nitrogen in grasslands, crops, forests, and savannas. It accounts for several agricultural management practices including planting, applying fertilizer, tilling, grazing, and adding organic matter. It simulates above and below ground plant production as a function of soil temperature and availability of water and nutrients.

In a recent study, the CENTURY model was used to predict changes in C content of Canadian agricultural soils, based on climate and soils data from sites across Canada. Information about farming practices was taken from recent Statistics Canada data. The study considered the predominant agricultural systems in Canada, but did not include all possible variations. Some of the factors not included were: a) biomass burning, a practice still somewhat used in the Red River Valley; b) soil erosion, which moves C around the landscape; c) manure addition; d) minor crops such as potatoes and annual legumes; and e) minimum tillage, which is intermediate between ‘conventional’ and no-tillage. Some of these may be included in future analyses.

The model predictions are in agreement with historical observations: soil C declines rapidly after initial cultivation, but the rate of decline gradually diminishes over time and the soils approach a new ‘steady-state’ where they no longer lose C. According to the model, current rates of C loss are negligible. The model predicts, further, that agricultural soils will begin regaining some of the lost C in the future, with the adoption of improved practices like no-till and reduced summerfallow. According to the model, the agricultural soils were losing C at a rate of about 3 Mt C per year in 1970, but would be gaining C at a rate of 0.4 Mt C per year by 2010 (W. Smith et al., 1997). Predicted rates of soil C change differ among regions, reflecting variable adoption of improved practices and differences in soil properties.

All of these predicted rates of change are very low compared to the total amount of stored C. For example, a C gain of 0.4 Mt per year amounts to a rate of <0.01 T C per ha per year, when averaged across all cultivated soils in Canada. This is a very small proportion of the total soil C, often about 60 to 100 T C per ha (W. Smith et al., 1997).

The CENTURY model predictions represent our current best estimates of soil C change across the country. Compared to actual data on the change in soil carbon under no-till, CENTURY estimates appear to be low by as much as 50%. The current estimates rely on several simplifying assumptions and have not yet been fully tested for all conditions across Canada. With further research, as the reliability of the models improve, these estimates may be adjusted.

1.4.7 Emissions from the Use of Fossil Fuel

The other major source of CO_2 in agriculture, aside from the biological C cycle, is burning of fossil fuel. Direct fuel use on Canadian farms releases almost 9 Mt of CO_2 annually (Janzen et al., 1998, E. Coxworth, 1995). Additional CO_2 is emitted from indirect sources, those associated with the production or transport of inputs. Of these, manufacture and transport of fertilizer (commercial) is the most important. Emissions from this source have been increasing steadily because of increasing rates of fertilizer applied to farmland. Large amounts of CO_2 are also emitted from manufacture of farm machinery, construction of buildings, and electricity generation. Altogether, CO_2 emissions from indirect sources amounted to about 16 Mt CO_2 in 1996 (Janzen et al., 1998, E. Coxworth, 1995).

Total CO_2 emission from fossil fuel use on Canadian farms, therefore, is about 26 Mt CO_2 (7 Mt C)(Janzen et al., 1998). In the calculation of national inventories, however, only the CO_2 produced from stationary combustion (about 1 Mt CO_2) is counted in estimates for agriculture; the remainder is included in emissions from manufacturing, construction, and transportation sectors.

1.4.8 Summary of CO_2 Emissions

Total emissions of CO_2 from Canadian agricultural activity are the sum of net soil C loss, emissions from direct use of fossil fuel, and emissions from indirect uses of fossil fuel. These estimates suggest that, in 1996, agricultural activity released about 28 Mt of CO_2 (8 Mt C) (Janzen et al., 1998) into the atmosphere, somewhat lower than emissions in 1981. Projections to the year 2010 suggest that total emissions will not change appreciably from those in 1996. Emissions from soils are predicted to decline and become negative (that is, soils will be gaining C) but, at the same time, emissions from indirect sources may increase, offsetting these benefits. These estimates, however, assume a 'business-as-usual' scenario, and do not yet take into account the benefits that could occur from concerted efforts to reduce emissions.

1.5 Methane

Though present in the atmosphere at very low concentrations, methane has a much greater warming effect than CO_2, about 21 times that of CO_2 over 100 years. This effect arises not only from the CH_4 itself, but also from the CO_2 to which it eventually converts and other indirect effects.

The concentration of CH_4 in the atmosphere which had been increasing at a rate of 1.1% is now increasing at about 0.6% per year. Globally, agriculture is a very prominent source of CH_4, accounting for about two thirds of human induced emissions (IPPC, 1996a).

Most of the methane emitted from agriculture is produced by the microbial breakdown of plant material. Normally, when oxygen supply is adequate, most of the C in decomposing plant material is converted to CO_2. But in the absence of oxygen, decomposition is 'incomplete', and the C is released as CH_4 instead. In agricultural systems, such conditions occur in the digestive system of ruminant livestock and in water-logged soils. Small amounts of CH_4 are also produced during burning of fuel or organic wastes, if there is incomplete combustion to CO_2. Methane and CO_2 therefore, are somewhat complementary: C not converted to CH_4 is largely released as CO_2.

The CH_4 emitted into the atmosphere has a lifetime, on average, of about 8 to 10 years. Most of the CH_4 is converted to CO_2 by chemical reactions in the atmosphere. A small proportion, probably less than 10% of that released into the atmosphere, is converted to CO_2 by microorganisms living in the soil.

1.5.1 Methane Emission by Livestock

Methane is produced by all animals when they digest feed. But emission is especially high from cattle, sheep, goats and other ruminants. These animals have a rumen, or "fore-stomach", where feed is pre-digested by microbial fermentation. Because of this process, ruminants can more efficiently digest coarse feeds. But since the fermentation process occurs under restricted oxygen supply, some of the C in the feed, often about 5 to 10%, is released as CH_4. Non-ruminant animals, like pigs and poultry, also emit some CH_4 during digestion, but the amounts released are much smaller, almost negligible by comparison.

1.5.1.1 Measurement of Methane Emission

The amount of CH_4 emitted by livestock can be measured in a number of ways. One method is to place the animal in an enclosed chamber and measure the accumulation of CH_4 in the airspace. This approach permits accurate analysis, but estimates may be distorted because the animal is removed from its normal environment. Recently, therefore, researchers have measured CH_4 emission from cattle in their natural setting. They measured the CH_4 concentration in air emitted from vents in a dairy barn, and calculated the emission of all cows in the barn, including the manure they produced. Using this approach, they were able to not only estimate average rate of CH_4 production per animal (about 0.81 litres per kg body weight per day), but also the daily and seasonal fluctuations in emission rates (Kinsman et al. 1995).

Measurement of CH_4 from cattle on pastures poses more difficult problems. But researchers now have a new technique, based on the use of a chemical marker, which allows direct measurement of CH_4 emission from grazing animals. This method, used in a grazing study in Manitoba, showed that emission rates were about 0.7 litre per kg body weight per day (0.5g CH_4 per kg body weight per day) (McCaughey et al., 1997).

1.5.1.2 Factors Affecting Methane Emission

The rate of CH_4 emission from ruminants is influenced by many factors. These are reasonably well-known because CH_4 loss reflects incomplete use of feed energy. As much as 5 to 10% of the gross energy in feed may be lost through CH_4 emission. As a result, researchers have studied the factors affecting CH_4 emission long before the environmental concerns about CH_4 became prominent.

One of the most important factors affecting the rate of CH_4 emission is the quality of the feed. In general, diets that increase the rate of digestion reduce CH_4 emissions, because the feed does not stay in the rumen as long. Thus, CH_4 emission is affected by the amount of roughage in the diet, preservation method, growth stage of forage plant, degree of chopping or grinding, the amount of grain in the diet, and the addition of oils. For example, CH_4 emission may be lower from legume rather than grass forage, from ensiled rather than dried feeds, and from high concentrate rather than high-roughage diets.

Another important factor is the amount of feed intake. When intake of feed is increased above maintenance levels, the amount of CH_4 emitted per animal increases, but the efficiency of feed utilization also increases. Consequently, CH_4 emission per unit of product is usually reduced at higher levels of feed intake. For this reason, it is often better to assess CH_4 emission per unit of product rather than per animal or unit of feed. For example, dairy cows in eastern Canada produce about 14g CH_4 per kg of milk, lower than values reported elsewhere, which may be as high as 242 g CH_4 per kg milk.

The animal itself – its breed, weight, rate of growth, and whether it is producing milk – affects CH_4 emission. The environment can also affect CH_4 emission; for example, some research suggests that emissions increase at lower temperatures, though the findings are still somewhat uncertain.

Because of the large number of factors that influence CH_4 release from livestock, it may be possible to reduce emissions by changing management practices.

1.5.1.3 Estimates of CH_4 Emissions from Livestock

Direct emission of CH_4 from Canadian farm animals can be estimated by multiplying the number of animals by an average emission rate per animal. Based on this approach, direct emission of CH_4 from Canadian farm animals in 1991 was about 0.771 Mt (R.L. Desardins, 1997). Of this, beef cattle accounted for 72% and dairy cattle for 25%. By comparison, direct emissions from other livestock were almost negligible.

Estimated CH_4 Emissions from Livestock and Manure in Canada for the Year 1991

	Number of Animals (millions)	**Mass of Manure (Mt)**	**Methane from Manure (Mt of CH_4)**	**Methane from Respiration And Flatulence (Mt of CH_4)**	**Total Methane (Mt of CH_4)**
Dairy Cattle	1.9	17	0.07	0.190	0.260
Beef Cattle	10.7	98	0.01	0.558	0.568
Pigs	10.2	19	0.102	0.015	0.117
Poultry	103	3	0.008	n/a	0.008

Sheep/Lambs	0.9	0.4	0.0002	0.0075	0.008
Horses	0.42	n/a	n/a	n/a	0.0055[1]
Total Livestock	127	137	0.190	0.771	0.961

Source: Ray Desjardins, 1997

[1] Total methane emissions for horses were calculated using the National Inventory statistic of 13 kg/head/year.

1.5.2 Emission of Methane from Manure

Methane is emitted not only from the animals themselves, but also from the C they excrete. Manure, like other organic materials, is decomposed by microorganisms. If the decomposition occurs under well-aerated conditions, most of the C is released as CO_2. When oxygen is deficient, however, a lot of CH_4 may be produced instead.
The ratio of CO_2 and CH_4 produced depends on how the manure is managed. Much of the CH_4 from manure is produced during storage. When manure is stockpiled, inadequate aeration inside the pile may lead to CH_4 production. Even higher amounts of CH_4 may be released from manure stored in liquid form because of limited aeration. Thus pig manure, often stored as a slurry, may emit high amounts of CH_4. Once manure is applied to the land, it produces very little additional CH_4 because of adequate exposure to air.

Only preliminary measurements of CH_4 emission from manure have been made under Canadian conditions. These estimates, however, are often lower than those found elsewhere. In an Ottawa study, CH_4 emissions from an underground covered storage tank amounted to about 15 litres per cow per day, a value about 10% of that reported in milder climates. Similarly, emissions from pig slurry were only about 10 to 20% of those found in other countries. These findings suggest that the cooler temperatures in Canada may result in lower CH_4 emission than elsewhere.

Using estimates of manure production and CH_4 emission rates, it is possible to approximate the amount of CH_4 emitted from manure in Canada. According to these estimates, emission from this source accounts for about 20% of the total CH_4 emitted by livestock (manure + direct emission). In particular, these estimates point to pig manure as an important source of CH_4, both because of large numbers of animals and because of the way the manure is stored.

1.5.3 Methane Emission and Absorption by Soils

Soils can either release CH_4 or absorb it, depending largely on moisture content. When organic materials decompose in soils that are under water, large amounts of CH_4 are released because the water reduces oxygen supply. In the agricultural soils of Canada, however, CH_4 emission is probably confined to localized wetland areas and perhaps to brief periods when low-lying soils are submerged during snowmelt or after high precipitation. Most soils have enough aeration that they do not produce CH_4; in fact, microorganisms in the soils convert CH_4 to CO_2 so that the soils are actually sinks for CH_4. The amount consumed depends to some extent on management practices. For example, CH_4 absorption is usually higher under grassland than in tilled soils, and is suppressed by application of N fertilizers.

Although CH_4 absorption by soils is an important mechanism in the global CH_4 cycle, the amounts absorbed by Canadian agricultural soils are probably very small compared to total emissions from farms. Net absorption of CH_4 by agricultural soils in Canada is estimated to be about 0.012 Mt CH_4 per year (R.L. Desjardins, 1997). This amount is clearly small compared to emissions from livestock. Even large increases in amount of CH_4 absorption by soils would offset only a small proportion of current emissions from livestock and manure.

Estimated Total CH_4 Emissions Produced from Canadian Agriculture for the Years 1981, 1986, 1991 and 1996

	1981	1986	1991	1996
Respiration & Flatulence	0.849	0.748	0.771	0.879
Manure	0.208	0.192	0.190	0.208
Soils	-0.012	-0.012	-0.012	-0.012
Fuels	0.001	0.001	0.001	0.001
Total (Mt CH_4)	1.045	0.928	0.950	1.075
Total (Mt CO_2 Equivalents)	22	20	20	23

Source: R.L. Desardins, 1997

1.5.4 Other Sources of Methane

Small amounts of CH_4 are released by volatilization and combustion of fossil fuels used in agriculture. This emission amounts to about 0.001 Mt CH_4 per year (R.L. Desjardins, 1997). Some CH_4 is emitted from the burning of crop residues, but amounts are small and will diminish further because this practice is becoming obsolete.

1.5.5 Estimates of Net Emission from all Sources

Virtually all of the CH_4 emission on Canadian farms is from livestock. According to current estimates, about 1Mt of CH_4 was emitted from Canadian farms in 1996 (R.L. Desjardins, 1997). Of this, about 80% came directly from livestock, the remainder from livestock manure.

Changes in emissions from year to year reflect differences in livestock numbers, which fluctuate depending on costs of feeds; market prices for meat, milk and eggs; and export markets. If livestock numbers increase as expected, there may be further increases in CH_4 emissions unless new methods are adopted that reduce emissions per animal.

1.6 Nitrous Oxide

Nitrous oxide (N_2O) occurs naturally in the atmosphere at very low concentrations (about 300 ppbv), but the concentration is now increasing at a rate of about 0.3% per year. Much of this increase comes from agriculture, which accounts for up to 70% of the N_2O emissions from human activity (Mosier, 1993).

The increase poses two potential threats. First, N_2O is a very potent greenhouse gas with a long lifetime in the atmosphere (about 170 years). Its warming potential is about 310 times that of CO_2 over a period of 100 years. Second, N_2O released in the atmosphere is eventually converted to nitric oxide (NO), a gas that breaks down ozone (O_3). Ozone in the upper atmosphere filters out ultraviolet (UV) radiation from the sun, so its depletion results in higher doses of harmful UV radiation reaching the earth's surface. Higher N_2O levels, therefore, not only contribute to the greenhouse effect, but may also increase indirectly the intensity of UV radiation.

Most of the N_2O from agriculture is produced in the soil. To understand the origins of the N_2O and the factors that affect its emission, it is helpful to review the overall N cycle on farms.

1.6.1 Nitrogen Cycle

In terrestrial ecosystems, there are three main pools of N: soil, plants, and atmosphere. The largest of these is in the atmosphere; in the column of air above an hectare of land there is about 0.076 Mt of N, roughly a million times the amount plants use in a year. Virtually all of this N, however, occurs as N_2, a gas that is almost inert and not directly available to plants.

Despite living in a sea of gaseous N, plants obtain most of the N they need through their roots, by absorbing nitrate (NO_3^-) and ammonium (NH_4^+) dissolved in soil water. When the plants later die, the N in the plant litter is returned to the soil, where it becomes part of the soil organic matter. This organic matter, in turn, is gradually decomposed by soil microorganisms, releasing NH_4^+, which may be further converted to NO_3^-. These forms are then available again for plant uptake, completing the cycle. In 'natural' systems, this cycle between soil and plants can continue almost indefinitely, with only very small inputs of N from the air via lightning or specialized soil bacteria.

In farmlands the N cycle is more complicated. Now large amounts of N are removed from the field in grain and other products. In fact, cropping systems are often designed specifically to maximize the amount of N (as protein) in the plant parts that are harvested and removed. In high-yielding wheat, for example, more than 100 kg N per ha is removed from the field in grain every year. Consequently, if the cycle is to continue and crop growth is to be maintained, the lost N has to be replaced with inputs from outside.

The main source of new N is the air. There are two ways of converting the otherwise inert N_2 into a form available to plants. One is the industrial approach, using energy from fossil fuel to convert N_2 into 'chemical' fertilizer. The other is a biological approach, planting legumes like alfalfa, clover, beans, and peas. Biological nitrogen fixation (BNF) supplies globally some 90 to 140 Mt of N per year to agricultural systems. Although more verification on these figures is necessary, most indications are that BNF contributes more N for plant growth than the total amount of synthetic N fertilizers applied to crops each year. These crops have 'nodules' on their roots, containing bacteria that convert N_2 into plant-available form. The plants absorb this N, and when they die and decompose, it is released back into the soil as NH_4^+.

The N from fertilizers and legumes have allowed large increases in food production and, if the growing population is to be fed, even larger amounts of N will be needed. Already, the global additions of N from these sources exceed inputs from 'natural' sources (mainly fixation by lightning and bacteria not associated with agricultural crops). While this injection of N sustains food production, it exerts pressure on the N cycle, and often results in losses or 'Leaks' of N into the environment. Approximately 10-20% of applied N may leach into the groundwater. As well, N may be released into the air in various gaseous forms: ammonia (NH_3), nitric oxide (NO), N_2, and N_2O. Most of these 'leaks' occur from the pool of plant-available N (NH_4^+, NO_3^-). Consequently, losses are highest when these forms are added in amounts greater than the plants can use or at a time when plants are not growing.

1.6.2 Nitrous Oxide Formation

Nitrous oxide (N_2O) can originate from two places in the N cycle: during nitrification (the conversion of NH_4^+ to NO_3^-), and during denitrification (the conversion of NO_3^- to gaseous N_2). Both processes are carried out by bacteria living in the soil.

1.6.2.1 Nitrification

Most of the N entering the soil is applied either as NH_4^+ or in a form that converts to NH_4^+. The N in crop residues is largely present in organic forms (like protein), but as it decomposes, the N is released as NH_4^+. Similarly, most of the N fertilizers used in Canada contain N as NH_4^+, or in a form (like urea) which is converted to NH_4^+ very soon after application. Most of the N applied to soil, therefore, passes through this nitrification process.

During nitrification, most of the N is released as nitrate (NO_3^-), but a very small proportion of the N (usually less than 1%) may be emitted as N_2O. In general, the more NH_4^+ applied, the more nitrification occurs, and the greater is the potential for N_2O release. But the proportion of N released as N_2O is not fixed; under conditions of good aeration and high NH_4^+, for example, less of the N will appear as N_2O than when oxygen or NH_4^+ concentrations are low. As a result, the amount of N_2O released from nitrification may not correspond directly to the amount of N entering the process.

1.6.2.2 Denitrification

When movement of oxygen into soil is restricted, nitrate (NO_3^-) can be converted into nitrogen gas (N_2) in the process called denitrification. Deprived of oxygen in air, some bacteria oxidize the nitrogen from NO_3^-, thereby releasing N_2. As for nitrification, however, a small proportion of the denitrified NO_3^- may be released as N_2O. The rate of denitrification is controlled by three main factors: the supply of oxygen, the concentration of NO_3^-, and the amount of available C (used by bacteria as an energy source). Highest rates of denitrification occur when all three factors are present: low oxygen, high NO_3^-, and high available C. The absence of any one of these three may reduce denitrification to negligible rates. Because it occurs only in the absence of oxygen, denitrification is most intense in water-logged soils. Some denitrification may also occur inside the root nodules of legumes.

The amount of N_2O released, however, depends not only on the rate of denitrification, but also on the ratio of N_2O to N_2 produced. This ratio is highly variable and tends to be lower under conditions favouring high rates of denitrification.

Often, we think only of the denitrification that occurs on farm fields. But the N that is lost from the soil may also be converted to N_2 or N_2O. For example, the NO_3^- that is leached from the soil eventually finds its way into the groundwater or into sediments of streams and lakes. Once there it can undergo denitrification. Consequently, the amount of N_2O produced from farm practices may be much higher than that which is emitted directly from the soil.

Of the two processes, denitrification is probably more important than nitrification as a source of N_2O in Canadian farms. Emissions of N_2O from denitrification may be several times higher than those from nitrification, but it is difficult to distinguish between the two sources, and their relative importance varies widely from place to place.

1991 and 1996 Nitrous Oxide Emissions Mt(CO_2 equivalent, with a 100 year time horizon)

	1991	**1996**
Direct Emissions from soils	17.9	21.5
Direct Emissions in animal production systems	6.7	7.6
Indirect Emissions from agricultural systems	9.6	11.8
Total Emissions	**34.3**	**40.9**

Source: Monteverde et al., 1997

1.6.3 Management Practices That Affect N_2O Emission

i) Form of Fertilizer Applied

A variety of commercial fertilizers are used in Canada to supplement soil N. Of these, urea and anhydrous ammonia (pressurized ammonia gas) are the most common, together accounting for almost 75% of the N applied in Canada in 1997 (M. Korol and G. Rattray, 1998). Most forms include N either as NH_4^+ or in a form which quickly changes to NH_4^+ after application. For example, anhydrous ammonia becomes NH_4^+ immediately upon reaction with water in the soil, and urea is converted by soil enzymes to NH_4^+ and CO_2 within days of application. As a result, most of the N in fertilizers passes through the nitrification process (conversion to NO_3^-) with the potential for some to be lost as N_2O.

During their initial reactions, fertilizers may affect pH, soluble C content, and other properties of soil in their immediate vicinity. These effects vary with fertilizer form so that N_2O formation during nitrification may vary among fertilizers. Indeed, some research suggests that there may be large differences in N_2O emission among fertilizer forms. Highest emissions (0.5% to 2.7% of N) may occur from anhydrous ammonia, and lowest (0.05% to 0.07%) from calcium nitrate, presumably because the N in the latter does not undergo nitrification.

Nitrous oxide emissions from various fertilizer formulations were compared in a study at Elora, Ontario. Equivalent amounts of N were applied to turfgrass in one of several forms: ammonium nitrate (NH_4NO_3), urea ($CO(NH_2)_2$), and slow-release urea. There was little N_2O emission from the slow-release urea, probably because its gradual N release coincided with plant N uptake, preventing the accumulation of NH_4^+ or NO_3^-. The other two sources showed significant N_2O emission, with slightly higher values from ammonium nitrate than urea.

The physical form and placement of fertilizers may also influence N_2O emissions. For example, results of a laboratory study suggest that emissions may be higher from large granules than from fine particles mixed into the soil. The finer fertilizer is more widely dispersed in the soil and , presumably, has less effect on the pH immediately next to individual particles. Banding fertilizer, similarly, concentrates the N in localized areas and may therefore also affect N_2O emission.

Although these and other data suggest that fertilizer formulation and placement may affect N_2O emission, this effect has not yet been fully defined. Because N_2O emissions also depend on other factors like rate of application, soil properties, and crop rotations, the effect of fertilizer formulation may not always be the same.

ii) Manure Management

Of the N consumed by livestock in feed, a large proportion may be excreted in urine and feces. In one year, for example, a dairy cow, under certain conditions, may excrete as much as 100 kg N or more. Consequently, animal manure contains very large amounts of N; in Canada, the N excreted each year by livestock may be roughly equivalent to amounts of N applied as fertilizer. Applying plant nutrients, especially N to soil as inorganic fertilizer or in organic forms can influence the C content of the soil. Proper management of manure can also lead to environmental and social benefits such as reduced odours and improved surface and groundwater quality.

Some of the N in manures is lost to the atmosphere as NH_3 either immediately or during storage, but most of the N is returned to the land. The N content of manures is highly variable, depending on animal, rations, and bedding material, but is typically about 2% of dry weight. This N occurs largely in two forms: NH_4^+ and organic N. The former is immediately available to plants and behaves in the soil like NH_4^+ from fertilizer. The organic N, however, acts more like a slow-release form, gradually being converted to NH_4^+ by the action of soil microorganisms.

The N applied in manure is often very susceptible to loss as N_2O. Since a large part of the N occurs as NH_4^+, some N_2O may be formed during nitrification to NO_3^-. Much higher amounts may be produced from denitrification, because manure is not only a source of N but also of available C. Applying high concentrations of N and available C together favours denitrification. In extreme cases, where soils have received excessive rates of manure for many years in succession, N_2O emissions may be as high as 50 kg N per ha per year, though emissions are usually much lower.

The amount of N_2O emitted from manured soils will depend on rate of application, type of manure, soil properties, and method of application. One study suggests that liquid manure applied in bands may produce more N_2O than manure applied uniformly on the soil surface. Placing the manure in bands concentrates the N and C, creating conditions more favourable for denitrification.

Manure management may also have indirect effects on N_2O emission. A large portion of N excreted from livestock, as much as 50%, may be released into the atmosphere as ammonia (NH_3) gas. This NH_3 is eventually deposited onto soil or water, where it reverts to NH_4^+ and can be lost as N_2O like N applied directly.

iii) Crop Residue Input and Soil Management

Large amounts of N are returned annually to the soil in the form of crop residues (e.g., straw, roots) and other plant materials. In many cases, this N is merely a recycling of N absorbed earlier from the soil. But legumes, which can capture N_2 from the air, can actually add ‘new’ N to the soil. Sometimes crops (known as ‘green manures’) are grown solely for the purpose of capturing N, and are then plowed back into the soil.

The amount of N_2O produced from the addition of these plant material depends on the rate of N release. Some residues, like wheat straw and corn stover, have a very low N concentration, often less than 0.5%. When these materials decompose, they release very little N; in fact, sometimes they even result in withdrawal of NH_4^+ or NO_3^- from the soil because the microbes need extra N to decompose the residue. In contrast, N-rich materials like legume residues or 'green manures' can quickly release large amounts of NH_4^+ (later converted to NO_3^-) during decomposition. Like animal manure, these materials also provide a ready source of available C, favouring the release of N_2O from denitrification. Thus, alfalfa residues may release 2 to 4 kg N_2O-N per ha and soybeans 0.3 to 2 kg N_2O-N per ha per year.

The way in which crop residues are managed may also influence N_2O emission. An important management tool in dealing with crop residue is tillage. Normally, crop residues are mixed into the soil by tillage, but in 'no-till' or other 'minimum tillage' systems, the residues remain on the soil, altering decomposition patterns. Some studies suggest that use of 'no-till' farming may increase N_2O emission; others conclude that no-tillage can reduce emissions. Tillage practices not only alter residue placement, but also influence soil moisture, temperature, and aeration, all of which affect N_2O production.

Soils, even without recent additions of residues or other N, can emit N_2O from the decomposition of their organic matter. This is especially true of organic soils, which can release N_2O at a rate of about 5 kg N per ha per year from the decomposition of their rich organic N reserves. Similarly, soils that are left unplanted for a year (summerfallow), may emit significant amounts of N_2O. The organic N in these soils is gradually broken down into NH_4^+ and NO_3^- by soil microbes, and because there are no growing plants to remove this N, it accumulates and is highly susceptible to loss via denitrification.

iv) Amount and Timing of N Application

Often, N_2O emission is assumed to be directly proportional to the amount of N applied. But a better measure may be the amount unused by the crop. If the NH_4^+ or NO_3^- released into the soil is matched precisely to the plant uptake, these N forms will not accumulate in the soil and N_2O losses will be minimal. Such ideal synchrony, however, rarely occurs. Often NH_4^+, and particularly NO_3^-, accumulate in excess of the plants' capacity to absorb them, resulting in high potential for N loss via leaching or denitrification. This is especially true if the NO_3^- accumulates after harvest, because then it is vulnerable over the fall, winter, and, especially, the following spring, when denitrification is particularly intense. Consequently, matching the amount and time of N application with plant N uptake pattern is a very important management tool to minimize N_2O emissions.

1.6.4 Variability of N_2O Emission

Nitrous oxide emissions are often very sporadic. Unlike CO_2, which is released from soil almost continuously, N_2O is usually emitted in bursts or 'flushes'. Under Canadian conditions, the most important of these flushes may occur in early spring, when the snow is melting. At a site in central Alberta, for example, most of the N_2O emitted in the entire year occurred in a 10-day period at the end of March. These bursts of N_2O emission at snowmelt may reflect very favourable conditions for denitrification and N_2O formation: high moisture content (oxygen deficiency), adequate NO_3^- and available C, and favourable temperature. Or the N_2O flush may reflect the abrupt release of N_2O that had been trapped under a layer of frozen soil or ice. Although the spring flush is often the largest, additional bursts of N_2O release may occur following heavy rains, which result in water-logging of soils, especially in low-lying areas. As well, there may be eruptions of N_2O immediately following nitrogen application because of the sudden availability of N.

Emission of N_2O is not only sporadic over time, but also across space. This variability stems, in part, from the differences in N and moisture (hence oxygen) content across the landscape. At any time, there may be minimal release of N_2O from most areas in a field, but high emissions from small 'hotspots' where conditions are ideal for N_2O production.

A further complication is that much of the N_2O is often produced in deeper soil layers. The release of this N_2O depends on its rate of diffusion to the soil surface, which is controlled by soil porosity and the presence of ice or water at the surface. The trapped N_2O may also be dissolved in soil water or be further converted to N_2 or to NO_3^- by microbes, so that the N_2O formed at depth is not all released to the atmosphere. Consequently, N_2O emission from soils depends not only on rate of formation, but also on rates of diffusion and conversion to other N forms.

Until recently, we thought there would be very little N_2O formation over winter because of low soil temperatures. But this may not hold true where snow insulated the soil. In parts of eastern Canada, for example, the soil is covered with a thick blanket of snow for up to five months per year, keeping soil temperatures above freezing. As a result, N_2O can be produced all winter and be released through the porous snow. At a site near Quebec City, a fertilized barley field, ploughed the previous fall, released up to 5 kg N_2O-N per ha during the winter and spring, equivalent to 5% to 10% of the fertilizer N applied. The same field released only 2 kg N_2O-N during the growing season.

Because of the sporadic and unpredictable pattern of N_2O release, estimating amounts of emission is very difficult. Hence, current estimates of N_2O emission are probably less reliable than those for the other greenhouse gases.

1.6.5 Estimates of National N_2O Emission

Nitrous oxide emissions from Canadian farms can be estimated only tentatively given our limited understanding of N_2O formation and release. Current estimates rely on simple equations, developed by the International Panel on Climate Change (IPCC, 1996), that calculate N_2O release from three sources: direct emissions from soils, direct emissions from livestock production, and indirect emissions from farms.

Direct emissions from soils include N_2O derived from fertilizer, land-applied manure, legumes, and crop residues. Emissions were calculated from the total N content of these sources, based on national statistics, assuming that a specified proportion of the N was released as N_2O (about 1%, depending on source). The calculation also included estimates of N_2O release from organic soils, though these amounts are very small. Based on this calculation, direct emissions of N_2O from agricultural soils in Canada in 1996 were estimated to be 0.070 Mt N_2O (Monteverde et al., 1997). When averaged over the area of cultivated land in Canada, this equates to about 1 kg N per ha per year. The estimated emission rates, however, vary widely among regions.

Direct emissions from livestock were calculated by estimating the amount of N in manure, and assuming that a specified portion of that N was emitted as N_2O. The fraction of N converted to N_2O was assumed to be 2% for grazed animals and 0.1 to 2% for other livestock, depending on waste management. According to this approach, direct emissions from livestock were estimated to be 0.024 Mt of N_2O in 1996 (Monteverde et al., 1997).

Indirect emissions were calculated from estimates of atmospheric N (e.g., NH_3) deposited on the soil, N leached from farm fields, and a production of human sewage. According to these calculations, leached N is the most important, accounting for more than 80% of the roughly 0.038 Mt of N_2O released from indirect sources in 1996 (Monteverde et al., 1997). This estimate assumed that 30% of the N applied as fertilizer or manure leached into the groundwater.

Based on the IPCC approach, total emissions of N_2O from agriculture in Canada in 1996 were about 0.132 Mt N_2O (Monteverde et al., 1997). Of this, direct emissions from soils accounted for about half.

The trend in N_2O emissions over time may be as important as the total amount. According to current estimates, N_2O emissions have increased steadily since 1981, increasing by 20% from 1991 to 1996 alone. Much of the increase resulted from higher N inputs as fertilizers and animal manure. With expected increases in livestock numbers, and higher crop yield expectations in the future, N_2O emissions may climb still further unless improvements are made in N management.

1.7 Summary of Agriculture's Contribution to Greenhouse Gas Emissions

The numbers in the table below should be considered "work in progress" as the accounting practices based on the IPCC guidelines are constantly evolving**.** For example, the 1996 IPCC Guidelines for National Greenhouse Inventories improved upon the 1995 IPCC Guidelines by revising the methodology and default data to estimate nitrous oxide emissions from agricultural soils and manure management. The revised methodology includes more sources of N_2O from agricultural activities while the new method accounts for the application of N-fertilizers to the soil and N uptake in crops. The new methodology provides a more comprehensive description of N_2O emissions from agriculturally-related activities by accounting for previously omitted N_2O sources.

These current estimates are not without uncertainty. All the processes that affect emissions are still not fully understood. Therefore, each estimate is subject to potential error. Of the three gases discussed in this paper, N_2O has the highest degree of uncertainty which could be off by as much as 50% or more. Despite their uncertainty, these values are the first comprehensive estimates of greenhouse gas emissions from Canadian agriculture and provide a benchmark for showing trends.

Summary of Agiculture's Contribution to Greenhouse Gas Emissions by Gas (Mt) based on 1996 IPCC Guidelines

	Emissions (Full Molecular Weight)		**Emissions (Carbon Dioxide Equivalent)**	
	1991	**1996**	**1991**	**1996**
CO_2	5	1.7	5	1.7
CH_4	0.95	1.1	20	23
NO_2	0.11	0.13	34	40
Total	6.05	2.9	59	64

Source: Canada's National Inventory

2. Factors affecting emissions growth and reduction opportunities

2.1 Growth of Crop and Livestock Sector

2.1.1 AAFC Medium Term Crop Baseline

The projected rising demand for meat in developing countries results in stronger expected growth in demand for feed grain relative to food grain. As a result, AAFC medium term baseline price trends are stronger for coarse grains than for wheat.

The international cereals market is currently in a state of re-alignment in response to sharply higher prices in the 1995/96 crop year. At that time, supply shortfalls in several key producing regions drove prices significantly higher. High prices caused increased production worldwide and rationed consumption. While cereal prices have already dropped significantly, the AAFC baseline assumes further moderate price declines in the 1998/99 crop year as growth in supply continues to outpace demand.

After 1998/99, the AAFC medium term crop baseline assumes accelerating demand growth results in modestly rising prices which are sustained over the baseline. This trend of demand driven rising prices is markedly different from the high prices induced by short term supply shortages in 1995/96. Nominal prices remain above those of the early 1990s, thus reducing the demand for export subsidies. However, real grain prices continue to follow their downward trend as technology and efficiency improvements continue to shift the supply curve outwards.

Oilseed prices have been high in recent years due to strong demand growth. The key demand factor for the oilseed sector is the consumption prospect in developing countries, where per capita oil consumption is currently low in comparison to developed economies. Asian economies, where per capita income levels and growth rates are high, account for the main source of growth.

The AAFC baseline assumes soybean oil prices strengthen from the relatively low levels of 1996/97. Increasing world vegetable oil demand over the medium term drives prices up into the higher ranges attained in 1993 and 1994. Following record high soybean meal prices in 1996/97, meal prices fall considerably in 1997/98 but remain above levels received in the early 1990s. Increasing feed demand continues to add strength to soymeal prices over the baseline.

With the large drop in meal prices, the AAFC baseline assumes soybean prices drop significantly from 1996/97 levels but remain well above prices of the early 1990s. Increasing world demand for vegetable oil and meal continues to fundamentally support oilseed prices at levels high enough to attract more acreage from cereal production.

In Canada, there is very little scope for bringing additional land into cereals production without reducing summerfallow or transferring it away from oilseed and specialty crop production. In this baseline, future growth in Canadian cereals production is largely a result of yield improvements. There is also some scope for reducing summerfallow, however, crop rotation considerations place a limit on this. It is assumed that total summerfallow area is reduced to 5.3 Mha by 2007 (AAFC, 1998).

Both wheat and durum prices remain strong relative to the prices received in the early 1990s. The extremely tight durum situation in 1997 is expected to be resolved in 1998 with the price spreads returning to more normal levels. While nominal U.S. prices in 2007 are in the same range as the 1992-96 average, Canadian prices are up slightly on the assumption that the market is free to export subsidies. The relatively strong wheat and durum prices bring wheat area back up to average 1992-96 levels. Exports of wheat in 2007 are about 9% higher that 1992-96 levels (AAFC, 1998). Growth in domestic milling and other food use results in increased exports of wheat products.

The AAFC medium term forecast assumes barley and corn prices remain at current levels over the baseline. Following the removal of U.S. Export Enhancement Program (EEP), Canadian barley prices are 6% higher than the 1992-96 period (AAFC, 1998). Prices at these levels induce significant plantings of corn and barley, maintaining area above 1992-96 levels. Barley exports fall substantially as a larger share of production is consumed by expanding livestock production in Western Canada. Barley exports over the baseline are primarily composed of malting barley.

Since canola has a higher oil component, it does not suffer the same price decline that soybeans have as a result of a significant drop in meal prices. Reasonably strong meal and oil prices help to support canola prices in a range similar to the average received between 1992-96. Strong cereal prices limit canola expansion from current levels in the medium term. Acreage in 2007 is slightly above 5 Mha, up 17% from the 1992-96 average but below the highs reached in 1994 and 1995 (AAFC, 1998).

Seed exports over the baseline are similar to the 1992-96 average. The domestic processing sector increases its consumption by more than 50% over 1992-96 levels, both by making better use of current capacity and by expanding capacity (AAFC, 1998). Consequently, exports of meal and oil increase over the baseline. Relatively strong cereal and oilseed prices limit further expansion of specialty crops.

2.1.2 Meat Baseline

2.1.2.1 International Red Meats

The AAFC medium term forecast assumes strong import demand, particularly from Asian economies, is met by increased meat exports from Australia and North America. This demand growth for meat underpins strength in other agricultural commodities (feed, protein meal, etc.) and is a principal feature of this baseline.

In most developed countries, red meat consumption is either stagnant or on a long term decline. Japan and Korea, where current levels of consumption are relatively low, are notable exceptions. Over the baseline, beef demand in developed countries remains weak due to long term shifts in preference and to a lesser extent, consumer fears of food safety. Anticipated recovery in EU demand for beef, and the export subsidy restrictions lead to lower EU beef exports.

The AAFC medium term forecast assumes beef prices increase relative to those of other meats in world markets over the baseline. Cattle prices had been low as production in North America reached the peak of the cattle cycle, but began to increase in 1997 and are expected to rise up to 2001. Thereafter, prices fall as the next peak of the production cycle is reached.

Pork prices in 1996 were at the high point of the price cycle. Price strength was further reenforced in 1997 by supply problems in key exporting countries (Classical Swine fever in the Netherlands, and foot & mouth disease in Taiwan). Over the long term, pork prices are expected to decline due to continued productivity gains, particularly related to the restructuring of the industry in the U.S. and Canada.

The U.S., the dominant influence on Canadian hog and pork prices, is rapidly becoming a major player in world pork markets. The growing importance of large hog farms and processors in the U.S. are projected to reduce future cyclical variations in output price. Long term contracts are becoming more prevelant, reducing supply response to short term price fluctuations.

2.1.2.2 Canadian Red Meats

Canadian cattle marketings are at a cyclical peak and are expected to decline for a few years as herds rebuild. Marketings are projected to begin to increase around the year 2000. Domestic cattle slaughter declined over the 1980s and early 1990s, but has recently begun to increase. The baseline shows domestic slaughter continuing to increase in line with increases in domestic packing plant capacity. As a result, live cattle exports to the U.S. decline. Growing cattle slaughter and stable beef consumption have resulted in growing exports. Canada became a net exporter of beef for the first time in 1996 and continues to expand its net exports over the baseline.

Currently, Canadian beef exports are mainly to the U.S.. Canada is a large net exporter of low-quality beef to the U.S. and a net importer of high quality beef from the U.S.. The relationship is reversed on the world market where Canada is a net exporter of high quality beef (largely to Japan) and a net importer of low quality beef (mainly from New Zealand and Australia). Trends in exports indicate increased low quality beef exports to the U.S. and increased high quality beef exports to the rest of the world.

The Canadian hog sector is undergoing a period of change. It is assumed that hog producers will make significant adjustments which will allow them to compete at lower world hog prices. Hog production shows strong growth over the long term, particularly in the west where some of the anticipated growth in capital investment is already beginning to take place. However, issues related to environmental impacts have yet to be resolved.

Restructuring in the domestic packing industry, in combination with expanded processing capacity, is predicted to result in continued increases in pork exports over the baselines. Live exports to the U.S. should decline as more hogs are slaughtered domestically. As with beef, the bulk of Canada’s current pork net exports go to the U.S.

(about 60% in 1996) (AAFC, 1998). The projected growth in Canadian pork exports is assumed to go to the U.S. and to Asian countries, particularly Japan and South Korea.

2.2 Fertilizer Usage

Plant nutrients (fertilizers) are essential inputs which, when properly used, contribute to maintaining soil health, optimize yields and increased soil carbon. Detrimental environmental impacts stem from excessive (inefficient) levels of application over and above plant requirements leading to build-up of fertilizer nutrients in the soil and their eventual loss in the environment. Of particular concern are nitrogen and phosphorus, both of which can contaminate water, leading to eutrophication or other forms of pollution and impacts on aquatic life. Secondly, volatilization of excess fertilizers in the form of ammonia and nitrous oxide can lead to acid precipitation, which damages the ecosystem and plant growth. These gases also contribute to climate change. Factors such as soil and weather conditions, method and timing of application, and manure handling/storage can aggravate or ameliorate the severity of environmental impacts. Conversely, under usage of fertilizer can also lead to a loss of residual soil fertility.

In the prairie region, the fertilizer use efficiency trend between 1983 and 1992 improved, with a high year to year variability. Over this period, fertilizer use efficiency increased at an annual rate of 2.3% (Narayanan, 1995). The environmental significance of this trend is interpreted as follows. First, this trend in efficiency relates only to chemical fertilizer use. In this regard, the increasing trend in fertilizer use efficiency means that in the prairie region, increase in crop output had outpaced the increase in chemical fertilizer use. The trend is therefore, in the right direction, conducive to a reduction in the risks of water contamination from nutrients. Given the historical under fertilization of prairie soils and reliance on organic matter as a nutrient source, this trend could also mean a diminishing rate of increase in chemical fertilizer use at the expense of residual soil nutrients and organic matter, which is clearly undesirable from the soil health point of view. Improved fertilizer use reduces the amount of excess nitrogen applied to crops which in turn reduces the amount of nitrous oxide that is released into the air through nitrification.

Nationally, the trend in fertilizer use efficiency is very similar to the Prairie region - downward sloping over 1983-1992 although the slope is less pronounced. This implies an increase in use efficiency estimated at a rate of 1.1% per annum - less than half of the prairie rate (Narayanan, 1995).

2.3 Movement of Soils to Sinks in 2000

2.3.1 Inclusion of Sinks in Kyoto Protocol

In Kyoto, Canada argued for the inclusion of human induced land use, land use changes, and forestry as sinks. The argument was accepted for reforestation and afforestation efforts which fix carbon from the atmosphere. These will be included in the first commitment period. As it now stands, soils as a source of CO_2 will be counted. In other words, Canada's national calculations of CO_2 emissions must include emissions from soils if they are a net source, as we think they were in 1990. And we can count reductions in these emissions toward any sectoral target you may have, but only up to the point where they cease to be a source.

Soils were excluded partly because of European opposition, but also because no country had really defensible numbers on net emission from agricultural soils. Canada appears to be the only country which has even tried to produce national numbers. There is a chance that soils could be added to the first commitment period over the next two or three years, but only if we are certain of our own numbers and only if we as a country can secure the agreement of enough other countries to their inclusion. So, for the time being, this is how the system works. Canada must include CO_2 emissions from agricultural soils in its measurement of its 1990 emissions. We can also claim credits for any reductions in emissions from soils, but only up to the point where they cease to become a source. If they become a net sink, we will not receive further credit.

2.3.2 Using Canadian Soil as a Carbon Sink

In 1996, the annual cropland area in Canada was about 45.5 million hectares. Almost 86% of this land was in the four western provinces with another 12.9% in Ontario and Quebec. About 8 million hectares of cropland were summer-fallowed in 1990. Conventional cropping techniques include tillage prior to seeding, single rate fertilizing and spraying of fields, and tillage again after harvest. The tillage practise in particular encourages the emission of CO_2 from the soil to the atmosphere. In 1996, no-till was practiced on about 16% of Canada's cropland and further increases in this area are expected. Bruce et al., 1998, estimated that adoption of "best management practices" on croplands could, on average, result in initial carbon gains of about 0.73 tonnes CO_2 per hectare per year. Depending on soil and climate, however, sequestration rates can vary significantly.

Canada has an extensive base of perennial grasslands totalling about 15.5 million hectares in 1990. Most of the grassland is extensively managed with seasonal grazing. If overgrazed, the pasture grasses will have their ability to sequester carbon significantly reduced. Undergrazing also reduces the ability of grasses to maximize carbon sequestration, as the length of vegetative growth during the growing season is shortened.

The pool of soil organic carbon in Canada's annual cropland is estimated to be about 6 billion tonnes to a depth of 1 meter. Historically, since cultivation of these croplands began, an estimated 1 billion tonnes of soil organic carbon has been lost (Bruce et al, 1998). Much of this loss occurred in the first couple of decades of cultivation, after which the rate of loss slowed when the readily decomposable soil organic carbon was depleted, and as farmers gradually adopted improved soil management techniques.

While 15 to 30 percent of the original soil carbon has been lost since cultivation, most of this loss occurred in the first two decades of cultivation (Acton and Gregorich, 1995). Smith et al, 1997, estimated from Century Model predictions that average annual emissions from cropland in Canada had dropped from 10 million tonnes of CO_2 in 1970 to about 7 million tonnes of CO_2 in 1990. This implied that soil carbon was reaching a new equilibrium, attributed to smaller amounts of land being converted into cropland, decreases in summer-fallow, increases in no-till farming and increased fertilizer use in the prairie provinces.

Smith et al, 1997, forecast that Canadian agricultural soils will change from a net source of CO_2 to a net sink of 1.8 million tonnes of CO_2 by 2010 without any major shifts in farm practices. They forecast that the biggest and earliest contributor to carbon sequestration will be Saskatchewan. Given that Saskatchewan has by far the largest proportion of annual cropland in Canada, it has the biggest influence on the overall agricultural soil carbon sink in Canada.

Others have suggested that soils could become a larger net sink than currently predicted by Smith et al., 1997, if farmers can be mobilized to adopt the land management techniques at a faster rate than they do now. Bruce et al., 1998, estimate that, based on experience with the adoption of no-till and other practices, C-conserving practices might be adopted on nearly 40% of the croplands within 2 decades. If this were achieved, the total C sequestered in the next 20 years from croplands would be 160 million tonnes CO_2. While the largest potential is on croplands, grasslands could also sequester a total of 18.6 million tonnes CO_2 over 20 years if 40% (1.7 million hectares) of them were subjected to conservation techniques. On a per year basis, the carbon sequestration rates on managed grassland are estimated to be about 0.73 tonnes of carbon dioxide per hectare (Bruce et al, 1998). With policy and economic incentives, Bruce et al., 1998, estimate that the gains would be much larger.

Another national estimate by the National Agriculture Environment Committee (NAEC) suggests that Canadian farmers could be sequestering 11 million tonnes more CO_2 in 2000 than 1990 baseline for Canada (NAEC, 1994) of 4 million tonnes CO_2 per year if using 7 million tonnes CO_2 in 1990 from Smith et al., 1997. They further project that by 2005 about 16 million tonnes more CO_2 could be sequestered by Canadian farmers. Their estimates include the adoption of various land management techniques (eg., reducing tillage, elimination of summer-fallow, planting more perennial forages, applying more nutrients as fertilizer or manures, etc.), and a significant component to account for improvements in plant breeding and increased crop yields. NAEC, 1994 also note that while a new equilibrium may be reached with full adoption of the management techniques known today, new techniques will undoubtedly arise in the next 20 years to allow farmers to continue to sequester carbon beyond this equilibrium to some higher level.

The next question is how much of the potential for carbon sequestration in agricultural soils can be realized over the next two decades? The answer is dependent on how many farmers and ranchers adopt the available techniques that encourage carbon sequestration.

Saskatchewan farmers have already adopted no-till farming, and in 1996, 22% of Saskatchewan's cropland was under no till. The rate of adoption over the past 4 years has averaged about 60,000 to 70,000 hectares per year. Should this momentum be maintained for another ten years, significant additional carbon gains could be realized. A similar proportion (20%) of Ontario farmers have adopted reduced or no-till farming (NAEC, 1994). Manitoba and Alberta farmers have also made good progress towards adoption on no-till farming (9% and 10% respectively).

Adoption of new practises by farmers generally follows a sigmoidal growth curve. The growth of no till farming is just reaching the steep part of the curve now, so it is likely that the rate of adoption may increase from the current trend as the practise becomes more mainstream.

Estimates of annual gains in soil carbon for the 2008-2012 commitment period include 1.8 million tonnes CO_2 per year, 11 million tonnes CO_2 per year without incentives, and 25.7 million tonnes CO_2 per year with incentives. Over the 2013-2017 commitment period, annual gains could be made between 12.9 and 34.6 million tonnes CO_2 per year, depending on the incentives. The discrepancy among estimates reflects the uncertainty about future land management practices and the impacts of these practices on soil carbon. The consensus that soils can become a sink for carbon, however, is sufficient justification to set in place a system to quantify future gains as they occur.

2.4 The Food and Beverage Processing Sector

2.4.1 Environmental Issues Associated with Food and Beverage Processing

The main environmental issues associated with the food and beverage processing industry are disposal of packaging wastes, quality of effluents and emissions released into air and water, and input use and efficiency. Effluent and emission releases from food and beverage industry are regulated by federal, provincial, territorial, and/or municipal statutes. Strategies to prevent and control pollution include effluent-treatment technology and use of "clean technology" in manufacturing processes. Packaging wastes are reduced through re-design of packaging materials, changes in packaging procedures, and consumer efforts to recycle and reuse packaging. Environmental and economic considerations also affect the types of inputs used in production processes, such as restrictions on the use of methyl bromide (an ozone-depleting substance) in fumigation, and economic incentives to use resource inputs, such as energy and water, more efficiently.

2.4.2 Energy Use

For energy use efficiency, both the food industry and the beverage industry recorded improvements between 1990 and 1992. Energy intensity (defined as energy consumed per dollar value of shipments) decreased over this period by 10% and 25% for the food and beverage sectors, respectively. This can be attributed to energy conservation efforts as well as to growth in product sales.

2.4.3 Water Use and Effluent Discharges

Between 1981 and 1991, both the food and beverage industries recorded slight decreases in total water intake, despite overall growth in product shipments.

Effluent discharges to water are regulated by provincial, territorial, or municipal governments. Facilities discharging into a municipal sewer or watercourse typically require a discharge permit and may be subject to monitoring or control requirements. If limits on certain substances are exceeded, surcharges may be levied that can pose a significant cost to food and beverage processors. The key parameters typically measured are biochemical oxygen demand, suspended solids, grease and oils, and total nitrogen. Control of pH is a concern for some sectors. The sectors most affected by water pollution abatement requirements are the meat, poultry, fish, fruit and vegetable processors. However, few national data exist to illustrate trends in releases of such substances or of compliance with regulations.

2.4.4 Air Emissions

As with water effluent, emissions to air are regulated provincially, territorially, or municipally. Permits are issued to control emissions of particulate and visible emissions, the key parameters. Ozone depleting chemicals, such as chlorofluorocarbons (CFC's), are used in refrigeration in the food and beverage processing sectors. Use of these chemicals is controlled by an international agreement (Montreal Protocol) and domestically by the Canadian Environmental Protection Act. As an industry that is heavily reliant on refrigeration, the food industry is very much implicated by the Montreal Protocol. As one of about 25 signatory countries, Canada has agreed to phase out all ozone-depleting substances including many refrigerants. CFC's are no longer manufactured and HCFC's will be phased out by 2020. This means that new refrigeration equipment will contain other, less harmful cooling liquids, and that older equipment must have its cooling liquids replaced. Food processors, grocery distributors and retailers, and foodservice operators are learning about their options, choosing appropriate refrigerants and replacing equipments and coolants as needed. Processors, distributors, and retailers are switching to alternative refrigerants in accordance with these government regulations. Grocery retailers no longer use either CFC propelled aerosols or foam trays containing CFC's.

Emissions of greenhouse gases (GHG) are not regulated (except for CFC's, which are also greenhouse gases); the national GHG emissions stabilization objective is being pursued through voluntary measures. Reductions of carbon dioxide emissions have been achieved in both the food and beverage processing sector due, primarily, to the reductions in energy use intensity noted previously.

2.4.5 Emerging Technological Measures to Reduce Greenhouse Gas Emissions and Address Other Environmental Issues in Food Processing

The following are examples of emerging technologies:

- Methods for reducing processing and packaging waste, e.g., life-cycle analysis of packaging alternatives.
- Waste treatment technologies.
- New refrigerants.
- Characterization of by-products, wastes, and air emissions generated at all stages of food production and processing.
- Means to reduce the quantity of by-products generated, e.g., bioprocessing of byproducts and waste into edible food, feed, fuel, and chemicals with industrial applications.
- Rapid analytical methods, for raw to finished products and for by-products, to determine the presence of desirable and undesirable substances.

2.5 Knowledge gaps and areas for further research/analysis

- adaptation to impacts of climate change and areas for further research and analysis
- data from food processing sector
- improving the accuracy of emission estimates
- identify measurement methods and their use to obtain a broader base of data to improve our confidence in the emission estimates
- which management practices can reduce GHG emissions by how much and at what cost

3. Review of Existing GHG Mitigation Efforts and Experience

3.1 Reducing CO_2 Emissions

Farming means managing carbon. On every ha of farmland, tonnes (Mg) of C are removed from the air every year and changed to organic materials by photosynthesis. At the same time, roughly equivalent amounts of CO_2 are released back into the air from decomposing organic matter and the burning of fossil fuels. Through the choice of farming practices, farmers can manage this cycle, altering it to reduce net emissions of CO_2 .

There are two main ways of reducing emissions: (i) to increase the amount of C stored in soil, and (ii) to burn less fuel. There are several practices already available to achieve each of these.

(i) Increasing Soil C

In soils that have been managed in the same way for many years, the C content is usually quite constant. A change in management, however, can result in losses or gains of C. To increase soil C, one of two things can be done: (a) increase the amount of C added to the soil, or (b) reduce the rate at which soil C is decomposed (decayed) back to CO_2 .

(a) Increasing Organic Matter Additions

Atmospheric CO_2 enters the soil by way of photosynthesis. This process traps CO_2 in organic forms, a portion of which is added to the soil as residues. The only direct way of increasing C additions, therefore, is to use practices that favour higher photosynthesis; in other words, practices that increase plant yield. Such increases can be achieved by using higher yielding crops and varieties, buy providing better crop nutrition (using fertilizers and manures), or by reducing water stress (by irrigation, water conservation, or drainage). Any action that improves soil quality will also promote higher yields. Perhaps most important is to use cropping systems that keep actively growing plants on the land as often and as long as possible. Some ways of doing this include: planting perennial crops (like grass), avoiding summer fallow, and planting winter crops.

Increased photosynthesis only helps soil C if at least some of the additional trapped C is returned to the soil. The more yield is removed from the field as grain or other products, the less the increase in soil C. Thus, soil C gains can be achieved by using cropping practices that keep all residues in the field, and by planting crops (like forage grasses) that store a lot of the their C in roots. Often, animals help recycle the C back into soil. In many livestock-based systems, a large part of the plant yield is returned to the soil as manure, and only a small portion is actually exported from the field or the pasture.

(b) Reducing Decay Rate

One method of slowing the rate of organic matter decay in the soil is to make conditions less favourable for soil microbes. For example, residues on the soil surface will keep soils cooler, slowing decay. Similarly, maintaining growing plants on the surface as along as possible slows decay, because plants dry out the soil and cool it by shading.

Decay rate can also be slowed by shielding the organic matter from soil microbes. Soils are usually granulated, with organic materials protected inside the granules (or aggregates). Breaking these aggregates open by intensive tillage exposes that organic matter to soil microbes. As a result, practices that use minimal disturbance of soils tend to preserve the soil C. Another way to shield organic materials is to place them where conditions are not suitable for decay; for example, they can be kept on the surface, where they tend to stay dry, or placed deep in the profile, where soil is cool.

3.1.1 Practices that Increase Soil C

There are many methods that can be used to promote soil C gain, either by adding more C or slowing decay (or both). The following are often effective, though the amount of C gain depends on climate and soil type.

- Reduce tillage : Tillage was once necessary to control weeds and prepare soil for planting. But now weeds can be controlled with herbicides, and new seeding equipment can place seeds directly into untilled soil. As a result, intensive tillage is no longer required; in fact, a growing number of farmers have eliminated tillage entirely, using ‘no-till’ or ‘direct-seeding’ practices. These practices protect soil C by shielding it inside aggregates, and by keeping crop residues on the surface where they decay more slowly and cool the soil beneath them. No-till and other ‘reduced-tillage’ practices also prevent erosion, thereby preserving soil quality, maintaining future photosynthesis. No-till practices are one of the most important ways of increasing soil C because they could be adopted on a large proportion of Canada’s cropland. Indeed, it was already practised on about 14% of cropland in 1996 and adoption is growing.
- Nutrient Managment: In cases where soils do not have enough nutrients, addition of fertilizers, animal manure, or green manure will increase yields, leading to higher inputs of C. Manures may also improve the physical condition or ‘tilth’ of the soil, further increasing yields and residue additions.
- Grow more perennial forage crops: Perennial crops often remain active for more months of the year than annual crops, trapping more atmospheric CO_2 . Because they dry out the soil more and there is no tillage, decay rates may also be slower. Perennial crops, like grasses, often have a more extensive rooting system than annual crops, and place more C below-ground. Together, these effects make perennial crops very effective in increasing soil C.
- Permanently remove land from cultivation: Probably the most effective way of increasing soil C is to allow the land to revert to its original vegetation, whether grasses or trees. Because there is little or no removal of C in products, virtually all of the C trapped by photosynthesis is returned to the soil. In theory, such ‘set-aside’ lands would eventually regain all of the C lost since cultivation began. Of course, this option means a loss in productivity so it is probably on feasible on marginal lands. The practice may also be applicable in small areas on a cultivated landscape by planting shelterbelts or gassed waterways to prevent wind and water erosion. Where the land is re-planted to trees, there may be additional storage in the wood that is produced.
- Eliminate summer fallow: Leaving land unplanted for a growing season helps control weeds and replenish soil moisture. But it results in soil C loss because, during the fallow year, no new residue is added, and the soil remains warm and moist, hastening decay. A shift to continuous cropping (growing a crop every year) therefore favours increases in soil C. The use of summer fallow has already declined in recent years, but there are still about 6 million ha every year. Complete elimination of summer fallow may not be practical in very dry regions, like parts of the southern prairies.
- Use cover crops: Where the growing season is long enough, a winter cover crop can be sown after the main crop has been harvested. This practice can add more residues to the soil and prevent erosion.
- Avoid burning of residues: When residues are burned, almost all their C is returned to the atmosphere as CO_2 , and amounts of C added to the soil are greatly reduced.
- Use higher yielding crops or varieties: Crops or crop varieties that have more efficient photosynthesis will often produce more residues and hence favour soil C increases. But because plant breeders choose varieties on the basis of marketable yield, residue and root yields of new varieties may not increase as much as the yield of harvested product.
- Improve water management: water is often the limiting factor to crop growth. In the southern Prairies, there is often a severe shortage of water. Here, yields can be increased by re-routing water from elsewhere (irrigation) or by trapping and storing water more effectively (e.g., using crop residue or windbreaks to trap snow). In parts of central and eastern Canada, conversely, crop growth may be limited by excess water in poorly-drained soils. In these conditions, crop growth and C additions to the soil can be increased by drainage.
- Integrate livestock into cropping systems: Feeding crops to livestock results in effective recycling of C if the manure is managed well. Thus, while production of forages and silage crop may result in large amounts of C removal from the field, much of this C can eventually be returned as manure. This manure not only recycles the C, but also promotes crop growth and photosynthesis, favouring further soil C inputs.
- Improving grazing management: the way a grassland is grazed can affect the C cycle in several ways. It influences the proportion of the plant ‘harvested’ by the animal, the redistribution of C in manure, the condition of the soil, and the species composition. Because of these many effects, the relationship between

soil C and grazing regime is still unclear. Overgrazing, however, can result in large losses of C via erosion. Reducing the number of animals per ha on such lands will likely increase the amount of C stored.

The amount of soil C gained by using these practices is still uncertain and will vary among regions, partly because the increase in soil C depends on many factors, including the initial soil C content, other soil properties, and climate. It is also hard to predict the extent to which these practices will be adopted across Canada, because that depends on crop prices, costs of production, and other factors that fluctuate from year to year.

Despite the uncertainty, some estimates suggest that agricultural soils in Canada could gain as much as several Tg of C per year if there were widespread adoption of these C-conserving practices. This would result in a net removal of CO_2 from the atmosphere. With time, however, the rate of C gain would decline because it becomes harder and harder to add additional C as the C content of soil goes up.

3.1.2 Storing C in Plant Material

The soil is the main storehouse of C in farm ecosystems. But there are other places to store additional C, notably in plant material. One way to store more plant C is to grow trees on farmland, either as shelterbelts or as woodlots alongside farmsteads. The net benefit of this practice for atmospheric CO_2 depends on the area of land devoted to trees, their rate of growth, and the fate of the wood. If the wood is burned, there is little long-term benefit unless its use reduces dependence on other fuels. Another way of storing plant C is to convert crop residues into products with a long lifetime. One approach is to construct fibreboard from cereal straws. These materials are used for construction and, whereas much of the C in straw returned to soil would normally decay back to CO_2 , the C in these construction materials would remain trapped for a long time.

(ii) Reducing Fossil Fuel Use

Farms rely on energy from fossil fuels to power machinery, heat buildings, dry harvested crops, and transport goods. Additional energy is used to supply materials used on the farm, like fertilizers, pesticides, machinery, and buildings. Most of these emissions are not attributed to agriculture in the national inventory of greenhouse gases. Even so, a reduction in fuel use on farms would reduce Canada's total CO_2 emissions.

There are several ways to reduce the amount of fuel used on the farm and in the supply of farm inputs:

- Reduce tillage - It takes a lot of energy to lift and turn soil during tillage. Reducing or stopping tillage can, therefore, save on fossil fuel use. One Ontario study showed a reduction in diesel fuel use from 30 litres per hectare for conventional tillage to only 4 litres per hectare in a modified no-till system. A study on the Prairies, which considered both direct and indirect use of fuel, showed that reducing tillage decreased emissions from direct fuel use by about 40% (E. Coxworth, 1995). Emissions for pesticide inputs were slightly higher under reduced tillage and emissions from fertilizer were unchanged. When all of the direct and indirect factors were counted, emissions from no-till were 92% of those in conventional tillage, and emissions from minimum tillage were intermediate.
- Use Fertilizer more efficiently - Making and transporting fertilizer is very energy intensive. For each kg of fertilizer N used, about 1 kg of C is released into the atmosphere as CO_2 . Consequently, fertilization methods that maintain yields at lower rates of application can reduce CO_2 emissions. Possible approaches include: More effective fertilizer placement; applying only as much as is needed, based on soil tests; and using variable rates of application on a field to reflect differences is soil fertility.
- Grow legumes - Legumes can often obtain much of the N they need from the air. When they die and decompose, they also release N into the soil. Careful use of legumes in cropping systems, therefore, can reduce the amount of N fertilizer needed, and thereby lower CO_2 emissions. For example, in a study at Melfort, Saskatchewan, introduction of pea into the crop rotation reduced CO_2 emissions from fossil fuel by about 25% (E. Coxworth, 1995).
- Use manure more efficiently - Animal manure contains a lot of nutrients. These nutrients, however, are not always used efficiently, in part because of the high cost of transporting the heavy, bulky manures. Avoiding

excessive application rates of manure in localized areas would not only prevent harmful loss of nutrients to the environment but also reduce the need for fertilizer manufacture.

- Increase energy use efficiency - Additional opportunities for reducing energy use include drying crops in the field wherever possible, using more efficient irrigation systems, and insulating farm buildings. As well, many of the energy conservation measures advocated for urban areas also apply to the farm.

An entirely different way of reducing emissions from fossil fuels is to grow crops that provide an alternate energy source. Most of this ‘bio-fuel’ would not be used on the farm, but, by displacing fossil fuel used elsewhere, it would indirectly reduce atmospheric CO_2 . In other words, instead of extracting C from deep within the earth and burning it to CO_2, bio-fuel production simply re-cycles the C originally removed from the atmosphere by photosynthesis.

The most efficient way of using crop material for fuel is to burn them directly. While this approach is used in some parts of the world, it is not practical in Canada, where the fuel often has to be transported great distances.

An alternative is to ferment crop, producing ethanol and mixing it, at proportions of about 10%, with gasoline. This mixture can be used in most gasoline engines, and reduces the amount of CO_2 produced from fossil fuel. The net savings in fossil fuel use, however, depends on the amount of fuel used to grow the crop in the first place.

The materials most easily converted into ethanol are those with high starch content. Thus cereal grains, like corn and wheat, are preferred for ethanol production. One study suggests that, if the CO_2 emitted in crop production are taken into account, use of corn-ethanol reduces CO_2 emissions by about 40%, relative to the emissions from the gasoline it replaces. If the emissions of other greenhouse gases are also taken into account, then use of ethanol from corn or wheat reduces the global warming potential by 25 to 30%. In Canada, about 30 million litres of ethanol are currently produced annually from wheat and corn, reducing CO_2 emissions by about 0.033 Mt CO_2 per year. If Canadian ethanol production reaches the expected 265 million litres by the end of 1999, reductions in net CO_2 emission will be increased by the same proportion.

Though ethanol is most easily made from high-starch materials, new methods now make it possible to make ethanol from fibrous matter, like crop residues, forages, and crop wastes. There may be about 2 Mt of straw and chaff produced every year, beyond the amount needed for animal bedding and preventing soil erosion. If all of this were used, that would produce about 500 million litres of ethanol, and replace about 0.5 Mt of fossil fuel CO_2 (equivalent to 2% of the emissions from agriculture). The process could also be used to produce ethanol from perennial grasses grown on marginal lands.

Still another way to reduce reliance on fossil fuel is to produce fuel for diesel engines (‘biodiesel’) from oilseed crops like canola, flax, soybean, and sunflower. Although technically feasible, producing biodiesel is still more expensive than producing fossil fuel.

3.1.3 Current Status of Methods to Reduce CO_2 Emissions

The C cycle is central to farming systems. Methods to reduce CO_2 rely mainly on managing that cycle more efficiently: re-cycling as much organic C as possible, minimizing disruption of soil, optimizing use of the sun’s energy, and relying less on energy from outside.

Because they promote efficiency, many of these methods also help sustain land resources, and may even be profitable. As a result, they are being adopted for reasons quite apart from their benefits to atmospheric CO_2 . For example, most farms in Canada now use less tillage than a generation ago, and an increasing proportion now use no-tillage practices. Similarly, the area of land devoted to summer fallow has fallen from about 11 million ha in 1971 to about 6 million ha in 1996 (Statistics Canada, 1998). The use of these and other C-conserving practices will likely continue to increase in coming decades.

The two general approaches – storing more C and relying less on fossil fuel – reduce CO_2 emissions over somewhat different time periods, Storing C in soils has highest benefits early, in the first few decades, but net removal of CO_2

declines with time because it gets harder and harder to add additional C as soil C increases. Carbon dioxide savings from reduced fossil fuel, on the other hand, may seem rather small in the short term, but can be very significant when viewed over many decades. The net removal of atmospheric CO_2 from soil C gains is finite; that from reduced fossil fuel can continue indefinitely.

In addition, the Government of Canada has provided funding for "Early Action" proposals (immediate action that can be taken to provide early reductions in greenhouse gas emissions) which will help Canada address our commitments under the Kyoto Protocol in climate science, impacts and adaptation. The agricultural sector has taken advantage of this funding. The just recently announced plans by Agriculture and Agri-Food Canada, Alberta Agriculture, Food and Rural Development, and GEMCo for an innovative project aimed at reducing agricultural carbon dioxide emissions in Canada is just one example of how the industry is contributing to reduce greenhouse gas emissions.

3.2 Reducing Methane Emissions

Methane, like CO_2, is part of the C cycle in farm ecosystems. It is released during decay of organic material when a shortage of oxygen prevents complete conversion of the organic C to CO_2. Although both CH_4 and CO_2 are greenhouse gases, CH_4 has a much higher warming potential, so that release of the C as CO_2 is preferred.

Most CH_4 from Canada's farms comes from the livestock industry, either directly from the animals or from the manure they produce. A number of methods have been proposed to reduce emissions from these sources, some of which are already in use.

3.2.1 Reducing CH_4 emissions from animals

Much of the CH_4 produced on farms is from ruminants – livestock like cattle and sheep that have a rumen for pre-digestion of feed. Specific practices that can reduce emissions from these animals include the following:

i) Change rations to reduce digestion time: Most of the CH_4 is released from the rumen, where feed is fermented in the absence of oxygen. The longer the feed remains in the rumen, the more C is converted to CH_4. As a result, any practices that speeds the passage of feed through the rumen will reduce CH_4 production. One study with steers showed that, when passage rate of matter through the rumen was increased by 63%, CH_4 emission fell by 29%. The passage of feed through the rumen can be hastened by: Using easily-digestible feeds like grains, legumes, and silage; harvesting forages at an earlier, more succulent growth stage; chopping the feed to increase surface area; minimizing use of coarse grasses and hays; and feeding concentrated supplements as required.

ii) Add edible oils: Addition of canola, coconut, or other oils to the diet may reduce CH_4 production by inhibiting the activity of CH_4 producing bacteria. Though quite effective, this practice may not always be economical.

iii) Use ionophores: Ionophores are antibiotics that inhibit the formation of CH_4 by rumen bacteria. These ionophores, already widely used in beef and dairy production, can reduce CH_4 emission. There is some evidence, however, that rumen microbes can adapt to a given ionophore, lessening its impact over time. For long-term effectiveness, it many be necessary to use a 'rotation' of different ionophores.

iv) Alter the type of bacteria in the rumen: In the future it may be possible to introduce into the rumen genetically-modified bacteria that produce less CH_4. Though research efforts are promising, such inoculants are not yet commercially available.

v) Improve production efficiency: Any practice that increases the productivity per animal will reduce CH_4 emissions because fewer animals are needed to achieve the same output. For example, giving animals more feed may increase CH_4 production per animal, but reduce amount of CH_4 emitted per litre of milk or per kg of beef. Any other practice that promotes efficiency will likewise reduce CH_4 emission per unit of product.

Many of these practices are already practical and economical. When used together, they can lower loss of energy through CH_4 release from about 5 to 8% of the gross feed energy to as low as 2 or 3%. Because feeding efficiency is increased, these practices also often have economic benefits. Consequently, they are already widely used on many firms, especially in dairy herds and beef feedlots.

3.2.2 Reducing CH_4 emissions from manures

Most of the CH_4 from manure is produced during storage. When the manure is stored as liquid or in poorly-aerated piles, lack of oxygen prevents complete decomposition to CO_2, resulting in the release of CH_4. Most of the methods of reducing emission, therefore, involve slowing decomposition rate, providing better aeration, or reducing the duration of storage. Specific methods include the following:

i) Use solid rather than liquid manure handling systems: Oxygen supply is usually better in solid manure, encouraging formation of CO_2 rather than CH_4.

ii) Apply manure to land as soon as possible: The longer manure is left in feedlots, in stockpiles, or in slurry tanks and lagoons, the greater will be the emission of CH_4. Frequent applications to the land can therefore reduce emissions. Unfortunately, storage of the manure is sometimes unavoidable because the land is frozen, too wet, or planted to crops.

iii) Minimize amount of bedding in manure: Incorporation of a lot of bedding material, like straw, increases the amount of C that can be converted to CH_4.

iv) Keep storage tanks cool: Lowering the temperature of tanks, by insulation or placing them below-ground, slows decomposition rate, thereby reducing emission of CH_4.

v) Burn CH_4 as fuel: Methane is a very effective fuel; indeed, it is the main constituent of natural gas. In some countries, CH_4 from stockpiled manure is already collected and burned. In Canada, this approach may not yet be widely practical or economical, but it is receiving growing interest. Burning CH_4 converts it to CO_2, which has a much lower warming potential.

vi) Avoid land-filling manure: Although most manure in Canada is applied to land, small amounts are still disposed of in land-fills. Because decomposition in land fills is usually oxygen-starved, large amounts of CH_4 can be emitted from this practice. (Furthermore, land-filling manure wastes valuable nutrients in the manure.)

vii) Aerate manure during composting: To make it easier to transport, manure is sometimes the first composted before applying it to the land. The amount of CH_4 released during composting can be reduced by aerating the stockpiled manure, either by turning it frequently or by providing a ventilation system inside the pile. This aeration encourages complete decomposition to CO_2 rather than release of C as CH4 .

These methods can reduce, to some extent, the CH_4 emission from animal manure. Because of high livestock densities in some areas, and the high cost of handling and transportation, manure management still remains a challenge, and other ways to reduce emissions may still be needed.

3.3 Techniques to Reduce Nitrous Oxides

Reducing N_2O emitted from farmland is achieved when excess NO_3^- in soil undergoes denitrification, either on farmland or after it is leached away. Preventing build-up of NO_3^- or avoiding soil conditions that favour denitrification can reduce emissions from this source. Some N_2O is also emitted during the conversion of NH_4^+ to NO_3^- (nitrification). These emissions can be reduced by adding less NH_4^+ or by slowing the rate of nitrification. Overall, the best way to reduce N_2O losses is to manage the N cycle more efficiently, thereby avoiding the buildup of excessive NH_4^+ or NO_3^-. Specific ways of doing this vary for farming systems across Canada, but some examples include the following:

Match fertilizer additions to plant needs: Perhaps the best way to reduce N_2O emission is to apply just enough N so that crops can reach maximum yield without leaving any available N behind. A perfect match is rarely achievable, but the synchrony can often be improved by basing fertilizer rates on soil tests and estimates of N release from residues and organic matter. In fields where fertility needs vary, applying N at different rates across the landscape ('precision farming') may also improve the match between the amount applied and the amount taken up by crops.

Avoid excessive manure application: Heavily-manured land can emit a lot of N_2O because the manure adds both N and available C. Moreover, manure is often applied to land as a means of disposal, so that rates can be excessive. Applying the manure at rates that just supply plant demands can greatly reduce N_2O emissions from this source.

Optimize timing of N application: The timing of N application is as important as the rate of addition. Wherever possible, the N should be applied just prior to the time of maximum uptake by the crop. Thus manure and fertilizer should not be applied in the fall. Similarly, the plow-down of N-rich crops, like legumes, should be timed so that N releases from the residues coincides with subsequent crop demands.

Improve soil aeration: Denitrification, and hence N_2O emission, is favoured by the low oxygen levels that usually occur in very wet soil. As a result, emission of N_2O can be reduced by careful management of soil water: draining soils prone to water-logging , avoiding over-application of irrigation water, and using tillage practices that improve soil structure.

Use improved fertilizer formulations: Some research suggests that certain forms of fertilizer emit more N_2O than others. Highest emissions may occur from anhydrous ammonia; lowest from forms containing NO_3^-. This suggests that N_2O release could be reduced by selecting appropriate fertilizers, though the differences among forms have not yet been widely verified in Canada. Another option is to use slow-release fertilizers, like sulfur-coated urea. These forms release available N gradually, feeding the crop yet preventing accumulation of available N. Though effective in reducing N_2O emissions, slow-release forms may only be economical for high-value crops.

Use fertilizer placement that improves efficiency: Placing fertilizer in close proximity to crop roots can improve the efficiency of nutrient use, allowing the farmer to achieve high yields with lower rates of application. On the other hand, placing the fertilizer too deep in the soil, or concentrating forms like urea in bands, may increase N_2O emissions.

Use nitrification inhibitors: Certain chemicals, applied with fertilizers or manures, inhibit the formation of NO_3^- from NH_4^+. Their use may suppress N_2O formation in several ways: it reduces N_2O formation during nitrification, it prevents denitrification of accumulated NO_3^- , and, because NH_4^+ does not leach easily, it prevents loss of N into groundwater where denitrification could occur.

Use cover crops: Where the growing season is long enough, crops can be sown after harvest to extract excess soil NO_3^- , preventing it from leaching or converting to N_2O.

Lime acid soils: Because it is favoured by acidity, N_2O emissions can be suppressed by application of neutralizing lime to acid soils.

Reduce tillage intensity: Though results are still inconsistent, some research studies in Canada suggest that N_2O emission may be lower in no-tillage than in conventional tillage. If confirmed, this observation may point to no-till as a method of reducing emissions, at least in some soils.

These practices can help reduce N_2O emissions in many settings. Because N_2O fluxes are so sporadic, however, all cannot yet be recommended with confidence across the soils and cropping systems of Canada. But those that improve the efficiency of N use are often already justified for reasons quite apart from reduced N_2O emission. Fertilizers account for about 9% of production costs on farms, and any method that reduces N losses has economic benefits.

4. Ongoing Research Activities on Mitigation Efforts to Reduce GHG Emissions from Agriculture

Currently, there are several research and economic/policy papers being completed for the Agriculture and Agri-Food Table on Climate Change. The purpose of these papers are to define the issues, describe existing knowledge and draw conclusions or identify options and the need for further research. The research papers focus on issues related to mitigation efforts to reduce GHG emissions from agriculture while the economic and policy papers address adaptation, mitigation and research initiatives to reduce vulnerabilities (Section 5.1) and examine the economics of various practices which could enhance the evaluation of emission reduction potential (Section 5.2). At the time this Foundation Paper was completed the papers had not yet been completed. However, where brief summaries or outlines could be provided they have been included.

4.1 Carbon Dioxide Mitigation Efforts

4.1.1 Quantifying, Predicting and Verifying Changes in Soil Carbon

B.H. Ellert

Soils contain more than twice as much carbon as the atmosphere on a global basis. Thus the exchange of carbon between land and the atmosphere has a critical influence on the amounts of CO2 in the atmosphere and on organic matter in surface soils. Concern about climate change has led to considerable interest in the potential for mitigating atmospheric CO2 increases by sequestering organic carbon in soils. Despite the history of research on soil organic matter, assessments of potential carbon sequestration still are constrained by the availability of suitable methods to quantify, predict and verify changes in soil carbon.

Soil C storage depends on soil area and thickness or mass. Areal inventories of vegetative cover, land use, and land management are required to estimate soil C on a regional or national basis. The starting point for such estimates is measurement of soil C stored per unit area at specific points in the landscape. At these points, soil samples of a known volume are collected and the organic C concentration is analyzed.

Accurate assessments of temporal changes in soil organic carbon storage provide valuable information on the net exchange of C between land and the atmosphere. Temporal changes in soil storage may be determined reliably for specific points in the landscape. The approach requires: a) representative sampling of the entire soil C pool, including coarse fragments of plant litter; b) interspersing of initial and subsequent samples to minimize the influence of spatial variations; c) accurate analyses of soil organic C concentrations; and d) comparisons based on an equivalent soil mass to adjust sampling depths for differences in soil bulk density. Despite providing useful information on soil organic C quality or decomposability, analyses of actively cycling fractions are difficult to standardize and the relationship between such fractions and total soil organic C may not be easily discerned.

The use of isotopic tracers at natural and artificially enriched levels to distinguish young soil C, recently derived from plant inputs, from older soil C is a powerful tool to investigate the production, decomposition, retention and stabilization of soil organic C. Isotopes are useful to assess the functional significance of various fractions of soil organic C defined by physical, biological or chemical methods. Further studies of the decomposition and persistence of ^{13}C- or ^{14}C- enriched plant litter are required to assess the dynamics of plant residue C under contrasting management and environments in the field. Such studies should help to reduce uncertainties about the extent to which soil C storage might be manipulated through residue management.

Spatial variability of soil organic C within ecodistricts and individual landscapes likely necessitates the use of some model to estimate potential changes in soil C storage. The direct measurement of soil C change in all possible landscapes would be impractical and scientifically unrewarding. Perhaps using observed crop yields to estimate annual plant residue inputs might better reflect site-specific conditions and avoid the added uncertainty of simulated plant growth. Complex simulation models of plant production coupled with soil C dynamics are valuable research tools to investigate interactions among ecosystem components and processes, but resulting estimates of temporal soil C changes may not be any more reliable than those from simpler models. Regardless of which model is selected to extrapolate from point measurements of soil C change to regional estimates, some assessment of probable errors in the estimates is essential.

4.2 Methane Mitigation Efforts

4.2.1 Rangeland Cattle Production and the Greenhouse Gas Effect, A Review

J.C. Kopp and K.M. Wittenberg

For years, scientists have been discussing and reviewing an important environmental issue, the greenhouse effect. Ruminants produce methane (CH_4), a colourless, odourless, nonpoisonous gas, and this has made them targets of environmental concern. Approximately 3.6% of Canada's land mass is used for grazing and forage. Though this percentage may seem small, there is growing interest in determining if a pasture system supporting cattle is a net producer or net consumer of greenhouse gases.

Proper grazing stimulates an increase in grassland productivity and improved health of the stand which will increase greenhouse gas uptake by the soil microbes and plants. The grazing animal returns a large proportion of consumed plant nutrients back into the soil and, therefore, pasture feeding represents a highly sustainable form of agriculture. The key word is recycling, grazing cattle do not use fossil-fuel C, but C that at one time came from the atmosphere and was used by plants in the form of CO_2. The nutrient cycle from plants to soil continues; if you add a herbivore the nutrient chemical structure is changed and returned to the soil as faeces and urine. Nutrients such as nitrogen and phosphorous from animal excreta are more readily available for plant use than nutrients that are simply recycled through the plant-soil interface. It is estimated that about 30-40% of the C consumed by cattle is returned to the soil.

Theoretically, all above ground forage biomass will die off and undergo some form of decomposition every year. The duration of the current model is one grazing season (120 d), therefore, the precise effect the grazing animal has on C storage in the rangeland cannot be assessed directly, however, inclusion of the herbivore into a grassland system does not appear to increase net greenhouse gas emissions. With the data published by Van Veen and Paul, an estimate of the rangeland C content can be characterized. The final results of such an evaluation would best be accomplished by using actual field data. However, a project of that magnitude would be very complex and require a competent group of scientists from many disciplines. Further research is needed to directly quantify the amount of C in the grasslands of different regions and the effect of grazing these regions.

4.2.2 Greenhouse Gas Emissions from Manure and Measures for their Mitigation

Daniel I. Massé and Francis Croteau

Animal production establishments and manure storage structures are fixed, permanent sources of various gas emissions. Since animal digestive processes are incomplete, and because microorganisms are present in the feces, there is a substantial amount of organic matter which can be converted to CH_4 when it decomposes in environments that are relatively warm, wet and anaerobic. These conditions are found, among other places, in manure slurry gutter and pits and in anaerobic lagoons. Management and storage of manures inevitably contributes to the increase in GHG concentrations of anthropogenic origin resulting from agriculture, primarily in the industrialized countries where a large proportion of livestock production is intensive.

Few experimental finding are available on actual CH_4 emissions resulting from various types and conditions of farm manure storage, and the data which do exist reflect fairly significant uncertainties. A number of external factors (physiocochemical properties of the manure, method of measuring gas emission, temperature variation, quantity of manure, fraction available for microbial degradation, age of the manure, formation of a crust on the surface of manure slurry, and so on) can influence CH_4 production, and these parameters are not monitored in the same way or even considered in certain studies. Therefore, it is rather difficult to really compare the values derived from the various studies and say with accuracy that they are the most representative data on actual CH_4 emission from various types of manure storage. However, we have found that most data seem to have the same order of magnitude and that there is indeed significant variability in the reported results on CH_4 emissions from manure.

Conventional methods for managing and storing manure in liquid or solid form are inescapable sources of GHG emission. If no reduction or mitigation measures are established, the increase in animal production will bring about a major increase in manure-related gas emissions. The main technologies available for reducing CH_4 emissions are covered anaerobic lagoons and anaerobic digesters. These systems provide microorganisms with conditions conducive to more complete, effective degradation of the organic matter. Such controlled anaerobic digestion would convert wastes from animal production establishments into a clean biological fuel, while minimizing the harmful effects of such organic waste on the environment and public health.

4.2.3 Potential for Reducing GHG Emissions from Domestic Monogastric Animals

Candido Pomar

The atmospheric concentration of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which affects the Earth=s radiation balance, is increasing at the rate of about 30%, 145%, and 15% respectively. Many GHG remain in the atmosphere for a long time. As a result, it has been predicted that the average earth temperature will increase by several degrees within the next century, changing precipitation and other climate variables. These changes will modify soil moisture, increase average sea level, and prospects for more severe extreme high-temperature events, floods, and droughts.

Nitrous oxide is a chemically and radiatively active greenhouse gas that is produced naturally from a wide variety of biological sources in soil and water. While N_2O emissions are much lower than CO_2 emissions, N_2O is approximately 310 times more powerful than CO_2 at trapping heat in the atmosphere over a 100-year time horizon. Major sources of nitrous oxide include soil cultivation practices, especially the use of commercial and organic fertilisers, fossil fuel combustion, nitric acid production, and biomass burning. Land-applied manure is a significant source of N_2O that can be estimated to 2 kg per cubic meter. Only in Canada, N_2O emissions from the swine industry may represent more than 40 millions kg per year.

There are different methods that can be used to reduce N_2O emissions from livestock manure. However, for swine and other monogastric domestic animals, the reduction of protein ingestion has been identified as a very cost-effective method of reducing nitrogen excretion and therefore, the emissions of nitrous oxide from land-applied manure. In fact, it is possible to reduce significantly the total amount of nitrogen excreted by pig by modifying the composition of diets. Moreover, this diet manipulation can be done with relatively simple techniques, at reasonable cost and very often without the use of any feed additive. Reduction of nitrogen excretion without impairing animal performance can be obtained by: a) a more precise adjustment of the protein intake to the requirements of the animal, that is avoiding protein excess in pig diets; b) increasing the quality of dietary protein and reducing the total amount of protein given to the pigs; c) by the progressive adjustment of the protein in the diet to the decreasing requirements of the animal (phase-feeding); d) by finding the right optimal dietary program from an economic and environmental standpoint since maximal revenue is not generally obtained at maximal growth rate. If all or part of these techniques are implemented in the farm, it is possible in many cases to reduce the total nitrogen excretion by pigs by more than 50%.

4.2.4 Ruminant Livestock Methane Emissions: Potential for Mitigation

D. Boadi and K.M. Wittenberg

Emissions from ruminants are estimated to contribute 15% of global atmospheric methane. Within Canada, ruminant livestock industry contributes about 1% of global methane production. Methane gas production is a natural by-product of feed fermentation in the gastrointestinal tract of the ruminant animal. It constitutes a loss of dietary energy away from animal production, and contributes to atmospheric GHG emissions. Estimates of methane emissions from livestock have been based on prediction equations and data collected in controlled animal chambers, which may not reflect actual emissions or ranges in a normal production environment. Canada has the potential to contribute to methane reductions and, therefore it is essential to understand the scientific requirements to establish the potential for reducing methane and to evaluate improvements that could be achieved in the livestock industry.

A number of strategies exist with the potential to either improve animal production efficiency or manipulate enteric fermentation with the end result being reduced CH_4 production per unit output. The use of production enhancing agents such as anabolic implants can reduce methane emissions by promoting reducing time required to achieve market weight and production of lean tissue. Any management strategies that reduce feed energy required for animal maintenance or tissue and milk fat production will reduce methane emissions. Animals under these situations become more efficient at converting feed into lean tissue or milk protein. Manipulation of rumen enteric manipulation to reduce methane emissions has been demonstrated in the laboratory, but has not been verified in commercial livestock production systems.

Emission reductions can also be accomplished with better grazing management, strategic supplementation, and use of good quality forages. Use of good genetic animals and improved nutrition of breeding heifers and cows will result in higher calving of percentages and heavier weaning weights. This will minimize both feed cost per unit of product sold and minimize cost of production and CH_4 emissions.

Future technology and research of methane mitigation strategies may lie in the use of more persistent ionophores that can be used for long term production and to induce a group of microorganisms known as acetogens, which have been isolated in the rumen. Rapid advancement of these technologies must include a component for testing with animals managed under typical commercial conditions.
There is also the need for further studies into making these strategies more cost and long-term effective, as well as evaluating the resource inputs associated with the mitigation strategies in terms of their contribution to total GHG. This has to be characterized for each technique to analyze the net benefit towards reduction of GHG.

4.2.5 Livestock Manure Management Systems and Greenhouse Gas Production

Sylvio Tessier and Alfred Marquis

Agriculture is the source of the three major “greenhouse gases”, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which contribute to the process of global warming, via the “greenhouse effect”. Undoubtedly, livestock agriculture is also a source of these three gases, which result from the animal’s inherent metabolic activity as well as a potential outcome of recycling of livestock manure as an organic fertilizer.

So far, current estimates of greenhouse gas (GHG) emissions from livestock agriculture are mostly crude estimates based on animal inventories, often with little regards to the specific management systems used. Within the scope of the development of an action plan to reduce agricultural emissions of GHG, it is important to correctly appreciate the relative impact of the various components of manure management systems on the overall GHG emissions from livestock agriculture. Under the hypothesis that manure management is a major contributor to GHG emissions from livestock agriculture, it would be justified to promote the adoption of systems and practices known to emit less GHG or else stoke the R&D required to develop the appropriate technology.

GHG can arise from some components of manure management systems when manure is allowed to develop partial or fully anaerobic conditions either via low oxygen availability or the predominance of anaerobic microsites on organic matter particles. Anaerobic bacteria essentially degrade manure solids into highly reduced compounds, inclusive of CH_4 and CO_2. N_2O is also a potential GHG produced from manure, which may or may not evolve in aerobic conditions, as a result of the nitrification of NH_3 in NO_3-, or in a subsequent oxygen deprived situation from the denitrification of the later via microbial activity. For this to occur over anyone of the components of a manure management system at the facility’s level, aerobic conditions must first prevail.

In barn emissions of GHGs come in two forms, liquid and solid manure management. Most liquid manure management systems involve shallow gutters with weekly to by-weekly evacuations of manure to the storage.

Some systems feature a small pre-storage structure collecting the manure into a central pumping station. While some amounts of anaerobic decomposition undoubtedly occurs within livestock housing, the amounts of CH_4 and CO_2 produced as a result of anaerobic fermentation could be very small.

In the case of solid manure management, the two systems commonly in use are gutter with daily evacuation and bedded manure packs. It is unlikely that significant CH_4 would be emitted from these operations. However, these conditions may be favourable to nitrification and denitrification processes, leading to N_2O emissions along with CO_2. Thus, it is likely that bedded manure packs systems may be the origin of some N_2O emissions, in particular when used for swine and egg laying operations since aerobic conditions are often present, as a result of the dry bed conditions maintained for optimum livestock production.

GHG emissions from manure storage systems are not likely a significant issue at this stage of manure management. The rationale for this is that the bulk of the manure in large manure storage systems are subjected to mostly anaerobic conditions, and hence limits the nitrification of NH_3 into NO_3, a necessary process which may lead to N_2O production.

Emissions of CH_4 from stored livestock manure in Canada may or may not be significant depending on climatic conditions in particular. In retrospect, large errors can creep into estimates of GHG emissions when emission factors developed in other countries are used to represent emission potential from manure storage structures and practices in Canada. For N_2O emissions, very little Canadian data can support the prediction which paints manure storage structures as major contributors to N_2O emissions. Thus, many questions need to be answered before a GHG reduction plan can be developed and successfully implemented for livestock agriculture.

4.3 Nitrous Oxide Mitigation Efforts

4.3.1 Developing Methods to Predict N_2O Emissions in Crop Production Systems

W.N. Smith, R. Lemke, R.L. Desjardins

Recent political events emphasize the growing concern regarding the increase of N_2O and other greenhouse gases on our global environment. Canada has committed itself to reducing national GHG emissions to 6% less than 1990 levels by 2008. In order to meet this objective we must first be able to accurately estimate those emissions, and to develop effective strategies to reduce emissions within a discrete period of time. Agroecosystems are managed systems, therefore there is opportunity to select for management strategies that would minimize greenhouse gas emissions. Indeed, since agricultural soils have lost about 25% of their organic carbon, it is hoped that innovative management strategies could cause an increase in soil organic matter. Agricultural soils would then serve as a net sink of CO_2-C by removing it from the atmosphere and storing it in soil organic matter reserves. In general, management strategies that increase N-use efficiency are most likely to decrease N_2O emissions. However, the conditions that govern N_2O production and emissions are complex, and many interactions must be considered.

The most important processes for N_2O production in soils are denitrification and nitrification. These processes are influenced by environmental factors such as temperature, rainfall/snowmelt, freezing, and thawing. Agricultural management practices such as manure/fertilizer application, incorporation of crops or crop residue, and tillage also influence N_2O production and emission. Several simulation models which describe nitrogen dynamics in soils have been developed.

To date, the IPCC methodology is still the central tool for estimating Canadian greenhouse gas emissions. The IPCC has developed a methodology for calculating national emissions of N_2O from agriculture, including direct emissions from agricultural soils, emissions from animal production, and N_2O emissions indirectly induced by agricultural activities. Direct emissions from agricultural soils are estimated by a simple linear extrapolation between anthropogenic N inputs and N_2O emissions. The methodology does not account for differing climatic or soil conditions, two important factors influencing N_2O emissions.

One of the more accurate models is the CENTURY model which is a site specific computer simulation model which makes use of simplified relationships of soil-plant-climate interactions to describe the dynamics of carbon and nitrogen in grasslands, crops, forests, and savannas. The model has traditionally been used to estimate CO_2 emissions, but after recent revisions, can also be used for N_2O emissions. CENTURY's ability to simulate N_2O emissions under Canadian conditions has not been tested.

It is difficult to address the level of uncertainty in modelling. Uncertainty exists in model input, model development, and in our understanding of the processes involved. In order to produce more accurate estimates of N_2O emissions scaling-up techniques and simulation models that are dynamic enough to account for the spatial and temporal variability are urgently needed. Appropriate models would improve the reliability of temporal and spatial integrations, but also test our current knowledge so that gaps can be identified and addressed. They are also needed as predictive tools for investigating and assessing the influence of changing management and/or climate scenarios on N_2O emissions.

4.3.2 Nitrous Oxide Emissions from Canadian Agroecosystems: Understanding the Process

R.L. Lemke, P. Rochette, and E. VanBochove

Nitrification and denitrification are considered the major sources of N_2O emissions arising from agricultural soils. The amount of N_2O produced is determined by both the rate of nitrification and denitrification, and the ratio of N_2O produced per unit of N processed. How much of this N_2O is released to the atmosphere also depends upon the amount of N_2O consumed during transport to the soil surface. The rates and ratios of N_2O produced are controlled at the cellular level by a complex interaction between O_2, NO_3^-, NH_4^+, available C, moisture, and temperature. In the field, conditions controlling N_2O production at the microscale are established by an integration of many regulating variables operating at much larger scales. Several landscape-scale studies have identified strong relationships between the magnitude of annual N_2O loss and differences in soil texture, drainage, and slope position, emphasizing the importance of selecting the appropriate indicators for the scale of the study. N_2O emissions are highly episodic, being associated with high soil-water contents following precipitation events or melting of the snow-pack in spring. The confluence of regional precipitation and temperature regimes produces regionally distinct seasonal distributions of N_2O flux.

Agricultural activities influence N_2O emissions primarily by changing the amount and pattern of N cycling through the soil-plant system. When accumulations of inorganic N, such as those following fertilizer N or manure application, legume residue incorporation, or fallow periods coincide with high soil-water contents and C availability, substantial losses of N_2O can occur. Particularly high losses of N_2O have been measured following manure and legume residue additions which increase available C as well as N. A few studies have indicated, however, that N_2O loss from standing forage or grain legumes is actually lower than from other grain crops. This suggests that the handling of legume residues is a critical consideration, and that all phases of the rotation must be considered. Most studies have reported increases in N_2O emissions as a result of fertilizer N, with the reported losses ranging between 1 and 3% of applied N. The relationship between fertilizer-N rate and N_2O emission is not necessarily linear, but depends upon many other factors such as site-specific characteristics, tillage, and fertilizer type and placement. Agricultural crops frequently take up 50% or less of fertilizer N applied. The fate of the remaining N remains unclear, but is of considerable concern since some fraction of this N is likely lost as N_2O.

Opportunities for limiting agricultural emissions of N_2O revolve around the careful matching of fertilizer N application to crop needs, and the timing of those applications to match crop uptake patterns. Fertilizer-N placement has been shown to increase crop uptake, and appears to be a promising avenue for limiting N_2O emissions. Advanced N management techniques such as timed release fertilizers and nitrification inhibitors, also show promise. Avoiding practices, such as summer fallowing and fall plow down of legume residues, that increase NO_3 accumulations prior to spring thaw could have a significant impact.

4.4 Other Research

4.4.1 Validating Greenhouse Gas Flux Estimates from Agroecosystems

E. Pattey and R.L. Desjardins

Agroecosystems in Canada contributed 13% of the total anthropogenic emissions, based on 1996 estimates. That is 30% of the CO_2, 25% of the CH_4, and 45% of the N_20. Although the total amount is rather small, it is meaningful because agroecosystems are intensively managed and the emissions can be controlled without creating serious difficulties to agricultural producers.

Although measuring techniques have been developed for more than 30 years, our knowledge of the sources and sinks of greenhouse gases (GHG) is still very limited. This is due to the difficulties associated with the extrapolation of flux measurements in space and time. As a result, regional, national and global flux estimates remain highly uncertain.
Several micrometeorological techniques and platform have been used to measure the GHG fluxes. Point measurements are provided by enclosures, fields are monitored by tower-based flux measuring systems while regional scale is covered using aircraft-based flux systems.

It is generally agreed that a nested type of approach, where several micrometeorological techniques are available, will become increasingly important for quantifying greenhouse gas emissions over target areas of special interest. This approach should involve enclosure and tower flux measurements, boundary layer sampling with balloon and aircraft, remote sensing and modeling to integrate and extrapolate to larger scales.

Because of the intermittency of GHG emissions and the scales involved, models are essential to obtain regional and national estimates. Several models are presently being tested for quantifying the change in soil C and the emissions of N_2O from agricultural sources. As far as improving the accuracy of CH_4 emission estimates, efforts should be directed at improving emission estimates from point sources.

Another approach that appears promising for validating soil C models is to compare model response over long time periods to actual measurements. This means comparing model estimates to CO_2 flux measurements over seasons, as well as actual observations of change in soil C over several years with model estimates run over the same time period.

In order to help Canada meet its Kyoto commitment, we need to improve our capability to estimate GHG emissions. We also need an elaborate validating scheme that can be used over a wide range of scales. This requires a co-ordinated effort both within and between ecozones. Performing intensive field experiments covering field, farm and regional scales with different platforms under typical environmental conditions and management practices will permit to improve our understanding of scaling up processes and should result in increased confidence in GHG estimates. This is essential in order to quantify agriculture’s role in contributing to climate change, to predict agroecosystems’ response to climate change and to propose suitable mitigation actions.

4.5 Identify knowledge gaps and areas for further research/analysis

Throughout the course of compiling this foundation paper a number of areas were identified for further research with respect to reducing or managing GHG emissions in agriculture. The following are areas where research is required:

- the interaction of mitigation practices for one gas with other gases
- planting winter crops
- planting perennial crops
- fertilizer formulations
- legumes
- other ways of reducing fossil fuels
- food industry mitigation efforts

5. Potential Measures to Reduce Emissions

5.1 Adaptation, Mitigation and Research Initiatives to Reduce Vulnerabilities

5.1.1 Greenhouse Gas Emissions from Agriculture and the Canadian Commitment to Kyoto

Charles Mrena

The Kyoto Protocol is the result of a consensus among the nations of the world that climate change caused by human activities is a definite risk and that concrete action must be taken. Canada has agreed to reduce its greenhouse gas emissions by six percent from 1990 levels by 2008-2012. Agriculture's contribution to GHG emissions is small compared to industry, nonetheless it is still considered significant. This impact can be attributed to the intensification of agriculture since the Second World War, with fewer people working on the land there has led to a greater energy input in terms of fossil fuels and chemicals while livestock stocking rates have greatly increased.

In Canada, in 1996, emissions from agricultural sources contributed about 10 percent of the total greenhouse gas emissions. The major sources were estimated to be enteric fermentation, 55 percent, agricultural soils, 24 percent, and manure 21 percent. Enteric fermentation and emissions from animal wastes are among the larger sources of methane which together contributed about 27 percent of Canada's methane emissions in 1995. Subsequent to the preparation of this paper, AAFC has released "The Health of Our Air" which contains more recent data.

5.1.2 IPCC Greenhouse Gas Accounting and Agriculture

Marie Boehm and Ira Altman

The international Panel on Climate Change (IPCC) has produced the 1996 Revised Guidelines on National Greenhouse Gas (GHG) Inventories, which provides detailed information about how countries are to report GHG emissions on a sector by sector basis. In 1997, the Kyoto Protocol changed the IPCC accounting guidelines for agricultural soils. In Article 3.3, the Protocol limited the activities that can act as carbon sinks to specific forestry activities, thereby excluding agriculture as a sink activity. The exclusion of agricultural sinks is a disadvantage to Canada, because the adoption of zero tillage and other soil-conservation farming systems is increasing carbon stores in agricultural soils. Removals of carbon in agricultural soil sinks could be used to offset emissions from other sources.

Policy makers should be aware that the IPCC inventory data, being sectoral, is not suitable for policy development or analysis in agriculture, which is a cross-sectoral activity. Policy to address emissions reductions from agriculture need to be based on net GHG emission data from whole farming systems.

5.1.3 Clean Development Mechanisms and Agriculture

Edward Tyrchniewicz

The Kyoto Protocol identified a number of "flexibility provisions" to enable Annex 1 countries like Canada to meet their targets for CO2 emission reductions in a lower cost manner. This includes: investing in activities which store carbon (e.g., sequestration) emissions, trading, and clean development mechanisms (CDM). This paper focuses on the potential for the use of CDMs in the agriculture and agri-food sector.

The essential element of CDMs is that they provide incentives for industrialized countries to invest in initiatives in developing countries that reduce net greenhouse gas emissions. Eligible initiatives typically focus on energy projects such as building small scale hydro plants or replacing old coal-fired electrical generating plants with high efficiency natural gas turbines. Under the CDM, the savings in CO2 emission will be recorded as a credit, which would be shared among the parties to the transaction.

There are some challenges associated with the implementation of CDM. Proponents of CDM, primarily from industrialized countries, generally emphasize the need of keeping transaction costs low to make the mechanism attractive to the private sector. Developing countries, on the other hand, are more concerned with their sustainable development, and tend to be skeptical of private sector driven initiatives. Another critical issue for CDM is the establishment of baselines in developing countries. This would need to move beyond the project-by-project basis quickly in order to reduce transaction costs and risks. Emphasis would need to be placed on ensuring verification and the integrity of the credits.

Very little has been written about the applicability of CDM to agriculture. Given the key role of technology transfer in the CDM process, and assuming that the implementation issues can be resolved, it is possible to identify some areas of agriculturally related technology for further consideration. These could include technology for livestock manure management, systems to improve irrigation energy efficiency, and systems to utilize agricultural wastes in the production of biofuels.

Bearing in mind the structure of agricultural production in terms of size of firm and level of international involvement, plus the uncertainty of implementation of CDM, it is unlikely that agricultural firms that are GHG emitters are likely to view CDM as a high priority approach to earning credits. Similarly, finding appropriate partners in developing countries to consider CDMs in agriculture may be equally challenging.

Accordingly, the preliminary conclusion that is being proposed is that the potential for the use of CDMs in agriculture, relative to other sectors, is marginal, and therefore GHG reduction initiatives in agriculture should be focussed on approaches with more potential for GHG reduction.

5.1.4 Land Use and Climate Change

The major greenhouse gases related to agriculture and land use are carbon dioxide and methane. Carbon dioxide is released to the atmosphere as a result of disturbance of soils when land is converted or the land management technique is changed. Methane may be released by wetlands and is influenced by the hydrological state of the location. In addition, the release of nitrous oxide takes place during the burning of biomass, a practice related to land use changes from forestry to agriculture.

Over the last few decades agricultural practices such as tillage have resulted in this form of land use being a net source of carbon dioxide. Tillage breaks up the soil, releasing carbon to the atmosphere, but also contributes to erosion, which results in a loss of organic matter and the long-term ability of the soil to sequester carbon.

Changes in practices can lead to a change in the role of a type of land use from being a source of greenhouse gases to become a sink. Practices that favour carbon accumulation, like reduced tillage and the use of perennial forages prevent erosion, preserving the productivity of soils. Carbon-sequestering practices may enhance the profitability of farming systems by increasing yields or reducing production costs. Finally, carbon sequestering practices may also have secondary effects beyond the boundaries of the agricultural ecosystems. They may have benefits to air and water quality through reduced erosion, positive or negative effects on water quality and potential impacts on rural economies through changes in cropping practices.

The concern over the losses of soil organic matter and net carbon release into the atmosphere has resulted in new research on cultivation practices, and implementation of zero and low tillage approaches. Preliminary results indicate that these methods do have the potential to conserve and even increase soil carbon storage. Thus, these techniques can decrease or eliminate the negative effects of cultivation on carbon balances.

5.1.5 Potential Impacts of Climate Change on Canadian Agriculture

Potential impacts of climate change on agriculture will be reflected most directly through the response of crops, livestock, soils, weeds, and insects and diseases to the elements of climate to which they are most sensitive. There have been a number of studies done which examine the possible effects on Canadian agriculture from climate change scenarios. One of these studies is the Canada Country Study which examined the impacts of climate change on various regions in Canada under the scenario that over the next century a further warming of 1^{o} to $3.5\ ^{o}$ C will occur.

To date however, few studies have fully accounted for future changes in climate variability, water availability, and the many ways by which farmers might respond to the changing climate. These factors may be as important as the direct effect of the change in climate itself. If appropriate adaptation strategies are identified and implemented in a timely fashion, the overall vulnerability of the region may be reduced. However, uncertainties exist about the feasibility of implementation and efficacy of technological adaptation.

5.1.5.1 Higher Temperatures

As the climate warms, crop patterns are shifting northward. In Canada, global warming could potentially extend the length of the potential growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season. Crop producing areas may expand poleward although yields in higher latitudes will likely be lower due to the less fertile soils that lie there.

5.1.5.2 Pests and Diseases

Conditions could be more favourable for the proliferation of insect pests in warmer climates. Longer growing seasons could enable insects to complete a greater number of reproductive cycles during the spring, summer, and autumn. Warming winter temperatures may also allow larvae to winter-over in some areas where they are now limited by cold, thus causing greater infestation during the following crop season. Altered wind patterns may change the spread of both wind-borne pests and of the bacteria and fungi that are the agents of crop diseases. Crop-pest interactions may shift as the timing of development stages in both hosts and pests is altered. Livestock diseases may be similarly affected. The possible increases in pest infestations may bring about greater use of chemical pesticides to control them, a situation that will require the further development and application of integrated pest management techniques.

5.1.5.3 Enhanced CO_2 on Crop Yields

Production from crops such as soybeans and wheat are expected to increase an average of 30% in response to a doubling of CO_2 concentration (wheat and soybeans belong to a physiological class that respond readily to increases in CO_2 levels). The magnitude of this response will be highly variable and will depend on the availability of plant nutrients, temperature, and precipitation.

5.1.5.4 Climate Variability

In addition to increased daily and interannual temperature and precipitation, there is a consensus among scientists that there will be an increase in the frequency and intensity of unexpected severe weather events (i.e., hailstorms, flash flooding, high intensity rains). These kinds of events can not only be enormously destructive to property, but droughts, floods, and increased risks of winter injury could contribute to a greater frequency and severity of crop failure. Increasingly violent weather events are alarming the insurance industry, especially the reinsurance industry, which eventually must underwrite the losses. Consequently, the insurance industry is now an active participant in all of the meetings of the climate change convention.

5.1.6 Adapting to Climate Change in Canadian Agriculture

Allen Tyrchniewicz

Canada has committed to reducing its GHG emissions by 6% from its 1990 levels. Canada's agricultural and agri-food sector will be expected to reduce its GHG emissions to assist Canada in meeting the commitments to the Kyoto Protocol. There are two strategies for responding to predicted climate change: mitigation and adaptation. Mitigation attempts to address the causes of climate change and can be classified into three broad areas: reducing sources of GHGs; maintaining existing sinks of GHGs; and expanding sinks of GHGs. Adaptation is concerned with responses to the effects of climate change. It refers to any adjustments that can be undertaken to ameliorate the expected or actual adverse effects of climate change.

While recognizing the need for efforts to reduce GHG emissions, agriculture needs to adapt to climate change for three main reasons. The first is that the climate is changing and production techniques need to change with it. Secondly, policy will change to assist Canada in meeting its goals for Kyoto. Finally, but of even more importance, farmers need to maintain a livelihood to support their families and to continue producing food and fibre. By adapting to climate change now, agriculture will be able to capitalize on the immediate benefits of the expected climate while minimizing the costs.

Agriculture will not only have to adapt to the physical aspects of climate change, but also the policy changes related to climate change in agriculture and sectors associated with agriculture. Assessing the climate change implications for agricultural policy is difficult due to the complex interactions between land use practices and the changes in greenhouse gas emissions. Agricultural policies have an impact on farming practices, such as land use, fertilizer use, irrigation and livestock activities, and as a result, have an affect on whether or not agriculture is a source or a sink for greenhouse gases. By removing policies that impact through negative incentives on land use changes, such as those that promote clearing more marginal land for crop production, the potential is to improve the role of the land as a sink as opposed to a source of greenhouse gases.

Adapting to changing climate and developing relevant climate policies requires information. The information needs to be timely, reliable and available to everyone who could benefit from it. To effectively manage the climatic changes facing agriculture, techniques are required that examine the changing climatic variables and the political climate. While the climate models are improving, they tend to offer information on a more macro scale than the typical user needs. As well they do not attempt to address other aspects of climate change, such as economic and social considerations. Models are required that incorporate social, economic and physical systems in addressing adaptation. The models should build on past experiences of adaptation, ranging from changes in policy, climate, technology and markets. It is with these models that policy results can be predicted before actually applying them.

Adaptation has successfully taken place in agriculture in a number of ways over the course of its development in Canada. Farmers have successfully adapted their production and management practices to a variety of changes, such as technology, policy and weather, but not all adaptation techniques are sustainable or successful. Specific climate research is required that outlines impacts in each region of Canada's agriculture. Crop and livestock research is required based on the climate change models. Improving the climate predictions is beneficial, but farmers, as well as other, need to have long term weather predictions. Finally, the most significant gap for agriculture to adapt to climate change is the redirection of policy affecting agriculture. Canada needs to outline its climate change strategy as soon as possible to provide the agricultural community an idea of what it needs to adapt to.

5.1.7 How Will Greenhouse Gas Policy Affect the Competitiveness of Canadian Agriculture?

Allen Tyrchniewicz

Canadian agriculture must understand how its competitiveness will likely be impacted by adapting to climate change. Determining the international competitiveness of Canadian agriculture is difficult as there are many variables affecting agriculture's competitiveness in the global market. Competitiveness can be assessed at many levels: international, national, sectoral, and even individual company. For the purpose of this discussion, we will consider the competitiveness of Canada's agriculture on an international basis while considering national impacts.

Canada exports a significant portion of its agricultural production, and as a result is very dependent on foreign markets to support its agriculture. Canadian and Provincial Ministers of agriculture and agri-food have set an export target of 4% of the total share of world agriculture trade by 2005. Such a target would translate into export sales of between $30 and $40 billion, depending on world trade growth and exchange rate assumptions; this compares to $20 billion in 1996. To increase Canada's market share, agriculture and related sectors will have to concentrate on increasing the exports of more value-added products and less on bulk products. With current agricultural production and processing technology, increased processing and production will be in direct conflict with the objective of greenhouse gas reduction as specified in the Kyoto Protocol. To fulfil both objectives will require a change in production techniques that is less dependent on carbon intensive energy. The international markets will become even more complicated to track accurately as the supply of and demand for agriculture products change due to the impact of response to climate change in other regions of the world. A much better understanding of the global impacts of climate change is required.

At a National level, Canadian agriculture's competitiveness is dependent on how Canada responds to the physical climate change as well as the Kyoto Protocol. Adaptation will be necessary that incorporates the impacts on the transportation, energy, and fertilizer sectors, just to name a few. Government policies that are developed to address climate change will require a review of many of these impacts to ensure that barriers are removed that will harm the agriculture sector and that new barriers are not established.

Agriculture itself will have to develop strategies for addressing climate change that reduce the direct conflicts with reducing greenhouse gas emissions. Strategies that remove the dependence on carbon intensive energy, for example, have the potential for reducing input costs of production and addressing the greenhouse gas emissions. This improves the competitiveness of agriculture in the national and international settings.

Farmers and processors will require information about the changing climate and the changing markets to remain competitive. As well both farmers and processors will need to have more knowledge about the availability of inputs and changing cost structures to develop their own business plans.

5.1.8 Complimentarities and Conflicts in Policies Relating to GHG and Agriculture

Edward Tyrchniewicz

By their very nature, government policies create conflicts. There are "winners" and "losers", as well as intended and unintended impacts. Yet, in some instances, policies and programs can create "win-win", or "no regrets" situations. The purpose of this paper is to explore, in a conceptual way, the notion of complimentarity and conflict in policies relating to GHG emissions and agriculture.

The challenge of policy making is to sort out the impacts of existing and proposed policies, and to offer realistic policy alternatives. Policies generally have three types of impacts: economic, environmental, and societal. Within the economic impact context, policies usually have the objective of income enhancement and /or income re-distribution. Conflicts arise as a result of the scope of the application of the policy. The environmental impact of policies usually relates to the impact on the quantity and quality of natural resources, both in the short and long term.

Typically, this includes land, water, and air but may also include wildlife and its habitat. The societal impact of policies focuses on people, their communities and institutions, and equity implications. This is complicated by the fact that equity considerations are usually focussed on income distribution and competing objectives in the use of natural resources.

The Great Plains Program in IISD has been involved for a number of years in evaluating agriculturally related policies from the perspective of sustainable development. The project involved identifying agricultural and sustainability issues on Canada's Prairies, and providing a set of principles, criteria and a framework for the resolution of agricultural sustainability issues on the Prairies. Through a consultative process, a number of key principles and criteria were identified. The principles for sustainable development in agriculture were grouped under three broad categories: stewardship, economic viability, and social concerns. With some modifications, this framework and process could be applied to assessing existing and proposed policies and instruments relating to the reduction of greenhouse gas emission in agriculture.

It is generally recognized that if Canada is to achieve its target of reductions in GHG emissions, incentives must be found that will encourage the private sector to adopt measures that will result in such reductions. In reviewing various documents, it is possible to identify an array of policy incentives that have an impact on greenhouse gas emissions in agriculture. These include: conservation policies that encourage carbon sequestration in soils, carbon credit trading, input subsidies for fuel and fertilizer, and tax incentives for development and use of technology that reduces GHG emissions.

Obviously, there will be some "win-win" or "no regrets" options that can achieve wide acceptance, while other incentives may result in conflicts within the agriculture sector, with other economic sectors, and with other groups in Canadian society. In an ideal world, one would design policies that please everyone. In reality, policy conflicts will continue to exist. Our challenge is to develop policies that minimize conflicts.

5.2 Economics of Various Practices Which Could Enhance Evaluation of Emission Reduction Potential

5.2.1 The Economics of Reduced Tillage and Reduced Summer Fallow in Crop Production in Canada: A Review of Available Evidence

Michael Rossetti and Glenn Fox

The last decade has witnessed substantial changes in the use of reduced tillage systems by grain and oilseed producers in Canada. Historically, producers have used mechanical tillage to control weeds and for seedbed preparation. This approach generally provided producers with higher and more stable short term incomes. More recently, improvements in technology and in management practices have made it more attractive for producers to reduce their reliance on mechanical tillage operations and to subsequently reduce their production costs. In addition, growing concern about the long term effects of traditional tillage practices on soil quality and about the off-farm effects of displaced sediment from tillage operations have been important regional issues.

Increases in adoption rates for reduced tillage practices during the last decade can be attributed to several factors. Increased availability of equipment required for seed and fertilizer placement in heavy crop residue, improvements in residue management, greater availability of non-selective herbicides and reductions in the recommended application rates have reduced production costs and improved weed and disease control have all contributed to improved economic performance of reduced tillage.

Reduced tillage also offers soil conservation benefits compared to that which can be obtained under conventional tillage. Reduced tillage management systems make use of anchored stubble to reduce water and wind soil erosion, conserve soil moisture levels, and maintain soil nutrient quality. By using zero tillage to maintain or improve soil quality, it is possible to have higher levels of soil carbon sequestration and lower levels of carbon dioxide released into the atmosphere when extended crop rotations are employed.

Another advantage of reduced tillage is that the producer spends less time transporting tillage equipment, often by road, from one field to another. This allows producers to realize economies of size in crop production. It has also increased competition for rented land in many areas because it is profitable for producers to travel farther to work rented land when fewer field operations are necessary.

Despite the large body of research showing the benefits of adopting zero tillage, available data and local expert opinion suggests that the rate of adoption of no-till in eastern Canada is slowing down. And the use of reduced tillage in the United States may be actually decreasing. Reduced tillage can often reduce some costs, especially fuel costs, but there can be a yield penalty associated with its use in some situations. And pest control may require increased use on chemical inputs with no-till or reduced tillage. And there is some evidence that suggests that leaching on nitrates to goundwater can be higher with reduced tillage.

There are some areas which require continued research in order to further improve the economic performance of zero tillage. These main areas include: a) develop improved methods of soil water conservation and stubble management in order to further enhance crop yields on a consistent basis; b) determine the suitability of present nitrogen fertilizer recommendations since they were developed for use in conservation tillage systems; c) develop more efficient herbicide programs and application methods in order to deal with weeds and to allow for lower application rates; d) determine the suitability of new crop types which can be included in cereal rotations in order to extend and diversify the rotations; and e) determine the long-term impacts of conservation tillage methods on soil quality and the environment. In general, more empirical research is needed to better understand the overall effects of tillage systems on energy use in crop production and to further investigate the economic performance of reduced tillage production systems in light of recent innovations in technology and management.

5.2.2 The Economics of Modified Manure Handling Systems for Greenhouse Gas Reductions

Gregory De Vos, Alfons Weersink, Peter Stonehouse

There are a number of environmentally significant gases which are associated with livestock barns, manure storage and the field application of manure. Gases released to the atmosphere from barns, manure management systems and land spreading manure as fertilizer may have local impacts, contributing to air, land and water pollution. Some of these gases are also of concern from a global perspective since they contribute to global warming and to the destruction of stratospheric ozone. Management choices related to the creation, storage and application of manure can influence the level of these gases. However, the practices selected by the farmer, and thus manure pollution levels, depend largely on relative on-farm profitability rather than off-farm environmental concerns.

Net benefits of manure to an individual farmer are generally negative implying it is a waste product to be disposed of at minimum cost. Thus, reducing environmental damages from manure will require policy makers to encourage the adoption of practices to reduce nutrient levels. Options to reduce these emissions include; a) altering the nutrient content of the manure through ration changes or multiple stage feeding; b) adaptions to the stabling and storage of manure; and c) low ammonia applications such as incorporation of manure. Measures to reduce N content in the diet offer the lowest costs per unit of emission reduction while the most costly are the measures to reduce ammonia volatilization from the barn and storage. These costs vary significantly between farm types and region, implying targeted policies and permitting flexibility in control options will be more cost effective than uniform regulations. The design of effective policies requires more information on costs and environmental impacts of alternative measures.

5.2.3 The Economic Feasibility of Modified Feed and Rumen Management to Reduce GHG Emissions

Scott R. Jeffrey

This paper examines and assesses possible methods of controlling ruminant methane emissions. Within agriculture, commercial livestock production (particularly ruminant production) has been identified as a significant source of methane, which is an important GHG. Effective methods of reducing methane emissions from ruminants have been identified and studied by scientists. There is no doubt that methane emissions from ruminant livestock production can be reduced through a combination of direct management of the rumen and its contents, dietary adjustments, and improved animal productivity.

The approach with the greatest immediate promise is improved productivity in beef and dairy production. This strategy has the advantage of reducing methane emissions per unit of production while at the same time having visible and significant advantages from a farm management perspective.

While improved productivity seems to hold the greatest promise in terms of adoption by livestock producers, there is a need for research related to the costs and cost effectiveness of the alternative methods of control.

5.2.4 Economics of Biofuels

Ewen Coxworth and Andre Hucq

Biofuels include a wide variety of energy products, ranging from waste wood through to synthetic fuels such as ethanol, vegetable oil methyl esters, and methanol. With the growing interest in and concern about global climate change, a number of world and national studies of methods to reduce the increase in greenhouse gases (GHGs) have placed surprisingly high emphasis on the production of biofuels, coupled with improvements in energy efficiency of all energy activities. This would require a major expansion in the production of biomass feedstocks worldwide, with significant effects on agriculture, agroforestry and forestry.

This paper discusses briefly a number of issues for Canadian agriculture. These include the amount of biofuels produced from agricultural feedstocks, and likely near-future production, comparisons with the total amount of bioenergy used in the Canadian economy, comparisons with agricultural fuel requirements, the GHG emissions from biofuels, including emissions from feedstock production, present economies, methods to reduce biofuel costs, present tax incentives and related benefits, future technology and the outlook for reductions in costs and GHG emissions.

5.3 Related Benefits from Reducing GHG Emissions

While the mitigation techniques described in this paper are primarily used to reduce GHG emissions, additional benefits are often derived from these efforts.

Conservation Tillage: Improved water quality; decreased runoff and erosion, reduced particulate emissions; lower incidence of root rot in wheat under zero-tillage than conventional tillage; reduced labour, fuel and machinery costs; reduced soil compaction; improved water infiltration; improved long term soil and crop productivity.

Erosion Control: Increased yields; improved water quality; reduced fertilizer requirements; maintain soil structure.

Soil Management: Continued fertility of soils.

Feed Additives for Livestock: Reduced cost of food production, increased production rates reduce methane.

Anaerobic Digesters: Reduced energy bills, revenues from high quality manure byproducts, savings on manure handling, reduced odours, enhanced fly control, improved surface and groundwater quality. There is also the potential to integrate algae of duckweed production into the system to substitute these high protein yielding aquatic feed sources for commercial feed.

Fertilizer Management Practices: Decreased contamination of surface and ground water, reduced fertilizer costs, improved crop yields.

Bioethanol: Production of a high quality protein co-products, such as DDG, a valuable feed supplement for cattle.

Manure Management: Reduction in ammonia emissions.

5.4 Specific Government and Industry Actions Required/involved, Opportunities for Offsetting Potential Negative Impacts Identified for the Sectors and for Capitalizing on Potential Benefits

Actions to reduce greenhouse gas emissions have major additional benefits in reducing local and regional air pollution, land degradation, traffic congestion, etc. Studies in Europe and North America suggest that these benefits can offset at least 30% of the mitigation costs, or as in the case of the United Kingdom, 100%.

"No regrets" measures are those whose benefits, such as reduced energy costs, and other environmental and economic benefits, equal or exceed their costs to a country, excluding the benefits of mitigation of climate change. They are worth doing anyway.

5.4.1 Market Instruments Options for Reduced GHG Emissions from Agriculture

Allen Tyrchniewicz

Market instruments have been used to achieve a variety of objectives in many policy areas. The paper will examine the possibility of using market instruments to assist in the reduction of greenhouse gases from agriculture. There is a complex assortment of approaches that Canada can use to reduce its greenhouse emissions.

To determine the effectiveness of market instruments in reducing greenhouse gases emissions three things need to be reviewed. The first step is to establish the types of greenhouse gas occurring in agriculture production and processing. Secondly, a review of the different types of market instruments is required. Finally, an analysis of the potential to use these market instruments in the reduction of the greenhouse gas emissions from agriculture is necessary. The results of the process will highlight the appropriate market instruments for the reduction of greenhouse gases in agriculture production and processing.

The Climate Change Task Group outlined a number of measures that could be used to reduce greenhouse gas emissions from Canada. This paper will touch upon three market instruments that could be used to reduce GHG from agriculture such as substance emissions trading, carbon credit trading, and conservation easements.

Substance emissions trading allows one party to purchase rights to emit GHG from another party that was able to cut its emissions below their assigned amounts. Substance emissions trading works well in situations where the points of emissions are known and there are distinct emitters.

Carbon credit trading tends to be used in areas where a reduction standard can not be used due to major differences in emitters and in particular the cost of controls are dramatically different. Credit trading is project based, and each trade requires that the following be reviewed and certified; an emissions baseline, permitted level, reduction plan and enforcement mechanisms. Government or another authority is required to monitor each transaction to ensure all requirements are in place. Credit trading structures are designed to have many players, including both emitters and those sequestering emissions.

A conservation easement is a legal agreement by which a landowner voluntarily restricts or limits the type and amount of development that may take place on his or her own property. Conservation easements can be used to preserve wildlife habitat, open space or agricultural land, or the historic features of a building, while allowing the landowners to continue owning and using the property.

Canada needs to find market instruments that can be used effectively to reduce greenhouse gas emissions from agriculture. While each of the market instruments has their place, all require better measurement and verification than is currently available.

5.4.2 Incentives for Early Action and Timing of Greenhouse Gas Policies for Agriculture

Richard Gray and Dan Monchuk

The Kyoto commitment, if met, will have a significant effect on the Canadian economy and will require significant investment in most sectors. These investments once made, are sunk costs that are not recoverable. With the financial uncertainty surrounding incentives for emission reduction there is an incentive for private firms to remain flexible and delay investment until more becomes known. On the other hand, given the time and resources required to develop and adopt new technologies, it is important that some investments be initiated early. The government may need to look at developing programs or policies that speed up the adoption process so that costly future adjustments can be avoided by ensuring that the adoption of such technologies by a certain portion of the target group occurs within a desired span of time.

When considering the implementation of GHG policies, it is important to discuss the investments that must be made by the appropriate groups. That is to say that when and if the invested capital is to be sold for salvage or to some other use, that the cost of the capital less depreciation is not fully recovered. This will imply that before an investment is made there must be a certain amount of certainty over the future conditions or the investment will not be undertaken. For the government this means that long-term commitments must be made and adhered to or there will be less of an incentive to undertake the required investment. Making these long-term commitments contributes to reducing future uncertainty and thus reduces the incentives to delay investment.

The implementation of GHG policies to meet Canada's emission reduction levels as outlined by the Kyoto protocol are hindered by a number of different factors. The major factors influencing the achievement of these goals are uncertainty, realizing the delays between action and outcomes, and determining the optimal approach to policy
structures. To determine the optimal approach requires sound knowledge of
a
potentially limit future gains that may be had by increased levels of GHG in the atmosphere. While a small number
the important factors are known with some degree of certainty, a lot of work has yet to be done to determine what is the best course of action for Canada's agricultural sector to take.

5.4.3 Non-Market Policy Instrument Options for Reduced GHG Emissions from Agriculture

The use of market and non-market policy instruments to control and correct problems of the environment has
in recent decades. Market-based instruments promote the creation or improvement of a market in order to
address
mechanisms that are not determined by the free choice of buyers and sellers.

Non-market
intervention; 1) voluntary programming initiatives, 2) financial incentives and taxes, and 3) prescriptive standards.

Voluntary
between producers and consumers to encourage 'green' consumer patterns, and to establish agreements between

Other non-market economic approaches commonly employ financial incentives to correct environmental problems.
governments are using more economic instruments, primarily because traditional command and control
instruments
applicable to agriculture. But such taxes are sometimes difficult to apply and are often unpopular. Furthermore while
glance a fossil fuel tax may appear to be a logical choice by which to reduce carbon emissions, the agricultural
production
agricultural sector of the economy.

"Stick" approaches are at the basis of all government intervention procedures to reduce GHG emissions. Prescriptive
standards are
However, non-market options may also involve prescriptive standards that tend to control the most obvious of
inequities in implementation
costs and rarely encourages innovation beyond the standard prescribed.

determine which non-market instruments might most effectively be employed to develop behaviour that leads to
GHG

be required to determine how to compare the effectiveness of one instrument over another. As well, constitutional legal considerations must be examined to determine which level of government can effective implement non-market instruments. Finally, the use of non-market policy instruments does not provide a complete solution to problems concerning the reduction of GHG emissions. They must be used in conjunction with market-based instruments if efficient solutions are to be found. Further research is necessary to determine how the two types of instruments -- market and non-market -- and the institutional arrangements used to implement them, can be used effectively in concert to achieve maximum impact for the reduction of GHG emissions in the agricultural sector.

5.5 Identification of knowledge gaps which need to be filled to further assess the potential of these measures

- Interaction between mitigation efforts
- Domestic effects - linkages and conflicts
- Offsetting international effects - linkages and conflicts
- Possible development of long-term comprehensive agricultural and agri-food climate change science strategy
- Additional information on the indirect benefits of the mitigation efforts
- Identification of potential emissions reduction scenarios as starting point of development of options

6. Next Steps

“Next Steps” should be determined by the Agriculture and Agri-Food Table.

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Appendix 1

Selected Research from OECD Countries

Canada

Major Legislation and Policy

Canadian Environmental Protection Act (CEPA)

The Canadian Environmental Protection Act (CEPA) was enacted in 1988. After a series of consultations, a new CEPA Act was drafted in 1996. Unfortunately, it did not make it through the legislation process during the last parliament session. It is anticipated that the bill will be put forward in the new Parliament.

The proposed new CEPA focuses on pollution prevention, and protection of the environment and the health of Canadians from toxic substances. CEPA incorporates the advancement made in environmental law, and concepts such as sustainable development and pollution prevention. It encompasses pollution prevention, managing toxic substances, clean air and water (fuels, vehicle emissions, international air and water pollution), controlling pollution and wastes (land-based sources of marine pollution, disposal at sea, movement of hazardous wastes and recyclable and of non-hazardous wastes, environmental matters related to emergencies, biotechnology, federal government operations and federal and Aboriginal lands, enforcement, information gathering, objectives, guidelines, and codes of practice, and public participation.

The Canadian Environmental Assessment Act

The Canadian Environmental Assessment Act was proclaimed on January 19, 1995. The three primary objectives of this Act include: 1) ensure environmental effects of projects receive careful consideration, 2) encourage actions that promote sustainable development, and 3) ensure the public has an opportunity to participate in the environmental assessment process.

The Act sets out the responsibilities and procedures for environmental assessment of projects involving the federal government. It also establishes a clear and balanced process to the environment assessment process. It allows the responsible authorities to determine environmental effects of projects early in their planning stage. The Act applies to projects for which the federal government holds decision-making authority, whether as proponent, land administer, source of funding or regulator. It includes proposals for policies or programs considered by Cabinet. Each ministry is responsible for the implementation of this Act (the Environmental Bureau with Agriculture and Agri-Food Canada is responsible for implementing this Act).

While this Act has an impact on air, water, soil and biodiversity, it targets government actions, but not individual agriculture and agri-food enterprises, unless the federal government is involved in the enterprise. The implementation of this Act has resulted in three Federal-provincial agreements relating to environmental assessment. These agreements allow the harmonization of environmental assessment studies on projects.

The Federal Policy on Wetland Conservation

The Federal Policy on Wetland Conservation is under the responsibility of Environment Canada and was enacted in 1991. The primary objective of this program is to promote the conservation of Canada's wetlands to sustain their ecological and sociol-economic function, now and in the future. One key strategy of this policy is to encourage recognition of wetland function in natural resource conservation and development strategies, such as those for forest, minerals, agricultural lands and water.

Strategy for Environmentally Sustainable Agriculture and Agri-food Development

The Strategy for Environmentally Sustainable Agriculture and Agri-food Development is administered by Agriculture and Agri-Food Canada and was enacted in 1997. Its primary objective is to provide a framework for integrating sustainable environmental considerations into policies and programs. In Canada's new environmental agenda, "A Guide to Green Government", each department is required to develop sustainable development strategies. AAFC's strategy sets out four directions for agriculture and agri-food sectors. These include:

1. Increase understanding of environmental issues;
2. Promoting environmental and resource stewardship;
3. Developing innovations and solutions; and,
4. Seizing market opportunities.

The goal of this strategy is long-term sustainable agriculture and agri-food development. To achieve this goal, all four areas of concern will require review and action plans.

National Soil and Water Conservation Program (NSWCP)

The National Soil and Water Conservation Program (NSWCP) is administered by Agriculture and Agri-Food Canada and was enacted in May 1997. This is a two-year initiative to provide funding for a program in each province addressing priority environmental sustainability issues facing the agriculture and agri-food sector. The targeted issue is conservation of soil and water in a sustainable environment.

NSWCP is established under the Canadian Adaptation and Rural Development Fund to assist the government and its agricultural industry partners to implement Canada's sustainable development strategy. In each province, a Soil and Water Conservation Program will be developed that addresses the priority environmental sustainability issues of the region.

United States

Major Legislation and Policy

North American Wetlands Conservation Act

The North American Wetlands Conservation Act was passed in 1989. Participation is voluntary and the primary objective of the Act is to encourage voluntary, public-private partnerships to conserve wetland ecosystems. The Act establishes an infrastructure and provides a source of funding to conserve wetlands, which results in the procurement of a real property interest in, or the restoration, management, or enhancement of a wetland ecosystem to benefit wildlife. Anyone can apply for a grant under the Act at any time, but certain criteria must be met to have a project funded. Congress elected to spend $9 million in 1995 and $6.75 million in 1996. Up to $30 million may be appropriated in 1997 and 1998 fiscal years.

Ruminant Livestock Methane Program

The Ruminant Livestock Methane Program was enacted in 1996 and is administered by EPA with USDA and local conservation districts. The primary objective of this program is to reduce methane gas production through profitable management plans. Land-grant universities and USDA researchers are conducting regional assessments to identify improved management practices, technologies, and marketing options that will improve productivity while reducing methane emissions. Extension services will promote the most profitable and appropriate options for reducing methane emissions from beef cows. Local conservation districts will promote cost-effective livestock management plans that will improve animal performance while enhancing forage resources. Outreach activities for this program will include keeping producers informed, integrating results into existing extension programs, evaluating the effectiveness of extension activities, developing management tools for producers to survey their operations and assess productivity options, and conducting hands-on demonstrations.

Pollution Prevention Act

The Pollution Prevention Act was promulgated in 1990 and the EPA is the lead agency. The primary objective of the Act is the reduction and prevention of pollution at the source whenever feasible. Pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible. Disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

The Act provides for regulations and compliance programs, state and local partnerships, strengthening of the national network of state and local pollution prevention programs, and seeks to integrate pollution prevention into state and local regulatory, permitting, and inspection programs supported with federal funds. Programs and policies related to this Act include the AG-STAR Program, Ruminant Livestock Methane Program, Pesticide Environmental Stewardship Program, and Agriculture In Concert with the Environment (ACE).

The Conservation Reserve Program (CRP)

The CRP, as a provision of the 1985 and 1990 Farm Bills, was intended to convert highly erodible land from active crop production to permanent vegetative cover for a 10 year period. The 1996 Farm Bill made major changes in the CRP - for example, it makes highly erodible land which best management practices (BMPs) can not protect, targets for temporary land retirement. Implementing CRP, like adopting a conservation tillage or residue management system, can lead to C sequestration in soil through erosion control, incorporation of biomass in the soil, etc.

Denmark

Environmental Protection Act and the Guidelines to Reduce Nutrient Leaching from Agricultural Land

This program is administered by the Environmental Protection Agency and its primary objective is to reduce pollution resulting from nutrient leaching. Industries were required to adopt best available technologies in their attempts to reduce pollution. Guidelines to reduce nutrient leaching (particularly N) from agricultural land were introduced in 1985-86 and included: requirements for sufficient manure slurry storage capacity to enable producers to apply when leaching is minimized; and other rules applying to livestock farms are stipulated by the Ministry of Environment and the Ministry of Agriculture and Fisheries include:

1. Storage capacity: Farms must have sufficient capacity to store their manure slurry as long as is necessary to comply with their fertilization strategy and the rules governing application of fertilizer; normally 6-9 months by 1996. For pig farms with more than 60 LU, a 100m3 manure slurry storage tank is required to store 9 months of slurry. Subsidies are available for 25-40% of the costs.

2. Sealed manure heaps: Farmers producing solid manure must store the manure on an impermeable base.

3. A reasonable relationship between manure production and area of the adjoining land: not more than 2 LU per hectare for cattle farms and 1.7 LU per hectare for pig farms. However, farmers can enter into a written agreements with other farmers to use their land.

4. Fertilizer application requirements: Animal fertilizer can only be applied at certain times of the year when there is vegetation in the fields to use the nutrients and therefore, the least potential for leaching.

5. Green cover: At least 65% of the farm has to be maintained with winter crops to take up nutrients in the winter.

6. Fertilization strategy and fertilization budgets: Farmers are required to draw up fertilization strategies twice a year based on specific figures for percentage utilization. For example, for pig manure slurry, the farmer must base his 1997 strategy on the assumption that 50% of the N manure will be utilized by plants and reduce his consumption of commercial fertilizer accordingly. In addition, authorities can also conduct spot checks for compliance.

Netherlands

Policy Document on Manure and Ammonia

Maximum levels of fertilizer application per hectare were established and measures to reduce emissions of ammonia introduced. Major areas covered in the 1996 policy to be implemented before the year 2000 include:

1. <u>Minerals Accounting</u>: a system for accounting for all inputs and outputs of minerals on the farm. If the losses exceed the standards for phosphate and nitrogen set for that year, the surplus is subject to a fine. Fines are 5 guilders per kg phosphate/ha over the surplus for the first 10 kg, and 20 guilders for additional surplus. The system is to enter into force on January 1, 1998. After 1998, farms with more than 2.5 Livestock Unit stocking rates must report their marginal losses and by 2002, farms with more than 1.5 LU must begin reporting.

2. <u>Use and Loss Standards</u>: Use rates for manure application on grasslands were lowered from 150 to 135 kg phosphate per hectare in 1996. In 1998, after mineral accounting has been implemented, the loss standard will be lowered to 40 kg/ha phosphorous and eventually to 20 kg/ha by 2008-2010. For nitrogen, the loss standard for grassland will be 300 kg/ha in 1998 and 180 kg/ha in 2008-2010.

3. <u>Encouragement and Restructuring</u>: A restructuring fund will be established to aid pig producers in areas where production is concentrated. Part of the fund may be used to take manure production rights via tenders out of the market or to reduce the manure surplus through restructuring. The hog production sector is expected to have the most trouble in meeting targets for manure production.

4. <u>The policy on ammonia</u> is directed towards emission reductions. Farmers with stocking densities over 2 LU will be obliged to construct low emission housing in 1998.

5. <u>The effects of the policy measures</u> will be monitored for amounts of manure produced, the development of different solutions for manure surpluses and the results reported annually.

Australia

Greenhouse 21C - A Plan of Action for A Sustainable Future

Specific to agriculture is Biosphere 21C. Key items in this initiative include:

1. Greater recognition of greenhouse issue in Landcare and forest policies;
2. Expansion of One Billion Trees program;
3. Labor market programs for expanded tree planting;
4. Cooperative action with States to monitor land clearance.

About 40% of Australia’s net greenhouse gas emissions are estimated to derive from land management and agriculture.

National Landcare Program

The National Landcare Program was introduced in 1992 with a primary objective of enhancing the efficient, sustainable and equitable management of the nation’s natural resources for the benefit of the overall community. This program replaces programs that have provided support to state and local governments for land conservation and water resource management. Major areas of concern are that most areas of cropland are affected by soil degradation - soil structure decline, waterlogging and salinity, water and wind erosion, soil nutrient balance and soil acidification. Poor soil, climate variability, concentration of agriculture on only 6% of land, loss of biodiversity are key pressures. The most critical factor in productive soils is the maintenance of cover which NLP is attempting to address.

Summary of national regulations and economic instruments employed by a select number of OECD countries

Issue	Canada	United States	Netherlands	Denmark	France	Australia
Nitrate and phosphate from manure and chemical fertilizers	No specific national program (some provincial regulation and programs)	No national program (Some state regulation and funding)	A number of national regulatory and economic programs. Instruments include quotas, levy on excess manure production, manure banks, restriction on timing of application, mineral accounting, and assistance to convert to organic farming.	Several national regulatory and economic programs. Most instruments focus on development of management plans, storage standard and needs, and timing and standard of application, and assistance to convert to organic farming.	Some national regulatory and economic programs. Instruments include tax on nitrogen emissions, manure storage requirements, maximum per hectare application of nitrogen, nitrogen balance sheets, and assistance to convert to organic farming.	No specific national program. (Voluntary Codes of Practice for hog and dairy production, and dairy processing)
Ammonia and methane emissions	No national program.	No national program.	National program targeting the reduction of ammonia emissions.	No national program.	No national program.	No national program.
Land management	Some programs providing payment for the planting of permanent covers and set-aside, improve farm practices, and other activities leading to land improvements.	Some programs providing payment to set-aside fragile land, development of management plans, and adoption of practices leading to the prevention of soil erosion and losses.	Approached land management by targeting nutrient management.	A combination of mandatory and voluntary programs. Mandatory programs target nutrient management while voluntary programs provide incentives for long-term fallow areas and maintenance of grassland areas.	Some programs offering incentives to maintain extensive grassland areas and conversion of arable land to grass land.	Some programs offering assistance for prevention of soil rosion, degradation from weed and pests, and accelerated capital depreciation for land improvements.

Issue	Canada	United States	Netherlands	Denmark	France	Australia
Surface and groundwater contamination	No national programs, but some provincial programs.	Federal government provides State government with resources to fund the adoption of management practices leading to the restoration or enhancement of water resources.	Most of the programs target the reduction of nutrient leaching and run-off from agricultural production.	Most of the programs target the reduction of nutrient leaching and run-off from agricultural production.	Complex system setup to manage water resources. The States are responsible for the development of water policy.	A range of programs offering funding for communities to manage local water resources, and a national audit program to collect information.
Preservation of wetland, habitats	No direct programs, but funds from some of the broad programs could be directed to the preservation of wetlands and habitats.	National programs providing payments to landowners for preservation and management of wetlands and habitats.	National programs consisting of management agreements for landowners to be compensated for maintaining wetlands and habitats.	National programs consisting of land acquisitions, management agreements with land owners, public afforestation projects and subsidies to favourable environmental practices.	Several national programs directed at the preservation of endangered species and protection of nature.	National programs directed at improving information, and preservation of native vegetation and wildlife.
Environmental stewardship & education	A component of a number of national programs.	Some specific programs directed at education. Training is also a component of a number of other programs. U.S. has an extensive extension system delivering a wide range of services.	Some national programs directed at improving environmental training for farmers.	Insufficient information to provide an assessment.	Some national programs providing training, technical support, and demonstrations.	National funding for training, and development of integrated farm management plan.

Appendix 2

The Canadian- IPCC Approach for Determining Methane Emissions from Animals

Methane from Enteric Fermentation

IPCC Tier 2 methodology is used to calculate CH_4 emissions from animals. The Tier 2 methodology is used for countries with large cattle populations such as Canada. Estimates were done for livestock reared in a cool climate. Emission factors have been determined from previous studies and are organized by region. The IPCC Tier 2 methodology takes into account the energy requirements of the livestock, and the variety and quality of feeds. Methane emissions from enteric fermentation in Canada were calculated using the livestock inventory data from Statistics Canada for the census year 1996. Table 2 presents the CH_4 emissions on a provincial basis. The emission factors used to calculate the CH_4 emissions are shown in Table 1. These emission factors include CH_4 emissions from respiration and eructations. Poultry emissions are not calculated using the IPCC methodology. Direct emissions from poultry are small, and even with a very large population, poultry do not contribute much CH_4.

IPCC methodology characterizes North American cattle as highly productive and commercialized. They are fed high quality forage and grains. The beef herds are separated and are primarily grazing animals with feed supplements seasonally. Fast growing beef steers and heifers are finished in feedlots on grain. Dairy cows are a small part of the population. The IPCC separate cattle into two categories, dairy cattle and non-dairy cattle. The non-dairy cattle included beef cattle, slaughter cattle and calves.

The emission factors for each category of animal are estimated based on feed intake and CH_4 conversion rates for each category. The feed energy requirements are estimated following the daily functions of the animal including maintenance, growth, grazing and lactation. Energy requirements for draft animals and for pregnant animals are also included. The following equations for energy intakes all contribute to the emission factor for each subcategory of animal. The subcategories for animals are dairy cattle, feedlot cattle, slaughter cattle, heifers and calves.

Maintenance: The required energy intake to keep the animal in energy equilibrium, i.e. there is no gain or loss of body tissues. These equations are specific to the type of animal. The following example is for cattle. Other animal energy intakes follow the same equation but with different constants. The net energy for maintenance of (NE_m) lactating dairy cows is slightly higher than normal cattle.

Normal Cattle: NE_m (MJ/day) = 0.322 x (weight in kg)$^{0.75}$
Lactating Dairy Cattle: NE_m (MJ/day) = 0.335 x (weight in kg)$^{0.75}$

Feeding: The additional energy required for animals to obtain their food. Grazing animals require more energy (NE_{feed}) than stall fed animals. Confined animals (pens or stalls) need no additional feeding energy.

Animals grazing in good quality pasture: 17% of NE_m
Animals grazing over very large area: 37% of $_{Nem}$

Growth: The energy requirements for growth (NE_g) can be calculated as a function of weight and rate of weight gain. NRC (1989) presents formulae for the large and small frame males and females, these estimates vary by about ± 25 %. The equation for large frame females is recommended since it is an average of the four types:
NE_g (MJ/day) = 4.18 x $\{(0.035\ W^{0.75} \times WG^{1.119}) + WG \}$

where:

W = animal weight in kg
WG = weight gain in kg/day

Lactation: The net energy for lactation (NE_l) is based on the amount of milk produced and its fat content.
NE_l (MJ/day) = kg of milk/day x (1.47 + 0.40 x Fat %)

Draft Power: The energy requirements for draft power (NE_{draft}) depend mostly on the strenuousness of the work and the length of time. These numbers vary considerably, so an average is taken. Draft animals are rarely used in North America but must be considered for an accurate emission factor.

NE_{draft} (MJ/day) = 0.1 x NE_m x hours of work per day.

Pregnancy: The energy requirements for pregnancy ($NE_{pregnancy}$) must be considered individually for each animal type. This is based on the length of the gestation period and the average weight of the newborn. The following example is for cattle:

$NE_{pregnancy}$ (MJ/281 day gestation period) = 28 x calf birth weight (kg)

where:

Calf birth weight (kg) = 0.266 x (cow weight in kg)$^{0.79}$

The total net energy intake (the sum of all individual activity intakes) is transformed into a gross energy intake by equating factors such as faecal losses, heat increment, urinary and combustible gas losses. To estimate the emission factor for each animal type, the gross energy intake is multiplied by the CH_4 conversion rate (Y_m). The CH_4 conversion rate is the fraction of the gross energy intake that is transformed into CH_4. This figure is a complex function of animal age, weight and feed quality. Conversion factors are used to balance out the emission factor equation to read kg of CH_4 /head/ year. The net emission rates are presented for each subcategory of animal in Table 1.

CH_4 emission (kg CH_4/hd/yr) = Gross energy intake (MJ/day) x Y_m x (365 days/yr) x (1 kg CH_4 / 55.65 MJ)

Table 1. Estimated CH_4 emission rates from livestock in Canada

Animals	kg CH_4/hd/yr [1]
Dairy Cows	118
Dairy Heifers	56
Bulls	75
Beef Cows	72
Beef Heifers	56
Heifers for Slaughter	47
Steers	47
Calves	42
Boars / Sows	1.5
Market Pigs	1.5
Sheep	8.0
Poultry	Not estimated

1 IPCCb, 1996

Table 2. Methane emissions from various livestock by province in 1996

Province	Dairy Cattle		Non-Dairy Cattle		Swine		Sheep		Poultry		Total Livestock	
	Pop[1] (10^6)	**CH_4 Mt/yr**	**Pop[1] (10^6)**	**CH_4 Mt/yr**	**Pop[1] (10^6)**	**CH_4 Mt/yr**	**Pop[1] (10^6)**	**CH_4 Mt/yr**	**Pop[1] (10^6)**	**CH_4 Mt/yr**	**Pop[1] (10^6)**	**CH_4 Mt/yr**
Atl.	0.1	0.009	0.2	0.012	0.3	0.0005	0.05	0.0004	8.6	n.a.	9.3	0.022
Quebec	0.6	0.060	0.9	0.044	3.1	0.005	0.14	0.001	27.2	n.a.	31.9	0.110
Ontario	0.5	0.056	1.7	0.084	3.3	0.005	0.22	0.002	39.0	n.a.	44.9	0.147
Manitoba	0.1	0.010	1.2	0.066	1.8	0.003	0.04	0.0003	7.2	n.a.	10.5	0.079
Sask.	0.1	0.010	2.6	0.139	0.8	0.001	0.09	0.0007	3.8	n.a.	7.5	0.151
Alberta	0.4	0.029	5.5	0.286	2.1	0.003	0.24	0.002	10.3	n.a.	18.6	0.320
B.C.	0.1	0.012	0.7	0.037	0.2	0.0003	0.08	0.0006	14.6	n.a.	15.7	0.049
Canada	1.9	0.185	12.9	0.669	11.7	0.018	0.85	0.007	110.8	n.a.	138.	0.879

[1] *Statistics Canada, 1996*

Methane from Enteric Fermentation:
Total Emissions from Enteric Fermentation (Mt/yr)=$\sum$*(Population of Livestock X Emission Factor for Enteric Fermentation (kg/head/year))*

Methane from Animal Wastes

The IPCC Working Group III has underlined the potential importance of CH_4 emissions from animal waste management. They suggest that under anaerobic conditions, uncontrolled emissions from waste management systems might be of similar magnitude as CH_4 emissions from livestock digestive processes. Animal wastes contain large amounts of organic matter which, if broken down by bacteria in the absence of oxygen, will produce significant quantities of CH_4. The potential for CH_4 generation from manure depends on its temperature, moisture and the bioavailable carbon content. The bioavailable carbon content is dependent on the type of animal, the nature of its feed and the handling of the wastes. North America liquid-based systems are commonly used for swine and dairy manure. Non-dairy manure is usually managed as a solid and is deposited on pastures or ranges.

The CH_4 emitted from livestock manure was also calculated using IPCC methodology. The IPCC estimates were based on the assumption that Canada is a developed country and in a cool climate region (average temperature <15°C). The emission factors from manure are based on four major factors: the animal type, the manure storage and management system, the climatic region and daily excretions per animal type. The volatile solid content (VS_l) of manure is of the most interest because it is this portion of the manure that contributes to the CH_4 production. IPCC methodology uses a CH_4 conversion factor (MCF) to express the amount of CH_4 that is converted for each manure handling system. Manure handling systems are effected by certain environmental conditions that favour the production of CH_4. 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. Anaerobic conditions are more predominant in sealed liquid handling systems than open liquid manure pits. Generally, the most moist the manure the more CH_4 that is produced. Variations in the manure management practices among regions and countries must be considered to develop emission factors for these animals. Conversion factors are needed to relate the emission factor to read kg CH_4 / head/ year.

Emission = VS x 365 days/yr x B_{oi} ^{3} of CH) x (Σ_{jk} MCF_{jk} x $MS\%_{ijk}$)

where:

VS_I = daily volatile solid excreted (kg) per animal type i.
B_{oi} = maximum manure CH_4 production capacity (m^3 CH_4/ kg VS) by animal type i
MCF_{jk} = CH_4 conversion factors for each manure management system j in climate region k
$MS\%_{ijk}$ = fraction of animal type i, manure, handled using manure system j in climate region k

Methane emissions from animal manure in Canada were calculated using the livestock inventory data from Statistics Canada for 1996 and is shown on a provincial basis in Table 3. The emission factors used to calculate the CH_4 emissions from manure are shown in Table 4. Poultry manure is included here in the inventory for CH_4 emission.

Table 3. Factors used in the calculation of CH_4 emissions from livestock manure

Type of Animal	CH_4 Emission rate (kg CH_4/head/yr)[1]
Dairy Cows	36
Dairy Heifers	36
Bulls	1
Beef Cows	1
Beef Heifers	1
Heifers for Slaughter	1
Steers	1
Calves	1
Boars / Sows	10
Market Pigs	10
Sheep	0.19
Chicken	0.078
Turkey	0.078

1 IPCCb, 1996

Table 4. Methane emissions from various livestock manure in 1996

Provinces	**Dairy Cattle** **CH_4 (Mt)**	**Non-Dairy Cattle** **CH_4 (Mt)**	**Swine** **CH_4 (Mt)**	**Sheep** **CH_4 (Mt)**	**Poultry** **CH_4 (Mt)**	**Total Livestock** **CH_4 (Mt)**
Atl. Prov.	0.003	0.0002	0.003	0.00001	0.0007	0.007
Quebec	0.020	0.0008	0.031	0.00003	0.002	0.054
Ontario	0.020	0.002	0.033	0.00004	0.003	0.057
Manitoba	0.004	0.001	0.018	0.00001	0.0006	0.024
Sask.	0.005	0.002	0.008	0.00002	0.0003	0.016
Alberta	0.015	0.005	0.021	0.00005	0.0008	0.042
B.C.	0.004	0.0007	0.002	0.00001	0.001	0.008
Canada	**0.070**	**0.012**	**0.117**	**0.00016**	**0.009**	**0.208**

Methane from Animal Wastes:
Total Emissions from Manure Management (Mt/yr) = ∑(Population of Livestock X Emission Factor for Manure Management (kg/head/year))

Canadian Methodology vs IPCC Methodology

Environment Canada has estimated CH_4 emissions from Canadian agroecosystems using emission factors derived from an American source (Casada and Safley, 1990b). The emission estimates for manure in the Environment Canada study incorporate factors such as the volatile solids excreted and the CH_4 emitted from these volatile solids. These emission factors are presented in Table 5. Although some of the emission factors vary quite considerably from the IPCC emission factors, the Canadian methodology values of total CH_4 emitted (Table 6) are very similar to IPCC total emission estimates (Table 7).

The Canadian methodology also includes fossil fuel as a minor source of CH_4, whereas the IPCC does not. Since fossil fuels only contribute a small amount of CH_4 to the atmosphere, compared to the other major CH_4 sources, the emissions from fossil fuels does not make a significant difference in the comparison of the two emission totals. Since Canadian methodology numbers are derived from an American study, the estimates for CH_4 emissions from Canadian agroecosystems follow the IPCC approach for a cool climate.

Table 5. Emission factors for various livestock in Canada

Type of Animal	Production of CH_4[1]	Production of volatile solids[1] (kg VS/ yr)	CH_4 emission rate (kg CH_4 / kg VS)[1]
Dairy Cow	105	2260.5	0.019
Dairy Heifer	62	2260.5	0.019
Bulls	92	1103.8	0.011
Beef Cattle	56	1103.8	0.011
Beef Heifer	52	1103.8	0.011
Slaughter Heifer	41	1103.8	0.011
Steer	44	1103.8	0.011
Calf	29	1103.8	0.011
Boar/Sow	3.3	561.5	0.043
Pigs	1.9	140.3	0.044
Sheep	8.4	338.8	0.019
Chicken	0.002	5.6	0.024
Turkey	0.01	22.6	0.019

1 Jaques, 1997

Table 6. Summary of CH_4 from agroecosystems using Canadian Methodology

Source	1981 (Mt CH_4)	1986 (Mt CH_4)	1991 (Mt CH_4)	1996 (Mt CH_4)
Livestock	0.723	0.635	0.651	0.738
Manure management	0.339	0.306	0.313	0.347
Soils	-0.011	-0.012	-0.012	-0.012
Fossil Fuel	0.001	0.001	0.001	0.001
Total (Mt CH_4)	1.052	0.929	0.952	1.074
Total (Mt CO_2 equivalents)	**22**	**20**	**20**	**23**

Table 7. Summary of CH_4 emissions from agroecosystems in Canada using IPCC

Source	**1981** **(Mt CH_4)**	**1986** **(Mt CH_4)**	**1991** **(Mt CH_4)**	**1996** **(Mt CH_4)**
Livestock	0.849	0.748	0.771	0.879
Livestock Manure	0.208	0.192	0.19	0.208
Soils	-12	-12.4	-12.3	-12.0
Fossil Fuel Combustion	0.001	0.001	0.001	0.001
Total (Mt CH_4)	1.045	0.928	0.95	1.075
Total (Mt CO_2 Equivalents)	**22**	**20**	**20**	**23**

Source: Agroecosystem Greenhouse Gas Balance Indicator: Methane Component, Report No. 21, Net Methane Emissions from Agroecosystems in Canada for the Years 1981, 1986, 1991 and 1996. R.L. Desjardins, June 1997.

Appendix 3

Methodology to Calculate Nitrous Oxide Emissions from Agriculture

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 then be subdivided into their main N_2O contributors.

Direct N_2O Emissions from Agricultural Soils

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

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. Fertilizer data by province is not available for 1981.

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 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 emissions of nitric oxide through nitrification after fertilization.

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

Fertilizer Type	%[1]
1. Anhydrous Ammonia	1.6
2. Ammonium Nitrate	0.3
3. Ammonium Sulphate (salts of Ammonium)	0.1
4. Urea	0.3
5. Calcium Nitrate	0.2
6. Phosphate	0.1
7. Potash and other fertilizer	0.1

[1] *Bouwman, 1996.*

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:

$$N_2O_{(fertilizers)} = \Sigma \text{ N Fertilizer Consumption (kg N/yr)} * 0.9 * EF_{(fert.\ type)} * 10^{-6} * 44/28$$

where: $EF_{(fert.\ type)}$ = Emission factor by fertilizer type;
10^{-6} = conversion from kg to Gg;
44/28 = conversion from N_2 to N_2O
$N_2O_{(fertilizers)}$ = Gg N_2O

N_2O Emissions from Animal Wastes (F_{AW})

It is difficult to estimate nitrogen 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, 1996b). The default factor used for nitrogen excretion is based on a study conducted by Midwest Plan Service (Livestock Waste Facilities Handbook, 1993) and the emission factors are based on the IPCC (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 EF[4]**
Dairy	70.5	0.0125	20	0.02
Non-dairy	56.4	0.0125	42	0.02
Swine	15	0.0125	0	0.02
Sheep	6.8	0.0125	44	0.02
Poultry	0.45	0.0125	1	0.02

[1] *Livestock Waste Facilities Handbook, 1993*
[2] *IPCC 1996b; Table 4-18*
[3] *IPCC 1996b; Table 4-7,*
[4] *IPCC 1996b; Table 4-8,*

Based on the livestock population and the nitrogen excretion factors from the Midwest Plan Service (Livestock Waste Facilities Handbook, 1993), N_2O emissions can then be calculated:

Equation 2:

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

Equation 3:

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

Equation 4:

$$N_2O_{\text{(animal wastes)}} = (\text{Total N}_{\text{(NEX)}} - \text{Manure N}_{\text{(during grazing)}})*(1-\text{Frac}_{\text{(GASM)}}) * 0.0125 * 10^{-6} * 44/28$$

where: $\text{Frac}_{\text{(GASM)}}$ = 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, 1996b, Table 4-17);
$N_2O_{\text{(animal wastes)}}$= Gg N_2O

The above data must 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.

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

The N_2O emissions from N-fixing crops are calculated by multiplying the %N in the specific crop by an emission factor to give the amount N_2O emitted. The production of N-fixing crops by province was obtained from Statistics

Canada (1996b). Alfalfa production was calculated from total area sown multiplied by the yield for each year. The emission factor of 1.25% kg N_2O-N/kg N was used to calculate N_2O emissions (IPCC, 1996b).

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 close to 15% for most crops, but varies slightly for different crops.

Equation 5:

$$N_2O_{(\text{N-fixing crops})} = 2 * [\text{Total production}_{(\text{kg dry biomass})} * (\text{N-content/kg of dry biomass})] * 0.0125 * 10^{-6} * 44/28$$

where: N-content/kg of dry biomass = 0.03 kg N/kg dry biomass;
$N_2O_{(\text{N-fixing crops})}$ = Gg N_2O

N_2O Emissions from Crop Residues (F_{CR})

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

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 90% of the crop residues from cereal crops remain on the field.

Equation 6:

$$N_2O_{(\text{crop residues})} = 2*[\text{Total Crop Production} * \text{Frac}_{(NCRO)} + \text{Total Seed Yield}_{(\text{pulses \& soybeans})} * \text{Frac}_{(NCRBF)}] * (1-\text{Frac}_{(R)})* (1-\text{Frac}_{(BURN)}) * 0.0125 * 10^{-6} *44/28$$

where: $\text{Frac}_{(NCRO)}$ = fraction of N in non-N-fixing crops (kg N/kg of dry biomass); Table 3;
$\text{Frac}_{(NCRBF)}$ = fraction of nitrogen in N-fixing crops (kg N/kg of dry biomass); Table 3;
$\text{Frac}_{(R)}$ = fraction of crop residue that is removed from the field as crop (kg N/kg of dry biomass); Table 3;
$\text{Frac}_{(BURN)}$ = fraction of crop residue that is burned rather than left on field; Table 3;
$N_2O_{(\text{crop residues})}$ = Gg N_2O.

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}	0.45 kg N/kg crop-N
Frac_{BURN}	0.0 in developed countries

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

N_2O Emissions from Histosols

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:

$$N_2O_{(histosols)} = \text{Area of cultivated organic soils} * \text{IPCC Def. Factor}_{(temperate\ regions)} * 10^{-6} * 44/28$$

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

Total Direct N_2O Emissions from Agricultural Soils

Equation 8:

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

Direct Emissions of N_2O from Animal Production Systems

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.

N_2O Emissions from Grazing Animals

Estimates of the total nitrogen content in manure from various types of livestock are based on a study conducted by the Midwest Plan Service (Livestock Waste Facilities Handbook, 1993). Their values are considerably lower than those given by the IPCC. Table 2 presents the default factors used in this study.

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

Equation 9:

$$N_2O_{(AWMS)} = [N_{(T=1)} * N_{(NEX=1)} * AWMS_{(T=1)} * EF_{3(AWMS)} + \ldots + (N_{(T=Max)} * N_{(NEX=Max)} * AWMS_{(T=Max)} * EF_{3\,(AWMS)})] * 10^{-6} * 44/28$$

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); (Livestock Waste Facilities Handbook, 1993);(Table 4-6);
$AWMS_{(T)}$=fraction of $N_{(NEX)}$ from pastures and paddocks for animals of type T; (Munroe, J., 1998)
$EF_{3\,(AWMS)}$ = 0.02; Table 2;
$N_2O_{(AWMS)}$ = Gg N_2O.

N_2O Emissions during Manure Storage

The data used to estimate emissions from animal manure was used in the calculation of N_2O emissions from AWMS. The IPCC (1996b), Livestock Waste Facilities Handbook (1993) and (Munroe, 1998) 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, 1996a).

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

Equation 10:

$$N_2O_{(AWMS)} = \Sigma_{(T)} [N_{(T)} * N_{(NEX)} * AWMS_{(T)}] * EF_3 * 10^{-6} * 44/28$$

where: $N_{(T)}$ = no. of animals of type T;
$N_{(NEX)}$ = N excretion of animals of type T (kg N/animal/yr); (Livestock Waste Facilities Handbook, 1993)
$AWMS_{(T)}$ = Fraction of $N_{(NEX)}$ that is managed in different waste systems for animals of type T (Munroe, 1998);

EF_3 = Emission factor (IPCC, 1996b; Table 4-8);

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

Animal	**N content**	**% Manure N produced in**			**Emission Factor EF^3**		
		LS	**SSD**	**OS**	**LS**	**SSD**	**OS**
Dairy	70.5	53	27	0	0.001	0.02	0.005
Non-dairy	56.4	1	56	1	0.001	0.02	0.005
Swine	15	90	10	0	0.001	0.02	0.005
Sheep	6.8	0	46	10	0.001	0.02	0.005
Poultry	0.45	4	0	95	0.001	0.02	0.005

1 Livestock Waste Facilities Handbook, 1993
2 Munroe, 1998
3 IPCC, 1996b; Table 4-8

Indirect Emissions of N_2O from Agricultural Systems

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.

Indirect Emissions from Atmospheric Deposition of NH_3 and NO_x

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 ($N_{(NEX)}$). Manures from grazing animals are not included here, as they have been previously included in their own category. 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, 1996b).

Indirect N_2O Emissions from N Leaching

The following inventory includes data that were used for the estimation of N_2O emissions from N leaching. The total nitrogen excretion from animal manures ($N_{(NEX)}$) includes the manure produced during grazing. The IPCC 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.

Equation 11:

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

where: $Frac_{GASM}$ = fraction of livestock nitrogen excreted that volatizes NH_3 and NO_x (kg NH_3-N and NO_x-N of N excreted) (IPCC, 1996a, Table 4-19)
$Frac_{GASF}$ = fraction of synthetic fertilizer nitrogen applied that volatizes asNH_3 and NO_x (kg NH_3-N and NO_x-N of N excreted (IPCC, 1996a, Table 4-19)
$N_2O_{(G)}$ = N_2O emissions due to atmospheric deposition of NH_3 and NO_x (kg N/yr.);
EF_4 = 0.01 kg N_2O-N/kg NH_3-N & NO_x-N deposited (IPCC, 1996b; Table 4-18);

Equation 12:

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

where: $Frac_{(LEACH)}$ = Fraction of nitrogen input to soils that is lost through leaching and runoff (kg N of N applied) (IPCC,1996b;Table 4-17);
EF_5 = 0.025 kg N_2O -N/kg N from leaching and runoff (IPCC, 1996b; Table 4-18);
$N_2O_{(L)}$ = N_2O emissions due to nitrogen leaching and runoff (kg N/yr);

Equation 13:

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

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

Nitrous Oxide Emissions from Municipal Sewage Treatment

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, 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 (IPCC, 1996b).

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

Equation 14:

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

where: $N_2O_{(S)}$ = N_2O emissions from human sewage (Gg N_2O);
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, 1996b; Table 4-18);
$Frac_{(NPR)}$ =Fraction of nitrogen in protein (default= 0.16 kg N/kg protein) (IPCC, 1996b;Table 4-19).

Estimates of Direct N_2O Emissions from Agricultural Soils

The direct N_2O emissions from the different agricultural sources for 1996 is summarized in Table 5.

Table 5: Magnitude of the sources of the direct N_2O emissions from agricultural soils in 1996

Province	**A** F_{SN} **(Mt N_2O /yr)**	**B** F_{AW} **(Mt N_2O /yr)**	**C** F_{CR} **(Mt N_2O /yr)**	**D** F_{BN} **(Mt N_2O /yr)**	**E** $F_{histosols}$ **(Mt N_2O /yr)**	**F Total Direct Emissions (Mt N_2O/yr)**
Atlantic Prov.	0.0001	0.00033	0.00047	0.0001	0	0.00087
Quebec	0.00034	0.00192	0.00259	0.00076	0.0001	0.00566
Ontario	0.00103	0.00225	0.00562	0.00411	0.0001	0.01307
Manitoba	0.00398	0.00117	0.00374	0.00167	0	0.01056
Sask.	0.00497	0.00158	0.00943	0.00308	-	0.01906
Alberta	0.00486	0.00349	0.00728	0.00276	-	0.01839
B.C.	0.00018	0.00059	0.0007	0.0004	0	0.00188
Canada	0.01544	0.01133	0.02952	0.01306	0.00012	0.06948
%contribution	22%	16%	42%	19%	0.2%	

Estimates of Direct Emissions of N_2O from Animal Production Systems

The summary of the results for direct N_2O emissions from grazing animals is presented in Table 6.

Table 6. Total N_2O emissions from grazing animals by province

	A				B	C			
Province	**N excreted N_{nex} (Mt N)**[1]				**(EF_3)[2] for Grazing**	**N_2O emissions from Grazing Animals (Mt N_2O)** C = (AxB)x(44/28)			
	1981	**1986**	**1991**	**1996**		**1981**	**1986**	**1991**	**1996**
Atlantic	0.01	0	0	0.01	0.02	0	0	0	0
Quebec	0.03	0.03	0.03	0.028	0.02	0	0	0	0
Ontario	0.058	0.05	0.05	0.046	0.02	0	0	0	0
Manito	0.026	0.02	0.02	0.029	0.02	0	0	0	0
Sask.	0.055	0.05	0.05	0.06	0.02	0	0	0	0
Alberta	0.094	0.09	0.106	0.128	0.02	0	0	0	0
B.C.	0.017	0.02	0.02	0.02	0.02	0	0	0	0
Canada	0.2878	0.257	0.278	0.3153	0.02	0	0	0	0

[1] *Statistics Canada*

[2] *IPCC, 1996b, Table 4-8*

Table 7 presents the N_2O emissions from different animal waste management systems (AWMS).

Table 7. Total N_2O emissions from animal waste management systems by province in 1996

Province	**A**				**B**				**C**
	Nitrogen Excretion N_{NEX} (AWMS) (Mt N)[1]				**Emission Factor for AWMS (EF_3)**[2]				**N_2O Emissions (Mt N_2O)**
	AL	**LS**	**SSD**	**OS**	**AL**	**LS**	**SSD**	**OS**	**C= (AxB)x44/28**
Atlantic Prov.	0	0	0	0	0.001	0.001	0.02	0.005	0.00034
Quebec	0	0.07	0.04	0	0.001	0.001	0.02	0.005	0.00153
Ontario	0	0.06	0.07	0	0.001	0.001	0.02	0.005	0.00229
Manitoba	0	0.03	0.04	0	0.001	0.001	0.02	0.005	0.00139
Sask.	0	0.02	0.08	0	0.001	0.001	0.02	0.005	0.00259
Alberta	0	0.04	0.173	0	0.001	0.001	0.02	0.005	0.00556
B.C.	0	0	0.03	0	0.001	0.001	0.02	0.005	0.00089
Canada	0	0.231	0.436	0.1	0.001	0.001	0.02	0.005	0.01449

1 Statistics Canada, 1997

2 IPCC, 1996b, Table 4-8

Estimates of Indirect Emissions of N_2O from Agricultural Systems

Table 8 indicates the indirect N_2O emissions from atmospheric deposition of NH_3 and NO_x for 1996.

Table 8. Indirect N_2O emissions from atmospheric deposition of NH_3 and NO_x

	N_2O Emissions (Mt N_2O)			
Province	**1981**	**1986**	**1991**	**1996**
Atlantic Prov.	0.00007*	0.00007	0.00007	0.00007
Quebec	0.00044*	0.00053	0.00052	0.00052
Ontario	0.00055*	0.00084	0.00074	0.00072
Manitoba	0.00018*	0.00055	0.0006	0.00072
Sask.	0.00029*	0.00074	0.00066	0.00113
Alberta	0.00050*	0.00096	0.0011	0.00137
B.C.	0.00012*	0.00015	0.00015	0.00017
Canada	0.00356	0.00385	0.00387	0.00474

* Emissions based only on animal manure contributions

Table 9 summarizes the N_2O emissions from N leaching and runoff.

Table 9. Indirect N_2O emissions from N leaching

	N_2O Emissions (Mt N_2O)			
Province	**1981**	**1986**	**1991**	**1996**
Atlantic Prov.	0.00036*	0.00036	0.00061	0.00064
Quebec	0.00200*	0.00284	0.0028	0.00281
Ontario	0.00275*	0.00501	0.00435	0.00428
Manitoba	0.00097*	0.00374	0.00405	0.0049
Sask.	0.00172*	0.00521	0.00455	0.00799
Alberta	0.00299*	0.00644	0.00737	0.0092
B.C.	0.00064*	0.00096	0.00089	0.00096
Canada	0.02205	0.02455	0.02463	0.03079

* Emissions based only on animal manure contributions

Table 10 shows the N_2O contribution from human sewage.

Table 10. N_2O emissions from human sewage by province

Province	**Total Population[1] (millions)**				**Total N_2O emissions (Mt N_2O)**			
	1981	**1986**	**1991**	**1996**	**1981**	**1986**	**1991**	**1996**
Atlantic Prov.	2.23	2.28	2.32	2.33	0	0	0	0
Quebec	6.44	6.53	6.90	7.14	0	0	0	0
Ontario	8.63	9.10	10.09	10.76	0	0	0	0
Manitoba	1.03	1.06	1.09	1.11	0	0	0	0
Sask.	0.97	1.01	0.99	0.99	0	0	0	0
Alberta	2.24	2.37	2.55	2.70	0	0	0	0
B.C.	2.74	3.28	3.28	3.72	0	0	0	0
Canada	24.34	25.31	27.30	28.85	0	0	0	0

[1] *Statistics Canada, Cat. No. 93-304*

Estimates of Total N_2O Emission from Agriculture

The estimated total N_2O emissions for 1996 is summarized in Table 11.

Table 11. Total N_2O emissions from agricultural sources by province in 1996

	A	B	C	D
Province	**Direct Emissions From soils (Mt N_2O)**	**Direct Emissions from Grazing Animals & AWMS (Mt N_2O)**	**Indirect Emissions NH_3 & NO_x; Leaching; Human sewage (Mt N_2O)**	**Total N_2O Emissions (Mt N_2O) D = A+B+C**
Atlantic Prov.	0.00087	0.00055	0.00092	0.00234
Quebec	0.00566	0.0024	0.004	0.01206
Ontario	0.01307	0.00374	0.00602	0.02283
Manitoba	0.01056	0.00231	0.00573	0.0186
Sask.	0.01906	0.00448	0.00922	0.03275
Alberta	0.01839	0.00958	0.01083	0.0388
B.C.	0.00188	0.00151	0.00147	0.00469
Canada	0.06948	0.0244	0.03824	0.13212
% contribution	53%	18%	29%	

Source: Agroecosystem Greenhouse Gas Balance Indicator: Nitrous Oxide Component. Report No. 20. Estimates of Nitrous Oxide Emissions from Agroecosystems in Canada for the Years 1981, 1986, 1991, and 1996, Using the Revised 1996 IPCC/OECD Methodology. C.A. Monteverde, R.L. Desjardins and E.Pattey. 1997.