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Development of a Farm-Level Greenhouse Gas Assessment:

Identification of Knowledge Gaps and Development of a Science Plan

Alberta Agriculture, Food and Rural Development
University of Alberta

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Abstract

An Alberta-wide greenhouse gas (GHG) forum was held in March 2000, during which consensus was reached by representatives of the agriculture industry, the scientific community, and government that comprehensive on-farm GHG emission assessments were necessary if agricultural producers and processors were to reduce their GHG emissions – they have to know where and how much GHG they are emitting before they can reduce them. Before the possibility of on-farm GHG assessments can be conducted, a review of the scientific literature is required. In 2001, an in depth review of the scientific literature was initiated to gather, evaluate and synthesize agricultural GHG research for the Prairie region. The first chapter of the report summarizes the state of knowledge of agricultural GHG research and identifies preliminary gaps in our knowledge. This chapter was peer reviewed by scientific experts across Canada who were brought together in a workshop format to discuss their findings. The workshop participants prioritized the gaps with respect to urgency and impact. The identification of knowledge gaps helped lay the foundation for the Agricultural GHG Science Plan (chapter 3), which prioritized research in the areas of soils and crops, livestock, land use and energy and whole farm systems. In addition, an Alberta-based Agricultural GHG Inventory was updated (chapter 2) for 2001. All three sections of this report clearly identify agricultural GHG research gaps and recommend there is currently not enough information available to produce on-farm assessments that will accurately reflect the GHG emissions of a typical farm within a reasonable range of error.

Implications to Alberta's Agriculture and Food Industry and/or Advancement of Agricultural Knowledge

Reduction of GHG emissions at the farm-level can be better managed if we have a clear understanding of where sources of GHG come from. This project:

- Developed a State of Knowledge report that will aid the research community in understanding what the current state of knowledge is and what additional research needs to be done.
- Developed a science plan that will contribute to efficient funding of GHG projects by preventing the duplication of projects and ensure high quality and relevant agriculture research with maximum benefit to the agriculture industry.
- Provided the initial groundwork for a farm-level GHG assessment, which allows producers to identify future changes they can make to reduce GHG emissions and provide producers a better idea of what their GHG management options are.

Chapter 1:
Agricultural Greenhouse Gas Assessment
State of Knowledge

Executive Summary

In 1997, Canadian delegates to 'The Third Conference of the Parties to the United Nations Framework Convention on Climate Change' signed the Kyoto Protocol. Ratification by the government followed in December 2002. This agreement commits the nation to reduce its greenhouse gas (GHG) emissions by 6% below 1990 levels between the period of 2008 to 2012. This means that Canada is committed to limiting its GHG emissions to approximately 565 Mt (megatonnes) of carbon dioxide equivalents (CO_2-E) annually. If no attempts are made to reduce GHG emissions, Canada's Kyoto gap will be more than the 245 Mt CO_2-E currently needed to reach it's Kyoto target.

The main GHG emissions from agriculture are nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). Globally, agriculture is responsible for 25% of total GHG emissions. Within Canada, GHG emissions from crops, pasture and livestock production account for 9% of the nation's emissions; farm fuel and agri-food processing emissions account for another 3%. Of that 12%, Alberta's agriculture industry contributes 30%. It is expected that agriculture industries in all provinces may be required to contribute to Canada's GHG reduction strategy.

An Alberta-wide GHG forum was held in March 2000, during which consensus was reached by representatives of the agriculture industry, the scientific community, and government that comprehensive on-farm GHG emission assessments were necessary if agricultural producers and processors were to reduce their GHG emissions – they have to know where and how much GHG they are emitting before they can reduce them. Before the possibility of an on-farm GHG assessment can be conducted, a review of the scientific literature is required, followed by evaluation and synthesis of information. The purpose of this report is to:

- Gather, evaluate and synthesize emission estimates for various farm-level GHG sources and sinks related to different management practices, soil types and livestock scenarios.
- Identify gaps in our knowledge of agriculture GHG emissions through a comprehensive, updated review of GHG research data, supplemented with expert opinion and information from other sources.
- Report back to the agriculture industry on the feasibility of farm-level GHG assessments and demonstration farms.

An extensive literature search encompassing books, trade journals, periodicals, national GHG inventories (government documents), and conference proceedings on agricultural GHG research was completed in January 2002. A PROCITE® bibliographic database was created to organize and identify the relevant literature. The main categories of research include soil and crop management, livestock management, land use and energy management and whole farm systems. A list of established facts and knowledge gaps is summarized below for each of the main categories found in the literature.

Soil and Crop Management

Summary of What We Know About Greenhouse Gas Mitigation Practices for Soil and Crop Management:

- Soils will sequester carbon if net primary production exceeds soil respiration.
- Summer fallow will increase net mineralization of carbon and nitrogen from soil organic matter, which decreases carbon sequestration. Therefore a reduction in the use of summer fallow in rotation increases carbon sequestration.
- Cropping rotations longer than two years without summer fallow and incorporation of forages tend to sequester carbon because the soil organic matter dynamics become more like those under perennial grass, native untouched fields and other forage pastures.
- Converting annual cropland to perennial forage decreases net GHG emissions by sequestering more carbon.
- Perennial grasses sequester more carbon than annual crops because of their fibrous root system. Perennial grasses store more soil carbon than perennial legumes.
- Fertilizer nitrogen is a source of N_2O. Changing the form, placement and timing of application can mitigate N_2O emissions. The closer fertilization is to crop uptake, the less N_2O is emitted. Nitrogen application rates based on soil nitrogen testing and crop requirement reduce N_2O emissions and increase carbon sequestration.
- Tillage enhances carbon and nitrogen mineralization because it allows soil microbes greater access to soil organic matter and introduces oxygen into the soil pores. Reduced or zero tillage increases carbon sequestration because carbon mineralization is minimized.

- Agricultural residues add carbon and nitrogen to the soil in addition to keeping the soil cooler by providing insulation.
- Manure is high in organic matter and soluble nutrients and in its raw form has a high water content. Liquid manure systems produce higher N_2O and CH_4 emissions when broadcast on land in contrast to solid and/or composted manure. Composted and digested manure contain stable forms of carbon and nitrogen, have low moisture contents and release nutrients at a slower rate than raw manure.
- Nitrogen fixation may produce N_2O emissions because fixed ammonium may nitrify and subsequently denitrify.
- Overgrazing exposes soil, creating conditions similar to fallow, therefore increasing soil carbon mineralization.
- Managed pasture (rotational grazing, fertility management, stocking rates, residual bio-mass) results in lower total net GHG emissions than unmanaged pasture.
- Laboratory incubations are still being used to estimate GHG emissions. Infrared gas analysis is being used for field measurements but most of these have been made on small field plots. Emission factors developed by the IPCC are being validated by comparison with direct field measurements.
- Soils are heterogeneous in microenvironment and microclimate. This results in temporal and spatial variation, which may produce a large degree of error when calculating net GHG emissions for a specific scenario.

Research gaps

Identifying the Research Gaps for Soils and Crop Management:

1) The majority of agricultural GHG research focused on annually cropped land but more rangeland and pasture GHG research is needed. Very few emission factors have been calculated for perennial cropping systems.

2) Greenhouse gas emissions from individual management practices and inherent soil processes have been measured in several studies. Greenhouse gas emissions from crop rotation, nitrogen fixation, irrigation, agricultural residues, freeze-thaw cycles, grazing and pasture fertilization in the Brown Chernozem and Gray Luvisol soils are needed. In particular, the interactions between these management practices and GHG emissions have not been explored.

3) Greenhouse gas emissions observed in laboratory and microplot-level experiments are well understood but farm-level observations are not. Caution needs to be applied when results that are well understood for one management practice are applied to other environmental conditions or spatial settings.

4) More basic research on the production and consumption of N_2O as well as the process of denitrification is needed. More specifically factors controlling the N_2O/ N_2 ratio in different spatial and temporal situations in addition to research on the amount of N_2O evolved from denitrification.

5) More carbon is sequestered in reduced- no-till soils than in conventionally tilled soils. However, more research is needed to quantifying if more N_2O is emitted from reduced- no-till soils than conventionally tilled soils before a net GHG balance could be determined.

6) Full-cycle accounting should be used to determine if irrigated crops emit more or less GHG than non-irrigated crops of equal management, farm type and climate.

7) It is not certain if surface applied manure results in higher GHG emissions compared to incorporated manure. More research is required to establish GHG emission coefficients for specific rates, time of year, and placement.

8) Research to fully understand how temporal and spatial variation influences the error associated with calculations required to scale up emission models to the whole farm level and place that error in context.

9) An accurate methodology needs to be developed to measure GHG emissions. This includes protocol to document and reduce the level of error associated with scaling up from micro plot to field scale.

10) More research with respect to methane consumption and production in agricultural landscapes is needed.

11) Research on the effects of management practices on the permanence of sequestered carbon.

Livestock Management

Summary of What We Know About Greenhouse Gas Mitigation Practices for Livestock Management:

- Methane emissions are influenced by species, animal type within species, weight, composition of diet, location, time of year, days on feed, productivity level and age.
- Beef cows emit more CH_4 than beef calves.
- Dairy cattle emit more CH_4 than beef cattle because they are managed for high production.
- Management for increased production efficiency reduces GHG production per unit production.
- Feed testing and ration balancing leads to reduced GHG emissions in livestock production systems.
- Cattle on forage-based diets produce more CH_4 than cattle on grain-based diets. Feeding higher-quality forages reduces CH_4 production from cattle.
- Formulated diets for reduced protein, maintaining the amino acid balance, will reduce manure N_2O emissions.
- Feedlot production is energy intensive because large cattle populations are housed and fed high energy diets including grains and grasses (Maynard, 1991; King et al., 2000).
- Researchers are currently designing integrated models that take into account the energy inputs by production system. This research assumes that livestock production is energy intensive because animal growth depends on diet.

Research gaps

Identifying the Research Gaps for Livestock Management:

1) The research is not conclusive whether genetic selection for feed efficiency reduces CH_4 emissions. Long-term research is necessary to determine the implication of genetic selection on livestock management practices.

2) Ionophores reduce CH_4 emissions for both beef and dairy cattle. However, this additive is known to be effective in the short-term (2-4 weeks). Methanogens in the rumen will likely develop immunity to ionophores after that time range. Long-term studies that include feeding various ionophores on a rotating basis are required.

3) It is not fully understood if enzymes given in mono-gastric rations can reduce manure output thereby reducing GHG emissions.

4) More research is required regarding feed supplementation, such as the introduction of lipids in ruminant diets to reduce CH_4 emissions.

5) Research is needed on GHG emission measurements from various cattle feeding production systems (e.g. does a dry lot cattle operation produce higher net GHG emissions compared to pasture-fed cattle?).

6) The suite of GHG emissions from specific practices within a management system is not complete. It is uncertain if one type of livestock feeding practice is better than others commonly used within that system (e.g. in a pasture-cattle system does a continuous grazing system emit more GHG than a rotational grazing system).

7) There is no scientific research that takes into account the GHG emissions from farm energy inputs for growing food for livestock and the growth and slaughter of livestock.

8) Manure excretion, handling, storage and application are common practices but few formal studies have been conducted in Alberta to measure GHG emitted from excretion to application.

Land Use and Energy Management

Summary of What We Know About Greenhouse Gas Mitigation Practices for Land Use and Energy Management:

- Manure is a source of GHGs—primarily CH_4 and N_2O. It is not recommended that raw manure be applied on soil without incorporation.
- Composting produces a product more concentrated in carbon and nitrogen per unit volume than raw manure but the process itself (depending on whether it is passive or active) produces GHGs.
- Applying composted manure to land emits less GHG than applying untreated manure
- Biofuels, such as ethanol and biodiesel, have potential as alternatives to conventional fuels.
- Woodlots and agroforestry are potential GHG sinks

Research gaps

Identifying the Research Gaps for Land Use and Energy Management:

1) Composting and anaerobic digestion research needs to be conducted in colder climates such as Northern Alberta.
2) More research measuring net GHG emissions from different types of manure, manure storage methods, different manure treatments, and different methods of application is needed.
3) Research measuring net GHG emissions from composting is needed. This should include different types of composting treatments (e.g. passive vs active) and different types of compost starting material (straw, wood, manure).
4) More research is needed to understand the stability of carbon and nitrogen in composted and anaerobically digested manure, especially for long-term applications.
5) More research to quantify GHG emission/sequestration from placing manure on direct seeded and pasture systems is needed.
6) More research is needed regarding the feasibility of on-farm energy production (e.g. solar, wind, biofuels).
7) Research measuring net GHG emissions from producing and burning biofuel as well as the reduction in GHG emissions from energy-efficient infrastructure (buildings, harvesting machinery, transportation) is needed.
8) Research on carbon sequestration in woodlots, including consideration for soil carbon and wood products is needed.
9) Research on shelterbelts and woodlots emphasizing interactions with surrounding land (e.g. Snow trapping leading to increase in spring GHG? Moisture/carbon competition with crops? What is net GHG balance?).
10) An accurate and comprehensive inventory of wetlands, streams, and riparian areas must be conducted. The proportion of wetlands, streams, and associated riparian areas on farms or directly impacted by farms must be determined.
11) More research is needed on the change of carbon stocks (including GHG emissions and sinks) resulting from wetland destruction and restoration. Research is needed on the change of carbon stocks in existing wetlands (GHG emissions and sinks) as a result of management practices on surrounding uplands.

Whole Farm Systems

Summary of What We Know About Greenhouse Gas Mitigation Practices for Whole Farm Systems:

- There are models available to estimate GHG emissions from different sections of the farm.
- Greenhouse gas estimates for the whole farm system will need to be calculated using models.
- The metabolic energy model is a comprehensive model that estimates of CH_4 emissions.

Research gaps

Identifying the Research Gaps for the Whole Farm System:

1) Development of a comprehensive model to deal with the whole farm system is needed. Integration of livestock estimates with soil and land-based models to account for removal of carbon (feeding of grain and forage) and input of manure (storage, treatment, and application) are needed. Livestock models are beginning to incorporate the animal-land interface in livestock GHG estimates but are still in the early stages. A partnership of both categories of models would benefit the whole farm scenario.

2) Modeling needs to include wetlands, riparian areas, woodlots, agroforestry and biofuels (including manure management). The input of this data may be limited because of the lack of GHG related research on these areas.

3) Validation of models is required using measured data that takes into account all temporal and spatial situations. The measurements should be repeatable within reasonable ranges.

4) Linkages between GHG audits to the environmental farm plan, agronomic software, commercial/farm data management software should be explored

5) A comparison study is needed to document the applicability of Statistics Canada Data and other existing databases to capture information on agricultural activities. In addition the Environment Canada National GHG inventory values should be compared to the GHG on-farm audits conducted in Alberta.

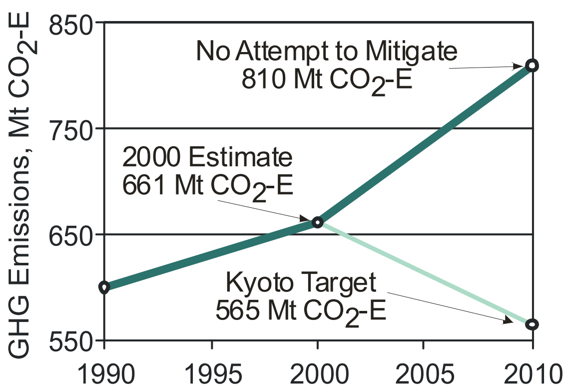
5) Development of databases that contain land management data such as land management change data is needed for more comprehensive modeling to be successful.

There has been significant advancement in the state of GHG research in the areas of soil and crop management, and livestock management. Land use and energy management and whole farm systems have large areas that have not been researched fully. Continuing progress on GHG emission measurements, modeling and experiments that integrate all components of the farm is needed. This report met the objective to gather, evaluate and synthesize current literature on agriculture GHG research for different soil and livestock management practices. Through the identification of knowledge gaps, there is currently not enough information available to produce an assessment that will accurately reflect the actual conditions of a typical farm within a reasonable range of error.

Introduction

In 1997, Canadian delegates to 'The Third Conference of the Parties to the United Nations Framework Convention on Climate Change' signed the Kyoto Protocol. Ratification by the government followed in December 2002. This agreement commits Canada to a 6% reduction in its greenhouse gas (GHG) emissions by the period between 2008 and 2012 (Nietzert et al., 1999). The Canada Kyoto target is approximately 565 MT (megatonnes) of carbon dioxide equivalents (CO_2-E) annually (Hyndman, 2002) if no further attempt to reduce GHG emissions is made (Figure 1).

Figure 1. Canadian GHG emission trends and Kyoto Protocol target, including forecasted emissions to the year 2012. Source: Natural Resources Canada Emissions Update 2000.



The main GHG emissions from agriculture are nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). Globally, agriculture is responsible for 25% of total GHG emissions. Within Canada, GHG emissions from crops, pasture and livestock production account for 9% of the nation's emissions; farm fuel and agri-food processing emissions account for another 3%. Of that 12%, Alberta's agriculture industry contributes 30%. It is expected that agriculture industries in all provinces may be required to contribute to Canada's GHG reduction strategy.

Agricultural emission sources are non-point and diffuse in nature. They are poorly understood in their magnitude and geographic distribution and quantifying these net emissions represents a major undertaking. Techniques for quantifying GHG sources and sinks at different landscape scales need to be developed to define the potential role of agriculture in meeting Canada's Kyoto target.

On a smaller scale, research suggests that management practices aimed at environmental sustainability in agriculture are either the same as, or similar to, those required to reduce agricultural GHG emissions (Janzen, 1999). Some agricultural practices that contribute to GHG emissions include:

- conventional tillage;
- nitrogen fertilization;
- land application of raw solid and liquid manure spreading;

- summer fallowing;
- certain crop rotation combinations, and;
- conventional animal feeding practices.

Recycling of certain farm by-products for energy production could offset some agricultural GHG emissions, including the use of:

- plant lipids for biodiesel;
- agricultural residues and lower grade grain for bioethanol;
- wood for heating, and;
- anaerobic digestion of manure for CH4/biogas.

A common interest in GHGs and environmentally sustainable agriculture was the theme behind an Alberta-wide GHG forum held in March 2000 (AESA Council, 2000). During the meeting, consensus was reached by representatives from the agriculture industry, the scientific community, and government that comprehensive on-farm GHG emission assessments were necessary. It was also agreed that such assessments would require knowledge of all biological, physical and chemical processes that contribute to agricultural GHG emissions.

In early 2001, an initial review of all recently completed and ongoing agricultural GHG-related research was compiled in order to document the current state of knowledge. At that time there were 100 research projects in progress within Canada; 40 of those were in Alberta (Chetner and Sauvé, 2001). The preliminary review was a first step in determining whether sufficient knowledge was available to develop an individual on-farm GHG assessment method.

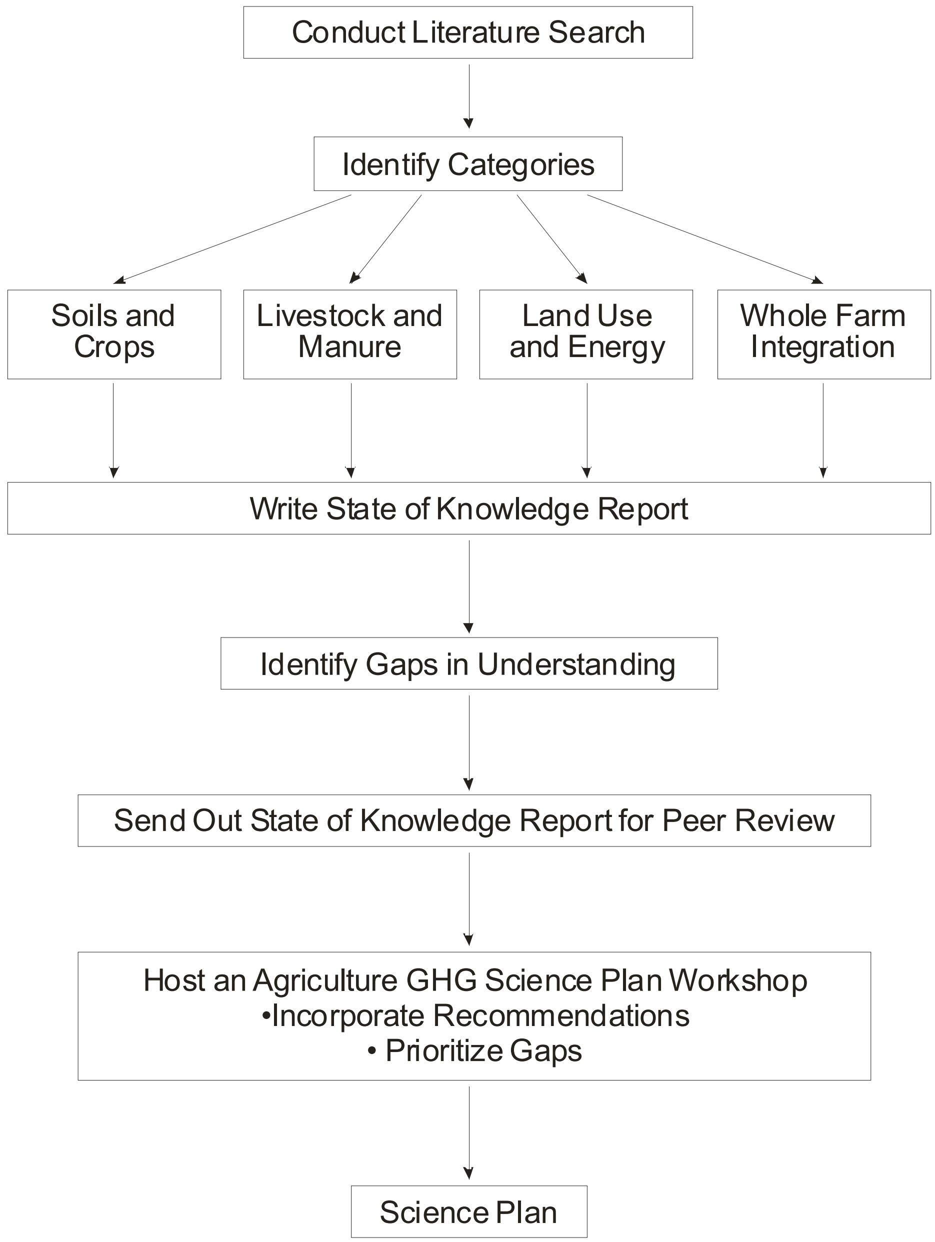
The objectives for this section of the project are:

- Gather, evaluate and synthesize emission estimates for various farm-level GHG sources and sinks related to different management practices, soil types and livestock scenarios.
- Identify gaps in our knowledge of agriculture GHG emissions through a comprehensive, updated review of GHG research data, supplemented with expert opinion and information from other sources.
- Report back to the agriculture industry on the feasibility of farm-level GHG assessments and demonstration farms.

Methods

The process used to write the 'State of Knowledge' report is illustrated in Figure 2.

Figure 2. Systematic approach to developing a GHG Science Plan for Agriculture.



Literature Search

An extensive, worldwide literature search was completed in January 2002. Sources included books, periodicals, national GHG inventories (government documents) and conferences on agricultural GHGs. The review concentrated on baseline and benchmark laboratory studies as well as pilot and field scale research dealing with GHG monitoring, assessment, and mitigation. Although some articles dated prior to 1990 were included, priority was given to research studies conducted in the Canadian Prairie Provinces (mostly Alberta) and published since 1990. A PROCITE® bibliographic database was created to organize the relevant literature.

Identification of Categories

The literature was separated into four primary categories: (1) livestock, (2) crops, (3) farm by-products and; (4) other. The livestock category was further separated by type of livestock, breed, age, gender and feeding system. The crop category was subdivided into specific management practices such as tillage, type of fertilizer, crop rotation, crop type (species and type), and use of amendments (manure, straw and agricultural residues). Other criteria in the crop category distinguished between soil type, climatic factors (temperature and moisture), and land use (pasture versus cultivation). The farm by-products category was separated into manure and biofuels, including the source of the biofuel (e.g., corn, rye, wheat, canola). The 'other' category included woodlots, riparian areas, wetlands and agroforestry areas. These areas constitute a small portion of the average farm and little is known about them in the agricultural GHG context.

Within each category, demographics, specific themes, and research direction were identified and classified. This classification provided insight into the location of information gaps, the accuracy of the scientific information and the feasibility of conducting on-farm audits based on current information.

General search and subject criteria were developed to evaluate and rank the literature in terms of its relevance to the project. The criteria included:

- Type of greenhouse gas (N_2O, CO_2, CH_4);
- Chronology (post-1990);
- Geography (Worldwide search-ranked in relevance to Canadian Prairies, in particular Alberta);
- Credibility (government records and data published by credible research institutes);
- Emissions quantification and GHG emission factors;
- The number of citations on each subject.

Five levels of relevance were applied: high (most relevant), high-medium, medium, medium-low and low (least relevant). Within these general criteria, additional standards were applied to rank the relevance of each citation, including:

- whether the citation provided an emission factor;
- the methods used for measuring or calculating the emissions factor;
- the conditions and assumptions under which the emissions factor was measured or calculated;
- the rationale describing the process behind the GHG emission (if it was new information);
- the accuracy of the emission factor (variability and confidence level), and;
- the mitigation strategies used (tried and tested versus newer strategies).

A research team of experts in the disciplines of Agrometeorology, Agronomy, Soil Science, Livestock Science, and Agricultural Policy worked together to implement the initial and ongoing aspects of the project. Members of the team exchanged information on a regular basis to refine search strategies and selection criteria, improve understanding of the material, and provide overall direction.

For a more detailed report on the construction and management of the database see appendix A.

Agriculture GHG Science Plan Workshop

Once the State of Knowledge Report was written, it was peer reviewed by scientific experts across Canada. A workshop was held in Canmore, Alberta on June 5 and 6, 2003 that gathered the experts together along with other invited guests to identify and prioritize the gaps in our knowledge. The recommendations from this workshop were incorporated into this document.

Results

Citation Statistics

Priority and general statistics

Twenty six hundred (2600) citations were reviewed and ranked according to the search and subject criteria described earlier. Approximately half (1274 of 2600) of the research and policy citations were ranked high to high-medium (Figure 3). The remainder was ranked medium or lower because they were published before 1990, they did not have a GHG context, they were non-agricultural, or they focused on policy rather than science. A few citations included national GHG inventories but were classified as medium because they were not specific to the Canadian prairies. Furthermore, some management practices, soil types and livestock species were not applicable to farming on the prairies.

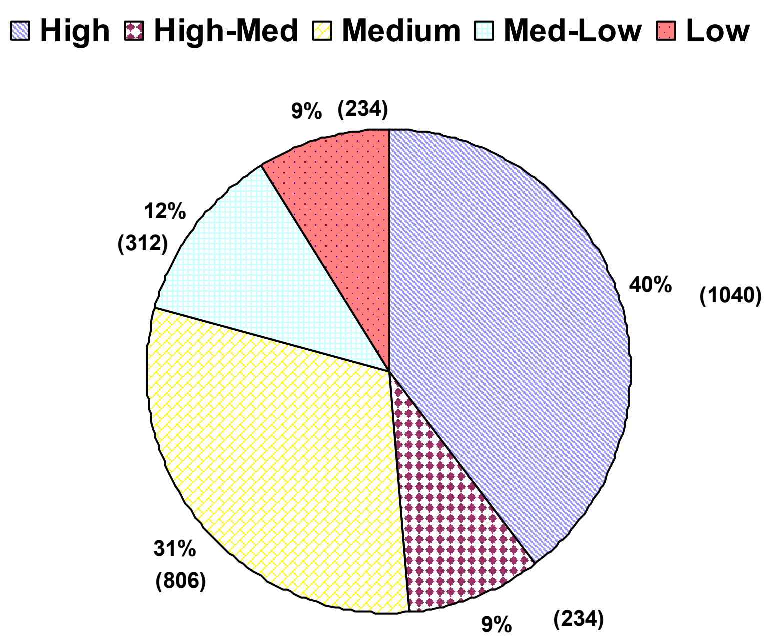


Figure 3. Ranking of 2600 evaluated scientific research and policy citations.

Time of publication and subject

The number of relevant scientific citations was reduced to 1820 by eliminating 780 of the 2600 that had a pure policy focus. Tables 1 and 2 summarize numbers of citations by year of publication, subject category and greenhouse gases examined.

Table 1. Greenhouse Gas Citations separated by time and subject.

Subject/Interval	1980-1989	1990-1995	1995-1998	1998-2002
Soil Crop	77	347	385	455
Livestock	42	97	113	135
Farm fuel/by products	14	73	90	149
Other	32	79	38	66
Policy	5	74	111	136
Total	170	670	737	941

Table 2. Scientific citations separated by subject and GHG.

Subject/GHG	CO_2	N_2O	CH_4
Soil/Crop	65%	30%	5%
Livestock	5%	0%	95%
Farm Fuel/by-products	30%	28%	42%
Other	20%	35%	45%
Total	44%	25%	31%

Of the 1820 scientific research-based citations, 364 (20%) described laboratory tests, 910 (50%) described microplot or individual animal studies, 455 (25%) described pilot scale research, and 91 (5%) described commercial scale research. Most microplot-level research does not take into account landscape induced variability. Three citations mention scaling up microplot results to larger land areas such as ecodistricts. Only 20 described studies lasting longer than 20 years.

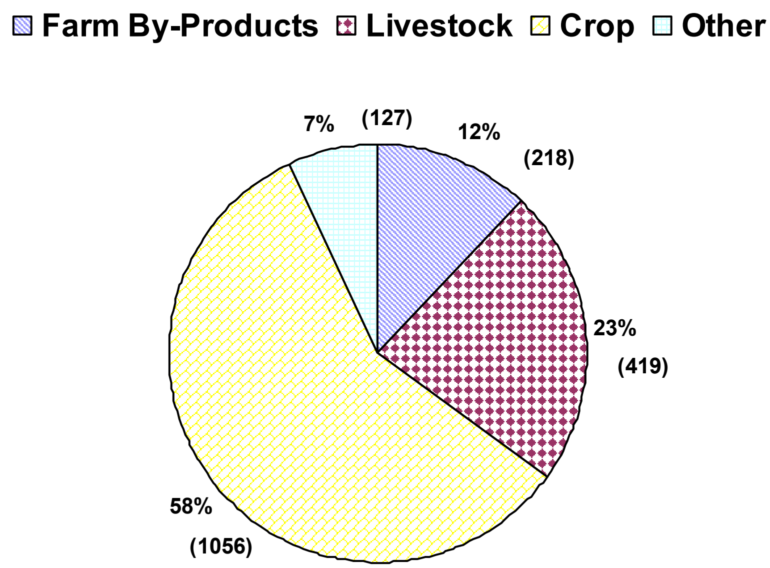
Geographic and research level categories

Research completed prior to 1990 accounts for approximately 260 (10%) of all citations in the bibliographic database. This 'classical' research includes observations, which may be used indirectly or as the basis of scientific principles in the current understanding of agricultural GHG emissions.

Overall, 286 of 1820 (11%) citations came from Alberta and the Prairie Provinces; 832 of 1820 (32%) came from Canada, including Alberta and the Prairies. Citations from the United States, Northern Europe and Australia provide measurement techniques, models and scaling up procedures that are of importance to Canada and the Prairies.

Primary subject categories are represented as follows: 1056 (58%) of 1820 citations address cultivated and rangeland soils; 418 of 1820 (23%) are on livestock management; 218 of 1820 (12%) are on farm fuels, farm by-products and biofuels; and 127 of 1820 (7%) deal with riparian areas, wetlands, woodlots and agro-forestry (Figure 4).

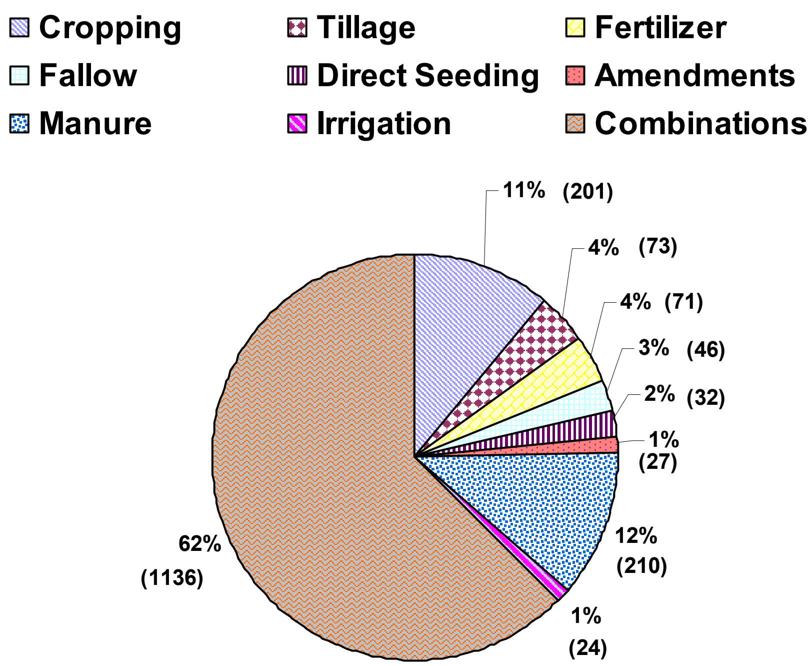
Figure 4. Proportion of scientific research citations by subject category.



Crops (soils and management practices)

The majority of the Alberta and Prairie agricultural GHG citations focus on cropping soils in the Dark Brown Chernozemic, Black Chernozemic and Gray Luvisol groups with three studies on Solonetzic soils. There are 12 citations dealing with studies on the Brown Chernozemic soil group (Lethbridge, Swift Current, Medicine Hat). Twenty-five citations make comparisons between the Dark Brown Chernozemic, Black Chernozemic and Gray Luvisolic soils with respect to soil carbon and soil nitrogen sequestration. Of all 1820 scientific research citations, less than half were on one management practice (Figure 5). More than 60% of the research represented more than one management practice combination.

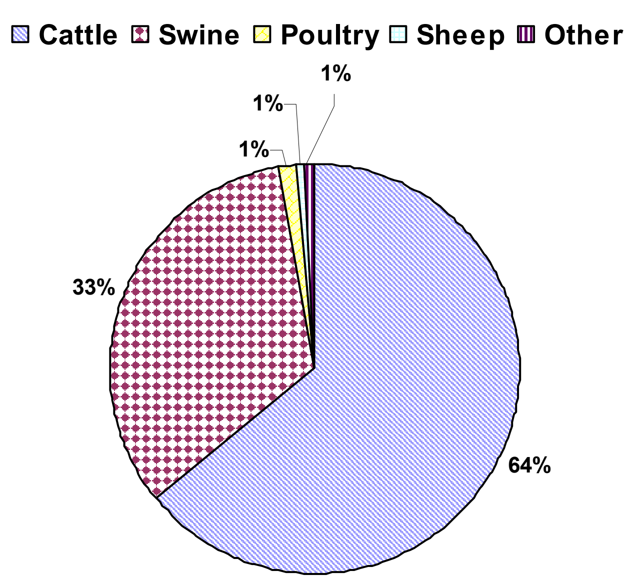
Figure 5. Crops and soils research categorized according to various management practices.



Livestock management

Approximately 419 of 1820 (23%) citations are on livestock management. Some 268 livestock citations focus on cattle (dairy and beef); 138 on swine; 6 on poultry; 3 on sheep; and 3 on bison, deer, caribou, emu, goats or horses (Figure 6). Within Canada, 234 citations focus on beef and dairy cattle and 91 on swine. The cattle research focuses on the physiology of the rumen to better understand the metabolic pathways of CH_4 production. Results have been used to devise mitigation measures appropriate to specific livestock types, breeds, ages, genders and feeding practices.

Figure 6. Livestock management research categorized by species.



Research on GHG emissions from swine operations has focused on manure application and storage. Because swine manure is liquid (does not normally include bedding) more CH4 and N2O is produced when it is stored and applied. Research citations on manure were categorized as by-products of production (rather than soil or livestock).

Of the 419 livestock citations, 13 dealt with abattoirs. Most of this research was on anaerobic digestion of abattoir/rendering wastewater.

Farm fuel and by-products

GHG research on farm by-products made up 218 (12%) of the 1820 scientific citations. Approximately 142 citations focused on manure treatments such as composting, anaerobic digestion, or storage of manure before land application. There were three international papers on GHGs emitted by burning manure as a source of fuel. Citations on farm-based biofuels include research on the use of anaerobic digestion to produce CH_4 from manure and non-manure substrates and on biodiesel, wood, and agricultural residue fuel pellets. Some of the research on transport of goods may be included in the farm fuels/by-products category. There are 60 citations on farm fuels that provide inventory emissions of off-site transport of goods and alternative fuel sources for transport. In the farm fuel category, 20 citations include research on alternative energy for heating and electricity. Another 20 citations provide public information on alternative energy.

A patent database was searched to identify new technologies for reduction of agricultural GHG emissions. Approximately 400 patent citations were identified. However, fewer than 10 patents were relevant. These provide technical information on non-manure anaerobic digestion, biodiesel, and bioethanol technology, which although not currently used in Canada, may have future potential for mitigation purposes.

Soil Carbon, Nitrogen Phosphorus and Sulphur

Soil organic carbon (SOC) represents the main terrestrial carbon reservoir and plays a major role both in global carbon cycling (Ellert and Bettany, 1995) and determining soil quality. In their native state, prairie grasslands are stable ecosystems, where carbon inputs balance carbon outputs and soils are neither a net source nor sink of atmospheric carbon (steady-state conditions). Cultivation management practices such as tillage, fallowing and removal of plant residues disrupt this balance. Historically, this resulted in decreases of up to 15 to 35% of pre-settlement soil organic carbon levels (McGill et al., 1988). Recent evidence suggests prairie soils are no longer a net source of CO_2 and have the capacity to act as substantial sinks for atmospheric carbon under certain management practices. These include typical soil conserving practices like reduced tillage, improved fertilizer and residue use and extended crop rotations, particularly with legumes and forage (Janzen et al. 1999). Over 80% of Canada's cropland resides in the Prairie Provinces (an estimated 20 million hectares), therefore significant carbon storage and mitigation of GHGs is possible through enhancing agricultural sinks.

The impact of soil organic matter management has been researched extensively because organic matter is the primary reservoir of nitrogen, phosphorus, sulphur and other essential nutrients. The extent to which these management practices can increase soil organic carbon depends on:

- initial SOC content;
- the balance between carbon inputs and outputs under the new management, and;
- duration of the management practice before SOC increases begin to decline.

Soils initially low in SOC tend to show much greater gains in SOC compared to soils initially high in carbon. Preliminary evidence suggests that under improved management, Dark Brown soils can increase SOC by as much as 8 to 10 tonnes per ha over the next two decades (Bremer et al, 2002). Similar carbon storage opportunities exist for the Thin Black and Gray Luvisolic soils. However, soils in the sub-humid regions, rich in SOC (Blacks and Dark Gray Chernozems), show less potential. Therefore, the interaction of soil type with management practices needs to be considered when estimating the extent and ability of carbon storage. Once an improved management system has been implemented, it takes approximately 15 to 25 years before the soil carbon sink becomes saturated and additional carbon cannot be sequestered (Cole et al. 1995; Dumanski et al. pers. comm.). Thus, prairie soils can only act as a net sink for carbon in the short term.

To evaluate management practices that are effective at storing carbon in specific agroclimatic zones, measurements need to be taken at long-term experimental sites to quantify the amount of carbon sequestered. Changes in SOC, particularly in soils inherently high in carbon (Chernozemic soils), may take four years or more to be detected (Ellert et al., 2000). In Alberta, enough long-term sites are needed in representative landscapes across the prairies but these simply do not exist because the costs associated with this kind of monitoring system. Further, finding a way to accurately extrapolate site-specific results to larger regions has confounded researchers trying to understand the global C cycle (Gifford 1994). Too often, the extrapolation process loses spatial connection between where certain management practices are occurring and on what kinds of landscapes (climate, types of soils and topography) (Izaurralde et al., 1996).

Soil contains three times as much carbon as the atmosphere. Therefore, the balance between soil carbon inputs and outputs has a critical influence on the concentration of atmospheric CO_2 (Post et al., 1999). The rate at which carbon is cycled between the soil and atmosphere is partly dependent on the particular carbon compounds found in soil organic matter. (Burke et al., 1990; Lal, 1997; Izaurralde et al., 2001). Based on the rate at which these compounds break down in soil, they can be classified into one of three forms of soil organic matter: 1) stable; 2) intermediate; and 3) labile or active. These three forms are found in varying proportions in soil with the least digestible (lignin) and the physically and chemically stable organic matter (humus) making up almost all of the stable organic matter pool (Jastrow et al., 1996; Amelung et al., 1998). Live and dead organisms (plants, animals, and microorganisms) (Paul and Clark, 1996) and partially transformed or decomposed organic matter (Bremer et al., 1994; Jastrow et al., 1996) make up the active fraction. The labile soil organic matter fraction consists of plant and microorganism-secreted sugars. The most stable forms have half-life turnover rates of hundreds of years (aromatics, derived mostly from wood-based materials); the most labile (easily decomposed) have half-life turnover rates of only a few hours (Amelung et al., 1998; Grant et al., 2001).

Over time, the addition of organic matter and nutrients (straw, manure, green manure, fertilizer, etc) will result in carbon sequestration if additions exceed aerobic decomposition of easily decomposable carbon (Golchin et al., 1995b; Brady and Weil, 1999; Follett, 2001). Carbon sequestration also depends on the type of organic matter being added (Golchin et al., 1995a). Additions of less decomposable forms (proteins, nucleic acids, dead organisms and litter) are likely to become stable organic matter. Stable forms of organic matter are the least accessible to microorganisms, both physically and chemically (Golchin et al., 1995b) because they are physically protected by mineral particles or they are in soil pores that are too small (less than 1-3 μm) for bacteria and fungi to reach (Paul and Clark, 1996). The chemical association of organic matter and mineral particles in soil will also make the sequestered carbon less accessible to soil organisms due to chemical resistance to microbial enzymes and, therefore, less accessible to soil carbon mineralization (Golchin et al., 1995b; Kay, 1998). Soil organic matter may also interact with the mineral components in the soil to influence aggregation and other soil properties (Ellert and Bettany, 1995).

A recent study by Bremer et al. (2002) demonstrated that tillage frequency and the presence of permanent grass cover influenced the accumulation of carbon in a Brown Chernozem near Bow Island, Alberta. Fallow-wheat (FW), fallow-wheat-wheat (FWW), continuous wheat (W) and permanent grass (G) rotations were studied for six years. The rates of carbon sequestration in these medium textured soils were 0.7, 1.5, and 3.0 Mg C ha^{-1} higher over six years in the FWW, W and G systems, respectively compared to the FW. However the carbon accumulated under permanent grass was found primarily in the more labile carbon fractions relative to the other three cropping systems. This demonstrated that in terms of absolute amounts, permanent grass facilitates greater carbon sequestration. However, this sequestered carbon will be subject to mineralization and return to the atmosphere should the permanent grass system be tilled again and revert to annual crop production. Thus, the stability of the sequestered carbon must be understood in the context of the soil management (tillage) system being used.

In addition to sequestering carbon, agricultural soils also emit CO_2 and CH_4. Carbon dioxide is emitted through soil respiration (oxygen consumption by roots) and soil organic matter decomposition (carbon mineralization). Carbon dioxide emission research focuses on management of soil organic carbon (Ellert and Bettany, 1995). The driving force of the research is to understand how carbon is accumulated and stored as stable organic carbon in soil. Most research uses well-drained soil because aerobic respiration (in the presence of oxygen) is predominant (Desjardins et al., 1997). This is generally true for cultivated lands where management is specific to crop needs (Janzen et al., 1998). Similar assumptions may be made for managed pastures (Brierley and Adams, 2002). However, it would not apply to cultivated lands that periodically become flooded (Wang and Bettany, 1995) or rangelands near water sources (Brierley and Adams, 2002) because severe oxygen depletion in soils.

Methane emissions from agricultural soils are predominately found in wetland grazing areas, periodically flooded farmland (rare in Alberta), and newly cultivated soils transformed from wetlands and organic (histosol) soils found in peat bogs (Monteverde et al., 1997). In anaerobic environments, microorganisms use fermentation to obtain their energy from organic compounds (Madigan et al., 1997; Paul and Clark, 1996). Fermentation uses a biochemical pathway different from aerobic respiration yielding by-products such as CH_4, propionic acid, butyric acid, and acetic acid (Immig, 1996; Mathison et al., 1998). In soil, temporary anaerobic microsites may develop from rainfall or from heavy aerobic respiration due to excess addition of a highly labile carbon source (i.e. fresh manure). Under these temporary conditions, microorganisms will switch to fermentation to survive (Paul and Clark, 1996) consequently producing methane gas. However, the production of CH_4 is miniscule compared to the production of CO_2.

Availability of nitrogen, phosphorus, sulphur and micronutrients affects whether microorganisms use active or stable organic matter as food to grow or maintain their present population. Studies of soil organic matter and nutrient cycling of nitrogen, phosphorus and sulphur emphasize the central role of organic carbon as a driving force for nutrient cycling (McGill and Cole, 1981). For the most part, the availability of nitrogen, phosphorus and sulphur limit the production of crops and pasture vegetation by limiting plant growth.

Soil nitrogen contributes to carbon sequestration because nitrogen is used for the production of plant and microbial proteins (Tisdale et al., 1993; Paul and Clark, 1996). These proteins may later be recycled back into the soil by plant and microbial secretion, the excretion of wastes, and the decomposition of tissues (Brady and Weil, 1999). Inorganic nitrogen is converted to organic nitrogen through nitrogen fixation and immobilization of nitrogen from mineral compounds on the Earth's crust dissolved in soil water (Tisdale et al., 1993). Inorganic nitrogen (nitrate) is considered highly mobile in soil systems because it is more water-soluble than other nitrogen compounds (Nyborg et al., 1997a).

Depending on the fertilizer or organic material that is added to the plant-soil system, soil available nitrogen may either be immobilized (taken up by microorganisms) or be mineralized (released from organic matter) (Tisdale et al., 1993). The balance between immobilization and mineralization is dependent on the ratio of carbon to nitrogen (C:N) in the soil organic matter. If the organic matter has a C:N of 25 to 30 then immobilization and mineralization processes will be in balance (Jenkinson, 1988). If the C:N of raw organic material is under 25, net mineralization will occur; if C:N is over 30, net immobilization will occur. A soil balanced between a state of net mineralization and net immobilization will be able to sequester carbon.

Denitrification is an anaerobic process where nitrate is primarily converted to dinitrogen gas (N_2) by a series of chemical and biological reactions (Paul and Clark, 1996). Within that series of reactions, N_2O is also produced, some of which escapes into the atmosphere (Malhi and Nyborg, 1988a). Three main factors control the rate of denitrification: the supply of oxygen, the concentration of nitrate, and the amount of available carbon (used by bacteria as an energy source) (Nyborg et al., 1990). Higher rates of denitrification occur when the concentration of oxygen is low and the concentrations of nitrate and available carbon are high (Nyborg et al., 1997a). The absence of any one of these may reduce denitrification to negligible rates. Denitrification is most intense under anaerobic conditions (low oxygen levels), found in waterlogged and poorly drained soils (Kimmins, 1987), but can also occur inside the root nodules of legumes (Madigan et al., 1997). The amount of N_2O released depends on the rate of denitrification as well as other variables that have yet to be proven, such as the ratio of N_2O to dinitrogen (Skiba et al., 1994; IPCC, 1996). This ratio is highly variable and tends to be lower under conditions favouring denitrification (Janzen, 1999).

Nitrification is a two staged aerobic process that converts ammonia to nitrite and then to nitrate. The factors affecting nitrification are aeration, moisture, soil pH and a temperature (Hausenbuiller, 1985). High concentrations of nitrate are favorable for the production of N_2O therefore net N_2O emissions may result.

It is a common management practice to apply fertilizer (commercial fertilizers, manure, or compost) to cropped fields and some pastures. Nitrous oxide emission research from agricultural soils generally focuses on the inefficiencies of applying nitrogen fertilizers and manure to cropping systems (Lemke et al., 1998b; Nyborg et al., 1990; Nyborg et al., 1997b; Laidlaw, 1993; Chang, 1998; Hao et al., 2000, Tenuta et al. 2001). The type and application method used is key to ensuring that the nitrogen will be used by the plant (McKenzie, 1998) and not lost through leaching, volatilization and denitrification (IPCC, 1996). The majority of the measurements compare N_2O emissions produced in different management practice scenarios. Other research measured N_2O emissions from nitrogen fixation (Lemke et al., 2002a), freeze-thaw cycles (Wagner-Riddle et al., 1997, Nyborg et al, 1997a, Smith et al, 2002), and from farmland that is periodically flooded (Monteverde et al., 1997). Evidence suggests there is a high level of uncertainty (50% or more) with regard to estimating N_2O emissions from cropping scenarios.

Phosphorus is important in the production of nucleic acids (DNA and RNA) and cell membrane lipoproteins in plants, animals, and microorganisms (Paul and Clark, 1996). In most cases, phosphorus is found in organic form in the A horizon, in microorganisms and decomposing organisms (McKenzie and Middleton, 2001). In the subsurface B and C horizons phosphorus is mostly found in inorganic form as a component of minerals naturally found in soil parent material (Tisdale et al, 1993; McKenzie and Middleton, 2001). In general, phosphorus is not mobile but can be better absorbed by plants if soil pH is between 6.7 and 7.5 (McKenzie and Middleton, 2001; Tisdale et al, 1993). Under acidic conditions, such as Luvisolic soils or agricultural soils where nitrogen fertilizer has decreased the soil pH, phosphorus is much less accessible to plants (McKenzie, 1998). If phosphorus is limiting, carbon sequestration may be restricted even if the soil is nitrogen- and sulphur-rich (McGill and Cole, 1981).

Sulphur is found in many forms in the soil. It is water-soluble and is more mobile in soil compared to phosphorus but not as mobile as nitrogen (Wyatt, 1936). There is a strong connection between the cycles of nitrogen and sulphur because both have essential roles in building proteins (Nyborg et al., 1997b). Nitrogen is present in all amino acids and sulphur is found in the amino acids methionine and cysteine. Sulphur is also involved in disulphide bonds, which give proteins their three-dimensional shape (Tisdale et al., 1993). In Alberta, it is common to find sulphur deficiency in the Luvisolic soils (Wyatt, 1936), which composes more than 15% of Alberta's farmland (Bentley, 1971).

Research demonstrated the need to link nutrient management and carbon sequestration. Eliminating nutrient limitations is a key consideration for the sequestration of carbon in soil. In general, sufficient nitrogen must be present to promote plant growth and carbon sequestration. However, excessive amounts of nitrogen may lead to N_2O emissions through denitrification. Conversely, phosphorus and sulphur deficiencies also have the potential to limit biomass production and, hence, carbon sequestration.

Soil Type and Land Use

Soils can be a carbon sink or source depending on management practices. For example, no-till soils sequester carbon and may produce small amounts of CO_2 and CH_4 emissions but depending on the fertilization practice (broadcast vs banding, fall vs spring application) can produce a large amount of N_2O emissions (Schuman et al., 2001). Also, maintenance of the carbon sinks is needed (Follett, 2001) because labile fractions of the sequestered carbon may be mineralized when the soil management system changes (change from a no-till system back to conventional tillage) (Izaurralde et al., 2001). Even though sequestered carbon may be temporary, it is still important because it increases soil quality.

Soil with lower organic matter content (1 to 3%, Luvisols) would initially sequester more organic carbon if conventional management practices were changed to beneficial management practices (e.g. no-till, crop rotations including forages) compared to soils with higher organic matter content (> than 3%, Chernozems)

(Janzen, 1998). Soil also needs enough moisture to produce sub-humid conditions and have a mean average daily temperature over 15°C (IPCC, 1996) to begin maximum soil organic matter mineralization. Some carbon is mineralized due to root respiration but if plant production exceeds root respiration, there is net carbon sequestration (Follett, 2001, Izaurralde et al., 2000).

Depending on the plant species, approximately 50 to 60% of the nutrients taken up by plants will produce stems and leaves while the remaining 40 to 50% will be part of the root system and root exudates (Campbell and DeJong, 2001; Follett, 2001). Therefore, a significant portion of the nutrients that go into roots and exudates becomes sequestered. For this reason, legumes, grasses and other perennial forages are valuable because they contribute large quantities of root matter and root exudates through their fibrous root network.

In general soils in cooler, dryer climates sequester less carbon than soils in wet, warm climates because biomass production is less (Frank et al., 2001; Reeder et al., 2001). Ecosystems that have cooler and wetter climates (central and northern Alberta) sequester carbon into soil or plant biomass less quickly than those with warmer, wetter climates where nutrient turnover is faster. However, mineralization of soil organic matter in both natural and cultivated pastures growing in cooler, wetter climates tends to be less than the biomass production in these climates resulting in net carbon sequestration (Povirk et al., 2001).

Soil Management Practices and Greenhouse Gas Emissions

On the farm different management practices as well as different agroclimatic conditions influence the amount of GHG emitted from the soil-crop system. Soil-crop management practices include summer fallow, crop rotations, application of fertilizers, type of tillage, use of irrigation, and residue and manure management. Conditions such as nitrogen fixation, and freeze thaw cycles also affect GHG emissions. Changing management practices from conventional methods to beneficial management practices, not only decrease GHG emissions it also increases the production efficiency of your farm.

Summer fallow

Summer fallow is defined as soil being left bare (without residue) for the winter and the following growing season. It is created either by tillage or by chemical herbicides. Research indicates that excessive use of summer fallow results in decreased levels of soil organic matter, increased soil erosion, dryland salinity, deterioration of soil tilth, reduced soil nitrogen, and less efficient use of available water by crops (Larney et al., 1994). Generally summer fallow may be a necessary practice in the Brown and Dark Brown soil zones, for moisture conservation (Campbell et al., 1991a). It is not common in the Black and Gray soil zones (Janzen, 1998) because these areas typically receive adequate moisture throughout the growing season.

Summer fallow is used in conjunction with other soil management practices such as tillage, fertilization, manure application, crop rotations, and residue incorporation (Wagner-Riddle et al., 1997). Tillage and summer fallow are generally practiced together, contributing to accelerated loss of soil organic matter because little residue is added to the soil (Izaurralde et al., 2001). Loss of soil organic matter can be a direct result of soil erosion because there are no plants to anchor the soil or it can be lost because of an increase in the rate of microbial metabolism due to higher soil temperatures (Grant et al., 1998; Grant, 1999). In non-fallow years plants protect the soil from solar radiation therefore soil temperature is lower than in fallow years. Both the decreased organic matter and increased microbial metabolism accelerates carbon mineralization in fallow soils (Doran et al., 1998).

When summer fallow is included as one of the crop rotations, CO_2 emissions decrease because of the reduced amount of soil organic matter (Izaurralde et al., 2001). However N_2O emissions increase, most likely due to the accumulation of nitrate in fallow fields because summer fallow promotes the mineralization of nitrogen. In particular, substantial amounts of N_2O can be produced during heavy rainfall periods when puddles on the soil surface produce anaerobic microenvironments (Monteverde et al., 1997). In addition both aerobic and anaerobic conditions may occur within the surface layers of the soil (Nyborg et al., 1990). Increased moisture could increase net GHG emissions because of increased carbon mineralization, denitrification of nitrogen (Nyborg et al., 1990) and small amounts of CH_4 (Desjardins and Mathur, 1997).

In the crop-fallow system common to the prairie region, the soil nitrogen removed by the crop generally exceeds the nitrogen gained from the addition of crop residues, manure, legumes and/or fertilizer (Campbell et al., 1997). Addition of amendments or application of agricultural residues onto fallowed fields prevents soil from eroding and contributes to soil aggregation, however, an increase in GHG emissions may also occur (Chang et al., 1998) by increasing N_2O and CO_2 emissions. One study from Ontario reported more nitrogen was mineralized from fallowed or bare soil that had nitrogen-rich manures (dairy cattle) applied to it (Wagner-Riddle et al., 1997). The study concluded that application of manure to soil increases N_2O emissions and that emissions are higher when applied to fallow soil (Wagner-Riddle et al., 1997).

Crop residues applied to summer fallow soils increase net CO_2 emissions from soil because the crop residue will be mineralized before the soil organic matter (Nyborg et al., 1997b). Long-term studies at the University of Alberta's Breton Plots indicate that with a decrease of summer fallow, soil carbon content increased by 30 % in the last 40 years (Izaurralde et al., 2000; Grant et al., 2001).

Cropping rotations

Cropping schedules (rotation or continuous) and the type of crops grown (annual or perennial) may impact the amount of GHGs emitted and carbon sequestered in the soil-crop system. Soil organic carbon for continuous cropping systems is higher than for crop rotations including fallow. In addition, rotations that incorporate legumes have higher soil organic carbon than monoculture wheat rotations (Campbell et al., 2000). This is probably because mono-cropping of cereals also returns fewer nutrients to the soil surface (Izaurralde et al., 1998). If the same crop is continually planted over many years, the soil will eventually become deficient in one or more of the nutrients needed for crop growth in subsequent years (Campbell et al., 1996a) decreasing its carbon sequestration potential.

Long cropping rotations (five years or more) that include nitrogen fixing and non-nitrogen fixing forages can enhance soil organic carbon and soil organic nitrogen at depths below 15 cm (McGill et al., 1986). This is because forages have fibrous root systems, which penetrate into denser sub-surface horizons of the soil, shed more large-chained polysaccharides and proteins that increase soil organic matter, and penetrate into smaller crevices in soil pores than annual plant root systems. Root hairs and complex sugars sloughed from fibrous root structures act as binding agents for soil aggregation and enhanced soil nitrogen availability in legumes (Juma, 2000; Campbell et al., 1997; Campbell and DeJong, 2001).

Longer rotations containing perennial forages more closely resemble the dynamics of native grasslands because the cycling of carbon is not as frequently interrupted by harvest, winter dormancy without cover, and spring seeding practices (McGill et al., 1986; Boehm et al., 2000). In the long-term studies at the Breton Plots, the total soil organic matter after 70 years was significantly higher in the five-year rotation of barley-wheat-oats-hay-hay than the two-year wheat-fallow rotation (Carcamo, 1997; Izaurralde et al., 2001; Grant et al., 2001). This increase in soil organic carbon may be a combination of the longer rotation, inclusion of perennials and/or the elimination of summer fallow in rotation.

The diversity of crops planted in the longer rotations may contribute to increased deposition of all forms of soil organic matter (Campbell et al., 1991a; Campbell et al., 1997). Native pasture, grassland and woodland are diverse in vegetation with at least 60 different species coexisting on the landscape at any one time (Liang et al., 1999). The diversity of vegetation also enhances the diversity of animals feeding on the vegetation as well as soil insects and soil microbes that use the exudates of the plants as carbon and energy sources.

When a cropping system is changed from one involving summer fallow to a continuous cereal cropping system, the nitrogen requirement increases (Robertson, 1979; McGill et al., 1986). The nitrogen requirement is greatest in the first few years of continuous cropping as nutrient cycling processes adjust to the new cropping system (Laidlaw, 1993). Hence immobilization of nitrogen will occur and more CO_2 will be emitted in those years (Solberg et al., 1998a).

The use of perennial forage crops in rotations with annuals such as cereals and oilseeds has long been recognized to provide nutrients back to the soil that were taken up by the annuals, especially in Luvisolic soils (Campbell et al., 1997). Several long-term crop rotation studies conducted in Western Canada indicate that crop rotations involving perennial forages tend to stabilize more soil organic matter compared to crop rotations involving summer fallow (Juma et al., 1997; McConkey et al., 1999).

Fertilizer practices

The large reserves of organic nitrogen present in the organic matter of prairie soils have been the major source of nitrogen in cropping systems (Broersma et al., 1997). To increase crop productivity, it is common practice to apply nitrogen fertilizer to cropped fields and some pastures. However, nitrogen is highly mobile and can easily volatilize, leach or denitrify (Nyborg et al., 1997a), potentially increasing the amount of nitrogen lost as N_2O.

Nitrous oxide emissions can be directly and indirectly (leaching and runoff) related to the application of nitrogen fertilizers. In general, soil moisture; soil mineral nitrogen, temperature and labile organic matter control the dynamics of microbial nitrification and denitrification and thus the supply of nitrate available for plant growth (Smith et al., 2002). In temperate and cooler climates, mineralization-immobilization turnover processes within agricultural soils contribute significantly to the supply of available nitrogen for crops (Monteverde et al., 1997). On a management level, loss of nitrogen as N_2O represents a loss of a costly input however production of N_2O can be controlled by type, placement, timing and chemical phase (solid, liquid, or gas) of fertilizers.

It has been suggested that fertilizer applied via broadcast will emit more N_2O than if applied via banding or pellet. However, there is not enough research available to confirm this statement. Broadcast application of pelleted fertilizers has an average nitrogen recovery rate in grain crops of 22 to 31 % in Alberta due to factors such as leaching, ammonia volatilization, and denitrification (Malhi et al., 1994). Broadcast fertilizer nitrogen is susceptible to volatilization and denitrification, especially in heavy storms where temporary water logging occurs and where the fertilizer has little time to be incorporated into the soil organic matter or be taken up by plants (Janzen et al., 1998). When an excess of nitrogen fertilizer is applied to soil, the mobile nitrogen will leach into ground water, streams and reservoirs and contribute indirectly to N_2O emissions somewhere else on the landscape, such as an adjacent discharge area (Nyborg et al., 1997c).

Studies on fertilization management practices indicate that banding reduces N_2O emissions (McKenzie, 1998) because it places fertilizer within the vicinity of the root zone for more efficient plant uptake (Malhi et al., 1988a). Banding has an average nitrogen recovery rate in grain of 32 to 42 % (Malhi et al., 1994) thereby facilitating greater uptake and subsequently decreased nitrate residence in soil. Deep banding (8 to 15 cm deep) has become a common method of applying nitrogen fertilizers (McKenzie, 1998) because deeper placement reduces nitrogen loss in extremely dry or extremely wet surface soil.

Fertilizer timing is another factor affecting the amount of N_2O emitted each year. When nitrogen fertilizer is applied in the fall, the nitrogen has time to nitrify to and then be subsequently denitrified to N_2O. Fertilizer applied before spring snow melt creates conditions favorable for denitrification and if fertilizer is applied before spring snow melt, run-off and heavy rains, then the result will also be higher N_2O emissions due to denitrification (Heaney et al., 1992). If nitrogen is applied after spring thaw these losses do not occur (Nyborg et al., 1997c; Lemke et al., 1998a). A study by Malhi and Nyborg (1993) reported that nitrogen use efficiency on zero-till barley in central Alberta was 0.34 bushels per pound nitrogen for fall broadcast versus 0.44 bushels per pound for spring broadcast. Similarly, efficiency was 0.50 bushels per pound for fall banding and 0.48 bushels per pound for spring banding. Although both timing and placement are important in decreasing N_2O emissions these results indicate that placement is more important than timing.

Nitrous oxide emission from fertilizer application can also vary with soil water content (Mahli and Nyborg, 1988a). Fall applied nitrogen fertilizer is lost by denitrification under wet soil conditions that can occur in early spring (during and after spring thaw), (Nyborg et al., 1997b; Hao et al., 1999). Under drier, aerobic conditions, denitrifiers are less active (Mahli and Nyborg, 1988b). Late fall banding of an ammonium form of nitrogen (e.g., 82-0-0 or 46-0-0) will reduce nitrogen losses compared with early fall banding and is almost comparable to spring banding when spring conditions are dry and cool (McKenzie, 1998).

The chemical phase fertilizer is applied (solid, liquid or gas) plays a role in the efficiency in which fertilizer reaches target plants, which effects N_2O production (McKenzie, 1998). Liquid and slurry applications may be inefficient fertilizer methods because the nutrients can leach into sub-surface horizons below the rooting zone. As well, liquid forms of nitrogen fertilizer would increase N_2O emissions by providing an anaerobic microenvironment (similar to the puddling effect after rain fall) (Lemke et al., 1998a). Bacteria responsible for releasing N_2O (nitrifiers and denitrifiers) are better adapted to anaerobic environments and will thrive in this situation (Laidlaw, 1993).

Apart from modifying fertilizer application timing, application methods and chemical phase, another mitigation strategy involves the use of nitrification inhibitors when fertilizing soil (Malhi and Nyborg, 1983; Malhi and Nyborg, 1988a). This was first researched in the 1980's to increase fertilizer use efficiency by plants. Laboratory tests from two Alberta studies found that nitrification inhibitors (2-ethynylpyridine, etridiazole, nitrapyrin, and N-Serve) could reduce nitrification by 20 to 30%. In later studies, nitrification inhibitors were used to increase fertilizer nitrogen recovery (Freney et al., 1993) and to reduce gaseous emission of nitrogen from irrigated crops (Freney, 1997).

Tillage

Conventional tillage is defined as the breaking of soil using a cultivator, causing vegetative residues to be left on the surface of the cultivated field, incorporated into the soil, or removed. Tillage disrupts and aerates the soil, which results in more N_2O emissions and enhanced decomposition of the dissolved organic carbon (Lemke and Desjardins, 2001). Aerobic decomposition of soil organic matter emits CO_2 (Sauvé, 2000). Globally, most tillage research focused on the impact of tillage on the microbial degradation of soil organic carbon, which can increase CO_2 (Alvarez and Alvarez, 2000).

Conventional tillage buries the protective crop residue cover and disturbs the soil in addition to promoting higher CO_2 emissions (Sauvé, 2000). Paul and Clark (1996) suggest that higher CO_2 emissions from tillage on Chernozemic and Luvisolic soil is because tillage mixes the first 15 cm of soil and gives microorganisms access to soil organic carbon and newly deposited soil organic matter. Conventionally tilled soils in the Black soil zone are about one degree Celsius warmer at the five cm depth than reduced- or no-till soils. For brief periods during spring, conventionally tilled soils can be as much as three degree Celsius warmer than reduced- and no-tilled soils. The warmer soil temperature usually lasts until mid or late June, when the fully established crop canopy shades the soil (Froebel and Howard, 1999). Warmer temperatures facilitate a greater rate of carbon mineralization as well as early initiation of the process in the spring.

Reduce- or no-till is defined as soil left undisturbed from harvest to planting. Crop residues are left on the surface, preventing soil erosion and loss of water. Net sequestration of carbon is common on land under reduced- or no-till with direct seeding, whereas land under conventional tillage usually has a net carbon emission (Campbell et al., 1996b; Biederbeck et al., 1997). Differences in CO_2 emissions between conventional tillage and no-till farming practices are significant and variable (Sauvé, 2000) and are dependent on tillage system, added residue, fertilization and crop rotation (Nyborg et al 1997c; Hao et al., 2001). Research has focused on measurements made on the Chernozemic and Luvisolic soil orders. There are no GHG measurements made on Solonetzic, Brunisolic and Organic soils comparing tilled and no-till soils. Because of the effects of tillage and the wide variability among soil types, calculated CO_2 emission and sequestration rates have large errors associated with them (Janzen et al., 1998), therefore caution should be used when trying to estimate CO_2 emission or sequestration from soil.

Research suggests that tillage reduces denitrification because it reduces the denitrifier and nitrifier populations (Biederbeck et al., 1997). Studies indicate that zero-tilled soils emit twice the amount of N_2O as conventionally tilled soils. The introduction of oxygen into tilled soils facilitates nitrate stability and therefore decreases denitrification (Palma et al., 1997; Baggs et al., 2000; Choudhary et al., 2001). However, Hao et al. (2001) reported that fall tillage of a field without straw but with nitrogen fertilizer added increased N_2O emissions compared to spring tillage of a field without straw but with nitrogen fertilizer added. Therefore, tillage may contribute to N_2O emissions if specific conditions are present. Higher soil temperatures in conventionally tilled soils may also increase the rate of denitrification in spring, releasing more N_2O than no-till soils. In addition, Lemke et al. (2001a) reported that estimated annual N_2O losses were consistently lower from a no-till system compared to the conventionally tilled systems regardless of the crop rotation.

Residue management

After harvest, plant residues (straw) may be left on, removed or incorporated into the soil. Agricultural residues provide protection and insulation to soil, thereby lowering surface soil temperatures and increasing spring soil moisture from snow captured in the winter. Some Alberta studies suggest that removal of agricultural residues after harvest may accelerate soil organic carbon mineralization due to an increase in soil temperature (Nyborg et al., 1997a; Solberg et al., 1998b). Apart from their physical properties, residues are a good carbon source for microorganisms (Nyborg et al., 1997b; Hao et al., 2001). Therefore, as turnover of the microbial population occurs, there is better cycling of the active organic matter pool (Juma et al., 1997).

Straw is composed of complex carbohydrates including cellulose, hemicellulose and lignin that are difficult to degrade by most microorganisms (Campbell et al., 1997). Residues with more lignin-based compounds are generally sequestered and increase soil organic matter (Nyborg et al., 1997b; MacKay et al., 1998). During the degradation of straw by heterotrophic microbes, nitrogen may become limiting due to straw's high C:N ratio. Therefore, nitrogen is immobilized to maintain population growth and turnover (Campbell and de Jong, 2001). If there is not enough nitrogen in the soil, then the majority of the carbon material will be respired as CO_2 and not sequestered (Nyborg et al., 1995; MacKay et al., 1998). However, when the activity of the microbes subside through lack of oxygen, the C:N ratio will return to approximately 10:1 (Brady and Weil, 1999). Therefore, the addition of carbon-rich agricultural residues may need to be supplemented with nitrogen-rich residues, manure and/or fertilizer in order to sequester carbon.

The plough-down of legumes before seeding forages or the addition of ploughed legumes to cereal crops may increase soil organic matter due to increased crop production. The quick decomposition of leguminous residues will produce a flush of ammonium into the soil-available nitrogen pool (Broersma et al., 1997). Nitrifiers will utilize this ammonium because the main limiting variable to nitrification and subsequent denitrification (resulting in N_2O emission) is ammonium availability in the soil (Tisdale et al., 1993), thus making nitrogen available for crop growth.

Manure management

Manure application is common practice in many tropical and some European agricultural areas (IPCC, 2001) and has been applied for centuries to fertilize agricultural land. In Canada, this practice has been largely replaced by the use of synthetic fertilizer (Statistics Canada, 2002). Depending on the treatment, manure applied to land could either emit or sequester GHGs. For example, one-year old stockpiled manure added annually over twenty years may emit between 0.7 and 56 kg N_2O ha^{-1} y^{-1} depending on how much manure is applied (Chang et al., 1998). Wagner-Riddle et al. (1997)

measured N_2O emissions from a Brunisol soil in Ontario that had manure applied to a fallow field ranging from 5.7 to 7.4 kg N_2O-N ha^{-1} y^{-1}. Looking at N_2O emission and carbon sequestration for a soil in Quebec which had pig manure applied to it, Lemke and Desjardins (2001) stated that a moderate application rate of manure did not increase N_2O emissions enough to offset the gain in soil organic carbon, resulting in a net decrease in GHG emissions.

Manure may be applied in many ways. Liquid manure can be spread on the surface, injected into soil, or distributed through an irrigation system (Statistics Canada, 2002). Research indicates that spreading raw solid or liquid manure emits more N_2O and CH_4 compared to spreading composted manure because raw manure contains more water as well as higher levels of water-soluble carbon and nitrogen (Huther et al., 1997; Van Melle et al., 1999).

Different manure types can also emit different amounts of GHGs. In a recent Alberta study, the N_2O emission rate from raw hog manure was 27 times higher than that from raw cattle manure (Zhang et al., 2002). Hog manure has higher nitrogen content than cattle manure, therefore, when hog manure is applied on the soil surface there is a higher risk of nitrogen volatilization and denitrification (temporary anaerobic conditions) compared to subsurface manure application.

Treatment of manure before its application as a fertilizer also influences the amount of GHG emitted after it is applied to land (Hao et al., 2000). The methods for treating manure common in Canada are : composting (Lopez-Real et al., 1996), and anaerobic lagoon (Statistics Canada, 2002). Anaerobic digestion of manure yields a product is similar to compost although it is produced in the absence of oxygen whereas composting is an aerobic process. Anaerobic digestion is not common in Alberta but the Alberta Research Council is currently conducting feasibility studies on the technology (Li and Borg, 2001). As a manure treatment, composting is preferred because manures in anaerobic lagoons may be stored for long periods of time, potentially emitting more N_2O (Tenuta et al., 2001).

Composted manure is transformed organic matter. It has a stable chemical form and, under analysis, has compounds similar to soil humus (Hao et al., 2000). Composting reduces the C:N ratio, which means adding more stabilized carbon to soil (Janzen et al., 1998).

Composting minimizes leaching of nitrogen into sub-surface horizons, reduces denitrification of liquid manure, and limits volatilization of nitrogen to ammonia because compost contains less moisture and is porous compared to raw manure (Paul and Zebarth, 1997a). There is a loss of GHG (N_2O, CH_4, and CO_2), nutrients and water through the composting process but carbon and nitrogen become concentrated in the final product (Paul and Zebarth, 1997b). Manure has high carbon and nitrogen content and, when composted, provides a slow release of nutrients to the soil such that plants and microorganisms may take up these nutrients as needed (Zeman et al., 2002). These nutrients stimulate microbial activity to cycle organic carbon and nitrogen, transforming them into inorganic forms that are more available to plants (Robertson, 1979).

Trials conducted near Guelph, Ontario, concluded that timing of compost application had a significant influence on the yields of both soybeans and corn (Alder et al., 1997). Test plots where compost was added in the fall had higher yields of both crops than similar plots that had compost applied in the spring. Higher yields result in greater organic matter cycling through the root zone of the soil (Juma et al., 1997).

Nitrogen fixation

Nitrogen fixation is a biological process that occurs in leguminous plants. Elemental nitrogen is taken from the air and through a series of catalytic reactions is chemically reduced to ammonium (Paul and Clark, 1996). Certain plants (alfalfa, soybean, clover) exhibit a symbiotic relationship with soil bacteria (Rhizobium, Bradyrhizobium, Azorhizobium, Photorhizobium, Sinorhizobium and Mesorhizobium species) (Madigan et al., 1997) where the plant provides an anaerobic habitat and food for the bacteria while the bacteria fixes nitrogen for the plant (Paul and Clark, 1996).

Depending on the amount of nitrogen fixation occurring, there is a steady rate of denitrification occurring at the same time. Denitrification occurs within the nodule portion of the plant such that nitrogen fixers obtain energy before providing the host plant with ammonium (IPCC, 1996). Some research suggests that ammonium may escape into the rhizosphere (soil in the root zone) where nitrifiers and denitrifiers utilize it to produce N_2O (IPCC, 1996). Nitrogen fixation also contributes to indirect N_2O emissions when excess ammonium escapes to the rhizosphere. The excess ammonium may be nitrified and the nitrates may either denitrify or leach to discharge areas of undulating landscapes where further denitrification can occur (Farrell et al., 1996). Additional research is needed to quantify the amount of N_2O that may escape from the nodules.

With respect to measurements of N_2O emissions due to nitrogen fixation, the only western Canadian published study measured N_2O from field peas in Alberta and lentils in Saskatchewan (Lemke and et al., 2002a). Results from the study indicate that rotations including legumes had lower N_2O emissions compared to the continuous wheat rotation for the same year (Lemke et al., 2002a). Nitrous oxide emissions from the Alberta site ranged from 450 to 2070 g N_2O-N ha^{-1} irrespective of tillage treatment (Lemke et al., 2002a). Research on nitrogen fixation is limited and therefore it is difficult to determine if nitrogen fixation significantly contributes to N_2O emissions.

Irrigation

Soil moisture is a major limiting factor to crop production in the southern part of the Prairie Provinces. Soil microbial activity and crop productivity are both increased when irrigated (Kulshestra and Junkins, 2001). However, irrigated systems have higher energy inputs due to the energy required to deliver water and fertilizer to the crops.

Recently, research began on GHG emissions comparing irrigated farms with non-irrigated farms in western Canada began. The research considers the whole farm, whereas most other GHG research focuses on only one sector of the farm enterprise. Some of the irrigation research focuses on the impact of climate change on irrigation practices while other research deals with GHG emissions where irrigation is one of a certain set of conditions (Hao et al., 2001). There is limited research comparing GHG emissions from irrigated and non-irrigated agro-ecosystems in western Canada. Only five studies have been identified, two of which are modeling studies using the Canadian Economics and Emission Model for Agriculture. Kulshrestra and Junkins (2001) measured an irrigated, Dark Brown Chernozem with an emission of 1.68 *T* CO_2-E ha^{-1}. It is difficult to determine whether irrigated systems emit more GHG emissions than non-irrigated systems because emission factors for other systems do not consider the whole system. Therefore more research is required to compare whole systems.

Freeze-thaw cycles

Research on GHG emissions from freeze-thaw cycles is limited. However, preliminary research suggests that freeze-thaw cycles may increase N_2O emissions from soil (Chen et al., 1995) and limit CH_4 oxidation due to abrupt temperature changes. A laboratory study by Chen et al. (1995) estimated N_2O emissions between 0.6 and 1.6 kg ha^{-1} day^{-1}. This study was conducted on a synthetically fertilized corn monoculture grown on conventionally tilled sandy loam soil. The results from a second laboratory study used clay-textured soils suggested that freezing and thawing cycle increased denitrification rates by 32% (Bochove et al., 2000). When comparing tilled and no-tilled soil slurries, the no-till soil under rotation exhibited denitrification rates 92% higher than those from conventional till under continuous cereal (Bochove et al., 2000).

A recent modeling study from Smith et al. (2002) uses the DNDC model (DeNitrification and DeComposition), which takes into consideration freeze-thaw cycles. The study used data from both eastern and western Canadian sites, both with a variety of crops, management practices, soils and climates. For the western Canadian sites, the model predicted cumulative N_2O emissions from a footslope and shoulder landscape position to be 0.19 and 0.63 kg N_2O-N ha^{-1} for one year, respectively.

Freeze-thaw cycles may limit the oxidation of CH_4. Graphical extrapolation from Stein and Hettlaratchi (2001) shows an exponential increase of methanotrophic enzyme activity with temperature. At zero degrees Celsius, activity is approximately 50 nmol h^{-1} g^{-1} dry weight whereas at 30 degrees Celsius, it was as high as 550 nmol h^{-1} g^{-1} dry weight. Stein and Hettlaratchi (2001) observed that moisture content in agricultural soils could also play a critical role in limiting a soil's CH_4 oxidation potential. For example, the oxidation rate of the agricultural soil in this study increased after increasing its moisture content from 6 to 10% weight-based (Stein and Hettlaratchi, 2001).

Grazing

Greenhouse gas emissions from grazed systems will depend on grazing management practices. A well-managed grazing system, on a short-grass pasture sequesters carbon and nitrogen through regular carbon and nitrogen turnover (Derner et al., 1997). Studies from the United States indicate that most pastures sequester carbon unless they are overgrazed (Schuman et al., 2001). A pasture that is overgrazed (more than 8 large ruminants per hectare) results in exposed soil that is subject to weathering and mineralization of soil organic matter in warmer climates (Abril and Bucher, 2001) and to some extent in cooler climates. Exposed soils in pastures are similar in physical condition to fallow soils.

Animal excreta could also contribute to increased N_2O emissions depending on climatic conditions because raw wastes with a high water content and labile carbon and nitrogen content are deposited on the surface (Rudaz et al., 1999), which can lead to denitrification.

Technologies that Measure Greenhouse Gas Emissions

The alkaline absorption method was used to measure CO_2 emissions as early as the 1970s and it is still being used in some long-term studies. In the laboratory, this method measures CO_2 release in closed chambers with an alkaline solution (NaOH) to absorb CO_2 coming from the soil. Carbon dioxide is measured by titrating NaOH with acid (HCl). The amount of acid used is the amount of CO_2 absorbed (Carter, 1993). This method has been modified for use in the field by setting an open-bottomed chamber over a sample plot with the alkaline solution placed within the chamber to absorb CO_2 coming from the soil. However, the alkaline absorption method should be used with caution as results may vary by up to 30% (Carter, 1993).

Some newer methods that have been used in current field studies include the LICOR^{tm}-IRGA (Infrared Gas Analyzer). Results with this instrument are relatively consistent with those from the alkaline absorption method (both field and laboratory chambers). The BOREAL^{tm} Tunable Diode Laser Trace Gas Analyzer (TDR TGA) is becoming more commonly used in the field for all GHG and moisture analyses (BOREAL, 1997). These instruments, used in conjunction with wind speed measurements, turbulent diffusivity, and eddy correlation calculations, can provide GHG emission estimates where a point source is not defined. However, deviations from the mean may still be over 40% within replicates. This is especially true of N_2O emission measurements where there are a variety of nitrogen inputs (e.g., fertilizers, manure, nitrogen fixation, crop residues, mineralization of soil organic matter, groundwater nitrates).

Soil emission factors for CH_4 have not been reported specifically for Alberta because agricultural soils in Alberta are generally a sink for CH_4. Those currently in use are averages of CH_4 emission measurements from well-drained soils across Canada. A Canadian internal federal government report calculated Canada's total soil

CH_4 emission to be 252 MT CO_2-E y^{-1} using an emission rate of 2.1 MT CO_2-E of CH_4 ha^{-1} yr^{-1} (Liu, 1995). Liu's equation may need to be modified to suit environmental conditions in Alberta, including poorly drained, flooded and organic soils.

The measurement and calculation of N_2O emissions from soil are more complex than those for CH_4 because they are dependent on several factors, including land use, fertilizer and amendment application, livestock demographics, climate, season timing, and soil type. Studies often simply measure the amount of N_2O produced during the denitrification process. However, dinitrogen (N_2) is the major end-product of denitrification; N_2O production is relatively minimal. Therefore, it is difficult to fully account for evolved N_2O from one management practice alone. For example, Lemke et al. (1998a) compared direct measurements of N_2O at six different soil sites in Alberta with the IPCC Tier 1 emission factors (IPCC, 1996). Direct measurements were taken by inserting heated soil covers between crop rows for one hour and randomly sampling three replicates. Gas was drawn from the headspace of the containers with 30 ml syringes and then transferred to vacuum-sealed containers. Analysis was done using gas chromatography (GC). The authors reported a range of 0.124 to 0.806 T CO_2-E of N_2O-N $ha^{-1}yr^{-1}$ for all soils measured. IPCC Tier 1 default emission factors for the same sites ranged from 0.341 to 0.651 T CO_2-E of N_2O-N $ha^{-1}yr^{-1}$. The IPCC factors failed to predict the extreme N_2O emission values observed because they did not account for variation in measurements or type of soil tested. Lemke et al. (1998a) concluded that the Tier 1 Emission Guidelines would be appropriate for medium textured soils but not for coarse and fine textured soils like those tested in the study. As well, the Tier 1 emission factors may represent an average of most, if not all, soils tested in the world (IPCC, 2001). The IPCC Tier 2 Emission Guidelines for GHG emissions from agricultural soils set by the country or region would need to reflect soil type, moisture, climate, and management practice specific to that geographic area.

The newer measuring technologies like IRGA and TDR TGA and calculations like eddy correlation, wind speed measurements, and turbulent diffusivity are useful in the field for non-point sources. However many measurements are needed to account for spatial and temporal variations of these sources. Variations in measurements may be up to 40%. Likewise, more research is needed to measure N_2O emissions due to the complexity of the process and sources that feed denitrifiers.

Heterogeneity of Soils: The Role of Microclimate and Microenvironment

Within similar soils, there is heterogeneity in microclimate including soil in a toposequence in one field. There is usually a large variation between all points of the field, which is influenced by growth of the vegetation, topography and variations in temperature and moisture. Topography has a strong influence on the hydrologic and pedologic processes in the landscape, which, in turn, regulate the soil factors controlling the N_2O emission at the micro-scale level (Corre et al., 1996). For example, one area in the field may be a on the shoulder of south-facing slope resulting in that area being warmer and drier compared to the foot of the same slope. The foot-slope area may be subject to more CH_4 and N_2O emission if there are larger organic carbon and nitrogen stores in that soil. However, the sloped area may have a higher CO_2 emission because the warmth may mineralize organic carbon in the soil. If it rains, some of the water may run off the slope and pool into the low level areas creating anaerobic microsites for production of CH_4 and N_2O.

With regard to N_2O, emission peaks may occur after rainfall during the growing season, after the application of nitrogen fertilizer, and during spring thaw (Van Kessel et al., 1993). Finer textured soils also have higher N_2O emissions than coarser textured soils (Corre et al., 1996). Specific land-use and management practices will further influence the production or sequestration of GHG.

Specific events such as rain and snowfall may induce spikes in CH_4 and N_2O production. A study by Corre et al. (1996) illustrated the importance of rainfall in deriving a reliable temporal sampling scheme that would include rainfall-induced episodic emissions to obtain meaningful N_2O flux estimates. As mentioned before, soil freezing will reduce nitrification and mineralization of soil organic matter but these processes will resume in the spring after snowmelt. It is difficult to determine annual GHG emissions when measurements are taken at specific points of time with long periods between measurements. This produces error when extrapolating to larger units of space and time.

Soil diversity, in addition to other natural and anthropogenic factors, contribute to N_2O emission in every microsite. Therefore, significant error is introduced when scaling up emission factors to regional levels. Laboratory-scale efforts to mitigate and reduce N_2O emission must reflect the landscape effect (Pennock et al., 1992). Similarly CH_4 emissions in soils at foot-slopes will vary with shoulder-slopes and therefore there is a need to take separate measurements of CH_4 depending differences in field landscape topography.

Greenhouse Gas Emission and Sink Factors for Soil and Crop Management

From the literature, GHG emission and sink factors for cultivated and rangeland soils for the Prairie Provinces are presented in Tables 3 and 4. Most of the research from which these estimates are derived was conducted in Central and Southern Alberta on Chernozemic (central and south) and Luvisolic (central) soils.

The Intergovernmental Panel of Climate Change (IPCC) requires signatory nations to submit an annual GHG inventory. The methodology used by IPCC out lines default emission factors for countries that do not have data available to make estimates (tier 1). If data is available, countries are encouraged to submit inventories with more detailed information (tier 2). Many of the measurements made from the research were taken at specific temporal and spatial points. This creates problems if a regional net GHG estimate was calculated. For example, the distribution of soil organic carbon in the landscape varies (e.g. higher in the depressions and lower on hill tops). Nitrous oxide emissions are highest after rain or during the spring when soil conditions are moist. Therefore basing emission or sink factors on these site-specific measurements creates high uncertainty and error when they are used to estimate GHG emission or sink for large areas of land. In addition, not all the emission factors for each soil type or zone are known contributing to the error when calculating estimates. For more information on the agricultural inventory for Alberta see Chapter 2.

Table 3. Alberta and Prairie Provinces' emission and sink factors for agricultural soils and practices for a typical year (positive is emission, negative is sink). Summaries of experimental methodology can be found in Appendix B.

Emission Factors				
A. N_2O Emissions	Brown	Dark Brown	Black	Grey Luvisol
Experiment 1		**kg N_2O-N ha^{-1} y^{-1}** 0.7 (0 Mg) 11 (60 Mg) 23 (120 Mg) 56 (180 Mg)		
Experiment 2			**kg N_2O-N ha^{-1} y^{-1}** 2.0 (56 N) 2.6 (100 N)	**kg N_2O-N ha^{-1} y^{-1}** 1.7-2.5 (25 N) 0.4-0.9 (56 N) 0.9-2.0 (100 N)
Experiment 3			**N_2O-N kg ha^{-1}** 0.48 (CBP*W) 1.02 (CBPW*) 1.11 (Cont W) 1.31 (WF*) 0.63 (W*F) *measurement taken in this rotation	
Experiment 4		**N_2O flux** **(g N ha^{-1} d^{-1})** No straw 1.18 (0 N, FT) 1.60 (0 N, ZT) 15.64 (fall N, FT) 5.74 (fall N, ZT) 4.60 (fall N, ST) 9.47 (spring N, FT) Straw 5.23 (0 N, FT) 8.55 (fall N, FT) 2.50 (fall N, ST) 4.34 (spring N, FT)		
Experiment 5			**g N_2O-N ha^{-1}** CBPW-pea: 450(CT), 540(ZT) CBPW-wheat: 1310(CT), 860(ZT) Cont wheat: 1560(CT), 730(ZT)	

Emission Factors				
A. N_2O Emissions	Brown	Dark Brown	Black	Grey Luvisol
Experiment 6	**N_2O loss (g N ha^{-1})** Wheat-lentil* 23 Lentil-wheat* 55 Cont wheat (N) 115 Cont wheat (0 N) 0 *measurement taken in this rotation			
Experiment 7	**DNDC Coefficients (kg N_2O-N $ha^{-1}y^{-1}$)**			
Control	0.86*	1.25*	1.40*	2.05**
No Till	-0.50***	-0.67	-0.73	-0.36
Reduced Fallow	-0.39	-0.47	-0.49	0.64
Fall Fertilizer	0.00	-0.03	-0.04	---
Permanent cover	-0.37	-0.58	-0.64	-1.39
	*N_2O emissions from wheat-fallow rotation ** N_2O emissions from a wheat-wheat-fallow rotation ***negative values represent a change in N_2O emissions from control			

B. Carbon sequestration	Brown	Dark Brown	Black	Grey Luvisol
Experiment 8			**MG C HA** No straw 0 (0 N) 0.046 (25 N) 0.038 (50 N) 0.008 (75 N) Straw 0 (0 N) **+0.18 (25 N)** **+0.12 (50 N)** 0.28 (75 N)	**MG C HA** No straw 0 (0 N) 0.008 (25 N) 0.26 (50 N) 0.48 (75 N) Straw 0 (0 N) 0.13 (25 N) 0.41 (50 N) 0.53 (75 N)
Experiment 9	**kg CO_2 ha^{-1} y^{-1}** 391 (CT) 776 (ZT)	**kg CO_2 ha^{-1} y^{-1}** 528 (CT) 1022 (ZT)	**kg CO_2 ha^{-1} y^{-1}** **+72** (CT) 392 (ZT)	**kg CO_2 ha^{-1} y^{-1}** 1093 (CT) 1687 (ZT)
Experiment 10	**Mg C ha^{-1}** 0.579 (FWW) 0.21 (FWW) 0.785 (Cont W) 0.222 (CWG)			
Experiment 11	**t CO_2 ha^{-1} y^{-1}** 0.73 (expert, ZT) 0.22 (Century, ZT) 0.08 (expert, MT)	**t CO_2 ha^{-1} y^{-1}** 0.73 (expert, ZT) 0.44 (Century,ZT) 0.16 (expert, MT)	**t CO_2 ha^{-1} y^{-1}** 1.34 (expert, ZT) 0.54 (Century,ZT) 0.26 (expert, MT)	
Experiment 12	**0.3 Mg C ha^{-1} y^{-1} for Cultivated Land**			

Emission Factors				
C. CO_2 emissions	Brown	Dark Brown	Black	Grey Luvisol
Experiment 13	**t CO_2-E ha^{-1} y^{-1}** 1.68 (AB) 2.61 (SK)			

Table 4. Alberta and Prairie Provinces' emission and sink factors for common rangeland soils and management practices (positive is emission, negative is sink). Summaries of experimental methodology can be found in Appendix C.

Emission Factors

Experiment 1	**Total C Mg C ha^{-1}**
	120 (0 kg N ha^{-1} y^{-1}, 0 kg S ha^{-1} y^{-1})
	113 (112 N, 0 S)
	121 (0 N, 11.2 S)
	128 (112 N, 11.2 S)
	110 (112 N, 11 elemental S)

Experiment 2	Depth	Location	Crop	CRP	Native Pasture
	(cm)	(**Mg C ha^{-1}**)			
	0-5	Kansas	6.4	7.3	17.1
		Kansas	7.2	11.4	12.6
		Texas	0.6	0.8	2.5
		Texas	0.7	0.9	4.7
		Nebraska	4.0	4.7	10.6
		Mean	3.8	5.0	9.6
	5-10	Kansas	6.1	6.4	11.2
		Kansas	6.5	8.8	1.8
		Texas	0.6	0.8	1.8
		Texas	0.7	0.7	2.6
		Nebraska	3.1	3.8	7.7
		Mean	3.4	4.1	6.5
	10-15	Kansas	4.9	5.1	8.7
		Kansas	5.3	6.7	7.6
		Texas	0.6	0.7	1.7
		Texas	0.7	0.6	2.2
		Nebraska	3.4	3.6	5.2
		Mean	3.0	3.3	5.1

Experiment 3	Brown	Dark Brown	Black	Grey Luvisol
	t CO_2 $ha^{-1}y^{-1}$			
Reduce Summer Fallow	0.15 (expert) 0.13 (Century)	0.16(expert) 0.29(Century)	0.08(expert) 0.20(Century)	
Crop to Forage Pasture	0.73(expert)	1.78(expert) 0.94(Century)	3.23(expert) 2.44(Century)	
Permanent Cover	2.93(expert) 0.88(Century)	2.93(expert) 1.15(Century)	2.93(expert) 3.3(Century)	

Experiment 4	**Mg C $ha^{-1}y^{-1}$**	
	Revegetated Land	0.8
	Pasture/Rangelands	0.2
	eroded soils	0.5
	salt affected soils	0.1
	severely disturbed land	0.5

The amount of carbon sequestered with certain beneficial management practices is presented in Table 5. However, these practices may not occur every year. Tables 3 and 4 separate cultivated from rangeland whereas Table 5 incorporates both types of land use.

The increased adoptions of beneficial management practices (e.g. zero tillage, reduced tillage, residue incorporation, manure application, banded fertilizer application, crop rotations and forage seeding) maintain soil quality, reduce GHG emissions and increase carbon sequestration. Carbon sequestration factors in Alberta, for various management practices and soil types, range from 0.068 T CO_2-E ha^{-1} yr^{-1} to 1.03 T CO_2-E ha^{-1} yr^{-1} (Sauvé, 2000).

Table 5. Beneficial management practices with associated sink factors (shown as carbon sequestered according to management practice) and associated benefits in Canada.

Beneficial Management Practices (BMP)	Additional Benefits
Reduced Tillage	Improved soil quality, fertility and productivity
No Tillage	Improved soil quality, fertility and productivity
Reducing Fallow	Decreased soil erosion and less sedimentation
Fertilizing Pastures	Improved pasture quality and productivity
Rotational Grazing (riparian)	Improved water quality and quantity
Crop to Grasslands	Maximum sequestration potential
Crop to Wetlands	More available and higher quality habitat
Shelterbelts	Energy efficiency on the farm, reduced soil erosion
Grassland to Woodlot	Increased biodiversity
Crop to Woodlot	Increased biodiversity
Soil Amendments	Nitrogen and other nutrient source
Crop Rotations	Better organic carbon and nitrogen cycling in soils

Summary of Knowledge about Greenhouse Gas Mitigation Practices for Soil and Crop Management

- Soils will sequester carbon if net primary production exceeds soil respiration.
- Summer fallow will increase net mineralization of carbon and nitrogen from soil organic matter, which decreases carbon sequestration. Therefore a reduction in the use of summer fallow in rotation increases carbon sequestration.

- Cropping rotations longer than two years without summer fallow and incorporation of forages tend to sequester carbon because the soil organic matter dynamics become more like those under perennial grass, native untouched fields and other forage pastures.
- Converting annual cropland to perennial forage decreases net GHG emissions by sequestering more carbon.
- Perennial grasses sequester more carbon than annual crops because of their fibrous root system. Perennial grasses store more soil carbon than perennial legumes.
- Fertilizer nitrogen is a source of N_2O. Changing the form, placement and timing of application can mitigate N_2O emissions. The closer fertilization is to crop uptake, the less N_2O is emitted. Nitrogen application rates based on soil nitrogen testing and crop requirement reduce N_2O emissions and increase carbon sequestration.
- Tillage enhances carbon and nitrogen mineralization because it allows soil microbes greater access to soil organic matter and introduces oxygen into the soil pores. Reduced or zero tillage increases carbon sequestration because carbon mineralization is minimized.
- Agricultural residues add carbon and nitrogen to the soil in addition to keeping the soil cooler by providing insulation.
- Manure is high in organic matter and soluble nutrients and in its raw form has a high water content. Liquid manure systems produce higher N_2O and CH_4 emissions when broadcast on land in contrast to solid and/or composted manure. Composted and digested manure contain stable forms of carbon and nitrogen, have low moisture contents and release nutrients at a slower rate than raw manure.
- Nitrogen fixation may produce N_2O emissions because fixed ammonium may nitrify and subsequently denitrify.
- Overgrazing exposes soil, creating conditions similar to fallow, therefore increasing soil carbon mineralization.
- Managed pasture (rotational grazing, fertility management, stocking rates, residual bio-mass) results in lower total net GHG emissions than unmanaged pasture.
- Laboratory incubations are still being used to estimate GHG emissions. Infrared gas analysis is being used for field

measurements but most of these have been made on small field plots. Emission factors developed by the IPCC are being validated by comparison with direct field measurements.

- Soils are heterogeneous in microenvironment and microclimate. This results in temporal and spatial variation, which may produce a large degree of error when calculating net GHG emissions for a specific scenario.

Identifying the Research Gaps for Soils and Crop Management

1) The majority of agricultural GHG research focused on annually cropped land but more rangeland and pasture GHG research is needed. Very few emission factors have been calculated for perennial cropping systems.

2) Greenhouse gas emissions from individual management practices and inherent soil processes have been measured in several studies. Greenhouse gas emissions from crop rotation, nitrogen fixation, irrigation, agricultural residues, freeze-thaw cycles, grazing and pasture fertilization in the Brown Chernozem and Gray Luvisol soils are needed. In particular, the interactions between these management practices and GHG emissions have not been explored.

3) Greenhouse gas emissions observed in laboratory and microplot-level experiments are well understood but farm-level observations are not. Caution needs to be applied when results that are well understood for one management practice are applied to other environmental conditions or spatial settings.

4) More basic research on the production and consumption of N_2O as well as the process of denitrification is needed. More specifically factors controlling the N_2O/ N_2 ratio in different spatial and temporal situations in addition to research on the amount of N_2O evolved from denitrification.

5) More carbon is sequestered in reduced- no-till soils than in conventionally tilled soils. However, more research is needed to quantifying if more N_2O is emitted from reduced- no-till soils than conventionally tilled soils before a net GHG balance could be determined.

6) Full-cycle accounting should be used to determine if irrigated crops emit more or less GHG than non-irrigated crops of equal management, farm type and climate.

7) It is not certain if surface applied manure results in higher GHG emissions compared to incorporated manure. More research is required to establish GHG emission coefficients for specific rates, time of year, and placement.

8) Research to fully understand how temporal and spatial variation influences the error associated with calculations required to scale up emission models to the whole farm level and place that error in context.

9) An accurate methodology needs to be developed to measure GHG emissions. This includes protocol to document and reduce the level of error associated with scaling up from micro plot to field scale.

10) Research with respect to methane consumption and production in agricultural landscapes.

11) Research on the effects of management practices on the permanence of sequestered carbon.

Livestock Greenhouse Gas Production

The process of CH_4 production in ruminants

The production of CH_4 is a normal digestive process in livestock, occurring in the rumen of ruminant animals and the large intestine of ruminant and monogastric animals. Methane production is the result of anaerobic fermentation of complex carbohydrates and protein through the coordinated action of bacteria, protozoa and fungi. During this enteric fermentation, complex carbohydrates and proteins are degraded to simple sugars and carbon skeletons through the action of primary fermenters. Primary and secondary fermenters further degrade these simple compounds, producing a mixture of volatile fatty acids (VFA), CO_2 and H_2. Acetic, propionic and butyric acids, the major VFA produced, are absorbed and utilized as energy sources by the animal. The H_2 produced during fermentation must be disposed of because molecular hydrogen acts as a feedback inhibitor of the fermentation process. Methanogenic bacteria utilize the excess H_2 as their energy source by reducing CO_2 to CH_4.

The majority of methane is produced in the rumen, with lesser amounts produced in the large intestine. Methane production is higher when conditions favour the production of acetate over propionate because the biochemical pathway leading to acetate results in a excess of H_2 whereas pathways leading to propionate and butyrate do not. In general, CH_4 production is greatest when fibre is fermented, intermediate for soluble sugars and lowest for starch. Forage-based diets promote the production of acetate along with significant amounts of CH_4. Forages with low digestibility increase CH_4 production in ruminants than those of high digestibility. Grain-based diets shift fermentation toward propionate production with reduced acetate and lower CH_4 production. Methane is produced in all practical diets; however, the amount produced can be manipulated by changing the diet. In addition, CH_4 production is influenced by dry matter intake (DMI). Higher DMI yields more CH_4 production per animal but less per kg of DMI, resulting in more energy available for productive purposes. Under these conditions, fewer animals are required to maintain meat, milk and fibre production, thereby reducing total CH_4 produced.

Methane escapes through eructation or flatulence with the majority of the CH_4 escaping through eructation (Immig, 1996). Among domestic animals, ruminants (e.g., cattle, buffalo, sheep, goats and camels) are the major emitters of CH_4 because of their unique digestive system (IPCC, 1996). The microbial fermentation that occurs in the rumen enables them to digest coarse plant material that cannot be used by non-ruminant animals. Ruminant animals, consequently, have the highest CH_4 emissions among all animal types (Jarvis and Pain, 1994).

Non-ruminant animals (e.g., swine, horses, mules, and poultry) produce CH_4 by enteric fermentation in the large intestine but in comparatively smaller quantities—generally less than 10% of ruminant CH_4 production (Desjardins and Mathur, 1997; Basarab et al., 1999). The majority of CH_4 emissions from non-ruminant livestock production comes from the anaerobic breakdown of their manure (Nietzert et, 1999).

In 2000, CH_4 emissions from livestock were estimated to account for about 4% of Canada's GHG emissions. Approximately 65% of CH_4 produced from livestock comes from beef cattle; 14% from dairy cattle (Basarab et al., 1999). This estimate does not include CH_4 produced from manure. Within Alberta, 97% of livestock-produced CH_4 emissions are from cattle with beef cattle contributing 90% of this.

Although per capita beef consumption is declining, beef consumption is still high in North America and demand is growing in other areas of the world. Therefore, efficiency of meat production is considered important, especially where large energy inputs are also required in the production process. Age gender, quality and quantity of feed consumed, type of feed and feeding system are important factors determining the overall efficiency of the animal (Basarab et al., 1999). Methane production is inversely proportional to the efficiency of digestion and utilization of absorbed nutrients (Kaharabata et al., 2000).

Researchers are looking for ways to increase energy utilization for productive purposes as a means of decreasing the cost of production. This would create the additional benefit of reducing CH_4 production. This is simply due to increasing the efficiency with which the animal digests carbon, channeling more of the energy toward productive processes with a consequent reduction in energy lost through methanogenesis (Mathison et al., 1998; Okine et al., 2001).

Current research focuses on genetics, physiology, microbiology and biochemistry to establish emissions of a typical animal unit of a given age, gender and breed when fed a specific diet. Most international GHG research focuses on beef feedlot cattle and dairy cows. Canadian research is focusing on dairy cows as well as beef heifers and steers.

Beef cow greenhouse gas research

In Alberta, more CH_4 is produced by beef cattle than by dairy cattle because of the greater size of the beef population (Statistics Canada, 2002). Emission estimates, taken from direct measurement and by calculation, range from 47 to 107.9 kg CO_2-E head^{-1} year^{-1} for western Canada. The variability in emission estimates is due to differences in measurement methods and differences in production systems between farms.

The amount of CH_4 produced and excreted by an individual animal depends primarily on the amount and type of feed it consumes (Mathison et al., 1998). In general, the greater the feed intake, the greater the amount of methane produced. However, at high feed intake the amount of energy lost as CH_4 per unit of feed consumed is reduced (IPCC, 1996). Feed intake is positively correlated with animal size and level of production (i.e., growth rate, milk production, wool growth, pregnancy and work) (IPCC, 1996; Environment Canada, 2001) and is influenced by diet digestibility. As diet digestibility increases, CH_4 production per kg of DMI decreases, resulting from a reduction in the amount of gross energy being diverted to CH_4 production (Blaxter and Clapperton, 1965). The consortium of rumen microorganisms, which develops in forage-fed cattle leads to a prevalence of acetate with a consequent large amount of H_2. Dihydrogen must be disposed of by greater CH_4 production. Methane yield from immature forages is less than that from more mature forages (Armstrong, 1960); less from legume forages than from grasses; (Varga et al., 1985; McCaughey et al., 1999)); and less with ensiled than with dried forages (Sundstol, 1981). McAllister et al. (1996) concluded that the properties of forages that decrease the rate of ruminal digestion or increase mean rumen retention time generally result in increased CH_4 production per unit of feed consumed.

Methane production by lactating beef cows grazing alfalfa-grass pasture was lower than it was by those grazing grass pasture (374 vs. 411 L head^{-1} d^{-1}) although DMI was greater on the alfalfa-grass forage. The reduced CH_4 was attributed to diminished CH_4 loss as a percentage of gross energy intake (7.1% vs. 9.5%) (McCaughey et al., 1999).

Feeding operations play a significant role in the amount of CH_4 produced by cattle (Jarvis and Pain, 1994; Basarab et al., 1999; Herd et al., 2001). Greenhouse gas emissions from beef cattle will depend partly on the production system employed (Boadi et al., 2002). For example, most cow-calf production is dependant on pasture grazing during the growing season followed by winter grazing of stockpiled forage, swath grazing, and/or feeding of harvested forage in dry lot. A large portion of the forage used in extensive grazing systems is medium to low quality, resulting in high CH_4 production. The digestibility of forage under intensively managed grazing conditions is higher than under extensively grazing and should result in less CH_4 production.

In Alberta, there are several production systems employed in the production of beef cattle and many variations within systems that will impact CH_4 production. This diversity must be recognized when estimating CH_4 production and when developing and applying mitigation strategies. In Alberta, feeding of stockpiled forage and swath grazing of the beef cowherd is becoming more common (Lewis, 1998). Because swath grazing cannot provide the energy required by calves, adolescents or cows that are pregnant or lactating, these cattle require nutritional supplements (Lewis, 1998). However, emission factors have not yet been derived for swath-grazed cattle or for cattle fed stockpiled forages.

Beef calf greenhouse gas research

Methane emissions for beef calves range from 24.1 to 63.7 kg head^{-1} year^{-1}. The lower end of the range is for calves from industrialized countries. The variability is due to the effects of calf age and the varied feeding systems employed. Calves produced under intensive grazing are heavier at the end of the grazing season with many ready for the finishing phase sooner than those produced under extensive grazing. This is due to increased growth from the greater milk production of the dam and to the improved efficiency of utilization of the more highly digestible, intensively managed forage. The high grain rations employed in the finishing process produce less CH_4 per unit of beef produced than do high forage diets. Lighter weight calves may have to proceed through a backgrounding period on high forage, moderate grain diets prior to finishing, resulting in more days to market and consequently greater CH_4 production. The information on the effect of creep feeding on performance of calves is equivocal and its effects on CH_4 are not known. Use of growth-promoting implants is known to increase growth in pastured calves and yearlings. The effect on CH_4 production is not known; however, the mode of action of these implants suggests that a reduction of CH_4 per kg of weight gain should result through improved feed efficiency and reduction in days from birth to slaughter.

Methane production from steers on pasture was reported to range from 68.9 to 73.3 kg hd^{-1} $year^{-1}$ for rotational grazing and from 63.4 to 80.4 kg hd^{-1} $year^{-1}$ for continuous grazing (McCaughey et al., 1997).

Beef backgrounding and fnishing cattle greenhouse gas research

Feedlot cattle research indicates that grain feeding reduces CH_4 emissions. Feed conversion efficiency is an important factor in the Blaxter and Clapperton equation (1965) used to calculate CH_4 production of an animal (IPCC, 1996). Methane emissions were measured using the sulphur hexafluoride (SF_6) tracer technique for non-lactating dairy heifers kept in a feedlot/paddock and for lactating dairy heifers housed in a barn. Methane emissions ranged from 0.39 for the lactating animals to 0.45 kg hd^{-1} d^{-1} for the dry heifers (Kaharabata et al., 2000). Heifers were found to emit less CH_4 compared to non-lactating cows and steers (Boadi and Wittenberg, 2002; Boadi et al., 2002).

Greenhouse gas emissions from beef feeder cattle have not been well researched. However, McAllister et al. (1996) found that CH_4 production was reduced when cattle were fed highly fermentable diets, which promoted rapid passage of feed particles out of the rumen. In a study where steers were fed a diet containing 86% barley grain, Beauchemin et al. (2001) concluded that more extensive processing of grain increases rumen fermentation rate and microbial protein synthesis while also increasing the risk of rumen acidosis.

Beef breeding bull greenhouse gas research

By extrapolation, Basarab et al. (1999) derived a CH_4 emission factor for breeding bulls of 83.4 kg hd^{-1} $year^{-1}$. No research was found which actually measured CH_4 production by bulls.

Beef replacement heifer greenhouse gas research

Daily CH_4 production was 0.207 kg hd^{-1} for heifers fed high and medium digestibility forage and 0.145 kg hd^{-1} for those fed low quality forage (Boadi et al., 2002). Methane as a % of gross energy intake was 6.0, 7.1 and 6.9 for the animals fed high, medium and low quality forage respectively. Breed did not significantly affect CH_4 emissions (Holstein vs. Charolais x Simmental).

Dairy milking cow greenhouse gas research

Estimated CH_4 emissions from dairy cows range from 105 to 165.2 kg hd^{-1} $year^{-1}$ (McAllister et al., 1996; Basarab et al., 1999; Kaharabata et al., 2000; Boadi and Wittenberg, 2002). With the exception of the paper by Kaharabata et al., (2000), no research measuring methane emissions of lactating dairy cattle raised under current Canadian conditions was found. The Kaharabata study measured CH_4 emissions of 542 L hd^{-1} d^{-1} in lactating dairy heifers. Levels of milk production, DMI, and diet composition were not reported in this paper. The published estimates appear to have been derived using the equations of Blaxter and Clapperton (1965) and Moe and Tyrell (1979).

Average milk production of Holstein cows has increased dramatically in recent years. The increase in energy intake needed to support this higher level of production appears to be due, in part, to increases in DMI and to improvements in diet formulation, quality of dietary ingredients, (including forages), diet digestibility and feeding management. Increased energy density of dairy cow diets through inclusion of fat supplements has become commonplace. Increases in DMI and the feeding of fat result in reduced CH_4 emissions due to increased passage of liquid and solids from the rumen and to the toxic effects of dietary fat on methanogenic bacteria (McAllister et al., 1996). These observations suggest that the equations of Blaxter and Clapperton (1965) and Moe and Tyrell (1979) may not be appropriate for estimation of CH_4 emission by lactating dairy cows managed as they are today.

Dry pregnant dairy cow greenhouse gas research

No research on methane emissions from dry or pregnant dairy cows was found in the literature.

Dairy bulls greenhouse gas research

No research on methane emissions from dairy bulls was found in the literature.

Methods to directly measure methane emissions from cattle

Methods commonly used for measuring CH_4 livestock emissions include micrometerological techniques (Johnson and Johnson, 1995), the mass balance technique (Khan et al., 1997; Harper et al., 1999) and non-radioactive, non-isotopic and isotopic tracer methods (Johnson et al., 1994; Johnson and Johnson, 1995; Johnson and Westberg, 2001).

Earlier studies used the closed respiration chamber method where the animal was in the chamber and the gas produced over a specific period of time (usually 24 to 72 hours) was collected and analyzed using gas chromatography (Holter and Young, 1992). There have been modifications to this system but the principles of the technique have not changed. Most of the subjects in these studies were dairy cattle fed high energy rations or conserved, processed forages (Holter and Young, 1992).

Because respiration chamber experiments are relatively easy to conduct (Blaxter and Clapperton, 1965), most beef cattle emission measurements have been made using cattle offered processed feeds (Van Soest, 1982; Johnson and Johnson, 1965). This has resulted in a skewed understanding of beef cattle CH_4 emissions because processed feeds account for only a small proportion of the feeds consumed over the lifetime of the typical beef animal and the type of diet has a major effect on the proportion of energy emitted as methane (Mathison et al., 1998).

Micrometerological measurements can be taken in non-intrusive, open respirator chambers (Johnson and Johnson, 1995; Harper et al., 1999) or in man-made wind tunnels adjacent to the grazing or feeding sites (Lockyer and Champion, 2001) where a stream of acetylene (C_2H_2) is passed over the headspace of the chamber or tunnel. The sample is collected and analyzed for the three GHGs in a gas chromatograph using the concentration of acetylene to calculate GHG production. Wind speed and direction is recorded to determine concentration over time (Johnson and Johnson, 1995; Harper et al.1999; Lockyer and Champion, 2001).

In the sulphur tetraflouride (SF_6) technique, a capsule containing a known amount of SF_6 is inserted into the rumen and an apparatus is placed around the animal's head to continuously measure the concentration ratio of SF_6 to CH_4 eructated over the course of a specified period of time in which a known amount of feed is ingested (Johnson et al., 1994; Johnson and Johnson, 1995;

McCaughey et al., 1997; McCaughey et al, 1999; Boadi et al., 2002; Johnson and Westberg, 2001). The amount of CH_4 emitted will be directly proportional to the amount of SF_6 emitted (Johnson and Westberg, 2001). Unfortunately this method does not account for CH_4 produced from flatulence (McCaughey et al., 1999; Kaharabata et al., 2000; Boadi et al., 2002).

Several papers (McAllister et al., 1996; Mathison et al., 1998; Lassey et al., 1997; Herd et al., 2001) document annual emission rates for beef and dairy cattle using the metabolic energy utilization method. This method uses feeding rates, types of feeding systems, and feed quality to predict CH_4 production. Recent research by Herd et al. (2001) confirms the repeatability of this method.

Mitigation research applicable to all types of cattle

Nutritional supplements and dietary changes are considered possible strategies to reduce CH_4 production; however, it is not known whether such changes are beneficial over long periods (over four weeks) time. Examples of methods to reduce CH_4 emissions from cattle include feeding easily digestible grains and forages, ionophores, and lipids (canola, corn and sunflower oils).

Forages comprise most of the diets of beef cows and growing stock. However, ingestion of mature forages will result in greater CH_4 production compared to immature forages and grain based diets (Blaxter and Clapperton, 1965; McAllister et al., 1996). Stage of maturity, species, and the climate in which the forages grow are major factors affecting the digestibility of forage. Methane yield is less from immature forages than from more mature forages (Armstrong, 1960); less from legume forages than from grasses;(Varga et al., 1985; McCaughey et al., 1999) and less from ensiled than from dried forages (Sundstol, 1981). Feeding of high-digestibility forages should reduce CH_4 production per unit of feed consumed (Boadi et al., 2002).

The beef cow herd produces the most GHG of all livestock in Alberta. However, many cow diets, particularly during the winter months, may not be balanced (Cow Calf Audit, 2001). For example, only one in five herds during the 1989-1991 production cycle and only one in three herds in the 1997-1998 production cycle tested their winter feeds and used these feed tests to balance cow diets.

Improperly balanced diets will increase CH_4 emissions. Therefore, providing incentives to cow-calf managers to test winter feeds and use these test results to formulate cow diets may be one of the most practical and effective ways to both reduce GHG emissions and increase production efficiency and profitability. Large- to medium-sized feedlots routinely use nutrition consultants to formulate cattle diets.

Studies have shown that forage species also influence enteric methane emissions. Legumes in general with condensed tannins may have lower CH_4 emission production potential relative to grasses (Varga et al., 1985).

Ionophores are antibiotics produced by *Streptomyces* bacteria, which disrupt the cellular membranes of certain CH_4-producing bacteria (Kennelly et al, 1998). However, their primary effect on the suppression of CH_4 production appears to be through inhibition of microorganisms that provide substrates for methanogens (McAllister et al., 1996). They function in the rumen, improving production efficiency by influencing energy and nitrogen metabolism and favouring the growth of propionic and succinic acid-producing bacteria (Kennelly et al., 1998). Two commonly used ionophores in Alberta are Rumensin® (monensin) and Bovatec® (lasalocid) (Kennelly et al., 1998).

Long-chain fatty acids (LCFA) also help shift rumen fermentation from the production of CH_4 and acetate to the succinic and fumeric acid metabolic pathway (Dong et al., 1997; Mathison et al., 1998). Dietary LCFA are directly toxic to protozoa and methanogens. Removal of protozoa from the rumen (defaunation) always results in reduction of CH_4 emissions because protozoa provide H_2 to methanogens. Therefore, reduction in the supply of H_2 through reduced protozoal numbers, combined with a reduction in the population of methanogens, results in reduced CH_4 production (McAllister et al., 1996). However, lipids also decrease the digestion of fibre in the rumen and the total digestive tract to varying degrees, depending on the nature and amount of fat given and animal type (Ferlay and Doreau, 1992).

Another CH_4 reducing strategy involves the removal of acetate-producing protozoa from the rumen. Approximately 20% of the CH_4-producing bacteria are attached to these protozoa and, if they are removed, CH_4 production is reduced by 20 to 50% (Kreuzer et al., 1986). There are several problems associated with this defaunation strategy:

- increased difficulty for the animal to digest starch and fibre;

- defaunation agents currently used are extremely toxic to the animal;
- defaunation may have the opposite effect and increase the retention time of feed in the rumen, thereby favouring methanogenesis (Van Nevel and Demeyer, 1996).
- methods need to be developed to remove the protozoa without harming the animal (Mathison et al., 1998).

The absence of CH_4-producing microorganisms changes the chemical make-up of the rumen such that microbes will use the propionate biochemical pathway (Hegarty, 1999a,b). Genetics also play an important role by increasing the production and efficiency of feed digestion. The most efficient and cost-effective strategy to reduce CH_4 emissions is to keep diets consistent and use a combination of some or all of these strategies.

In addition to the above factors, studies have shown that genetic selection can influence enteric methane emissions. Methane energy losses as percent gross energy were higher in in Holstein Friesian x Hariana cross cattle than in Holstein Friesian cattle or buffaloes (Lal et. Al, 1987). In addition, Galbraith et al (1998) reported methane losses of 6.6, 5.2 and 3.3% of gross energy intake for bison, wapiti and white-tail deer, respectively, when these animal were fed alfalfa pellets.

Research on non-bovine livestock

Greenhouse gas emissions from non-bovine livestock are low either because their populations are relatively small (sheep) or because they are not ruminants (swine, horses and poultry). Although non-ruminant animals produce CH_4 from fermentation in their large intestines, the quantities emitted are minor—less than 10% of ruminant CH_4 production (Nietzert et al., 1999). The majority of CH_4 production from non- ruminants comes from the anaerobic breakdown of their manure.

Most of the GHG research related to these species deals with the management of swine manure lagoons and storage areas. Methods employed include the mass balance, micrometerological, gas chromatography and infrared gas analysis techniques used for estimating emissions from soils (Husted, 1994). There are no citations on the actual measurement of swine, sheep, goat, horse, or poultry GHG emissions in Canada apart from what is estimated from the emissions factors in the 1996 IPCC Guidelines and Regulations and related documents. These numbers are very broad and may not be applicable to Alberta because the work has been conducted in tropical countries and in Europe.

Livestock Greenhouse Gas Emission Factors

Livestock GHG emission factors from international research are presented in Table 6. There have been few research studies in western Canada compared to the number conducted in other parts of the world. Western Canadian livestock emission factors are higher compared to those measured in Europe and more tropical countries.

Methane emissions are higher from cattle and swine manure compared to other livestock because cattle produce a larger volume of manure per head and swine manure emits more CH_4 and N_2O in the medium and long-term. Swine manure storage and application approaches also determine the medium to long-term emissions from manure.

Table 6. Livestock Emission Factors from international research.

Animal Type	CH_4 emission factor (kg CH_4 $head^{-1}$ y^{-1})
Cow (Beef or B)	47[3] (International), 50[13] (United States), 57.3[5] (Canada), 59.76[10] (Australia), 71[1](Canada), 79.9[2](Aus), 94.5[2](Aus), 97.9[8] (grass)(Can), 107.6[8] (alfalfa-grass)(Can), 60-71[17](United States), 54-69[16] (United States), 84[18](AUS-United States), 68.6[19](U.S),54[24](Germany), 47.1-51.5[26] (grazing w/ supplements-Mexico), 69.3-70.5[26](large area grazing-Mexico), 55.4[32](Japan),
Calf (B)	24.1[1] (Can), 29.1[5](Can), 38[13](less than 2yr-United States), 13.8[19](United States), 51[24](6-24 mon.-Germany), 27.2[30] (New Zealand), (63.7,61.2, 57.2) [31](steers on barley-Canada)
Breeding bull (B)	83.4[1] (Canada), 99.5[19] (United States)
Steers (B)	69.1, 73.3(Rotational[7]-Canada), 63.4, 80.3 (Continuous grazing[7]-Canada), 67[21] (early grazing-Canada), 95.3[21] (midseason grazing-Canada), 89.6[21] (late grazing-Canada), 65[24] (weighted average-Germany), 54.1[32](Japan), 67.9[32](Japan)
Repl. Heifer (B)	39.5[1](Canada), 57.6[19](United States), 59.8[22](forage-*ad libitum*-Canada) 72.9[23](chopped alfalfa/supplement-United States), 65[24] (weighted average-Germany)
Backgrounder (B)	39.5[1](Canada), 52.9[19](U.S)
Finisher (B)	34.7[1](Canada)
Cows (Dairy or D)	118[3] (International), 95.6[4](New Zealand), 105[1](Canada), 113.52[10](Australia), 137[9] (lactating-grazing-United States), 91.1[5](Canada), 19.5-117.3[11](U.K), 41.1[12](U.K), 71[13](lactating-United States), 49[13](dry-United States), 109-126[17](United States), 84-118[16] (U.S), 35-46[16] (Indian), 140[19](U.S-high end), 55[19] (low milk prod-United States), 66[19] (moderate milk prod-United States), 128.8[19](United States), 84[24](Germany), 96.0[27](New Zealand), 141.9[29] (barn-Canada), 165.2[29](feedlot-Canada), 121.5[32](lactating-Japan), 70.3[32] (pregnant &dry-Japan)
Calf (D)	24.1[1](Canada), 29.1[2](Aus), 38[13](less than 2yr-U.S), 30[20](United States), 13.8[19](United States), 51[24](6-24 mon-Germany), 27.2[30] (New Zealand),
Bulls (D)	95.3[1] (Canada), 99.5[19](U.S), (60.5, 60.0)[25](India),
Heifer (D)	56.4[1](Canada), 57.6[19](United States), 62.3[22](forage-*ad libitum*-Canada)
Feedlot Cattle[10] (B)[24]	76.54[10] (Aus), 14-65[16] (United States), 25.6[18], (Aus), 40.1[19] (U.S), 65[24] (Germany), 31.7-34.2[26] (Mexico), 141.9[29] (barn-Canada), 165.2[29](feedlot-Canada)
Swine	14.5[1](Canada), 1.5[3] (International), 1.6[5](, 1.10[10] (per head), 1.31[19](per head), 1.5[24]
Sheep and lambs	8[1] (Canada), 7[5](Canada, 6.7[10](Australia), 5.0[19](United States), 8[24](Germany), (17.7, 19, 20.1)[27](New Zealand), 7.3[28](Rumen and Caecum-Denmark), 4.9[30] (N.Zealand), 7.5[3] (incl goats-international)
Poultry	(0.002, 0.013, 0.01) [1](Canada), 0.005[5] (Canada)
Horses	18[1] (Canada), 18[10] (Australia),
Alpaca and Llamas	19.4[19](United States), 18[24](Germany), 19.3 [1] (Canada), 10[10] (alpacas only-Australia)
Bison Bull	80.3 [1] (Canada), 55[10] (Australia)
Bison Cow	63.8 [1](Canada), 50-53[16] (buffalo- United States), 31.6[14] (Canada), 50[24](Germany),
Bison Calf	35[1] (Canada)
Deer/wapiti	10.7[10] (deer-Aus), 8.64[14] (deer-Canada), 22.8[14] (wapiti-Canada), 15[24] (includes both deer and wapiti-Germany), 3[24] (Roe deer-Germany)
Ostriches/ Emus	5[10](Australia),
Manure type[6]	CH_4 emission factor (kg CO_2-E $head^{-1}$ y^{-1})[1]
Cow	10.5 [1]
Heifer	5.3 [1]
Swine	14.5 [1]
Sheep	0.19 [3]
Horses	1.4 [3]
Poultry	0.078 [3]
Goats	0.12 [3]

[1] Exception made for swine manure. Reported in sow units not heads (defined as one sow and 15 pigs raised from birth to slaughter at 100 kg). One sow unit produces 304.5 kg $CO_{2/}$ equiv/sow unit/ yr of CH_4 from manure and 434 kg CO_2 equiv/sow unit/ yr of N_2O from manure (Basarab et al., 1999)
[2] Herd, R.M. et al., 2001
[3] IPCC, 1996
[4] Lassey et al., 1997
[5] Desjardins and Mathur, 1997
[6] based on production of manure yr^{-1} $animal^{-1}$
[7] McCaughey et al., 1997
[8] McCaughey et al., 1999
[9] Kinsman et al., 1995
[10] For all beef, dairy, feedlot cattle, sheep, pigs, other in 1990. Feedlot cattle are a more generalized class based on whether they are exported or domestic and length of stay in the feedlot because of the high energy diet they are fed- similar to finisher and backgrounder cattle. Australian Greenhouse Office. 1998.
[11] Jarvis and Pain, 1994
[12] Moss, 1992
[13] Eggleston and Williams, 1989
[14] Galbraith et al., 1998
[15] Mathison et al., 1998
[16] Johnson and Ward, 1996
[17] EPA, 1993
[18] Harper, et al. 1999
[19] Johnson et al., 1997a
[20] Johnson et al., 1997b
[21] Boadi et al., 2002
[22] Boadi and Wittenberg, 2002
[23] Johnson et al., 1994
[24] Crutzen, et al., 1986
[25] Huque and Chowdhury, 1996.
[26] Ruiz-Suarez et al., 1997
[27] Ulyatt et al., 1997
[28] Immig, 1996
[29] Kaharabata et al., 2000
[30] Lockyer, 1997
[31] Okine et al., 2001
[32] Shibata et al., 1993
Note: 10 of the 32 references are applicable to western Canada.

Emission factors used to calculate emissions from livestock populations

The IPCC Tier 1 method used to calculate CH_4 emissions from livestock takes into account type of animal, animal population, quality of feed, feed intake, milk production and climatic region. Weight, age, gender, and feeding system factors are averaged or assumed similar throughout the group. This method is limited and does not include factors such as weight gain and feeding differences. The IPCC Tier 2 guidelines describe a preferred method to calculate CH_4 emissions because they consider important factors such as weight, age, gender and feeding system (IPCC, 1996, IPCC, 2001).

Okine et al. (2000) developed an Alberta-based method (IPCC Tier 2) for estimating CH_4 production. This method uses experimental data to predict feed intake through linear regression and uses mass balance or efficiency of rumen digestion to calculate emissions. This process involves feeding the subject animal a diet with a specific metabolizable energy concentration. The cattle are weighed weekly to monitor gain. The growth of the animal is modeled using linear regression of weight over time to estimate average daily gain and mid-test weight. Feed intake is calculated by taking the daily energy intake of different rations (if the animal was fed more than one type of ration) and adjusting it with the common energy intake between the various rations. The feed conversion ratio is calculated as dry matter intake (DMI) divided by the average daily weight gain in the animal. Metabolic body weight was calculated as mid-test weight raised to the power 0.75. The linear regression feed intake model was used to predict mean average daily feed intake of the animal population. The metabolizable energy needed for maintenance and metabolic energy intake are required to calculate GHG emissions. Methane from enteric fermentation as a %age of gross energy intake and CH_4 production per day is calculated using an equation that takes into account digestibility of the feed and feed intake relative to the amount of feed needed for maintenance (AGO, 1998). This method was originally derived from the Blaxter and Clapperton equation (1965) (Jarvis and Pain, 1994; IPCC, 1996; Lassey et al., 1997; Basarab et al., 1999; AGO, 1998; Herd et al., 2001; IPCC, 2001).

Summary of Knowledge About Greenhouse Gas Mitigation Practices for Livestock Management

- Methane emissions are influenced by species, animal type within species, weight, composition of diet, location, time of year, days on feed, productivity level and age.
- Beef cows emit more CH_4 than beef calves.
- Dairy cattle emit more CH_4 than beef cattle because they are managed for high production.
- Management for increased production efficiency reduces GHG production per unit production.
- Feed testing and ration balancing leads to reduced GHG emissions in livestock production systems.
- Cattle on forage-based diets produce more CH_4 than cattle on grain-based diets. Feeding higher-quality forages reduces CH_4 production from cattle.
- Formulated diets for reduced protein, maintaining the amino acid balance, will reduce manure N_2O emissions.

- Feedlot production is energy intensive because large cattle populations are housed and fed high energy diets including grains and grasses.
- Researchers are currently designing integrated models that take into account the energy inputs by production system. This research assumes that livestock production is energy intensive because animal growth depends on diet.

Identifying the Research Gaps for Livestock Management

1) The research is not conclusive whether genetic selection for feed efficiency reduces CH_4 emissions. Long-term research is necessary to determine the implication of genetic selection on livestock management practices.

2) Ionophores reduce CH_4 emissions for both beef and dairy cattle. However, this additive is known to be effective in the short-term (2-4 weeks). Methanogens in the rumen will likely develop immunity to ionophores after that time range. Long-term studies that include feeding various ionophores on a rotating basis are required.

3) It is not fully understood if enzymes given in mono-gastric rations can reduce manure output thereby reducing GHG emissions.

4) More research is required regarding feed supplementation, such as the introduction of lipids in ruminant diets to reduce CH_4 emissions.

5) Research is needed on GHG emission measurements from various cattle feeding production systems (e.g. does a dry lot cattle operation produce higher net GHG emissions compared to pasture-fed cattle?).

6) The suite of GHG emissions from specific practices within a management system is not complete. It is uncertain if one type of livestock feeding practice is better than others commonly used within that system (e.g. in a pasture-cattle system does a continuous grazing system emit more GHG than a rotational grazing system).

7) There is no scientific research that takes into account the GHG emissions from farm energy inputs for growing food for livestock and the growth and slaughter of livestock.

8) Manure excretion, handling, storage and application are common practices but few formal studies have been conducted in Alberta to measure GHG emitted from excretion to application.

State of Knowledge: Greenhouse Gas Emissions from Land Use and Energy Management

Farm by-products, including manure, agricultural residues and wood, produce GHG emissions when they decompose. Current research focuses on the reduction of atmospheric emissions through improved management practices, the capture of decomposition end products for use as fuel and the sequestration of GHGs in non-cultivated areas of the farm.

Greenhouse Gas Emissions from Manure and Manure Treatments

Cattle manure deposited directly onto pasture emits less N_2O and CH_4 because it has a lower water content (78% to 85%) than either hog manure or semi-solid dairy manure (90 to 99%) (Kachanoski et al., 1997). Liquid manure provides an anaerobic environment for microbes therefore liquid manure systems and anaerobic lagoons emit more N_2O and CH_4 than solid manure (Husted, 1993; Kaharabata et al., 2000). However, there are few estimates in the scientific literature of the actual quantities of GHG produced by these systems.

Greenhouse gas emissions from manure are measured using methods similar to those used for soil (IRGA, micrometerological with eddy correlation, and TDL TGA). The sulphur tetrafluoride (SF_6) tracer technique has been used to compute the mass balance between the animal and its excreta. A more recent field measurement technology includes INNOVA Inc. photo-acoustic gas monitors that measure all three GHG's for compost heaps and manure lagoons. In dung pats, measurements are generally taken daily (or multiple times per day) over a period of 10 to 20 days whereas measurements from compost may be taken daily over 30 to 60 days (Holter, 1997).

Composting

Composting involves the aerobic breakdown of organic matter. As discussed previously, there is a loss of GHG (N_2O, CH_4, and CO_2), nutrients and water through the composting process but carbon and nitrogen become concentrated in the final product (Zhang et al., 2001). Composting of manure, agricultural residues and combinations of these with other organic by-products has become a popular method of turning wastes into marketable products.

When manure is composted, anaerobic microsites in the manure will produce CH_4 and N_2O emissions. These sites are normally disrupted when the compost is handled—denitrification and CH_4 production is minimal in properly managed aerobic composting (St. Jean, 1997). Li et al., (2001) suggested that the aerobic composting in contrast to anaerobic digestion of liquid manure from hogs and slurry/anaerobic lagoons would solidify the liquid manure.

Most of the reported manure composting projects in Alberta have been conducted in the southern part of the province. These have included composting manures from different animal types (cattle, swine) and management systems, (feedlot, pasture, free-stall barns). Scientists at Agriculture and Agri-food Canada's Lethbridge Research Centre have reported emission levels of 6.3 g CH_4 kg^{-1} fresh manure and 0.11 g N_2O kg^{-1} fresh manure from passive composting systems. In active composting systems, emissions were 8.1 g CH_4 kg^{-1} fresh manure and 0.19 g N_2O kg^{-1} fresh manure (Larney et al., 1997; Hao et al., 2000), suggesting that passive composting may emit less GHG, although passive composting is a slow process the yields poor product. Windrow and active composting of manure and other organics were more common 15-20 years ago but nitrogen losses limit the effectiveness of these methods. The majority of nitrogen losses are due to leaching and ammonia volatilization with lesser amounts associated with N_2O emission (St. Jean, 1997, Tenuta et al., 2001, Zeman et al., 2002)

In-vessel compost systems are becoming more common. A company based in British Columbia designed an Edmonton composting facility owned by the University of Alberta. Transform Compost Systems (TCS) designed and built this 10,000 tonne per year facility to handle all the cattle manure, liquid hog manure, and poultry litter from the University of Alberta Edmonton Research Station (University Farm). The enclosed facility has a biofiltered to eliminate odours and reduce GHGs because residential housing surrounds the farmlands.

Feedstocks used in the TCS system are pre-blended using an auger-mixer and then loaded into the composting channels. The four concrete channels are ten feet wide by eight feet high and 130 feet long. Centrifugal fans drive air through five aeration zones in the floor to ensure aerobic conditions and maintain compost temperatures at 55 to 60°C. A compost turner rides on top of the concrete walls, mixing and aerating the material as it moves along the length of each channel. Raw waste is placed in one end and compost is removed from the other end of the system after four weeks. The compost is then stockpiled on an adjacent concrete pad to cure for up to a year. This is one example in which composting may be widely used for the treatment of manure to reduce its GHG emission potential.

Anaerobic digestion research

Research on the anaerobic digestion of farm by-products and manure has focused on the details of digester technology. The majority of digesters in use today are sequence batch reactors, complete mix digesters, or plug flow digesters. All ferment organic wastes (e.g., manure, crop residue, wood chips, etc.) to produce biogas (CH_4 and CO_2) and effluent (the anaerobic equivalent to compost). Similar technologies are employed in Alberta for treatment of municipal waste.

Much of the commercial development of anaerobic reactor technology has been done in Europe and the United States. These technologies can be adapted to function year round in Alberta's colder climate. An impediment to their application in rural Alberta is the high investment cost of the current technology.

Examples of biogas digesters

The following are examples of how anaerobic digestion is currently being used in farm and small community systems:

In Minnesota, the USEPA AGSTAR program has installed a prototype anaerobic digester on the Haubenschild Farm. Manure is digested to produce energy, which provides heat and electricity to the farm. At present, the farm is a 950 cow dairy operation that produces 40,000 to 50,000 kW day^{-1} of electricity, which is 33% more energy than required for the farm itself. The excess energy is sold to East Central Energy to provide power and energy to neighbouring homes. The residual solid material is used as fertilizer on 283 ha of cropland (Nelson and Lamb, 2000, USEPA, 2001).

A pilot scale project in Guelph, Ontario uses municipal organic wastes to produce heat, electricity and a stabilized organic fertilizer. The process produces a continuous electrical energy contribution to the power grid (5 kW) as well as thermal energy (8.120 MJ h^{-1}) (Vogt and Holbein, 2001). Because the waste streams being fed into the Guelph digester are quite different than those produced on-farm, the residual output is also different than that produced by a farm digester. Farm digester inputs are more homogenous by-products and wastes that may complement each other.

Within the Prairies there are two pilot projects on anaerobic digestion of farm organic wastes. The first, in Saskatchewan, has finished the first year of the pilot phase. This project has become commercialized from 2002 to digest manure and residue wastes. The second project, in Alberta, is called the Integrated Manure Utilization System (IMUS). Feasibility studies have been completed and the pilot phase is just beginning. It is on the path for commercialization in 2004.

There is an operating digester located at a Hutterite colony near Viking, Alberta. The digester treats several waste streams from the colony and has experienced few technical difficulties. A second commercial digester is being proposed within the same county.

Bioethanol, Biodiesel and Other Renewables: Research Themes

There has been limited published, non-commercial western Canadian research on the production of agricultural biofuels from 1990 to the present. Much of the early work on the use of yeasts to generate CO_2 and ethanol was done by the food processing industry to improve the production of baked goods and alcoholic beverages. There is published research on biodiesel and bioethanol from the energy crisis of the 1970's. Little research was published between the period between the early 1980's and the late 1990's.

Citations dealing with the production of fuel ethanol from barley and wheat increased again between 1999 and 2001. Some studies have focused on the characterization of yeasts and their alcohol yield efficiencies. The fermentation vessels are also characterized for capacity, and ability to minimize contamination from other yeasts and bacteria. More recent citations focus on using enzyme digestion technology to convert ethanol from cellulose that comes from energy crops and biomass by-product (from straight grain production). This is intended to improve the economics of ethanol production and to some extent net energy content on a life-cycle analysis. Production of ethanol for clean-burning gasoline-ethanol blends is becoming more common in Canada. There is one commercial production facility currently operating in Alberta with ethanol as a secondary product.

Biodiesel is an alternative fuel, produced from vegetable oils, which can be blended with petroleum diesel to create biodiesel blends. Biodiesel is made through a chemical process called transesterification whereby glycerin is cleaved from vegetable oil glycerides. The process yields two products: fatty acid methyl esters (the chemical name for biodiesel) and glycerin, a valuable by-product sold for use in soaps and other products.

The most recent research work on biodiesel has come from the United States. Biodiesels like rapeseed methyl esters and soy methyl esters have been thoroughly researched and have been manufactured commercially in the United States and Europe since the early to mid- 1990s (International Energy Agency, 1994). Research has focused more on manufacturing technologies than on the emissions produced by the process.

Most biofuel research has compared the physico-chemical qualities of biofuels with fossil fuels, including comparisons of GHG emissions from their combustion. Quantitative emissions values from studies that repeatedly test biodiesel are absent, however qualitative criteria are known. Alternative Fuels Handbook reported "in a pre-chamber diesel engine using a transient eight-mode test, straight soy methyl ester showed a significant reduction in hydrocarbon emissions, no significant change in carbon monoxide emissions, and a slight reduction of nitrogen oxides. These results may be less favourable if the engine were recalibrated to the same maximum power output as when using No. 2 diesel fuel" (Bechtold, 1997). The GHGs emitted during the production of biofuels have not been characterized in formal studies.

Wetlands, Streams, Riparian, Woodlots, Agroforestry (WSRWA)

There is little research on specific GHG emission factors in riparian areas, wetlands, streams, woodlots, and agroforestry, studied in an agricultural context. Many of the citations look at these areas as potential agricultural GHG sinks.

Carbon sequestered in woodlots, shelterbelts and agroforestry are aboveground carbon and are considered temporary because the trees may be harvested (Kort and Turnock, 1996; Johnston et al., 2000). The research focuses on the amount of carbon each different tree species sequesters per year (Bozic, 2001).

Riparian areas, where moist to wet conditions support lush vegetation, are generally considered carbon sinks (Crill et al., 1992). However the wetland bed (bottom of ponds and fens) is considered a source of CH_4 because accumulated organic carbon is subject to slow anaerobic decay (Crozier et al., 1995). Nitrous oxide is also emitted because the mineralized nitrogen is denitrified (Desjardins and Mathur, 1997, Freeman et al. 1997). Wetlands, streams and their associated riparian zones could play a significant role in net GHG balance of a region (Environment Canada, 2001) because of the carbon sink potential, however, the area of land this occupies on the land is a small percentage on farms (Environment Canada, 2001).

Greenhouse Gas Emission and Sink Factors for Land Use and Energy Management

There are many benefits implementing the use of farm by-products (Table 7 and 8). Some emission factors for certain practices are cited in the literature however; for the most part emission factors are not quantified. General conclusions on whether these practices increase or decrease GHG compared to conventional methods can be made.

Table 7. Benefits of using manure management and associated emissions factors.

Manure Management	Benefits	Emission Factors
Manure Additives	o Odour control/reduction/ measurement o Reduced NH_3, N_2O, and CH_4 emission than conventional methods o Direct seeding compatible o Replacement of energy intensive fertilizers for land application	Phosphogypsum, wood chips, straw (0.00009-0.0073 tonne CO_2E per tonne manure) Other high C waste co-products (corrugated cardboard = 0.0015 tonne CO_2E/ tonne manure)
Aerobic Treatment	Same as manure additives o May emit more N_2O but reduction in CH_4 is offset	None found
Manure Storage Covers	Same as manure additives o Low water quality risk o Easier measurement of GHGs o Geotextile and impermeable covers (No research in AB)	None found
Enclosed Composting	o Reduced CH_4 and N_2O o Reduced odour o If digested, option for reducing nitrogen/P loads on land o Destruction of weed seeds and pathogens	0.11-0.19 kg N_2O $tonne^{-1}$ manure (passive and active)
Solid-liquid Separation	o Reduced CH_4 emission o Reduced odour o Liquid and nutrients retained	None found
Anaerobic Digestion	o Reduced CH_4 emissions (CH_4 is burned to produce H_2O and CO_2) o Reduced odour o Destruction of weed seeds and pathogens o Nutrient are converted to a form that is more readily available to crops o Biogas generation (CH_4- 50-75%) – can be used as an on-farm energy/heat source	None found

Table 8. Benefits of using bioenergy and biofuels and associated emissions factors.

Bioenergy/biofuels	Benefits	Emission Factors
Bioethanol	○ Less dependent on fossil fuels for machinery ○ Less GHG emissions ○ Renewable	None found
Biodiesel (Rapeseed Methyl Ester)	Same as bioethanol ○ No research in Alberta	None found
Agricultural Residues	Same as bioethanol ○ Used for heating buildings ○ Economical ○ No research in Alberta	None found
Wood (woodlots and shelterbelts)	Same as bioethanol	-16 to -32 tonnes CO_2 E ha^{-1} yr^{-1} (Kort and Turnock, 1996)
Wood (agroforestry)	Same as bioethanol	-0.14 to -1.36 tonne CO_2E ha^{-1} yr^{-1} (AAFRD, 2000)

Summary of Knowledge About Greenhouse Gas Mitigation Practices for Land Use and Energy Management

- Manure is a source of GHGs—primarily CH_4 and N_2O. It is not recommended that raw manure be applied on soil without incorporation.
- Composting produces a product more concentrated in carbon and nitrogen per unit volume than raw manure but the process itself (depending on whether it is passive or active) produces GHGs.
- Applying composted manure to land emits less GHG than applying untreated manure
- Biofuels, such as ethanol and biodiesel, have potential as alternatives to conventional fuels.
- Woodlots and agroforestry are potential GHG sinks

Identifying the Research Gaps for Land Use and Energy Management

1) Composting and anaerobic digestion research needs to be conducted in colder climates such as Northern Alberta.
2) More research measuring net GHG emissions from different types of manure, manure storage methods, different manure treatments, and different methods of application is needed.
3) Research measuring net GHG emissions from composting is needed. This should include different types of composting treatments (e.g. passive vs active) and different types of compost starting material (straw, wood, manure).

4) More research is needed to understand the stability of carbon and nitrogen in composted and anaerobically digested manure, especially for long-term applications.

5) More research to quantify GHG emission/sequestration from placing manure on direct seeded and pasture systems is needed.

6) More research is needed regarding the feasibility of on-farm energy production (e.g. solar, wind, biofuels).

7) Research measuring net GHG emissions from producing and burning biofuel as well as the reduction in GHG emissions from energy-efficient infrastructure (buildings, harvesting machinery, transportation) is needed.

8) Research on carbon sequestration in woodlots, including consideration for soil carbon and wood products is needed.

9) Research on shelterbelts and woodlots emphasizing interactions with surrounding land (e.g., Snow trapping leading to increase in spring GHG? Moisture/carbon competition with crops? What is net GHG balance?).

10) An accurate and comprehensive inventory of wetlands, streams, and riparian areas must be conducted. The proportion of wetlands, streams, and associated riparian areas on farms or directly impacted by farms must be determined.

11) More research is needed on the change of carbon stocks (including GHG emissions and sinks) resulting from wetland destruction and restoration. Research is needed on the change of carbon stocks in existing wetlands (GHG emissions and sinks) as a result of management practices on surrounding uplands.

Scaling-Up

Whole farm inventories focus on summing all the emissions from the main practices in crop production, livestock, energy inputs, heating, and transport to estimate total farm GHG emissions. The inventories that use the Intergovernmental Panel on Climate Change (IPCC) Tier 1 coefficients assume that farms in the same agricultural region (e.g. North America) have similar if not identical management practices, and the same farm type (Desjardins et al., 1997, Lemke et al., 1998a). This assumption results in sizeable error.

Only three Canadian research studies have considered the farm as a whole in attempts to scale-up GHG emission measurements to the ecodistrict level. However, this technique is new and authors have identified problems due to variations in farm sizes, differences in practices between farms, differences in microclimate, and differences in the spatial and temporal scales over which GHG processes operate. Some of the polygons (area of land) used for regional and overall monitoring have unequal numbers of farms. A township may have anywhere from one to five farms and all of them may have different production systems and different management practices. Scaling homogenous plots to heterogeneous ecodistrict measurements is a technique that will improve over time. At present, the limitation to scaling-up is the insufficient availability of farm management change data and of reliable estimates of spatial and temporal variation in GHG processes.

Models

Most modeling research is limited to soil and land-use based models and they do not take into account all the GHG emissions and sinks from all components on the farm. The main soil carbon and nitrogen models include:

- CENTURY (carbon and nitrogen balance-United States);
- EPIC (soil environmental indicators-United States);
- CQUESTR (user friendly continuation of CENTURY);
- ecosys (carbon, nitrogen and phosphorus balance-northern climates, Canada);
- BOREAS (carbon and nitrogen balance-northern climates, Canada);
- FACE (CO_2 emissions and soil fertilization scenarios-World model);

- expert-N (nitrogen- utilization efficiency-United Kingdom);
- DNDC (denitrification-decomposition of soil organic nitrogen, United Kingdom, United States), and;
- CEEMA (CRAM-GHG, farm models, Canada).

The CQUESTR model is the newest model and it had one citation on its technical structure. The CQUESTR model incorporates management practices on agricultural and rangeland soils but it does not considered livestock, farm fuels and by-products. Its calculations may not be appropriate for Canada's northern climate because its default inputs are for US climates. Most of the other models are used for agricultural soil scenarios but do not include pastures, woodlots or riparian/wetland areas. CENTURY is widely used for cultivated and rangeland soils but it is not user-friendly.

The most holistic citations were those that used the CEEMA-CRAM-GHG model produced by Agriculture and Agri-food Canada from 1998 to 2001. CEEMA-CRAM-GHG looked at all components of the farm. Some of the newer modeling scenarios include irrigated and non-irrigated farms. One citation examined the difference between irrigated and non-irrigated lands through the CRAM-GHG or CEEMA models in 2001 (Kulshestra and Junkins, 2001). Future research may provide a more integrated insight to all combinations of management scenarios on the farm. However this model can only handle one change in management practice during a single modeling run. In addition, it is an economic-based model, which does not account for all the complexities of the science behind GHG emissions. This model will need some improvements before it can be used as a Canadian GHG assessment model.

Livestock researchers have produced independent estimates regarding CH_4 emission using the metabolic energy method (Herd et al., 2001). These emission factors are useful for incorporation into simulation models. There are separate models (or calculators) that are currently being used to calculate GHG emissions from livestock but these have not been integrated with the soil models.

Biofuel production is not included in any modeling scenarios and, similarly, there are no modeling scenarios that considers manure or crop residues as biofuels. This may be because manure is spread on such a small percentage of the agricultural land base in Alberta

(5.3%) (Statistics Canada, 2002) and, at present, agricultural residues are not being used as a biofuel in Alberta.

Summary of Knowledge About Greenhouse Gas Mitigation Practices for Whole Farm Systems

- There are models available to estimate GHG emissions from different sections of the farm.
- Greenhouse gas estimates for the whole farm system will need to be calculated using models.
- The metabolic energy model is a comprehensive model that estimates of CH_4 emissions.

Identifying the Research Gaps for the Whole Farm System

1) Development of a comprehensive model to deal with the whole farm system is needed. Integration of livestock estimates with soil and land-based models to account for removal of carbon (feeding of grain and forage) and input of manure (storage, treatment, and application) are needed. Livestock models are beginning to incorporate the animal-land interface in livestock GHG estimates but are still in the early stages. A partnership of both categories of models would benefit the whole farm scenario.

2) Modeling needs to include wetlands, riparian areas, woodlots, agroforestry and biofuels (including manure management). The input of this data may be limited because of the lack of GHG related research on these areas.

3) Validation of models is required using measured data that takes into account all temporal and spatial situations. The measurements should be repeatable within reasonable ranges.

4) Linkages between GHG audits to the environmental farm plan, agronomic software, commercial/farm data management software should be explored

5) A comparison study is needed to document the applicability of Statistics Canada Data and other existing databases to capture information on agricultural activities. In addition the Environment Canada National GHG inventory values should be compared to the GHG on-farm audits conducted in Alberta.

6) Development of databases that contain land management data such as land management change data is needed for more comprehensive modeling to be successful.

Conclusions and Recommendations

This report gathered, evaluated and synthesized the current state of agricultural GHG research focusing on soils and crop management, livestock management, land use and energy management and whole farm systems. From this synthesis and evaluation of current research, gaps were identified in the current state of knowledge on agricultural GHG research. This report was then peer reviewed by scientific experts across Canada at a workshop in Canmore, Alberta in 2003. The workshop provided feedback on this document in addition to providing information for a subsequent document, the Agricultural GHG Science Plan for the Prairie Provinces (see Chapter 3 of this report).

Soil and Crop Management

There has been significant advancement in the state of GHG research in the areas of soil and crop management. Past research concentrated on carbon sequestration and CO_2 emission from soil. More recently, research is instead focusing on N_2O emissions from soils because it has a higher global warming potential than CO_2.

For the Prairie Provinces, most of the research is conducted in the southern area of the provinces limiting the extrapolation of results to northern regions. In addition, these measurements are site- and management-specific. As well the interaction between different management practices (e.g. GHG emissions from an irrigated field fertilized with manure with a wheat-wheat-legume-barley-oilseed rotation) is unknown. All of these factors make it difficult to produce an accurate measurement of GHG emissions across the Prairies.

Further research is needed to determine the permanence of newly sequestered carbon in soils and the effect of nutrient limitation on carbon sequestration. In addition, future research should concentrate on the different sources of N_2O and ways to accurately measure these emissions.

Livestock Management

Methane emission estimates are well documented for beef cattle in Western Canada, although measurements do not accurately reflect the effect age, weight, gender, feed amount, feed quality, and feeding practices have on CH_4 emission. Feeding a high quality diet (balance of forages and grains) is an effective mitigation practice that reduces CH_4 emission. In addition, feed additives and antibiotics such as ionophores are continuing to be tested to determine the long-term effectiveness in reducing CH_4 emission. In Alberta, beef cattle contribute 90% of the GHG emissions; therefore as their population grows so do their emissions. New research should consider the effects of emergency feeding situations which arise from drought, abnormally wet growing seasons, early frost or higher than normal summer temperatures.

Although both dairy cattle and swine contribute a smaller amount of Alberta's GHG emissions, it is still vital to determine a mitigation strategy. For swine and dairy systems, emissions could be extrapolated from eastern Canadian figures but a province-based figure is needed to help reflect the Prairie's unique management practices. Current swine research focuses on GHG emissions from manure excretion and storage. Therefore, if populations of these animals continue to grow, GHG emissions from the animals and their manure will also continue to grow. Little research has been conducted on GHG emissions from horses, exotic livestock and poultry. The need for GHG research in these areas depends upon increasing populations.

Additional research needs to focus on ways to reduce GHG emissions from this sector and to find ways to accurately measure on-farm CH_4 and N_2O emissions.

Land Use and Energy Management

At the current time, research on GHG emissions from land use and energy is limited. The volume of composting research is increasing and the gaps identified within this report should help guide research in this area. Biofuels (bioethanol, CH_4 from anaerobic digestion, biodiesel) research is primarily driven at the commercial level, which results in little published scientific literature. This area of research has a large potential to provide GHG mitigation strategies and increase production efficiencies on the farm.

Whole Farm Systems

One of the primary goals of this report was to determine the feasibility of calculating GHG emissions from a whole farm system. To accomplish this goal it is essential that emission measurements include all components of the farm. One method is to take site-specific measurements and scale up to the whole farm level. However due to variability in soil properties, topography, microclimate and soil and livestock management practices there is increasing error in GHG emissions estimates associated with scaling up from site-specific measurements to the whole field, whole farm, or multiple farm level.

Another method to determine GHG emissions at the farm level is to utilize models. Although individual models that determine GHG emissions from soils, crops or livestock have been developed, few are capable of integrating the different systems to give an accurate assessment of GHG emissions. In addition, modeling results need to be validated with field measurements, however at this time field measurements of GHG emissions from whole farm systems have not been completed.

In theory, a combination of site-specific measurements and data modeling may be the best way to estimate GHG emissions from the whole farm. However this is difficult to achieve because a township may have anywhere from one to five farms and have different production systems and different management practices, which may not be representative of any particular farm. As well, both microclimate and topography need to be considered in the scaling estimates. On the other hand, specific sites may provide too much detail for the development of regional simulation models. These two schools of thought are both important, and striking a balance between the two is needed. However this is not feasible until a complete inventory of verifiable measurements for all soil and livestock scenarios for the Prairie Provinces can be produced. In addition, the research community needs to decide how large of an error is acceptable when scaling up from site-specific measurements to a regional level.

Continuing progress on GHG emission measurements, modeling and experiments that integrate all components of the farm is needed. This report met the objective to gather, evaluate and synthesize current literature on agriculture GHG research for different soil and livestock management practices. Through the identification of knowledge gaps, there is currently not enough information available to produce an assessment that will accurately reflect the actual conditions of a typical farm within a reasonable range of error.

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APPENDIX A:

PROCITE DATABASE NOTES

Compiled by

Connie L. Hall, M.L.S.
and
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For

Alberta Agriculture, Food & Rural Development

ProCite Database Notes

By

Connie L. Hall
October, 2002

OVERVIEW

The Agricultural Greenhouse Gas Emissions (Ag GHG) Literature project of 2001/02 included a plan to review the science-based literature concerning greenhouse gases produced as a consequence of agricultural operations. In order to facilitate this review, it was necessary to identify and to compile the literature resources concerning carbon dioxide, nitrous oxide, and ammonia emissions with respect to farm-level activities.

A comprehensive database of related literature was created from July to December 2001 using a bibliographic management software product of ISI Research_Soft known as **ProCite** (Version 5.0), available for trial or purchase via the world-wide web at http://www.procite.com/). This software simplifies the collection, downloading, editing, and compiling of references to scientific literature from numerous databases and agency web sites.

Sources of citations included commercial databases specific to related topics within agriculture that deal with the greenhouse gases -- CO_2, N_20 and NH_4 -- which were:

--**Agricola** (all years available, searchable online via WebSpirs);
--**CAB Abstracts** (available on CD-ROM in the AAFRD Library).

Additional commercial databases searched for carbon dioxide, nitrous oxide, and ammonia (or CO_2, N_20 and NH_4) emissions with respect to farm-level activities in Canada or Alberta were:

--**Conference Index** (database available via University of Alberta and AAFRD Library).
--**Current Contents** (database available via University of Alberta);
--**Environmental Science & Pollution Abstracts** (Cambridge Scientific database available via University of Alberta and Alberta Environment libraries);
--**NTIS** (all years; database available via University of Alberta);
--the **Patents** database of Canada (available online); and
--**SWS** (SouthWest Sciences) Papers and Patents (database available via University of Alberta).

Also, internet searches were conducted via Google, and in the Amazon book search services web site, to identify further sources. Agency web sites were included for comprehension and balance, such as: --

the Alberta Agricultural Research Institute (AARI) [primary funder], the Alberta Research Council (ARC), Alberta Environment, the Canadian Economic and Emissions Model for Agriculture (CEEMA), Climate Change Central, the David Suzuki Foundation, the Intergovernmental Panel on Climate Change (IPCC), Environment Canada's *Green Lane*, the American Meteorological Society, Canadian Meteorological Service, Environment Canada, United Nations, and World Meteorological Organization (WMO).

Electronic journals from the NEOS Consortium and the departmental agricultural library (subscribed) collections were also searched, along with manual literature searches performed in specifically related professional journal publications, notably: --

[American Meteorological Society publications]
Canadian Journal of Agricultural Economics
Canadian Journal of Animal Science
Canadian Journal of Plant Science
Canadian Journal of Soil Science
Climate Change Digest
[CRC Press publications: Advances in Soil Science]

Functional Ecology
[I.P.C.C. publications]
Journal of Dairy Research
Journal of Dairy Science
[Cambridge University Press publications]
Journal of Animal Science
Journal of Environmental Quality [*a primary source]
Journal of Range Management
Journal of Soil & Water Conservation
Journal of Sustainable Agriculture
Nature
Science
Soil Science Society of America Journal [*a primary source]

In addition, citations were located via standard library research, through:

-- the online **NEOS** consortium catalogue (which includes the **AAFRD Library** holdings plus The University of Alberta's *The Gate)*;
--AAFC's online **Canada Agriculture Library** (CAL) and CISTI (Canadian Institute for Scientific and Technical Information, part of the National Libraries of Canada, or NLC) search services;
--**LibNET**;
--USDA's online **National Agriculture Library** (NAL);
--from Alberta's university and college libraries and web sites;
--from other university and college libraries in Canada, Australia, and the United States;
--and from the **World Wide Web**.

Finally, the greatest contribution of both citations and articles for review for this project came from:

--resources already on hand in the **C&D** research (Agdex) files,
--office collections of **expert staff**,
--citations recommended as relevant by the Conservation & Development branch's Greenhouse Gas Committee, the intradepartmental committee, as well as external researchers with **AARI, ARC, AAFC,** and the **University of Alberta;**
--and from scrutiny of the bibliographies and references cited by the authors and researchers of GHG-related literature themselves.

The core scientific literature was thus identified, and then copies of articles of greatest relevance were obtained largely via the interlibrary loan services of the library within Alberta Agriculture, Food and Rural Development (AAFRD--now known as one component of the 'Alberta Government Library' or AGL in 2002). All articles were included in the database of literature, using ProCite 5.0 software, with input of their bibliographic elements, electronic links, and abstracts where possible. Value-added deliverables also included an extensive subject classification via keywords input within each record, per article, so that output can be generated in the form of custom-designed bibliographies or publishable bibliographic and Internet products; reviewer's ranking by assignment of priority codes; and reviewer's comments regarding content.

Procedures

The entire process may be summarized as follows:

- Identify the literature
  - Search strategies
  - Search existing document files
  - Consult staff and experts
  - Examine bibliographies and references cited
- Conduct online searches in: --
  - Library catalogues (local, regional, provincial, federal)
  - NEOS: Alberta Agriculture, Food & Rural Development Library, University of Alberta's Gate/library system, Alberta Environment Library, Alberta Research Council Library

- National Library of Canada's CISTI-CAL, to search: Canada Agriculture Library, Canadian Institute of Scientific and Technical Information for Environment Canada Library, Natural Resources Canada Library, etc.
- Other: universities and colleges: Calgary, Lethbridge, Simon Fraser, British Columbia, Fairview College, Lakeland College, Olds College Library, (+ other local libraries) etc.
- Databases
  - Agricola
  - CAB Abstracts
  - ESPA, NTIS, PATENTS, SWSI, Current Contents, Conference Index
  - Internet and WWW
  - Agency websites (provincial, national, international)
  - Search engines (Google, others)

- Structure the Database
  - Include required bibliographic elements
  - Consult researchers re value-added fields
  - Incorporate needs
  - Develop evaluative Criteria for inclusion
- Compile the literature
  - Obtain interlibrary loans
  - Arrange for photocopying
  - Conduct file management: coding, access, labeling, special collection retrieval processes
- Develop Ranking and Relevance indicators
  - Collaborate with reviewer and experts
  - Test the database and ranking factors
  - Make any required modifications
- Maintain the database and Library of documents
- Make value-added enhancements
- Make products available[1]

STRUCTURING A LITERATURE DATABASE USING PROCITE

Viewing or navigating the ProCite database

The ProCite software allows a user to change views of the database between a table of all records or an individual record. The individual record may also be viewed on a split screen, to show the workform plus the formatted reference as it would appear when cited or reported in a list.

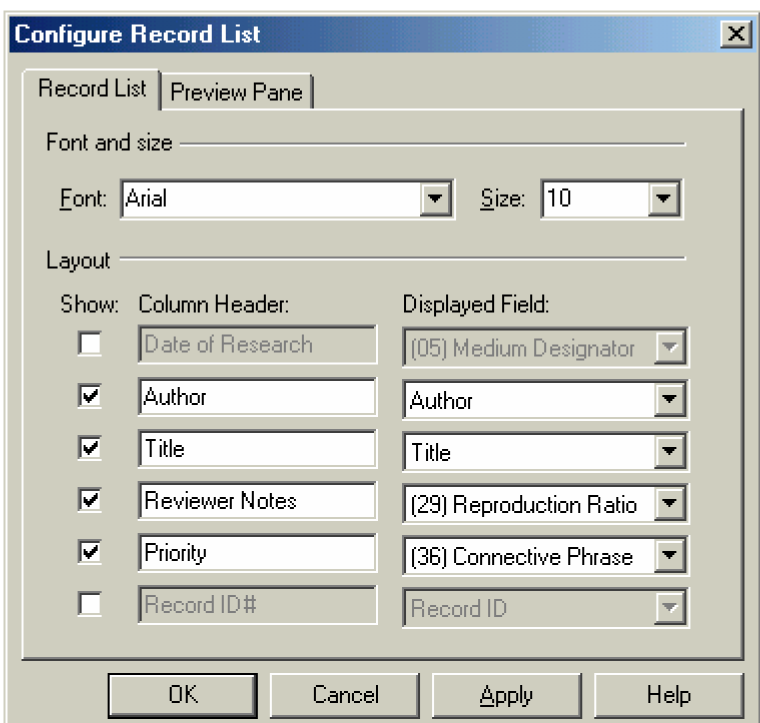
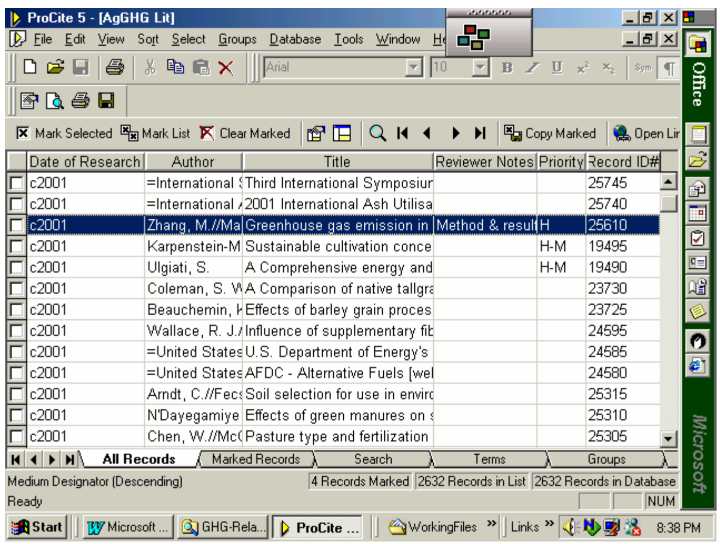


Figure 1. Ag-GHG Lit. Database – showing Fields in a Record List within ProCite

The tabular or "spreadsheet" view will appear when a ProCite database is opened, presenting columns of data. Sorting may be done by clicking on a column heading. A "Sorting Database" pop-up box will appear to show progress for the sort operation, and the rearranged data will appear on-screen after the software has performed the sort.

A standard view has been produced in the Ag-GHG Literature database, by selecting these fields in the following order for viewing: Record ID Number, Author, Date, Title, Significance, Location
The database can be manipulated to order records alphabetically by author or by title, or numerically by date or by Record ID.

Figure 2. Ag-GHG Lit. Database – showing Structure elements



The view can be changed, by going to View > Configure Record List > Record List tab, and selecting or deselecting from the check boxes and drop-down lists of fields. The order of the fields can also be changed, by retyping column headings into the template and using the drop-down lists to choose other fields to view. (ProCite allows only 6 columns for viewing on-screen, however.) By un-checking the check boxes, fields may be "hidden" from view (for example the Record IDs or locations may be "turned off" in this way). Lines between columns can be resized just as in any spreadsheet or database viewer, by dragging the line pointers to where you wish them to be on the viewing screen.

Searching:

There are two ways to search a ProCite database. The Quick Search is activated by clicking on the "Go To Record" or spyglass icon on the taskbar, where a drop-down text box will appear and give options for common ways to search (such as by Author, Date, Title, or Record ID). The full Search is activated by choosing the Search tab at the bottom of the screen, and then specifying among the multitude of fields and operators, and by typing keywords into the text box and then hitting the Search button or Enter key on your keyboard. Results for each search will be displayed on-screen immediately.

Further instructions may be found by using the Help feature within ProCite, or through access to the database manual.

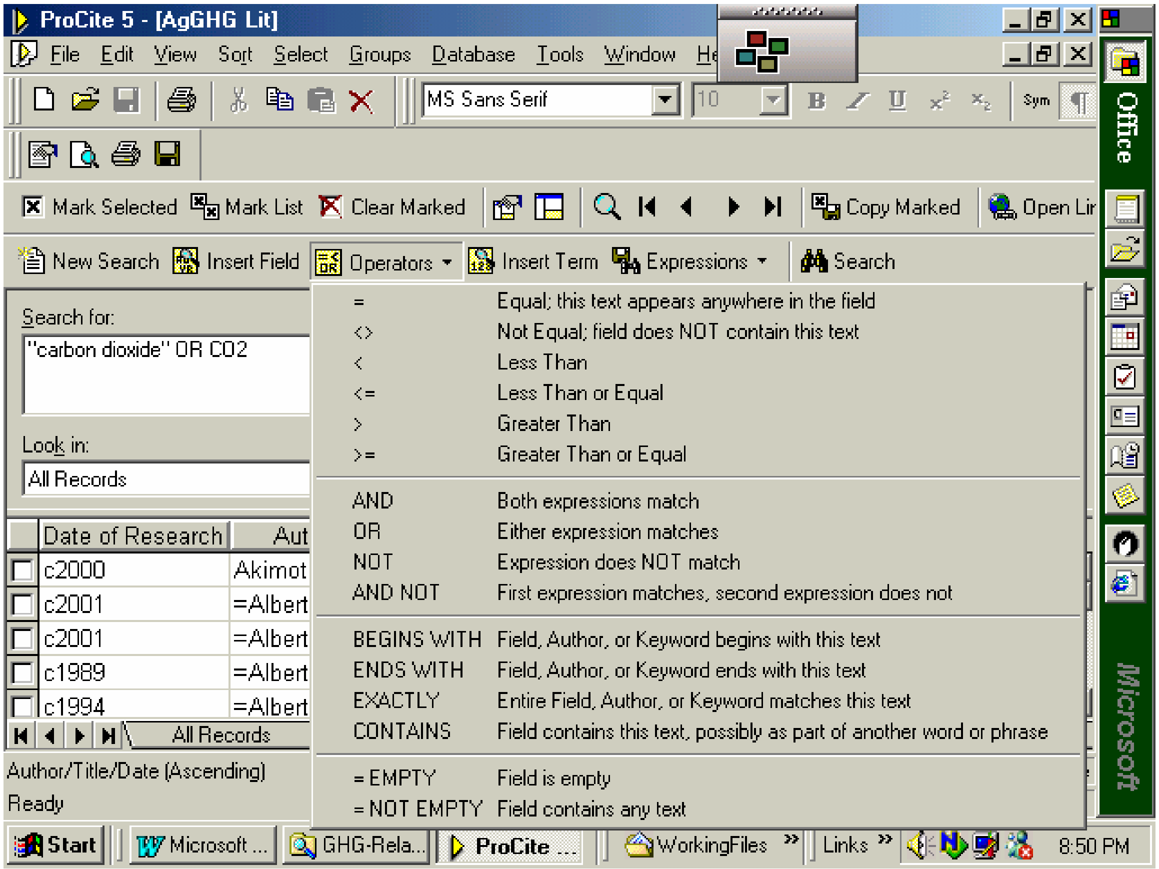


Figure 3. Ag-GHG Lit. Database 2002 – showing Search capabilities

Producing output (lists, bibliographies, subject groupings):

ProCite will allow for the creation of various printed products, such as lists of references cited. Basically, this is done by first identifying the records wanted and either marking or highlighting and then grouping them based upon what is wanted.

The simplest method is to perform a search, identify the records by using the Mark Selected or Mark List features on the taskbar, or by individually marking specific records by clicking on the box to the left of each one to select a subset. Next, go to the Marked Records tab at bottom of the screen, perform any sorting desired, remove by unmarking any unwanted selections. Then, go to File > Print Bibliography. A menu box opens, and it is here that you specify what is wanted in your output. You can Show All Records in List, Show Marked Records, Show Highlighted Records in the first drop-down selection box.

Also, you must specify Output Style from among numerous options on the middle drop-down menu, and need to spend some time in selection among all the scientific journal options. Choose the Workform option if you want each record to appear in full; otherwise the ANSI standard is the most common and generic. If you need to cite in the Author. Date. Title. Format, with dates appearing before the title, you need to find a science title that does so, with punctuation according to your preference. The next button with three dots … selects the full output styles that the ProCite software contains. The next option button (on the right) labeled "Configure" allows you to further specify in Reference List, Fields, and Page Labyout templates many further options. Of special note on the Reference List tab is the text box allowing you to type a TITLE for your output pages. Some time and experimentation are required, before your final product is printable. You may then Print or Save to a word-processor file for further manipulation before printing.

Opening Links:

Within the database, you may also automatically open web links to the Internet, if you have a browser running at the same time that ProCite is running. Just doubleclick the link in the URL field, or if this does not work, you can cut-and-paste into your browser's Location or Address window box, or click on the WebLink icon on the ProCite database taskbar. This should take you to the electronic document or link given in the database.

ProCite database structure

The ProCite software provides up to 45 fields of data presented in 39 different work-forms for bibliographic information, as follows:

Workform Fields

Record Number: Numeric, from 001 to 999. Exception: Alphanumeric, when one work is *within* another; e.g. a conference presentation published as one article within a proceedings, or one chapter within a compilation of related scientific papers on a topic or common theme, or one linked portion of a website.

Author, Analytic: Main author responsible for a work, listed by: Surname, Firstname or Initial. Second Initial. Coauthors next listed in order they appear on the main title page. Separators in ProCite 5.0 are: two forward slashes between authors; Corporate author entries are preceded by an "equals" sign, so that they will format properly at output, as distinct from personal authors' names.

Author Role: This field is usually BLANK.

Author Affiliation: Agency, institution, or workplace of author(s).

Article Title: Title, entered in "title case" (i.e. First significant word is capitalized, as are proper names, followed by lower case for all words) of the article, presentation, or paper.
NOTE: This field is treated as the primary title for viewing by ProCite.

Medium Designator: This field has been customized to reflect the DATE OF RESEARCH completed, and is preceded by a "c." To stand for copyrighted or publicly-performed material. It was set up to accommodate multi-year projects of scholarly research, which could have produced more than one published source or paper, as well as for very recent GHG science. This is the primary field for sorting by date.

Connective Phrase: This field is usually BLANK, but may state: "IN" if the article is from a collected work, conference, or compilation. Chapter number will be given here if relevant.

Author, Monographic: This field is used for the author of a book, editor of a proceedings or collection.

Editor/Compiler: The field label appears as this if the workform is for a conference.

Author Role: This field is usually BLANK, but may state: "Editor" or "Editors" where applicable.

Editor/Compiler Role: The field label appears as this if the workform is for a conference.

Title, Monographic: This field is used for books, and is the Main title field when a collected work or monograph is being referred to (as opposed to an "article"). Books have a separate workform, so most often this field does not appear in the record template, unless it is a book.

Proceedings Title: Gives the name of the conference, congress, symposium, workshop, or proceeding, as it appears on the main title page. On occasions where a conference paper is (also) published as a journal article, the reprint is always treated as an Article and so should be given in that field and not in this one.

Journal Title: Name of the periodical is given IN FULL (not abbreviated wherever possible). Use the drop-down menu to the right of the field for a full list of titles in the database.

Report Title: This field is used for all scientific and technical, government, agency, or industry reports, and is preferred to the "Article Title" field when the item IS a report in and of itself, and NOT an article published in a journal or periodical, or an excerpt from the full report. On occasions where a portion, summary, revision, or synthesis of a report is published as a journal article, the reprint is always treated as an Article and so should be given in that field and not in this one.

Newspaper Name: Gives the name of the newsletter, newswire service, or newspaper or newsmagazine title where applicable, for news items and not for periodical articles.

Source: This field stands in for, or replaces, the title field when the sources is an Electronic Citation (workform).

Date of Meeting: Gives the start date, dash, end day, Month, Year of a conference, if it was not listed in the Proceedings Title field above; and is omitted here if it was given above, to avoid duplication upon output from ProCite. This field only appears with a conference paper workform.

Place of Meeting: Gives the location of a conference, usually city, state or province, and country (if applicable); and is omitted here if it was given as part of the title in the Proceedings Title field above, to avoid duplication upon output from ProCite. This field only appears with a conference paper workform.

Reprint Status: This field may report that an item is On Request, On File, or Not on File, and gives the Date of the entry of data into the record.

Edition: This field is usually BLANK, but may indicate the date of a work, especially if it is an edition of a book or government publication that may have been revised.

Author, Subsidiary: This field is usually BLANK.

Author Role: This field is usually BLANK.

Place of Publication: City, and State or Province (abbreviated to its two-letter international code) where the article or work was published.

Publisher Name: Full name of publisher; if a government or country or institution or agency, the broadest or "highest" category is given first, followed by a comma, then the next level.

Date of Publication: Copyright date or official Date published, year only. (Months or days are given in the Notes or Edition fields, or under Issue if a periodical).

Date of Copyright: This field is usually BLANK, but may state the year when the official copyright symbol © is present. In that case, precede the year by " c. " (without the quotation marks) or c period .

Date of Access: Appears when the main title is for a Web Page workform

Last Update: Appears when the main title is for an Electronic Citation or website workform.

Volume Identification: Number of periodical or journal volume, when the article is in a journal or serial publication.

Section: Appears when the "volume" is for a newspaper title workform.

Issue Identification: Number and/or Date given when article is published in a journal or periodical. Format used was the number, followed by a space, and abbreviated month(in brackets) where provided on the source of information.

Column Number: Appears when the “volume” is for a newspaper title workform.

Page(s): Start page, dash, End page of article, chapter, presentation in printed publication or work. This field does NOT give the total length of the work (see Extent of Work field below), but is reserved for where the specific pages consulted for the literature review occur inside the whole work, such as in a periodical or as a book chapter.

Report Identification: Gives a report number where applicable.

Extent of Work: Total number of pages, or volumes, of the whole work where given in the source of bibliographic information.

Packaging Method: Use a “ p. “ to denote “pages” as in “ the total number of pages.”

Reviewer's Notes (29) This field is usually BLANK; but was CUSTOMIZED to include specific Reviewer's Notes where directly applicable to the publication. These notes are therefore SEARCHABLE by keywords.

Series Title: Name of a publisher’s or agency series, such as “Technical Report” series.

Series Volume ID: This field is usually BLANK, but may state the Number of the Report within a report series.

Series Issue ID: This field is usually BLANK

Connective Phrase (36): This field has been customized for use to indicate the PRIORITY AND RELEVANCE or significance of the article/paper/work in terms of the literature review project.

H=High M=Medium L=Low

➔ **Reviewer ranking = ________________________ Date: ___/____/2001**

[NOTE: The refinement and assignment of the RANKINGs was determined solely by the reviewer; the above criteria were specifically used in compiling the database and in presenting options to the reviewer for consideration.]

HIGH Ranking IF:

__ •Science-Based

__ •Relates to Western Canada or Alberta or Canadian Prairies

  __ • OR, has potential applicability to Alberta, if study was elsewhere

__ • Deals with a statistical method or model of direct relevance

__ • Is 'Classic' research, Contains historical or time series data of direct relevance

__ •Deals with current research (within 10 years)

__ •Is refereed or peer-reviewed, authoritative, demonstrates subject expertise

__ •Contribution is modelling or simulation

__ •Deals with qualitative aspects considered very significant to apply to this project

__ •Has applicability for Alberta's Farmer-level Survey

For firther Ranking --

__ •Discussion paper, review, or narrative, quantitative in nature, and of interest to Alberta

__ •Deals with crop, pasture, range lands, livestock, or riparian areas in terms of greenhoue gases or in relation to the project

__ •Deals with farm-level practices for a particular region or industry (or their patents)

__ •Deals with planning or policy; risk management, mitigation, emissions reduction; government-, community- or agency-action plans; or GHG emissions responses

__ •Deals with public education related to Ag-GHG emissions

Address/Availability: Where to locate a copy of the article or book.

Location/URL: If Conservation & Development Branch of AAFRD has a copy, then this appears as “c&d”. May also contain notes such as: “On Request” or “AAFRD Library”. Always shows the URL if the item is available on the Internet/WorldWideWeb.

CODEN: This field is usually BLANK

ISSN: International Standard Serial Number is given in this field; for periodical titles.

ISBN: International Standard Book Number is given in this field; for book or report titles.

Notes: **Ag-GHG Literature Review Project -- Information provided:**

➔ Record downloaded from [database name and Date]; OR,

➔ Reference cited in: [Title of Source article or publication, Author(s), Date: Page range]

➔ Any bibliographic notes.

A Table of Contents listing is included when important to this project.

Abstract: Usually gives the Author(s) Abstract, **included when important to this project,** as all words are searchable within ProCite. Descriptive abstracts are useful for the information they can provide concerning greenhouse gas research or literature analyses. The “author abstract” note with page number are given in italics, to denote that the abstract was, indeed, provided by the author or search service.

Call Number: Given when provided during searches, in order to locate the literature.

Keywords: Subject-analytic terms, classification of the literature, author(s)’ recommended terms when given, search engine descriptors and identifiers when the citation has been downloaded from literature indexes and search services or library catalogues’ subject headings used to describe their holdings. Use the drop-down menu to the right of this field for a list of the subjects in the database.

DATA ENTRY and RECORD ID NUMBERING

Records with ID numbers from 0 to 16990 were compiled by selecting from existing databases (ag air, climate, compost, and odor) on the intranet within the Conservation and Development Branch of the Alberta Agriculture, Food & Rural Development department of the provincial government. These databases contained configured records downloaded from Agricola or input manually, had been automatically assigned a record id# in increments of 10, ostensibly to be able to include other, updated, records over time in the numbered intervals. In consultation with staff of the branch where the Ag-GHG Emissions Literature database was to reside, it was determined that this software-assigned incremental numbering process should be kept and continued. However, there was enough overlap and duplication of some records in these databases to require a significant amount of editing during the initial stages of database design and testing on the current project. [Errors in the Ag-GHG Emissions Literature database are the responsibility of the compiler, and standardization occurred in data entry fields only as time permitted during our project.]

Records with ID numbers between 17000 and 18000 were reserved for resolving of duplications, for records from NEOS and University of Alberta e-journals searches, and late additions to the database. To keep the integrity of automatic number assignments by the software, and in view of the estimate that 2,000 or so records would likely be amassed, it was arbitrarily decided to start the initial database entries with Record ID #20000. Therefore, items identified via Agricola searches were first downloaded and edited during the data entry initial phases beginning at Record ID #20000 and upwards, in increments of 5. After initial database structural design and testing, some record numbering sequences were in-filled further, as the search results were expanded and refined, and as the database grew. When it was finally determined that the numbering no longer would effect database statistics to any significant degree, the concern for preserving equal increment assignment of the record ids was lessened. The only remaining significance of the database numbering is for filing purposes, as a means to organize the large (file-cabinet filling) collection of articles and reports. The database is thus the index and finding aid for items in the print-copy collection of research papers and government documents acquired for the project (and subject to copyright law), which is now housed within the Conservation and Development Branch, AAFRD, for research purposes.

CONCLUSION

Searches in multiple databases and in library catalogues following standard bibliographic research procedures identified over 2600 citations to scientific literature related to agricultural emissions of the greenhouse gases -- Carbon dioxide, Nitrous oxide, and Ammonia. Records were created and a research collection of documents was compiled for review. The database resulting from this process was managed with ProCite software, and was made available on CD-ROM to the AAFRD Library and department staff. Detailed analyses together with the literature review are published elsewhere.

[1]APPENDIX: To View The 'Ag-GHG Emissions Lit.' Database:

On the AAFRD Intranet, from the Desktop, go to
My Computer, and look at the list of all of the drives on AAFRD's network.

Select the **J:** drive, which is labelled:
Agcdd on 'Agsrv03' (J:)

Look for the
Climate folder, Select and open it.

Within this folder, look for the
Work Archive subfolder. Select and open it.

The **ag GHG** database is in the subfolder.
Select and open it, then open the
Database folder.

Open the first
ag GHG file listed -- this is the ProCite 5.0 database.
(The second **ag GHG** listed is the index file for the first file)

*If you do not have ProCite 5.0 installed on your machine, talk to Jonathan Specht about your options for accessing this **ag GHG** database file.
The AAFRD Library has a copy of this database on CD-ROM, which may be used within the library facility for performing searches of agricultural greenhouse-gas related literature citations.

You can refer to, freely use, and download information from the **ag GHG** database records, but please do not make changes to the data here.
Thank you.

IN SUMMARY:

Agcdd on 'Agsrv03' (J:) > Climate > Work Archive > ag Drought > Database > Drought

will take you to this resource database!

[2]APPENDIX: Search Expressions in ProCite 'Ag-GHG Emissions Lit.' Final Database

The following searches were used to create Groups within the ProCite database, and were run for the entire database upon its completion. They are saved as 'Search Expressions' within the Search tab data panel within the Ag-GHG Emissions Lit. Database (ProCite software).

The keywords and phrases used to run the searches for data groupings are as follows:

<u>For Emission of Types of Agricultural GreenHouse Gases</u>

CARBON DIOXIDE
"carbon dioxide" OR CO2

METHANE
"methan*" OR CH4

[Note that the * or truncation/wildcard symbol is used within a search expression to allow for broadening, for variations, in this case to include variants such as 'methanogenesis' etcetera.]

NITROUS OXIDE
"nitrous oxide*" OR N2O OR nitrogen

EMISSIONS
emit OR emission*

<u>For Aspects of Agriculture</u>

COMPOST, MANURE
compost* OR manure* OR slurry OR slurries OR waste* OR amendment*

CROPS
crop* OR wheat OR grain* OR barley OR soy* OR hay* OR straw* OR grass* OR rotation* OR corn* OR maize OR oat*

LAND-USE
"land-use" OR "land management" OR afforestation OR deforestation OR "tree-planting" OR pasture* OR riparian OR grazing OR grassland* OR wetland*

LIVESTOCK
livestock OR cattle OR steer* OR cow* OR sheep OR lamb* Or poultry OR hen* OR hog* Or swine OR pig* OR stock OR chicken* OR elk OR deer OR animal* OR rumina* OR rumen*

RANGELANDS, PASTURE
pasture* OR range* OR graz* OR grass*

RIPARIAN AREAS
riparian

SEQUESTRATION & SINKS
sequest* OR sink* OR "carbon stor*"

SOILS

soil* or "carbon sequestration" OR organic OR biomass

For Aspects of Research Methods & Reporting of Results
(as in types of studies and types of literature or publication)

FIELD STUDIES

"field study" OR "field studies" OR "field plot*"

LAB STUDIES

"lab study" OR "lab studies" OR "laboratory study" OR "laboratory studies"

CONFERENCES

congress* OR workshop* OR symposium OR symposia OR meeting* OR conference*

MODELS, MODELLING

model* OR simulat* OR computer*

REVIEWS, BIBLIOGRAPHIES

"bibliograph* OR "literature review*" OR "review of literature" OR "review article"

For Other Related Aspects

FARM FUELS, EQUIPMENT, ENERGY

fuel* OR power OR engine OR equipment OR diesel OR biofuel* OR "alternative fuel*" OR machinery OR truck* OR tractor*

BIOFUELS

biofuel* OR "alternative energy"

POLICY, ECONOMICS

Policy OR policies OR government OR federal OR provincial Or municipal OR legislat* Or planning OR tax* OR econom* OR politic* OR "international agreement*"

[Note: KYOTO Protocol and related documents can simply be found by searching for:
"Kyoto".
CLIMATE CHANGE would be "climate change*" or "climatic change" or "change* in climate".
These sorts of searches were not kept as groupings, as their nature was deemed to be obvious in the database, and outside the immediate parameters of greenhouse gas emissions literature compilation with a 'farming for the future' focus.]

[3]APPENDIX: Label for CD-ROM disc containing ProCite 'Ag-GHG Emissions Lit.' Final Database, On File with AAFRD & the Alberta Government Library (AEAG)

<u>DEVELOPMENT OF FARM LEVEL GHG (GREENHOUSE GAS) ASSESSMENT –</u>
<u>TO IDENTIFY KNOWLEDGE GAPS & DEVELOP A SCIENCE PLAN</u>
2600-Citation PROCITE (v.5) Database (7.23MB)

Conservation & Development Branch,
Alberta Agriculture, Food and Rural Development
AARI '*Farming for the Future'* Research Project, 2001-2003
<u>(PH.) 780-422-4385</u>

--*Analyst/Reviewer*: Shampa Chakraborty
--*CoChairs*: Shane Chetner & Les Fuller
--*Compiler/Librarian*: Connie Hall
--*Review Committee Members*: *2000-2003*: John Basarab, Mafiz Khan, Mingchu Zhang, Tara Banks, Karen Haugen-Kozyra, Jilene Sauvé

1. **OPEN PROCITE**
2. **Insert CD into CD-Drive**
3. **OPEN <u>FIRST</u> FILE Listed as: "AgGHG_Emissions" [.pdt]**
4. **Set File Properties to "Read Only" to avoid data alteration**
5. **See "View" to change appearance of data**
6. **See "Help" for assistance using ProCite**

[4]APPENDIX: Primary Keywords

afforestation
agricultural management practices
agricultural soils
air pollution
air quality
alternative fuels
AMMONIA
Ammonification
animal waste
beef production
biofuels
biogas
carbon cycle
CARBON DIOXIDE
carbon sequestration
CEEMA
climatic change
CO2
compost
crops
deforestation
denitrification
economics
emissions
emissions trading
energy
environmental impacts
farm equipment
field studies
forests
global warming
greenhouse gases
Kyoto protocol
lab studies
land use

livestock
manure
methanogenesis
modelling
NH4
nitrification
NITROUS OXIDE
NO2
off-highway equipment
planning
policy
riparian ecosystems
ruminants
science plans
simulation
soil carbon
soil nitrogen
soil organic carbon
soils
statistics
trace gases
trees
water quality

Appendix B: Experimental Summaries from Table 3

Experiment 1

Authors: Chang et al. 1998
Location: Lethbridge, AB
Soil Type: Dark Brown Chernozem

Solid feedlot cattle manure applied annually since 1973 at 0, 60, 120 and 180 Mg ha^{-1} under irrigated conditions and cropped to barley.

N_2O fluxes from soil measured weekly using vented chamber in November 1993 (8d after manure application) until October 1994 and analyzed using gas chromatography.

Values given in Table 3 list cumulative N_2O emissions over 1 year from November 1993 until October 1994.

Experiment 2

Authors: Lemke et al. 1998
Location: Breton, Cooking Lake, Eckville, Ellerslie, and Josephburg, AB (Rycroft, AB also included in study, but no relevant data appears in table).
Soil Type: Grey Luvisol, Grey Luvisol, Grey Luvisol, Black Chernozem, Black Chernozem, respectively.

All plots under conventional till management and continuously cropped (wheat, wheat, barley, wheat, wheat, fallow (Rycroft)) with a broadcast application of fertilizer (0, 25, 56 and 100 kg N ha^{-1}) in late May or early June.

N_2O measured using vented soil covers from spring 1993 until spring 1995 and analyzed using gas chromatography.

Sites monitored for N_2O emissions as soon as snow pack melted (early spring) and continued until N_2O emissions were negligible (late September to early October) with periodic measurements of N_2O made in November, January, February and early March.

Values given in Table 3 list cumulative N_2O emissions from 1994-1995 season.

Experiment 3

Authors: AAFRD 2000
Location: Three Hills, AB
Soil Type: Black Chernozem

Prior to the experiment, the site was managed with a cereal-oilseed rotation with fallow occurring every 3-4 years until test site established in 1991 and whole area seeded to canola.

Nine different crop rotations (phases rotated yearly), however only three rotations were selected to study N_2O emissions:

- Canola-Barley-Peas-Wheat (CBPW);
- Wheat-Fallow (WF);
- Continuous Wheat (CW).

Only the peas and wheat phase of the CBPW rotation and both the fallow and wheat phase of the WF rotation were used in the study.

In fall 1994, conventionally seeded and direct seeded tillage treatment systems were added to the three rotations studying N_2O emissions.

All plots, except fallow, received banded application of fertilizer (urea, 67 kg N ha^{-1}).

N_2O emissions measured periodically from April until November 2000 using vented soil covers and analyzed using gas chromatography.

Values given in Table 3 are an average of both conventional and direct seeded treatments for each rotation.

Experiment 4

Authors: Hao et al. 2001
Location: Lethbridge, AB
Soil Type: Dark Brown Chernozem

From 1986 to 1996, site was continuously cropped in a wheat-wheat-oat rotation, until 1997 when the oat rotation was replaced by canola.

Starting in 1986, 5 straw-tillage treatments (straw-fall plow, straw-spring plow, no straw-fall plow, no straw-spring plow or no straw-direct seed), 4 N fertilizer application rates (0, 50, 100 or 200 kg N ha-1) and 2 broadcast fertilizer application times (fall (October) or spring (May)) were applied to the site.

N_2O emissions measured from select plots in October 1996 until August 1997 using a vented chamber and analyzed using gas chromatography.

Values given in Table 3 give the average N_2O emissions during 1996-1997 season.

Experiments 5 & 6

Authors: Lemke et al. 2002a
Location: Swift Current, SK and Three Hills, AB
Soil Type: Brown Chernozem and Black Chernozem

Swift Current, SK

Experiment started in 1967 and included 10 cropping systems.

3 cropping systems were examined for this study: continuous wheat with N and P fertilizer applied as required; continuous wheat with no N applied and P fertilizer applied as required, and both phases of a wheat-lentil rotation.

Nitrogen fertilizer was broadcast on the wheat phases based on fall soil nitrate levels and according to Saskatchewan Advisory Council recommended guidelines.

Lentil phase received P fertilizer as required.

Three Hills, AB

Site established in 1991.

2 cropping systems examined in this study: continuous wheat and canola-barley-peas-wheat (CBPW), where only the pea and wheat rotation were monitored for N_2O.

In 1994 plots divided into two tillage systems: conventional tillage (CT) and no till (ZT).

At seeding, all plots received a banded application of urea (67 kg N per hectare).

Ammonium phosphate was applied with the cereal seed (33 kg P_2O_5 per hectare) and with the pea and canola seed (20 kg P_2O_5 per hectare).

Plots sampled 1-2 times a week from seeding until mid-July and once a week during the latter part of the season when soil water was low.

N_2O samples taken using vented soil chambers and concentration of N_2O determined through gas chromatography.

Values given in Table 3 give the average N_2O emissions from May 2000-April 2001 for Three Hills and from May 2001-April 2002 for Swift Current.

Experiment 7

Authors: Lemke and Desjardins 2001
Location: Lethbridge, AB, Swift Current, SK, Three Hills, AB, Brandon, MB, Harrow and Woodslee, ON and St. Lambert, QC
Soil Type: DNDC simulations were carried out for three soil textures (sandy loam, loan and clay loam) in each of the seven major soil groups used in agriculture

Model performance was tested for six location representing a diverse combination of soil-climate-management combinations.

Models used and compared: DNDC, Expert-N, and Century.

Values in Table 3 are average values predicted using the DNDC model for 2000 to 2030.

Control values created by running the model for a conventional tillage system for various crop rotations within a soil group from 1970-2030.

Coefficients represent the average yearly change in N_2O emissions when changing from conventional management to a new management practice.

Example: if a one-hectare piece of land was conventionally tilled (with the same properties assumed in the model), it would have a N_2O emission coefficient of 0.86 kg N_2O-N ha^{-1} y^{-1}. If that same piece of land was converted to no-till, its N_2O emission would be –0.50 kg N_2O-N ha^{-1} y^{-1} less than the conventionally tilled system (control). In other words, its N_2O emission coefficient would be 0.36 kg N_2O-N ha^{-1} y^{-1} for that same one-hectare piece of land.

Experiment 8

Authors: Solberg et al. 1997
Location: Breton and Ellerslie, AB
Soil Type: Grey Luvisol and Black Chernozem

Prior to the start of the experiment, Breton site was continuously cropped to cereal grain and forage and the Ellerslie site was continuously cropped to cereal grain.

In spring of 1983, both sites cropped to barley with both a fertilizer (0, 25, 50 and 75 kg N ha^{-1}) and a straw handling (retained or removed) treatment.

An additional blanket application of P (22 kg ha^{-1}), K (33 kg ha^{-1}) and S (11 kg ha^{-1}) applied to Breton plots and only P and K applied to Ellerslie plot, both annually.

N content in both straw and grain determined by either Kjeldahl method or by colorimetric analysis.

In August 1995, soil cores composited by depth intervals, with bulk density being determined through air drying.

Total C determined by LECO Carbon Determinator and total N determined by the method of Technicon Industrial Systems.

Light fraction organic matter (LFOM) also determined, where the C and N content measured by Dumas combustion on a Carlo Erba analyzer.

Values given in Table 3 give the cumulative increase in C storage with applied N for the 0-15cm depth over 1 year (experiment ran for a total of 13 years).

Positive values indicate a loss of carbon.

Experiment 9

Author: Sauvé 2000
Location: Throughout Alberta
Soil Types: Various

Estimated sequestration rates for conventional (CT) and no-till (ZT) soils were predicted using a first order kinetics model.

Predicted sequestration rates were dependent on the initial soil organic carbon content, tillage and cropping practice. Differences in landscape position and temperature were incorporated for each Ecoregion.

Each Ecoregion (soil group) considered proportions of land cropped in cereals, oilseeds, forages and fallow.

Experiment 10

Authors: Campbell et al. 2000
Location: Swift Current, SK
Soil Type: Brown Chernozem

Prior to start of experiment, area cropped to a fallow-wheat rotation with only P applied.

Experiment started in 1987 with nine rotations: four 3 year rotations (F-W-W, F-Hy-Hy, CF-WW-W and GM-W-W), one 4 year rotation (F-W-W-W), one continuous wheat rotation, two flex-cropping rotations and a crested wheatgrass (CWG) rotation.

The 3 year rotation allowed for analysis of different wheats (W) (Hard red spring wheat and high-yeilding CPS wheat), tillage management practices (conventional fallow and chemical fallow) and legume green manure plow down (GM) (versus fallow rotation).

Crops in each rotation fertilized for N based on soil tests taken the previous fall and for P based on general fertilizer recommendation guidelines.

Soil samples taken from 0-120 cm depth.

In fall 1990, 1993 and 1996 soil samples from 0-15 cm depths (except in 1996 where soils sampled from 0-60 cm) taken from each plot during each rotation to determine C and N (analyzed by automated combustion equipment (Carlo Erba)).

Bulk density only measured in spring 1994 and fall 1996, data provided in article.

Used empirical equation to determine SOC.

Values given in Table 3 give the measured increase in SOC over one year (data determined from measurement taken from 1990-1996).

Experiment 11

Authors: Boehm et al. 2000

Report provides a summary of GHG mitigation associated with sink enhancing agricultural scenarios, including analysis using the CEEMA model.

In the table, carbon sequestration coefficients developed from empirical data and expert opinion were provided by McConkey, B.G., et al. (1999) (see Appendix of Bruce et al. 1998).

The second set of carbon sequestration coefficients developed using the Century Model and were provided by W. Smith, personal communication.

Values in table are either from expert opinion or the Century model for zero till (ZT) or minimum till (MT).

Experiment 12

Authors: Bruce et al. 1998

Literature review document put together by the Soil and Water Conservation Society whom conducted a workshop in May 1998 with a group of scientists, policy analysts and practitioners dealing with carbon sequestration in soils.

Figure given on the potential rates of carbon sequestration for cultivated lands through changes in management practices comes from a review of 17 Canadian studies and 26 long-term studies done in both Canada and the USA.

Experiment 13

Authors: Kulshreshtha et al. 2001
Location: throughout Alberta (AB) and Saskatchewan (SK)
Soil Types: Various

To estimate level of GHG emissions from irrigation, both irrigated and dryland production conditions were simulated on the same tract of land.

GHG emissions estimated separately for 1998 for both Alberta and Saskatchewan.

Estimation of GHG emissions from both dryland and irrigated production conditions through the use of the Greenhouse Gas Emissions Sub-Model of CEEMA (Canadian Economic and Emissions Model for Agriculture) which is a policy model designed to test the effectiveness of GHG mitigation strategies compared to baseline conditions.

Direct emissions included both crop and livestock production and on-farm transportation.

Indirect emissions included atmospheric deposition and leaching from both fertilizer and manure use and from farm input manufacturing.

Obtained 1998 level of irrigation for both Alberta and Saskatchewan based on irrigation licenses, all other data obtained from Statistics Canada, Alberta Agriculture and Saskatchewan Agriculture and Food.

Values taken from Table 3 give only the GHG emissions obtained from direct emissions (crop and livestock production and on-farm transportation).

Appendix C: Experimental Summaries from Table 4

Experiment 1

Authors: Nyborg et al. 1997
Location: North Central Saskatchewan
Soil Type: Dark Grey Luvisol

Site cultivated from 1927-1933, but due to poor productivity left to revert back to grasslands, unused for either hay or pasture.

Dominant grasses include: bromegrass, Kentucky bluegrass, Wild Rough hair grass and various herb species.

Soil samples taken in 1995 indicated the soil was deficient in both N and S.

Experiment initiated in 1981 with 5 fertilizer treatments applied each spring: No N or S fertlizer, 112 kg N ha^{-1} y^{-1} only, 11.2 kg S ha^{-1} y^{-1} only, both N and S (same levels as above) and 112 kg N ha^{-1} y^{-1} with 11.2 kg elemental S ha^{-1} y^{-1}.

Grass samples taken annually in late summer for biomass yield, except in 1992-1994.

In 1992, 1993 and 1994 no plots were fertilized or harvested, however in 1995 the 3 year grass residue was sampled.

Core samples taken from 0-37.5cm, composited by depth intervals with bulk densities being determined by the soil core method.

Total C was determined using a LECO Carbon Determinator and total organic N was determined by the method of Technicon Industrial Systems.

Light fraction organic matter was separated and the C and N content of the light fraction was measured by Dumas combustion using a Carlo Erba instrument.

Values given in the table give the cumulative mass of C in the soil from 1981 until 1991.

Experiment 2 *Authors:* Gebhart et al. 1994
Location: Big Spring and Seminole, Texas; Colby and Atwood, Kansas; Valentine, Nebraska
Soil Type: Various

Big Spring and Seminole, Texas

Fine-loamy, mixed, thermic Aridic Paleustalf

Cropland and CRP (Conservation Reserve Program) initially plowed and cropped to cotton in 1958 and 1963.

1987 the CRP land in both locations seeded to weeping lovegrass.

Native pasture have supported moderate year long cattle grazing for more than 40 years and dominated by sand dropseed, little bluestem, perennial threeawn, shen oak and blue grama.

Colby and Atwood, Kansas

Fine-silty, mixed mesic Aridic Haplustoll.

Cropland and CRP land initially plowed and cropped to a wheat-fallow rotation in late 1930s.

1987, CRP land at both locations seeded to native mixture containing blue grama, indiangrass, little bluestem, big bluestem and western wheatgrass.

Native pasture have supported spring-summer cattle grazing for more that 50 years and dominated by blue grama, western wheatgrass, little bluestem and buffalograss.

Valentine, Nebraska

Mixed, mesic Typic Ustipsamment.

Cropland and CRP land initially plowed and cropped to irrigated corn-sorghum roation in 1978.

1987, CRP land seeded to native mixture including big bluestem, little bluestem, sand bluestem, blue grama, sideoats grama and switchgrass.

Native pasture has supported winter cattle grazing for more than 40 years and dominated by little bluestem, sand bluestem, prairie sandreed, neddle-and-thread and blue grama.

Soil samples taken from each location and land use combination to a depth of 3 m (300 cm) in the summer of 1992.

An additional soil sample taken at that time for bulk density analysis.

Soil samples dried and then analyzed for organic carbon content using dry combustion infrared instrumental procedure.

Values given in the table give the mass of C in the soil in 1992.

Experiment 3 *Authors:* Boehm et al. 2000

Refer to Experiment 10 in Appendix B for summary of experimental methodology.

Experiment 4 *Authors:* Bruce et al. 1998

Refer to Experiment 11 in Appendix B for summary of experimental methodology.

Chapter 2:
Alberta Agricultural Greenhouse Gas Assessment Emissions Inventory

Executive Summary

Greenhouse gases (GHG) are present in the atmosphere from natural and anthropogenic sources. In 1997, developed nations of the world agreed that the increased concentration of GHG in the atmosphere is causing atmospheric temperature to rise. At that time, Canada signed the Kyoto Protocol committing to reduce GHG emissions to 6% below 1990 levels (equal to 240 megatonnes carbon dioxide equivalents (Mt CO_2 E)) between 2008 and 2012. The Canadian Government ratified the agreement in December 2002.

In Canada, GHG emissions have increased by 19.6% (119 Mt CO_2-E) since 1990. The largest contributors to this increase are vehicles, electricity and steam generation and fossil fuel industries. Agriculture's increase in GHG emissions was 2.7%. Agriculture is unique because most of these emissions are from non-energy sources. In addition, agriculture has an opportunity to remove CO_2 from the atmosphere offsetting the total reduction in GHG emissions.

The three main GHG emitted from agriculture are nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). The majority of on-farm sources of CO_2 in Alberta come from fuel combustion for heating farm buildings and operation of farm machinery. On-farm sources of CH_4 include livestock (primarily dairy and beef cattle) digestion processes, anaerobic respiration of organisms in riparian areas, and manure (e.g. stockpiled, lagoons, anaerobic digestion, and land-applied). The primary on-farm sources of N_2O are soil (especially in areas with N-fixing plants (e.g. legumes)), manure, and fertilizer (organic and chemical).

As part of the International Climate Change process, Canada is required to annually report the amount of GHG emitted by each sector. Canada's GHG inventory documents GHG emissions from three areas: enteric fermentation, manure management, and agricultural soils. For the most part Canada's GHG inventory used IPCC Tier 1 methodology and default emission factors, which may not accurately reflect Canadian conditions; therefore an Alberta-based approach is proposed.

Alberta's GHG inventory will be used to meet its own Climate Change Action Plan with the objective to inventory agricultural GHG that reflect all farm activities and related practices. With this type of inventory it is also possible to measure the reduction in GHG emission if mitigation strategies were put in place. Alberta's GHG inventory is segregated into five categories: enteric fermentation, manure management, agricultural soils, transportation and farm fuels, and agri-food processing.

Alberta based GHG emissions were calculated for enteric fermentation, transportation and agri-food processing. At this time, better methodology to calculate GHG emissions from agricultural soils and manure management was not available so the estimates from Canada's GHG inventory were used. Alberta Agriculture Food and Rural Development's GHG Technical Team is currently investigating the applicability of improving methodologies to measure GHG emissions from agricultural soils and manure management. In addition, methodologies to estimate GHG emissions from woodlots, agro-forestry, agricultural wetlands, streams, and riparian areas as well as biofuels are being explored.

Total GHG emissions for the agricultural sector in Alberta are estimated to be
26 303 kt CO_2-E per year. There is a significant potential for agricultural soils, rangelands and pastures to sequester carbon. Preliminary assessments estimate 6 873 400 kt CO_2-E per year therefore making Alberta's agricultural sector a net sink of GHG emissions.

Compared to the AAFRD 1996 inventory of GHG emission from the agriculture sector in Alberta, emissions from livestock, manure management and transportation increased 2%, 3%, and 3%, respectively while GHG emissions from Agri-food processing, soil and fertilizer decreased 1%, 1% and 6% respectively (AAFRD 1999a).

Introduction

In 1997 Canada signed the Kyoto Protocol committing to reduce greenhouse gas (GHG) emissions to 6% below 1990 levels between 2008 and 2012 (first commitment period; Nietzert et al. 1999). The Canadian Government ratified the agreement in December 2002. Presently, Canada needs to reduce GHG emission levels by 240 megatonnes carbon dioxide equivalents (Mt CO_2-E) by the first commitment period (Nietzert et al. 1999).

Canada's GHG emissions were 607, 658 and 726 Mt CO_2 E for 1990, 1995 and 2000, respectively, indicating that GHG emissions have increased by 19.6% or by 119 Mt from 1990 to 2000 (Olsen et al., 2002). The energy sector is responsible for 96.6% of the 119 Mt increase in GHG emissions, with the largest contributors to the increase being vehicles (33 Mt), electricity and steam generation (33 Mt) and fossil fuel industries (15 Mt). In 2000, Canada represented about 2% of the total global GHG emissions. However, on a per capita basis, Canada ranks second in the G8 nations and ninth in the world for CO_2 emissions, primarily due to its energy intensive economy. In 2000, the energy sector was responsible for 80.9% of the emissions, with 73.4% resulting from the combustion of fossil fuels and 7.4% resulting from fugitive emissions from mining and oil and gas production (Olsen et al., 2002). Other sectors contributing to GHG emissions were agriculture (8.3%), industrial processes (7.0%), waste and waste management (3.3%), land use change and forestry (0.3%) and solvents and other product use (0.1%). Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the major GHG gases, contributing 79%, 12% and 7% to Canada's total emissions, respectively (Olsen et al., 2002). These three GHG are also the primary GHG emitted from agro-ecosystems.

As a member of the Intergovernmental Panel on Climate Change (IPCC), Canada is required to annually report the amount of GHG emitted by each sector. The GHG emissions figures are calculated using the 1996 IPCC Guidelines for Emissions Inventories. The methodology used by IPCC out lines default emission factors for countries that do not have data available to make estimates (Tier 1). If data is available, countries are encouraged to submit inventories with more detailed information (Tier 2). As mentioned, the agriculture sector accounted for 8.3% (or 60.5 Mt) of the emissions for Canada in 2000, which was an increase of 2.7% since 1990 (Olsen et al., 2002). Agriculture is unique because most of these emissions are from non-energy sources. According to Canada's inventory in 2000, N_2O contributed approximately 63%, CH_4 approximately 48% and CO_2 removed 0.4% of the emissions for the agriculture sector (Olsen et al., 2002).

Canada's inventory estimates GHG emissions from three areas: enteric fermentation, manure management, and agricultural soils. Enteric fermentation uses IPCC Tier 1 methodology, manure management used IPCC Tier 1 methodology as well as expert opinion, and agricultural soils uses CENTURY model predictions and IPCC Tier 1 methodology to calculate total emissions. The estimates calculated in Canada's GHG inventory may not accurately reflect Canadian conditions since the emission factors are more applicable on a global scale; therefore an Alberta-based approach is proposed.

Alberta's GHG emissions were 171, 200 and 223 Mt CO_2-E for 1990, 1995 and 2000, respectively (Olsen et al., 2002). This represents 28 to 31% of Canada's total output of GHG emissions. Alberta's GHG inventory will be used to meet its own Climate Change Action Plan with the purpose to inventory agricultural GHG that reflect all farm activities and related practices. This section of the report will assess the IPCC methodology and emission factors used in Canada's GHG inventory and determine whether improved estimates for Alberta can be made for the following categories: enteric fermentation, agriculture soils, manure management. Alberta based emissions from transportation and farm fuels as well as agri-food processing will also be calculated.

The objectives for this section of the project is:

- To update the 1996 agricultural GHG emissions inventory for Alberta.

Enteric Fermentation: Livestock

The primary GHG emitted from the livestock sector is CH_4. On-farm sources of CH_4 include livestock digestion processes (primarily dairy and beef cattle), anaerobic respiration of organisms in riparian areas, and manure (e.g. stockpiled, lagoons, anaerobic digestion, and land-applied). Other potential CH_4 sources include abattoirs, waste lagoons (non-manure) and mineralization of crop residues.

The emissions of GHG from enteric fermentation in Alberta's livestock were 5.1, 6.2 and 6.5 Mt CO_2-E for 1990, 1996 and 2000, respectively (Olsen et al., 2002). This represents 2.9 to 3.1% of Alberta's total output of GHG emissions and 0.8 to 0.9% of Canada's total output of GHG emissions. These GHG emissions are based on the IPCC Tier 1 guidelines that use single value CH_4 emission factors from the United States (IPCC 1996). As an example, total Alberta beef cattle from Census of Agriculture numbers (Statistics Canada 2002) are multiplied by 47.0 kg CH_4/head/year to obtain total CH_4 emission from enteric fermentation in beef cattle. Total GHG emissions in CO_2-E are obtained by multiplying CH_4 emissions by 21. This approach ignores animal type (calf vs. cow), diet, physiological status, gender, weight, growth rate, activity level, age and climate, which means more comprehensive methodologies need to be investigated. The objectives of this study were to calculate CH_4 emissions from enteric fermentation in Alberta's livestock using IPCC Tier 2 guidelines (IPCC 2000) and actual CH_4 emission factors obtained from Canadian research trials for 1990, 1996, 2001.

Methods

This study quantified CH_4 emissions from enteric fermentation in Alberta's domestic livestock. Ruminants produce large quantities of CH_4 during the normal digestive process of enteric fermentation. In this process microorganisms digest carbohydrates into simple molecules for absorption into the bloodstream, with CH_4 being produced as a by-product. Methane is then emitted by eructation and exhalation and, later in the digestive process, by flatulation. Nitrous oxide (N_2O) emissions from pasture and paddock systems were allocated as agricultural soils emissions as outlined in IPCC guidelines (IPCC 2000). Emissions of GHG from manure management practices were taken directly from Olsen et al. (2002).

Alberta livestock inventories were taken from the Census of Agriculture numbers, which is an inventory of Canadian agriculture taken once every five years, as required by the federal Statistics Act (Statistics Canada, 2002; Table 1, Table 2). National in scope, the Census uses a survey approach to capture data from all Canadian agricultural operations. The survey is taken on May 15 of the census year (i.e., 1991, 1996, 2001) by Statistics Canada. Additional inventory numbers were obtained from AAFRD in those instances where livestock numbers were not included in the Census of Agriculture inventory.

Table 1. Inventory of beef cattle on farms in Alberta for 1990, 1996, and 2001.

Animal Type	1990[z]	1996[y]	2001[y]
1. Beef Cows	1 567 000	2 016 889	2 099 288
2. Calves, under 1 year	1 478 000	1 858 679	2 169 607
3. Breeding bulls, 1 year plus	94 000	118 600	111 379
4. Beef heifers, 1 year plus[w]	625 000	905 887	1 102 522
5. Beef steers, 1 year plus	568 000	892 696	991 554
Total Beef Cattle and Calves	4 332 000	5 792 751	6 474 350
Fed Cattle Production	1 385 156	2 160 178	2 507 923

[z] Numbers are based on July 1, 1990 data, Statistics Canada, Agriculture Division.
[y] Numbers are based on May 15 census data, Statistics Canada, Census of Agriculture.
[w] Heifers minus dairy cows and dairy replacement heifers or 95.1% of total census number.

Table 2. Alberta's dairy cattle, hog, poultry, horse, sheep and diversified livestock inventory for 1990, 1996, and 2001.

Animal type	# of months of yr	Avg. Wt (kg)	CH_4 (kg/yr)	No. of animals		
				1990	1996	2001
1. Milking Cows[z]	12	635.0	105.0	109 000	102 000	90 000
2. Dairy calves	6	145.2	24.1	with beef	with beef	with beef
3. Dairy bulls	12	907.2	95.3	with beef	with beef	with beef
4. Dairy heifers[z]	12	450.0	56.4	49 000	44 000	38 000
5. Sow units[z]	12		14.5	173 000	174 195	200 478
6. Hens/chickens[z]	12		0.077	7 525 000	9 485 635	12 175 246
7. Horses[z]	12	400	18.0	180 000	149 960	159 962
8. Sheep[z]	12	50	8.0	275 000	259 817	307 302
9. Alpaca/Llama[y]	12	100	19.3	2000	3692	12 894
10. Bison - Bulls[y]	12	680	80.3	2224	4447	15 548
- Cows[y]	12	500	63.8	6913	13 825	48 397
- Calves[y]	12	225	35.0	2255	4510	15 787
11. Elk[y]	12	300	38.0	3110	7875	31 304
12. Deer[y]	12	100	19.3	490	2812	8331
13. Goats[y]	12	45	7.4	15 000	32 960	42 270
14. Emu[x]	12	40	0.52	2000	3500	500
15. Ostrich[x]	12	100	6.4	15 000	11 500	500
16. Rhea[x]	12	30	0.39	2500	2500	500
17. Wild Boar[y]	12	50	3.3	6000	4499	8067

[z] Numbers are based on July 1, 1990, and May 15, 1996 and 2001 (Statistics Canada 2002).
[y] Numbers for 1990 were derived from Chuck Huedepohl and Doug Bienert, AAFRD. Numbers for 1996 for these diversified livestock are based on AAFRD. Numbers for 2001 (May 15) are from Census of Agriculture (Statistics Canada, 2001).
[x] Numbers were derived from C. Huedepohl and D. Bienert, AAFRD.

Two methods were used to calculate CH4 emissions from enteric fermentation in Alberta's domestic livestock. The first method used IPCC Tier 2 guidelines (IPCC 2000) that required subdividing the livestock populations by animal type, physiological status (pregnant or lactating), gender, weight, growth rate, activity level and age. This resulted in 30 distinct categories of beef cattle (Table 3), four categories for dairy cattle (Table 2), three categories for bison and one category for each of hogs, poultry, horses, sheep, alpaca/llama, elk, deer goats, emu, ostrich, rhea and wild boar (Table 2). The second method applied enteric fermentation emission factors found in the Canadian literature to these livestock categories. In beef cattle, the CH4 emission factors were based on the following four studies: 1) pregnant beef cows (544.3 kg) in confinement producing 5 kg CH4/yr (Okine et al. 1989); 2) beef yearling heifers (319 kg; 12 mo) fed these various forage qualities under ad libitum, confined feeding conditions producing 67.7±3.1

kg CH_4/yr (Boadi and Wittenberg 2002); 3) first-calf lactating beef heifers averaging 561.2 kg during a 69-day grazing period producing 97.8±3.9 kg CH_4/yr on an alfalfa-grass (78%: 22%) pasture and 107.7±3.5 kg CH_4/yr on a 100% meadow brome-grass pasture (McCaughey et al. 1999); 4) steers (400 kg) grazing pastures comprised of 60.0% alfalfa, 28.6% meadow brome-grass, and 4.9% Russian wildrye producing 0.69±0.1 L CH_4/kg body weight/day[1] or 72.3±10.5 kg CH_4/yr (McCaughey et al. 1997). In a similar study, steers (387 kg) grazing legume-grass pasture produced 67.0, 95.3 and 89.6 kg CH_4/yr during early, mid and late-season grazing (Boadi et al. 2002). In dairy cattle, emission factors are based on work by Jaques (1997) where a 635 kg lactating dairy cow produced 105 kg CH_4/animal/yr. In hogs, the CH_4 emission factor was based on a sow unit (one sow plus 15 pigs raised from birth to slaughter at 100 kg) that produced 14.5 kg CH_4/sow unit/yr (Golder Report, 1998). Emission factors for poultry, horses, sheep, and diversified livestock are based on McAllister et al. (1996), Mathison et al. (1998) and Galbraith et al. (1998).

Livestock Population Characterization

Beef cattle

The beef cattle categories were as follows (Table 3):

- *Category 1-3:* Within a year, total beef cows from census data are grouped according to physiological status (i.e., pregnant, lactating), diet and time of year. Category 1 beef cows are fed high roughage diets (i.e., hay or barley silage, straw and some barley grain) for four months, are confined in smaller pastures, and are in their third trimester of pregnancy. These cows will, on average, calve during the third week in March (Alberta Cow-Calf Audit 2001). Category 2 beef cows have calved, are lactating and will be placed on pasture for the next five months. Category 3 beef cows are dry, in their second trimester of pregnancy, and are either grazing crop aftermath, fall pastures or fed stored forages in a confined area for the next three months.
- *Category 4-5:* Within a year, breeding bulls over one year of age from census data are grouped according to diet and time of year. Category 4 bulls are in confinement during the cold months of the year (Jan.-Apr.; Nov.-Dec.). The same bulls are termed Category 5 when they are grazing pastures from May to October.
- *Category 6:* These are local calves born within the census year during February, March, April and May, are less than 6-7 months

[1] One litre of methane equals 0.7174 g of methane (CH_4).

of age on May 15 and graze on pasture with their mothers (Category 6) until weaning in the fall. Unfortunately, the census numbers may include import calves that are less than 9 months of age and for this reason an adjustment is made to the beef calves census numbers. The Alberta Cow-Calf Audit (2001) indicates that the calf crop born in spring and weaned in the fall has a survival rate of approximately 94.4% (4.2% calf death loss, birth to weaning; 1.4% of wintered cows not calving). Thus, if the census beef calf numbers are greater than 94.4% of the census beef cow numbers, then the beef calf numbers are 94% of the census beef cow numbers. For example, 2,169,607 calves were born from 2,099,288 beef cows in 2001, giving a calf crop percentage of 103.3%.

- *Category 7-8:* These are import steer and heifer calves that are approximately 8-9 months of age and weighing approximately 318-340 kg (700-750 lb). If census beef calves is greater than 94% of census beef cows then import calves equals census beef calves minus 94% of census beef cows. This value is then split equally between heifer and steer calves that go directly to a feedlot for finishing in six months.
- *Category 9-13:* These are Alberta born calves (Category 6) that are weaned in October. Of these calves, 17% are selected as replacement heifers (Category 9), 16.5% as heifers for backgrounding (Category 10), 25% as steers for backgrounding (Category 11), 16.5% as heifers for direct finishing (Category 12) and 25% as steers for direct finishing (Category 13). These values are based on the assumption that 17% of the calf crop was required each year for herd replacements and, of the remaining calves, 50% are placed in a feedlot at a slower rate of gain (backgrounding diet) and 50% are placed in a feedlot at a faster rate of gain (finishing diet).
- *Category 14-16:* Replacement heifers that are 8-9 months at the beginning of the census year are estimated at 17% of the previous year's calf crop. Calves born in the previous years for 1989, 1995 and 2000 were 1,421,000, 1,780,000 and 1,790,000 head, respectively (Statistics Canada, 2002). Therefore, 8-9 month old replacement heifers are estimated at 241,570, 302,600 and 304,300 for 1990, 1996 and 2001, respectively. Within each year, these replacement heifers are fed a high forage diet for five months (Jan.-May) in a confined area (Category 14), placed on pasture to

graze for four months (Category 15), and then placed back into a confined feeding area for three months (Category 16).

- *Category 17-20:* Heifers to be fed for slaughter are determined by subtracting the 8-9 month old replacement heifers from the census beef heifers over one year of age (i.e., 625,000-241,570=383,430 heifers). One-half of these heifers go directly to a feedlot where they are fed a high concentrate diet until finished for slaughter (Category 17). The remaining heifers are placed in feedlots where they are fed a backgrounding diet (lower rate of gain) for 5 months (Category 18). Once adequate pasture is available, these heifers are grazed on good quality pasture for four months (Category 19) and then into feedlots for finishing for three months (Category 20).
- *Category 21-24:* Steers to be fed for slaughter are taken directly from the census beef steers over one year of age. One-half of these steers go direct to feedlots where they are fed a high concentrate diet until finished for slaughter (Category 21). The remaining steers are placed in a feedlot where they are fed a backgrounding diet (lower rate of gain) for 5 months (Category 22). Once adequate pasture is available, these steers are grazed on good quality pasture for four months (Category 23) and then into a feedlot for finishing for three months (Category 24).
- *Category 25-30:* Net feeder cattle imports are estimated based on total fed cattle production in Alberta for 1990 (1,385,156 hd), 1996 (2,160,178 hd) and 2001 (2,507,923) minus beef calf imports (Category 7-8) and minus heifers and steers fed for slaughter. For example, there were 1,385,156 feeder cattle fed to slaughter in Alberta in 1990, yet the census taken in July only accounted for 951,430 head (625,000 beef heifers – 241,570 replacement heifers + 568,000 beef steers = 951,430). Thus, total fed cattle (1,385,156) minus feeder cattle counted in census (951,430) minus beef calf imports (0) gives an estimate of net imports of feeder cattle to Alberta or 433,726 head. These cattle are then divided into heifers placed on pasture (25%; Category 25) then into a feedlot for finishing (Category 26), heifers placed directly into a feedlot for finishing (25%; Category 27), steers placed on pasture (25%; Category 28) then into a feedlot for finishing (Category 29), and steers placed directly into a feedlot for finishing (25%; Category 30).

Table 3. Categories of beef cattle for Alberta.

Categories	Age (months)	Location	Time of year	Time (months)	Weight (kg)	Number of animals		
						1990	1996	2001
1. Beef cows - pregnant	Unknown	Confined	Jan-Apr	4	612.4	1 567 000	2 016 889	2 099 288
2. Beef cows - lactating	Unknown	Pasture	May-Sep	5	612.4	1 567 000	2 016 889	2 099 288
3. Beef cows - pregnant	Unknown	Confined	Oct-Dec	3	612.4	1 567 000	2 016 889	2 099 288
4. Breeding bulls	Unknown	Confined	Ja-Ap/No-De	6	907.2	94 000	118 600	111 379
5. Breeding bulls grazing	Unknown	Pasture	May-Oct	6	907.2	94 000	118 600	111 379
6. Beef calves, local	<6	Pasture	Apr-Sep	6	145.2	1 478 000	1 858 679	2 169 607
7. Beef calves, import/steer	8-9	Feedlot	Jan-Jul	6	483.0	0	0	93 940
8. Beef calves, import/heif.	8-9	Feedlot	Jan-Jul	6	458.0	0	0	93 940
9. Replacement heifers	6-7	Confined	Oct-Dec	3	280.3	251 260	315 975	368 833
10. Backgrounder heifers	6-7	Feedlot	Oct-Dec	3	280.3	243 870	306 682	357 985
11. Backgrounder steers	6-7	Feedlot	Oct-Dec	3	294.3	369 500	464 670	542 402
12. Finisher heifers	6-7	Feedlot	Oct-Dec	3	280.3	243 870	306 682	357 985
13. Finisher steers	6-7	Feedlot	Oct-Dec	3	294.3	369 500	464 670	542 402
14. Replacement heifers	8-9	Confined	Jan-May	5	352.0	241 570	302 600	304 300
15. Replacement heifers	13-14	Pasture	Jun-Sep	4	443.6	241 570	302 600	304 300
16. Replacement heifers	17-18	Confined	Oct-Dec	3	538.9	241 570	302 600	304 300
17. Finisher heifers	8-9	Feedlot	Jan-Apr	4	467.2	191 715	301 644	399 111
18. Backgrounder heifers	8-9	Feedlot	Jan-May	5	352.0	191 715	301 644	399 111
19. Grasser heifers	13-14	Pasture	Jun-Sep	4	443.6	191 715	301 644	399 111
20. Finisher heifers	17-18	Feedlot	Oct-Dec	3	555.7	191 715	301 644	399 111
21. Finisher steers	8-9	Feedlot	Jan-Apr	4	467.2	284 000	446 346	495 777
22. Backgrounder steers	8-9	Feedlot	Jan-May	5	352.0	284 000	446 346	495 777
23. Grasser steers	13-14	Pasture	Jun-Sep	4	443.6	284 000	446 346	495 777
24. Finisher steers	17-18	Feedlot	Oct-Dec	3	555.7	284 000	446 346	495 777
25. Import heifers	8-9	Pasture	Jun-Sep	4	378.0	108 432	166 049	132 567
26. Import heifers	12-13	Feedlot	Oct-Dec	3	505.0	108 432	166 049	132 567
27. Import heifers	8-9	Feedlot	Jun-Sep	4	467.2	108 432	166 049	132 567
28. Import steers	8-9	Pasture	Jun-Sep	4	378.0	108 432	166 049	132 567
29. Import steers	12-13	Feedlot	Oct-Dec	3	505.0	108 432	166 049	132 567
30. Import steers	8-9	Feedlot	Jun-Sep	4	467.0	108 432	166 049	132 567

Other Livestock Inventory

Alberta's dairy cattle, hog, poultry, horse, sheep and diversified livestock inventory for 1990, 1996, 2001 are presented in Table 2. For the most part inventory numbers are based on Census of Agriculture (Statistics Canada, 2002). However, inventory numbers for diversified livestock for 1990 and 1996 were derived from various Alberta Agriculture specialists and are a source of uncertainty. This uncertainty is only of minor concern as GHG emissions from diversified livestock account for less than 2% of Alberta's total GHG emissions from enteric fermentation.

Results And Discussion

Beef cattle

Emissions of GHG from Alberta's beef cattle population, as calculated by IPCC Tier 2 guidelines, were 4.75, 6.28, and 6.66 Mt CO_2-E in 1990, 1996, and 2001, respectively (Table 4). A similar result was obtained when GHG emissions were calculated using actual emission factors from western Canadian sources (Table 5). Greenhouse gas emissions calculated using actual emission factors were 6.1% to 6.5% higher than GHG emissions calculated from IPCC Tier 2 guidelines. These CH_4 emission factors were, on average, 17.6% higher than those calculated by IPCC Tier 2 guidelines. These results reflect the uncertainty associated with estimating CH_4 emissions from enteric fermentation in livestock and support the degree of the uncertainty of ± 20% estimated in the IPCC guidelines (IPCC 2000).

Methane emission factors from enteric fermentation in beef cattle, as calculated by IPCC Tier 2, ranged from 22.4 kg CH_4/animal/yr for 6-7 month old feeder steers on a high concentrate diet to 120.9 kg CH_4/animal/yr for breeding bulls on pasture. Methane emission factors from western Canadian sources ranged from 27.3 kg CH_4/animal/yr for 6-7 month old feeder heifer on a high concentrate diet to 140.2 kg CH_4/animal/yr for breeding bulls on pasture. These results demonstrate the large variation that exists in the CH_4 emission factors from different cattle types. They also demonstrate that management practices that reduce GHG emissions are most effectively applied to the cattle types that produce the most CH_4 (i.e., beef cows, replacement heifers, grazing cattle and backgrounding cattle).

Table 4. Methane emissions from enteric fermentation in Alberta's beef cattle as determined by IPCC Tier 2 guidelines for 1990, 1996, and 2001.

Categories	Age in months	Location	Time of year	CH_4 (kg/hd/yr)	CH_4 (tonne/yr)		
					1990	1996	2001
1. Beef cows - pregnant	Unknown	Confined	Jan-Apr	59.9	31 265	40 241	41 885
2. Beef cows - lactating	Unknown	Pasture	May-Sep	111.5	72 774	93 667	97 494
3. Beef cows - pregnant	Unknown	Confined	Oct-Dec	68.9	26 998	34 749	36 169
4. Breeding bulls	Unknown	Confined	Ja-Ap/No-De	99.2	4664	5885	5527
5. Breeding bulls grazing	Unknown	Pasture	May-Oct	120.9	5682	7169	6733
6. Beef calves, grazing	<6	Pasture	Apr-Sep	34.0	25 122	31 593	33 685
7. Beef calves, import/steer	8-9	Feedlot	Jan-Jul	32.5	0	0	1527
8. Beef calves, import/heif.	8-9	Feedlot	Jan-Jul	32.5	0	0	1526
9. Replacement heifers	6-7	Confined	Oct-Dec	35.7	2241	2818	3004
10. Backgrounder heifers	6-7	Feedlot	Oct-Dec	35.7	2175	2735	2916
11. Backgrounder steers	6-7	Feedlot	Oct-Dec	35.9	3313	4166	4442
12. Finisher heifers	6-7	Feedlot	Oct-Dec	22.5	1370	1723	1837
13. Finisher steers	6-7	Feedlot	Oct-Dec	22.4	2072	2605	2778
14. Replacement heifers	8-9	Confined	Jan-May	42.3	4259	5335	5365
15. Replacement heifers	13-14	Pasture	Jun-Sep	68.5	5512	6905	6943
16. Replacement heifers	17-18	Confined	Oct-Dec	58.2	3517	4406	4431
17. Finisher heifers	8-9	Feedlot	Jan-Apr	33.0	2107	3315	4386
18. Backgrounder heifers	8-9	Feedlot	Jan-May	42.3	3380	5319	7037
19. Grasser heifers	13-14	Pasture	Jun-Sep	61.5	3929	6182	8180
20. Finisher heifers	17-18	Feedlot	Oct-Dec	37.6	1800	2832	3747
21. Finisher steers	8-9	Feedlot	Jan-Apr	31.7	3003	4719	5242
22. Backgrounder steers	8-9	Feedlot	Jan-May	41.0	4854	7628	8473
23. Grasser steers	13-14	Pasture	Jun-Sep	60.6	5732	9008	10 006
24. Finisher steers	17-18	Feedlot	Oct-Dec	36.1	2565	4031	4477
25. Import heifers	8-9	Pasture	Jun-Sep	50.2	1813	2777	2217
26. Import heifers	12-13	Feedlot	Oct-Dec	35.0	948	1451	1158
27. Import heifers	8-9	Feedlot	Jun-Sep	33.0	1192	1825	1457
28. Import steers	8-9	Pasture	Jun-Sep	48.8	1764	2701	2156
29. Import steers	12-13	Feedlot	Oct-Dec	33.6	911	1396	1114
30. Import steers	8-9	Feedlot	Jun-Sep	31.7	1146	1755	1401
Total CH_4 production (tonne/yr)					226 109	298 939	317 316
Total CO_2 equivalents (tonne/yr) (total annual CH_4 production x 21)					4 748 283	6 277 709	6 663 630

Table 5. Methane emissions from enteric fermentation in Alberta's beef cattle as determined by actual emission factors from Western Canada sources for 1990, 1996, and 2001.

Categories	Age (months)	Location	Time of year	CH_4 (kg/hd/yr)	CH_4 (tonne/yr[u])		
					1990	1996	2001
1. Beef cows - pregnant	Unknown	Confined	Jan-Apr	71.0[z]	37 090	47 739	49 689
2. Beef cows - lactating	Unknown	Pasture	May-Sep	104.4[z]	68 177	87 750	91 335
3. Beef cows - pregnant	Unknown	Confined	Oct-Dec	71.0[y]	27 818	35 804	37 267
4. Breeding bulls	Unknown	Confined	Ja-Ap/No-De	95.3[z]	4481	5654	5310
5. Breeding bulls grazing	Unknown	Pasture	May-Oct	140.2[y]	6590	8314	7808
6. Beef calves, grazing	<6	Pasture	Apr-Sep	33.8[x]	24 987	31 423	33 503
7. Beef calves, import/steer	8-9	Feedlot	Jan-Jul	41.0[w]	0	0	1926
8. Beef calves, import/heif.	8-9	Feedlot	Jan-Jul	39.4[w]	0	0	1851
9. Replacement heifers	6-7	Confined	Oct-Dec	61.4[v]	3859	4854	5175
10. Backgrounder heifers	6-7	Feedlot	Oct-Dec	27.3[w]	1662	2091	2229
11. Backgrounder steers	6-7	Feedlot	Oct-Dec	28.3[w]	2613	3286	3503
12. Finisher heifers	6-7	Feedlot	Oct-Dec	27.3[w]	1662	2091	2229
13. Finisher steers	6-7	Feedlot	Oct-Dec	28.3[w]	2613	3286	3503
14. Replacement heifers	8-9	Confined	Jan-May	72.9[v]	7336	9190	9242
15. Replacement heifers	13-14	Pasture	Jun-Sep	78.1[x]	6292	7881	7925
16. Replacement heifers	17-18	Confined	Oct-Dec	64.5[z]	3896	4881	4908
17. Finisher heifers	8-9	Feedlot	Jan-Apr	40.0[w]	2556	4022	5321
18. Backgrounder heifers	8-9	Feedlot	Jan-May	32.3[w]	2584	4066	5379
19. Grasser heifers	13-14	Pasture	Jun-Sep	78.1[x]	4993	7856	10 395
20. Finisher heifers	17-18	Feedlot	Oct-Dec	45.6[w]	2184	3436	4546
21. Finisher steers	8-9	Feedlot	Jan-Apr	40.0[w]	3787	5951	6610
22. Backgrounder steers	8-9	Feedlot	Jan-May	32.3[w]	3828	6016	6682
23. Grasser steers	13-14	Pasture	Jun-Sep	78.1[x]	7397	11 625	12 912
24. Finisher steers	17-18	Feedlot	Oct-Dec	45.6[w]	3235	5084	5647
25. Import heifers	8-9	Pasture	Jun-Sep	69.3[x]	2505	3836	3062
26. Import heifers	12-13	Feedlot	Oct-Dec	42.4[w]	1149	1760	1405
27. Import heifers	8-9	Feedlot	Jun-Sep	40.0[w]	1446	2214	1768
28. Import steers	8-9	Pasture	Jun-Sep	69.3[x]	2505	3836	3062
29. Import steers	12-13	Feedlot	Oct-Dec	42.4[w]	1149	1760	1405
30. Import steers	8-9	Feedlot	Jun-Sep	40.0[w]	1445	2213	1767
Total CH_4 production (tonne/yr)					239 838	317 916	337 365
Total CO_2 equivalents (tonne/yr) (total annual CH_4 production x 21)					5 036 601	6 676 228	7 084 670

[z] Based on 544.3 kg beef cows under confined feeding producing 65.0 kg CH_4/yr or 0.5768 kg CH_4/kg $wt^{0.75}$/yr (Okine et al. 1989).
[y] Based on first-calf lactating beef heifers averaging 561.2 kg during a 69-day grazing period producing 97.8±3.9 kg CH_4/yr (0.8482 kg CH_4/kg $wt^{0.75}$/yr) on an alfalfa-grass (78%: 22%) pasture (McCaughey et al. 1999).
[x] Based on steers (400 kg) grazing pastures comprised of 60.0% alfalfa, 28.6% meadow brome-grass, and 4.9% Russian wildrye producing 72.3±10.5 kg CH_4/yr or 0.8083 kg CH_4/kg $wt^{0.75}$/yr (McCaughey et al. 1997).
[w] Based on feedlot steers (467.2 kg) on a finishing diet producing 40.0 kg CH_4/yr or 0.0.3980 kg CH_4/kg $wt^{0.75}$/yr (Mathison et al. 1989).
[v] Based on beef yearling heifers (319 kg; 12 mo) fed various forage qualities under *ad libitum,* confined feeding conditions and producing 67.7±3.1 kg CH_4/yr or 0.8969 kg CH_4/kg $wt^{0.75}$/yr (Boadi and Wittenberg 2002).
[u] Methane produced from each type of animal is calculated as follows: (Methane Emission Factor x n x (mon/12))/1000, where n equals number of animals in each category from Table 2 and mon equals months animal spend in this category from Table 2.

Dairy cattle

Emissions of GHG from enteric fermentation in dairy cattle represent approximately 3% of the GHG emission from enteric fermentation in Alberta's livestock. During the period from 1990 to 1996, GHG emissions from Alberta's dairy cattle decreased by 7%, with an additional 12% decrease occurring from 1996 to 2001 (Table 6).

Table 6. Methane emission from enteric fermentation in Alberta's dairy cattle as determined by IPCC Tier 2 guidelines and actual emission factors for 1990, 1996,and 2001.

Animal type	Number of months of year	Average Weight (kg)	CH_4 Emission Factor (kg/hd/yr)	CH_4 (tonne/yr[y])		
				1990	1996	2001
IPCC Tier 2						
1. Milking Cows[z]	12	635	162	17 666	16 531	14 586
2. Dairy calves	6	145	With beef	With beef	With beef	With beef
3. Dairy bulls	12	907	With beef	With beef	With beef	With beef
4. Dairy heifers[z]	12	450	72	3545	3183	2749
Total enteric fermentation CH_4 produced (tonne/yr)				21 211	19 714	17 335
Total CO2 equivalents (total annual CH_4 production x 21)				445 422	414 002	364 045
Emission factors from Canadian sources						
1. Milking Cows[z]	12	635	105	11 444	10 709	9449
2. Dairy calves	6	145	With beef	With beef	With beef	With beef
3. Dairy bulls	12	907	With beef	With beef	With beef	With beef
4. Dairy heifers[z]	12	450	56	2764	2482	2143
Total enteric fermentation CH_4 produced (tonne/yr)				14 208	13 191	11 592
Total CO2 equivalents (total annual CH_4 production x 21)				14 208	13 191	11 592

[z] Numbers are based on July 1, 1990, July 1, 1996 and July 1, 2001, Statistics Canada, Agriculture Division.
[y] Methane produced for milking cows is calculated as follows:
$((Wt^{0.75} \times 0.8300) \times (mon/12) \times n)/1000$, where $wt^{0.75}$ equals metabolic weight, 0.8300 is the value for CH_4 production per kg of metabolic weight per year (105 kg/hd/yr from a 635 kg lactating dairy cow; Jacques 1997), mon refers to the number of months in a particular animal type and n refers to the number of animals by animal type. The CH_4 production value used for dairy heifers is 0.5773 kg CH_4/kg metabolic weight.

Hogs

Emissions of GHG directly from hogs only represent approximately 0.8% of the GHG emissions from enteric fermentation in Alberta's livestock (Table 7).

Table 7. Methane emission from enteric fermentation in Alberta's hogs as determined by actual emission factors for 1990, 1996, and 2001.

Animal type	mon of year	Avg. Wt (kg)	CH_4 (kg/yr)	CH_4 (tonne/yr[y])		
				1990	1996	2001
1. Sow units[z]	12		14.5	2509	2526	2907
Total CO_2 equivalents (total CH_4 produced x 21)				52 689	53 046	61 047

[z] Numbers are based on July 1, 1990 and July 1, 1996, Statistics Canada, Agriculture Division.
[y] Methane produced is based on a sow unit which is defined as one sow plus 15 pigs raised from birth to slaughter at 100 kg. A sow unit produces 14.5 kg CH_4/sow unit/yr (Golder Report, Dec. 1998).

Other livestock

Emissions of GHG directly from poultry, horse, sheep and other diversified livestock hogs represent approximately 3.6% of the GHG emissions from enteric fermentation in Alberta's livestock (Table 8).

Table 8. Methane emission from enteric fermentation in Alberta's poultry, horse, sheep and other diversified livestock for 1990, 1996, and 2001.

Animal type	mon of yr	Avg Wt (kg)	CH_4 kg/yr	CH_4 (tonne/yr[w])		
				1990	1996	2001
Hens/chickens[z]	12		0.077	579	730	937
Horses[z]	12	400	18.0	3240	2699	2879
Sheep[z]	12	50	8.0	2200	2079	2458
Alpaca/Llama[y]	12	100	19.3	39	71	249
Bison – Bulls[y]	12	680	80.3	179	357	1249
- Cows[y]	12	500	63.8	441	882	3088
- Calves[y]	12	225	35.0	79	158	553
Elk[y]	12	300	38.0	118	299	1190
Deer[y]	12	100	19.3	9	54	161
Goats[y]	12	45	7.4	111	244	313
Emu[x]	12	40	0.52	1	2	1
Ostrich[x]	12	100	6.4	96	74	3
Rhea[x]	12	30	0.39	1	1	1
Wild Boar[y]	12	50	3.3	20	15	27
Total enteric fermentation CH_4 produced, tonne/yr				7113	7665	13 109
Total CO_2 equivalents (21 times total CH_4 production)				149 373	160 965	275 289

[z] Poultry, horse, and sheep are based on July 1, 1990, and May 15, 1996 and 2001 (Statistics Canada, 2002).
[y] Numbers for 1990 and projections to 2008-12 were derived from the following specialists: poultry - Martin Zuidhof; sheep/lambs/rams, Wray Whitmore; diversified species, Chuck Huedepohl and Doug Bienert. Numbers for 1996 for these diversified livestock are based on AAFRD. Numbers for 2001 (May 15) are from Census of Agriculture (Statistics Canada, 2002).
[x] Numbers were derived from C. Huedepohl and D. Bienert, AAFRD.
[w] Methane produced for the various species are as follows: poultry, 0.077 kg/bird/yr (0.0671 kg/kg metabolic weight/yr) from The health of our air, AAFC, 1998; sheep &goats, 8.0 kg/hd/yr direct, 0.4255 kg/kg metabolic weight/yr(McAllister et al. 1996, Mathison et al. 1998); horses, 18 kg/animal/yr (McAllister et al. 1996); bison, 121 l/d from 196 kg (31.4 kg/hd/yr or 0.6031 kg/kg metabolic weight/yr); wapiti, 87 l/d from 151 kg (22.5 kg/hd/yr or 0.5269 kg/kg metabolic weight/yr); deer, 33 l/d from 34 kg (8.6 kg/hd/yr or 0.6108 kg/kg metabolic weight/yr); emu and rhea , broiler/breeder value times weight of Emu or Rhea; ostrich, 0.2013 kg/kg metabolic weight/yr (based horse value); wild boar, 3.3 kg/animal/yr (Golder Report). One L CH_4 equals 0.7174 g of CH_4 (Galbraith et al. 1998).

All livestock

Emission of GHG from enteric fermentation in Alberta's livestock were 5.40-5.54, 6.91-7.17 and 7.36-7.66 Mt CO_2-E /yr in 1990, 1996 and 2001, respectively (Table 9). Regardless of method used to calculate GHG emissions, there has been a 36-38% increase in GHG emissions from 1990 to 2001. Olsen et al. (2002), in their document on "Canada's Greenhouse Gas Inventory: 1990-2000" reported that emissions of GHG from enteric fermentation in Alberta's livestock population were 5.1, 6.2 and 6.5 Mt CO_2-E/yr for 1990, 1996 and

2000, respectively. These values are based on IPCC Tier 1 calculations and are 5.9-11.5% lower than IPCC Tier 2 calculations and 8.6-15.6% lower than calculations using CH_4 emission factors from Canadian sources. These results indicate that a more comprehensive methodology should be used when calculating GHG emissions from livestock populations.

Table 9. Greenhouse gas emissions from enteric fermentation in Alberta's livestock as determined by IPCC Tier 2 guidelines and actual emission factors for 1990, 1996, and 2001.

Livestock type	1990 (t/yr)	1996 (t/yr)	2001 (t/yr)	% of total, 2001 emission factors
1. Beef cattle-IPCC Tier 2	4 748 283	6 277 709	6 663 630	
1. Beef Cattle-emission factor	5 036 601	6 676 228	7 084 670	92.4
2. Dairy cattle-IPCC Tier 2	445 422	414 002	364 045	
2. Dairy cattle-emission factor	298 368	277 011	243 432	3.2
3. Hogs	52 689	53 046	61 047	0.8
4. Horses[z]	68 040	56 679	60 459	0.8
5. Sheep/lambs[z]	46 200	43 659	51 618	0.7
6. Poultry[z]	12 159	15 330	19 677	0.3
7. Diversified species[z]	22 974	45 297	143 535	1.8
Total using IPCC Tier 2	5 395 767	6 905 722	7 364 011	
Total using emission factors	5 537 031	7 167 250	7 664 438	100.0

[z] CO_2 equivalents includes CH_4 produced directly from the animal plus CH_4 and nitrous oxide emissions from manure. It does not include emissions from manure storage systems.

Integrated Livestock Manure and Pasture Systems Emissions

The above sections dealt specifically with emissions from enteric fermentation in Alberta's livestock. These emission values should be increased by 25% due to manure production and manure management practices in Alberta's livestock (IPCC 2000). Thus, emissions of GHG for Alberta's livestock are 6.75 to 6.93, 8.64 to 8.96, and 9.20 to 9.58 Mt CO_2-E per year for 1990, 1996, and 2001, respectively. In addition, the beef cattle industry is an integral part of forage and range lands that sequester carbon. As of 2001, there were 10.72 million hectares of tame pasture (1.98 million ha), hay (2.06 million ha) and range lands (6.68 million ha) in Alberta (Statistics Canada 2002) that are estimated to sequester 1.10 tonne carbon per ha per year for tame pasture, 0.9 tonne carbon per ha per year for hayland and 0.35 tonne carbon per ha per year for rangeland (Mapfumo et al. 2002: Schnabel et al. 2001). Thus, Alberta's tame pastures, hay lands and rangelands are sequestering

23.4 Mt CO_2-E per year[2]. These data suggest that the forage livestock production systems in Alberta in 2001 sequestered 13.8 to 14.2 Mt CO_2-E per year more GHG than they emitted. If an aggressive livestock growth scenario (20% Cows: 50% feeder cattle) was achieved by 2008 to 2012, then Alberta's forage livestock production systems would be sequestering 11.9 to 12.3 Mt CO_2-E per year more GHG than they were emitting, leaving Alberta's forage livestock production systems in a position to sell carbon credits. In addition, improvements in pasture management practices could further improve the sequestering capability of Alberta's tame pastures, hay and rangelands.

[2] One tonne of carbon (C) equals 3.667 tonne of carbon dioxide equivalents.

Manure Management

Canada's GHG inventory estimates CH_4 and N_2O emissions from manure management and storage. As livestock population increases the amount of manure also increases. In Canada, emissions from manure management increased from 8270 kt CO2 E in 1990 to 10 100 kt CO_2E in 2001 (Environment Canada 2003). In Alberta, emissions from manure management increased from 1770 kt CO_2E in 1990 to 2400 kt CO_2E in 2001, which can be attributed to the increase in the livestock population.

Methods

At present we do not have Tier 2 methodology available (Olsen et al. 2002). Further analysis of the current methodology is required to assess whether an Alberta-based estimate can be made.

Methane

Canada's GHG inventory used IPCC default emission factors for a developed country with a cool climate (Olsen et al. 2002). This research is from the US and more research is needed to verify IPCC cool climate emission factors for Canadian conditions. Emissions were estimated by applying animal specific emission factors to domestic animal populations. Animal populations were obtained through Statistics Canada. Manure management systems were not considered in estimating CH_4 emissions.

To calculate Tier 1 CH_4 emission for manure management, multiply animal population by the animal specific emission factors (Table 10).

Table 10. Tier 1 Emission Factors for Animal Categories and Manure Management Systems for Canada's Inventory.

Category	Enteric Fermentation (kg CH_4 head^{-1} year^{-1})	Manure Management (kg CH_4 head^{-1} year^{-1})
Cattle		
Bulls	75[z]	1
Dairy Cows	118	36
Beef Cows	72[z]	1
Dairy Heifers	56[z]	36
Beef Heifers	56[z]	1
Heifers for Slaughter	47	1
Steers	47	1
Calves	47	1
Swine (all pigs)	1.5	10
Poultry	Not estimated	0.078
Other Livestock		
Sheep	8	0.19
Goats	8[z]	0.12
Horses	13[z]	1.4
Buffalo Mules/Asses Camels and Llamas	Consider a negligible source of GHG emissions in Canada.	
Pasture and Paddock	N/A	0.01[y]
Liquid Systems	N/A	0.1[y]
Solid Storage and Dry Lot daily spread	N/A	0.01[y]
Other Manure Management Systems	N/A	?

Source: adapted from Olsen et al. 2002
[z]Different than IPCC emission factors
[y]Methane conversion factors taken for Table 4-8 IPCC

Nitrous oxide

Canada's GHG inventory used default IPCC emission factors to calculate N_2O emissions from manure management systems and Tier 1 methodology. The utilization rates of various manure management or animal management systems are based on expert opinion. Emission factors were assigned to the most common systems in Canada:

- Pasture and paddock (emissions allocated to agricultural soil emissions)
- Liquid systems
- Solid storage or drylot
- Other

Animal population data were used to estimate the total manure nitrogen excreted.

Canada's GHG inventory calculated N2O from manure management systems by:

equation 1

$$= N_2O_{MMS} \times \sum \left[animal\ number \times N_{ex} \times MMS_T \times EF \right]$$

where:

N_2O_{MMS} = proportion of manure nitrogen lost as N_2O for different manure management systems (Table 13)

N_{ex} = proportion of nitrogen excreted by different animal types (Table 11)

MMS_T = proportion of manure nitrogen produced by different manure management systems (Table 12)

EF = emission factor for different manure management systems (Table 14)

Table 11. Nitrogen Excretion (kg N head^{-1} y^{-1}) for Each Animal Type.

Animal Type	Nitrogen Excretion
Non-dairy Cattle	44.7
Dairy Cattle	105.2
Poultry	0.36
Sheep and Lambs	4.1
Swine	11.6
Other (Goats and Horses)	49.3

Source: Olsen et al. 2002

Table 12. Percentage of Manure Nitrogen Produced by Different Manure Management Systems.

Animal Type	Liquid Systems	Solid Storage and Drylot	Other Systems	Pasture Range and Paddock
Non-dairy Cattle	1	56	1	42
Dairy Cattle	53	27	0	20
Poultry	4	0	95	1
Sheep and Lambs	0	46	10	44
Swine	90	10	0	0
Other (Goats and Horses)	0	46	8	46

Source: Olsen et al. 2002

Table 13. Percentage of Manure Nitrogen Lost as N_2O for different Manure Management Systems.

Animal Type	Liquid Systems	Solid Storage and Drylot	Other Systems	Pasture Range and Paddock
Non-dairy Cattle	0.1	2.0	0.5	2.0
Dairy Cattle	0.1	2.0	0.5	2.0
Poultry	0.1	2.0	0.5	2.0
Sheep and Lambs	0.1	2.0	0.5	2.0
Swine	0.1	2.0	0.5	2.0
Other (Goats and Horses)	0.1	2.0	0.5	2.0

Source: adapted from Olsen et al. 2002

Table 14. Emission Factors for Different Manure Management Systems.

	Liquid Systems	Solid Storage and Drylot	Other Systems	Pasture Range and Paddock
Emission Factor (range)	0.001	0.02 (0.005-0.03)	0.005	0.02 (0.005-0.03)

Source: IPCC, 1996; IPCC, 2001

Both N_2O and CH_4 values were converted to CO_2-E by multiplying the values by 310 and 21, respectively. The total GHG emission from manure management was the sum of the two converted values in kt CO_2 E.

Results and Discussion

Based on animal population and manure management systems in Canada, Canada's GHG inventory reports an annual emission of 2400 kt CO_2-E in 2001 for Alberta.

Further refinements to this methodology could include:

- An assessment of the nitrogen content of manure. Manure nitrogen is dependent on diet quality fed to animals. If their diets can be controlled there is a way to control the amount of nitrogen in the manure
- The estimate may not reflect the temporal nature of N_2O emissions due to the fact that at certain periods of the year, emission of N_2O may be non-existent.
- Further investigation of the CH_4 emission factor under Canadian conditions is needed.

Agricultural Soils

The primary gases emitted from agricultural soils in Alberta are CO_2 and N_2O. In periodically flooded soils, CH_4 may be emitted from soils. However it is assumed that this is negligible because the majority of the agricultural soil zones are in sub-arid to sub-humid climates, where evapo-transpiration exceeds precipitation. In 2001, Canada's GHG inventory estimated an annual emission from agricultural soils in Alberta of 10 000 kt CO_2E. This was comprised of a direct N_2O emission of 8070 kt CO_2E and an indirect emission of 1980 kt CO_2E.

Methods

At present we do not have Tier 2 methodology available (Olsen et al. 2002). Further analysis of the current methodology is required to assess whether an Alberta-based estimate can be made. Canada's inventory estimates net CO_2 and direct and indirect N_2O emissions. The following is a brief summary of the methodology used by Canada's GHG inventory.

Carbon dioxide emissions

Net CO_2 emissions were calculated using the CENTURY model. This emission estimate is an aggregated emission from each of the western and eastern provinces.

Nitrous oxide emissions

Canada's GHG inventory followed the same framework set out by IPCC, Tier 1. Nitrous oxide emissions are recorded as either direct or indirect. The following describes the methodology used by Canada's GHG inventory for both direct and indirect sources. Table 15 summarizes the default emissions factors and parameters used.

Table 15. IPCC Default Emission Factors and Parameters.

Emission Process	
Synthetic Fertilizer	0.0125 kg N_2O-N kg^{-1} N
Biological N Fixation	0.0125 kg N_2O-N kg^{-1} N
Animal Waste applied as Fertilizer	0.0125 kg N_2O-N kg^{-1} N
Crop Residue Decomposition	0.0125 kg N_2O-N kg^{-1} N
Cultivation of Histosols	5 kg N_2O-N ha^{-1} y^{-1}
Volatilization and Deposition of N	0.01 kg N_2O-N kg^{-1} N
Leaching and Runoff	0.025 kg N_2O-N kg^{-1} N
Fraction of Fertilizer N available to volatilize	0.1 kg N kg^{-1} N
Fraction of manure N available to volatilize	0.2 kg N kg^{-1} N
Fraction of manure and fertilizer N available to leaching and runoff	0.15 kg N kg^{-1} N
Fraction of N contained in legume crops	0.03 kg N kg^{-1} dry mass
Fraction of N contained in non-legume crops	0.015 kg N kg^{-1} dry mass
Fraction of tame hay assumed to be alfalfa	0.60

Source: Olsen et al. 2002

Direct Sources

Synthetic fertilizer –the emission factor for all types of fertilizer was 1.25% N_2O-N per kg N. The amount of applied N was reduced by 10% to account for volatilization. The amount applied was obtained from yearly fertilizer sales data.

Animal wastes applied as fertilizer – does not include manure from grazing animals. Uses data from the manure management section; assumes that all manure handled by manure management systems is applied as fertilizer. The amount of manure nitrogen excreted was reduced by 20% to account for volatilization.

Biological N fixation – average dry matter fractions were 86% for crops such as wheat, barley, corn, oats, rye, mixed grains flaxseed, canola, buckwheat, mustard seed, sunflower seed, canary seed, peas, beans, soya, lentils and tame hay. Silage corn, potatoes, and sugar beets were assumed to contain 30, 35, and 20 % dry mass, respectively. Alfalfa was assumed to be 60% of tame hay production.

Crop residue decomposition – nitrogen fixing crop residue was set at 0.03 kg N per dry kg and other crops were 0.015 kg N per dry kg. The emission rate was 1.25% N_2O-N per kg N (IPCC default). It was estimated that 55% of the crop mass remained on the field as residue

Grazing Animals – calculates the emissions from manure excreted by grazing animals.

The following calculation [Eq.2] was used to calculate N_2O from Direct Sources:

equation 2

$$= \left[\left(N_{fert}\left(kgNy^{-1}\right) + N_{manure}\left(kgNy^{-1}\right) + N_{biolNfix}\left(kgNy^{-1}\right) + N_{residue}\left(kgNy^{-1}\right)\right) \times EF_1\right] + Area_{histosol} \times EF_2$$

where:

N_{fert} = the total amount of fertilizer applied minus the amount volatilized

N_{manure} = the total amount of manure excreted minus the amount volatilized or excreted while grazing

$N_{biolNfix}$ = the total amount of nitrogen in nitrogen fixing plants

$N_{residue}$ = total amount of nitrogen in crop residue

EF_1 = emission factor for different direct nitrogen sources

$Area_{histosol}$ = total area where histosol soils are found

EF_2 = emission factor for histosol soils

For more information on emission calculations see IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories: Reference Manual (Volume 3).

Indirect Sources

For Alberta conditions, only the following indirect sources of N_2O are relevant.

Volatilization – Used IPCC default methodology; assumed to be 10% of synthetic fertilizer and 20% of manure N. This was multiplied by IPCC emission factor.

Leaching – This estimate was modified from IPCC. Runoff and leaching were estimated at 15% of the N applied as synthetic fertilizer or manure. This was multiplied by IPCC emission factor.

Results and Discussion

According to Canada's Inventory, synthetic fertilizer and crop residue decomposition were the most significant direct sources of N_2O emissions (2427 and 1321 respectively out of 8074 kt CO_2-E). Further investigation of improving these methodologies is needed (Table 16).

Table 16. Summary of Direct and Indirect Sources of Greenhouse Gas Emissions for Alberta Agricultural Soils for 2001.

Greenhouse Gas Source or Sink	CO_2 E (kt)
Direct Soil Emissions	8074*
Synthetic fertilizer	2427
Manure applied as fertilizer	917
N-fixing crops	575
Crop residues	1321
Manure on Pasture	1177
Indirect Soil Emissions	1975
Atmospheric deposition	546
Leaching and Runoff	1429
Total	10 050

Source: Laing, Pers. Comm.
*Totals don't add up because only sources of N_2O are listed

It is difficult to differentiate between management practices for rangeland and for cultivated land. In addition there is a range of temporal and spatial scenarios that are not accounted for in the IPCC Tier I (N_2O emissions calculations).

According to Canada's GHG inventory, Alberta's agricultural soils have reached equilibrium; they are not a sink or a source of CO_2. These estimates are based on the model CENTURY, which is sensitive to the amount of zero till practiced in a region. The CENTURY modelers acknowledge limitations in using CENTURY to estimate prairie soil C sequestration and are looking at alternative methods of quantifying changes in soil carbon. There still is potential for Alberta's agricultural soils to sequester more carbon if practices continue to change. Using an Alberta based model, Alberta's agricultural soils could potentially sequester between 4 700 and 9 000 Mt CO_2-E per year (Sauvé, 2000). This estimate does not includes the potential to sequester carbon on rangeland or pastures.

Currently the federal government is looking at more accurate methodology to calculate CO_2 emissions and removals from soil. The National Carbon and Greenhouse Gas Emission Accounting and Verification System (NCGAVS) estimate the amount and uncertainties of soil carbon stock changes and GHG emissions at the provincial, regional, and national level. It includes land use and management databases linked to ecological models and temporal and spatial scaling processes. Standard methodologies for measuring soil carbon and GHG emissions from agricultural land are key components of NCGAVS and provide the basis for future GHG monitoring and verification programs in agriculture. At present, work focuses on developing and establishing an accounting system for soil carbon change, CO_2 and N_2O emissions from agricultural land. Scientists at Agri-food and Agriculture Canada, Natural Resources Canada, Environment Canada, and numerous universities are developing this system across Canada for the year 2005. There is a potential to partner with NCGAVS to provide a better estimate of GHG emissions for Alberta.

Transportation and Farm Fuel

Agricultural transportation is not a separate category in Canada's GHG Inventory. It is located in fuel combustion under the categories of off road gasoline and off road diesel fuel. In 1996, transportation was estimated to be 10% of agricultural emissions in Alberta (AAFRD, 1999a).

Farm fuels are energy inputs needed to produce marketable agri-food products. Emissions from these fuels are categorized by type of fuel and purpose and include fuels used to operate machinery (mobile and stationary, to heat farm buildings, etc.). Farm by-products are defined as wastes that are recycled into fuel. These are renewable fuels in which the production may offset the potential decrease in emissions from using them, resulting in a net emissions change of zero. By-products used for production of energy include manure, biofuels, agricultural residues, crops produced specifically to produce ethanol, and biodiesel.

Methods

Alberta based emissions from agricultural transportation were calculated using data from Statistics Canada, which included personal and agricultural use of fuel. Personal fuel use was removed from Statistics Canada data by using personal fuel use percentages from previous emission inventories. Gasoline was reduced by 21%, diesel by 11%, NGL's by 60% and natural gas by 50% for 1997, 51% for 1998, 52% for 1999 and 53% for 2000. To ensure consistency, personal fuel use percentages were obtained from the previous (1986 – 1996) emissions inventory. The emissions factor for each fuel type came from Canada's 1997 GHG Inventory (Table 17).

Table 17. Emission factor for each fuel type.

Fuel Type Used	Emission Factor (g/L)
Natural Gas	1880
Gasoline (Motor Line)	2360
Diesel (Fuel Oil)	2730
NGL's (Gas Plant)	1530

To calculate GHG emissions for agricultural transportation, the following equation was used:

equation 3

$$= \left[\frac{Q_{Fuel}}{CF_1} \times EF_1 \right] \div CF_2 \text{ (results given in kTCO}_2\text{ E)}$$

where:

Q_{Fuel} = quantity of fuel used by agricultural industry (Statistics Canada, 2002)

CF_1 = conversion factor where 1L = 3.86×10^{-8}PJ

EF_1 = emission factor for each fuel type (Table 17)

CF_2 = conversion factor where 1kT = 1×10^9g

Results and Discussion

Fossil fuel use in Canada contributes approximately 81% of the total amount of GHG emitted each year. In 2000, this was 587 000 kT CO_2 E (out of 726 000 kT CO_2 E) emitted in Canada. Greenhouse gas emissions from farm fuel use in Canada made up 1.4% of total Canadian emissions in 2000. Greenhouse gas emissions from farm fuel use in Alberta in 2000 were 2972 kT CO_2 E (Table 18). This equates to 1.3% of all emissions from Alberta or 0.4% of total Canadian emissions (Olsen et al. 2002)

Between 1990 and 2000, the total amount of GHG emitted in Canada increased by 20%, as compared to Alberta where the total amount of GHG emissions increased by 30% (Table 19). The amount of GHG emitted as a result of farm fuel use in Alberta increased 16% between 1990 and 2000, whereas GHG emissions from farm fuel use in Canada increased 26%. The ratio of Alberta's emissions compared to Canada's emissions, resulting from farm fuel use, remained consistent between 1990 and 2000 at 30%, although the amount of GHG emitted as a result of farm fuel use in Alberta in 1990 (2557 kT CO_2 E) was less than the amount emitted in 2000 (2972kT CO_2 E).

Table 18. Total emissions from farm fuels in Alberta (off-road transport, heating, operation of equipment) in kT CO_2E.

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Natural gas	236	202	218	207	211	199	226	285	171	156	191	168	105	148	146
Gasoline (motorline)	921	859	895	1021	962	803	678	608	522	573	659	684	746	750	698
Diesel (fuel oil)	1241	1213	1118	1299	1323	1156	1160	1347	1365	1497	1600	1808	1965	1986	2124
NGL's (Gas Plant)	39.6	40.4	50.9	60.9	61.4	25.8	44.2	7.7	2.1	5.1	4.8	6.62	3.96	6.50	4.51
Total	2437	2314	2282	2588	2557	2183	2109	2248	2059	2232	2455	2666	2819	2890	2972

Table 19. Percent increase in farm fuel use in Alberta between 1986 and 2000.

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Percent of Canadian totals	33	31	30	30	30	28	28	29	26	27	27	28	30	30	30
Percent above 1990 levels	N/A	N/A	N/A	N/A	N/A	0	0	0	0	0	0	4	10	13	16

Agri-Food Processing

Emissions from agri-food processing result from the combustion of fossil fuels. In the national GHG inventory for Canada, agri-food processing is categorized under manufacturing. Agri-food processing involves activities such as livestock slaughter, grain milling, honey extraction and packaging, fruit and vegetable packaging, beverage production, production of dairy products and food oil production. In 1996, GHG emissions from the agri-food processing sector were estimated to be 3% of the total agricultural emissions in Alberta (AAFRD, 1999a).

Methods

Census data from the agri-food processing sector was difficult to obtain because the reported information changed from quantity of energy used to the number of dollars spent on energy (per energy type) for agri-food processing as of 1997 (Table 20 to 22). Therefore dollar figures need to be converted to quantity using the price of fuel (which may be a challenge to find). Once the quantity of fuel is determined, emission factors from Canada's Inventory were used to calculate the total GHG emissions for this category.

Table 20. Amount of $$ spent on natural gas from 1997 to 1999.

SIC Category	1997 ($ '000)	1998 ($ '000)	1999 ($ '000)
Meat and Products	4475	3454	5836
Fruit and Vegetable	888	N/A	N/A
Canned and Preserved Fruit and Vegetables	359	22086	27148
Fluid Milk Products	N/A	548	N/A
Frozen Fruit and Vegetables	529	N/A	N/A
Dairy Products	1302	22086	27148
Flour, Cereal	2496	N/A	N/A
Cereal Grain	205	N/A	N/A
Prepared Flour	166	N/A	N/A
Feed Industry	2125	N/A	N/A
Bread and Other Bakery	542	506	54296
Other Food	757	22592	27148
Beverage	3456	22086	27148

Table 21. Amount of $$ spent on liquid petroleum products (propane) from 1997 to 1999.

SIC Category	1997 ($ ‘000)	1998 ($ ‘000)	1999 ($ ‘000)
Meat and Products	124	4	4
Fruit and Vegetable Industry	93	N/A	N/A
Fluid Milk Industry	N/A	9	N/A
Canned and Preserved Fruit	88	434	642
Frozen Fruit and Vegetables	5	N/A	N/A
Dairy Products Industry	9	434	642
Flour, Cereal	47	N/A	N/A
Cereal Grain	0	N/A	N/A
Prepared Flour	0	N/A	N/A
Feed Industry	47	N/A	N/A
Bread and Other Bakery	76	39	1284
Other Food	0	473	642
Beverage	78	434	642

Table 22. Amount of $$ spent on heating oil (light and heavy) from 1997 to 1999.

SIC Category	1997 ($ ‘000)	1998 ($ ‘000)	1999 ($ ‘000)
Beverage Industry	24	12	418
Canned and Preserved Fruit and Vegetables	N/A	12	418
Dairy Products	N/A	12	N/A
Other Food Products	N/A	198.90	418
Bread and Other Bakery	N/A	N/A	20.9

Dollar figures were converted to amount of energy used by dividing the dollars spent per energy type (Table 23) by the price of fuel. The amount of fuel used was converted to GHG emitted using the emission factors in Table 24 and Eq.4. Price information was obtained from Statistics Canada and Alberta Energy for natural gas, propane (liquid petroleum products) and heating oil (combined as light and heavy fuel oil).

Table 23. Price of fuel from 1997 to 1999.

Fuel Type	1997	1998	1999
Propane (LPP)	\$0.2753/L	\$0.2479/L	\$0.2488/L
Heating Oil	\$0.4340/L	\$0.4162/L	\$0.4107/L
Natural Gas	\$1.865/GJ	\$1.84/GJ	\$2.35/GJ

Table 24. Emission factors for different fuel types.

Fuel Type	Emission Factor
Propane (LPP)	1467
Heating Oil	2960
Natural Gas	1880

To calculate GHG emissions for the agri-food processing sector, the following equation was used:

$$= \frac{A_{Fuel}}{P_{Fuel}} \times CF_1 \times CF_2 \times EF_1 \times CF_3 \quad \text{(results given in kTCO}_2\text{-E)}$$

where:

A_{Fuel} = Amount of money (\$) spent on fuel

P_{Fuel} = Price of fuel (GJ)

CF_1 = conversion factor where 1PJ = $1x10^6$GJ

CF_2 = conversion factor where 1L = $3.86x10^{-8}$PJ

EF_1 = emission factors for different fuel types (Table 24)

CF_3 = conversion factor where 1kT = $1x10^9$g

Results and Discussion

In 1999, the total GHG emissions from the agri-food processing sector were 3517 kt CO_2 E (Table 25). This emission may actually be higher because the agri-food processing industry reports their energy use on a voluntary basis. The majority of agri-food processing businesses are not required to report their energy usage therefore access to accurate information is limited.

Table 25. Total emissions from agri-food processing reported in kT CO_2E.

Agri-food processing component	NG[z] 1997	LPP[y] 1997	HO[x] 1997	NG 1998	LPP 1998	HO 1998	NG 1999	LPP 1999	HO 1999
Meat and meat products	116.55	-	0.661	91.43	0.0237	-	120.95	-	-
Fruit and vegetable industries	23.13	-	0.496	-	-	-	-	-	-
Canned and preserved fruit	9.35	-	0.469	584.61	2.57	0.0853	562.65	-	3.01
Frozen fruit and vegetables	13.78	-	0.027	-	-	-	-	-	-
Dairy products	33.91	-	0.048	599.11	2.62	0.0853	562.65	-	3.01
Flour cereal food and feed industries	65.01	-	0.25	-	-	-	-	-	-
Cereal Grain Flour Industry	5.33	-	-	-	-	-	-	-	-
Prepared flour mixes and cereal foods	4.32	-	-	-	-	-	-	-	-
Feed Industry	55.34	-	0.25	-		-	-	-	-
Bread and Other bakery products industry	14.11	-	0.40	13.39	0.231	-	1125.3	-	0.151
Other food products industry	19.71	-	-	598.0	2.80	1.41	1125.2	-	6.02
Beverage Industries	90.01	0.164	0.415	584.61	2.57	0.0853	562.65	-	3.01
Total	450.55	0.164	3.02	2471.2	10.8	1.67	3502.4	0	15.2

[z]NG = natural gas
[y]LPP = liquid petroleum product or propane
[x]HO = heating oil

Conclusion

Alberta based GHG emissions were calculated for livestock, transportation and agri-food processing. At this time, Tier 2 methodology to calculate GHG emissions from agricultural soils and manure management is not available. However AAFRD's GHG technical team is currently investigating the applicability of improving these methodologies. In addition, methodologies to estimate GHG emissions from woodlots, agro-forestry, agricultural wetlands, streams, and riparian area as well as biofuels are in the development stages.

Over 90 percent of livestock that produce GHG in Alberta are beef cattle. Greenhouse gas emissions from Alberta's livestock, based on IPCC Tier 2 guidelines, were 5.40, 6.91 and 7.36 Mt CO_2-E per year in 1990, 1996 and 2001, respectively. Emissions based on methane emission factors from Canadian research trials were 5.54, 7.17 and 7.66 Mt CO_2-E per year in 1990, 1996 and 2001, respectively. Emissions of GHG from enteric fermentation in Alberta's livestock have increased by 36 to 38% from 1990 to 2001. These emissions were 5.9 to 13.5% higher than those presented in Canada's Greenhouse Gas Inventory, indicating that IPCC Tier 1 guidelines underestimate GHG emissions from enteric fermentation in Alberta's livestock.

The amount of GHG emitted as a result of farm fuel use in Alberta increased 16% between 1990 and 2000. The amount of GHG emitted from farm fuel use in Alberta in 1990 (2557.1 kT CO_2 E) was less than the amount emitted in 2000 (2972.28 kT CO_2 E).

Total GHG emissions from the Agri-food processing industry from 1997, 1998, and 1999 are 453, 2484, and 3518 kT CO_2 E. Analysis of the results indicates that the Agri-food processing industry emitted less GHG than farm fuel use between 1996 and 2000. This result could be an artifact of the voluntary reporting system for energy use in Agri-food processing because the majority of agri-food processing businesses are not required to report their energy usage, which makes access to this information difficult.

Compared to the 1996 inventory of GHG emission from the agriculture sector in Alberta, emissions from livestock, manure management and transportation increased 2%, 3%, and 3%, respectively while GHG emissions from agri-food processing, soil and fertilizer decreased 1%, 1% and 6% respectively.

To summarize the data presented in this report (Table 28), total emissions from the agriculture sector in Alberta are 26.3 Mt CO2-E per year. If potential sequestration estimates are correct for agricultural soils, pastures and rangeland, the agriculture sector is a net sink of GHG emissions.

Table 26. Summary of GHG Emissions and Potential Sequestration Estimates for Alberta's Agriculture Sector.

	GHG emissions (kt CO_2-E per year)
Livestock	7 364
Manure Management	2 400
Agricultural Soils	10 050
Farm Fuel	2 972
Agri-food Processing	3 517
Total	26 303

	Potential Carbon Sequestration (kt CO_2-E per year)
Agricultural Soils	5 970
Pasture and Rangeland	23 400
Total	29 370

Estimates from this inventory provide a guideline to components of the farm that have high GHG emissions and those that can offset GHG emissions. There are opportunities to increase carbon sequestration in cropland, pasture and rangelands, woodlot, and riparian areas. There is also a potential to reduce GHG emissions through the production and burning of biofuels, CH_4 (biogas) capture in manure management systems, and better feeding systems in livestock.

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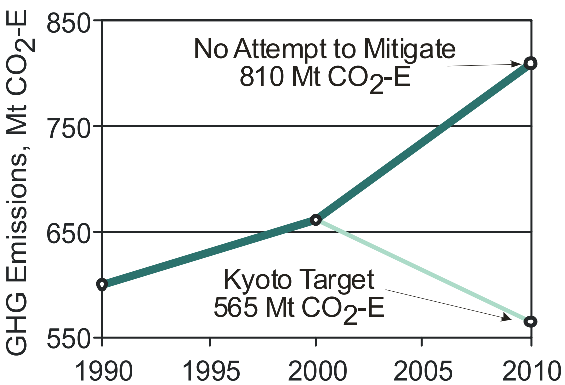
Chapter 3:
Alberta Agricultural Greenhouse Gas Assessment Science Plan

Introduction

In 1997, Canadian delegates to 'The Third Conference of the Parties to the United Nations Framework Convention on Climate Change' signed the Kyoto Protocol. Ratification by the federal government followed in December 2002. By the period between 2008 and 2012, Canada is committed to limiting its greenhouse gas (GHG) emissions to approximately 565 Mt (megatonnes) of carbon dioxide equivalents (CO_2-E) annually. This target is 6% below the amount produced in 1990 and some 245 Mt less than the amount likely to be emitted by 2010 if no attempt is made to mitigate emissions.

Figure 1. The Canadian Kyoto Protocol GHG emission target is 565 Mt CO_2 equivalent, 6% less than the nation's 1990 GHG emissions level and 245 Mt less than that expected to be emitted in the absence of mitigation measures.



The main GHG emissions from agriculture are nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). Globally, agriculture is responsible for 25% of total GHG emissions. Within Canada, GHG emissions from crops, pasture and livestock production account for 9% of the nation's total emissions; farm fuel and agri-food processing accounts for another 3%. Alberta's agriculture industries are responsible for approximately 30% of agricultural GHG emissions in Canada. It is expected that the agriculture industry will be required to contribute to Canada's GHG reduction strategy.

The broad objective of this Science Plan is to identify significant agricultural GHG sources and sinks in Alberta and to propose areas for research that might lead to mitigation of future emissions. The ultimate goal is to develop an on-farm assessment tool that will facilitate evaluation and mitigation of GHG emissions on individual farms. Primary sources of information used to develop this Science Plan were the 'State of Knowledge' that appears as Chapter 1 of this report as well as feedback received from the agricultural GHG Science Plan workshop held in Canmore, Alberta in June 2003.

The objective for this chapter of the Agricultural Greenhouse Gas Assessment report is:

- To develop a science plan which will guide researchers and funding agencies in the establishment of future research priorities.

Emission Estimates for Alberta's Agriculture Industries

Total annual GHG emission estimates for Alberta's agricultural industry between 1999 and 2001 are shown in figure 2. Negative emissions indicate net sequestration. The large amount of carbon sequestered by pasture and rangeland soils results in a net negative

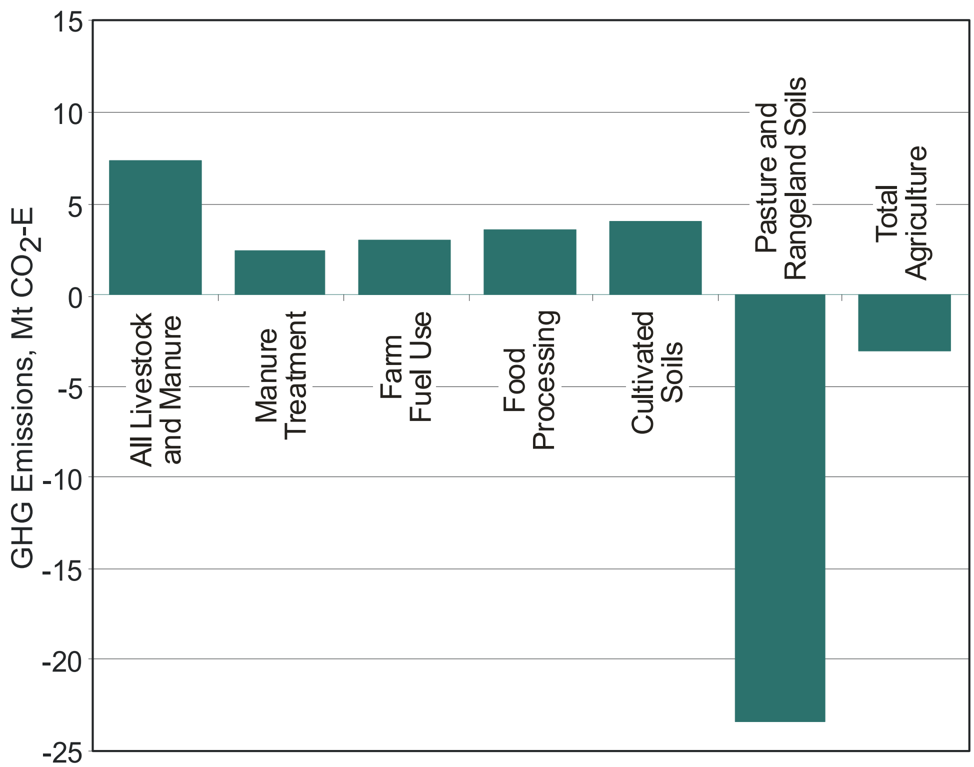


Figure 2. 1999-2001 GHG emission estimates for segments of Alberta's agriculture industry. source: Agricultural Greenhouse Gas Emissions Inventory for the Province of Alberta for 1991-2001, Alberta Agriculture, Food and Rural Development.

emission estimate for Alberta's agriculture industry as a whole. The rate of carbon sequestration by these soils is expected to increase by 2008-2012 as more farmers adopt sustainable management practices that reduce carbon losses associated with soil cultivation.

Among agricultural GHG sources, livestock and the manure they produce are the most significant. Beef cattle accounted for over 90% of the estimated 9.76 Mt of CO_2-E emitted by livestock and their manure in 2001. Expansion of livestock numbers is expected to further increase GHG emissions by 2008-2012.

Mitigation Strategies: Potential to Reduce GHG Emissions

Soils and Crops

Expanded application of sustainable soil and crop management practices have the greatest potential to reduce Alberta's total agricultural GHG emissions since:

- Reduced tillage limits the CO_2 and N_2O losses that result from the soil heating and aeration introduced by cultivation.
- Limiting the use of summer fallow reduces nitrogen mineralization and the carbon losses which result from erosion and mineralization of soil organic carbon.
- Extended crop rotations incorporating perennial forages promote soil carbon sequestration.
- Grazing management practices which promote pasture biomass production support carbon and nitrogen sequestration.
- Maintenance of optimum soil nutrient levels through fertilization promotes sequestration of carbon and limits denitrification.
- Strategic timing, rates and methods of applying nitrogen fertilizer can significantly reduce soil N_2O emissions.
- The addition of stable organic matter to soils (e.g. crop residues, fermented manure) results in the long-term accumulation of carbon.

Livestock and Manure

There is some potential to mitigate GHG emissions from livestock and the manure they produce. Beef cattle account for over 90% of livestock GHG emissions in Alberta, so emphasis should be placed on applying mitigation strategies to this segment of the industry because:

- Dietary modification can be used to increase the efficiency of rumen fermentation, consequently reducing the production of CH_4. Methods include more accurately balancing rations and feeding more digestible diets by utilizing higher quality forages and more concentrates. Dietary supplements that have been shown to reduce methanogenesis include ionophores, long-chain fatty acids and selective defaunation agents.
- Composting (aerobic fermentation) reduces the carbon (CH_4, CO_2) and nitrogen (N_2O, ammonia) losses associated with the application of raw manure to soils, providing stabilized organic matter and a more concentrated source of nutrients. Emissions of CH_4, CO_2 and N_2O produced during composting can be captured

by conducting the process in an enclosed environment, directing exhaust gases through an absorbent biofiltration medium.

- Anaerobic digestion of manure produces large quantities of heat and ‘biogas’—largely CH_4 and CO_2. Capture of the heat and use of the biogas as a fuel to generate electricity can reduce farm reliance on external energy sources. Residual solids provide stabilized organic matter, more suitable as a crop amendment than the raw manure from which they are produced.

Development of GHG Emission Assessment Tools for On-farm Application

An Alberta-wide GHG forum was held in March 2000. During that meeting, consensus was reached among members of the agriculture industry, the scientific community and government that a comprehensive, on-farm GHG emission assessment was required. It was also agreed that such an assessment would require knowledge of all biological, physical and chemical processes that contribute to agricultural GHG emissions.

Assessment Framework

In June 2003, a workshop was held to gather input from a range of technical experts into the requirements for the present Agriculture GHG Science Plan. Participants were asked to consider how to reduce the range of error when conducting an on-farm GHG emissions assessment. The outcome was a conceptual framework that would be based upon a geographic information system (GIS) and would include the following five levels of analysis:

- *Level 1*: Climatic zone and land use (estimated GHG category, based upon satellite photo analysis—e.g. soil type, climate, topography).
- *Level 2*: Land management unit (more specific GHG category, estimated from more detailed aerial analysis of field and farm—e.g. hectares of oilseed production, hectares of naturalized range for cattle grazing, size of hog confinement area).
- *Level 3*: Farm management (e.g. number of beef cattle, tillage practices, crop rotation, yield).
- *Level 4*: Specific on-farm factors affecting GHG (e.g. zero tillage, ruminant diet, irrigation, composting).

- *Level 5*: Specific on-farm measurements or hypothesis testing (e.g. GHG changes by fertilizer application, by timing of operations, by integration of farm systems, or by bio-fuel or on-site wood supply use).

The range of error in the estimate of net GHG emissions would be significantly reduced as assessment proceeded from one level to the next (higher) level.

Current Technologies

At the present time, most GHG emission estimates are based on calculation from published emission factors. In many cases, these factors have been determined in environments that are quite dissimilar from those to which they are applied.

As a signatory to the Kyoto Protocol and a member of the Intergovernmental Panel on Climate Change (IPCC), Canada is required to report annually on GHG emissions from each sector of its economy. These emissions are calculated using the 1996 IPCC Guidelines for Emissions Inventories. The emission factors recommended in these Guidelines are designed for broad application and are of little value in the accurate assessment of GHG emissions on individual farms.

Research trials conducted in Alberta and other parts of Canada have measured emission factors applicable to specific agricultural management practices used in this province. Significantly more research will be required to measure factors that apply to the full range of practices and their interactions.

Current Research 2000-present

Current agricultural GHG research projects being conducted in Canada are listed in Appendix A. The list was derived from two primary sources:

- records in the Inventory of Canadian Agri-Food Research (ICAR) database, and;
- projects submitted by participants in the June 2003 workshop.

Knowledge Gaps and Research Priorities

At the June 2003 workshop, information was gathered from a range of technical experts into the requirements for the present Agriculture GHG Science Plan. Participants identified gaps in current scientific knowledge which are viewed as impediments to the accurate assessment of farm GHG emissions. Each of these gaps was then rated to determine:

- how urgently the research is needed to address an immediate application or establish a precedent for other research (low, medium or high).
- how great an impact the research would have in moving toward an accurate GHG assessment (low, medium or high).

On the pages which follow, a number of statements generated at the workshop identify knowledge gaps within each of five areas of farm management. The graphs on the bottom of each page illustrate the relative urgency and potential impact of addressing each of the identified gaps, as perceived by the participants at the workshop.

Soil and Crop Management

A Rangeland and pasture GHG research - as very few emission factors have been calculated for perennial cropping systems.

B More research on complex interactions and combinations of management practices on soil, including GHG management over entire crop rotation cycles.

C There's a need to better define the interaction between climate, soil type and management practice and the significance to estimating the GHG emissions.

D Research to fully understand the complex interactions that affect the factors controlling the N_2O/N_2 ratio in different spatial and temporal situations.

E Research to fully understand the net GHG effect of beneficial management practice of reduced or no-till soils.

F Research to fully understand how temporal and spatial variation influences the error associated with calculations required to scale up emission models to the whole farm level and place that error in context.

G Protocol to document and reduce the level of error associated with scaling up from micro plot to field scale.

H Understand the distribution of snow and snow melt and its effect on GHG.

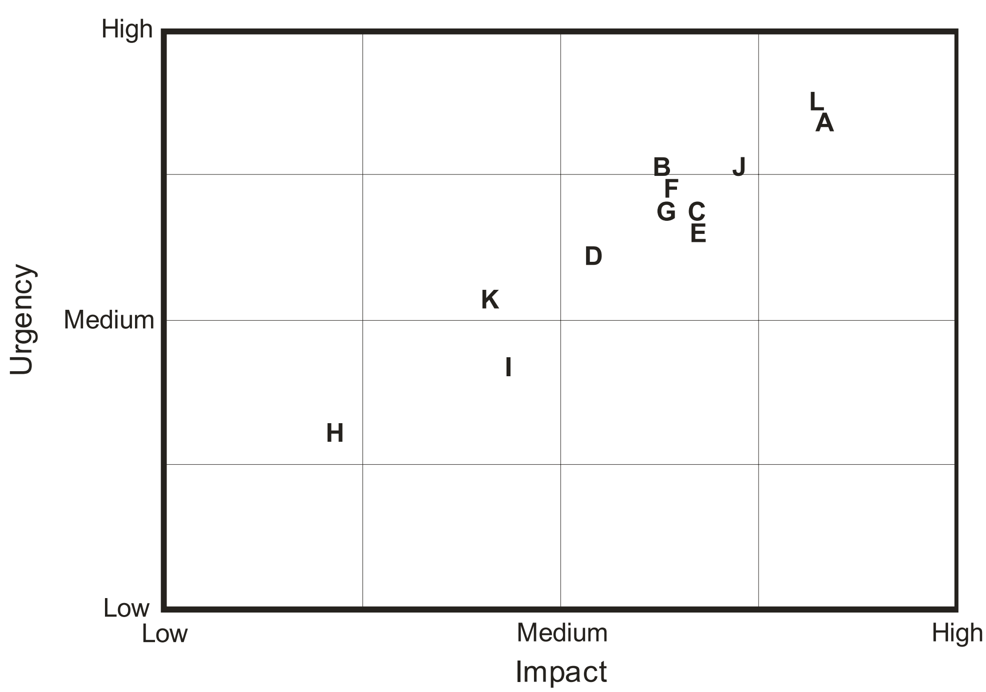
I Improve linkage between assessment, mitigation and adaptation - including assessment of co-benefits.

J Research on the fundamental biology of nitrous oxide production and consumption.

K Research with respect to methane consumption and production in agricultural landscapes.

L Research on the effects of management practices on the permanence of sequestered carbon.

Figure 3. Impact/ Urgency matrix for knowledge gaps and research priorities in soil and crop management.



Manure Management

A More research is needed to answer questions about GHG emissions from different sources of manure and different treatments.

B More research needed on GHG emissions from different facilities (barns, pens).

C Quantify GHG emission from unmanaged manure.

D Full life cycle assessment from a managed system: compost, anaerobic, solid stack, direct application and bio-gas).

E GHG research on economic cost benefit and issues of scale (small, medium and large scale operations) for manure/waste management on farms (e.g. anaerobic digesters).

F Examine treatment opportunities to use climate and timing to enhance manure processing (i.e. composting).

G Research into the technology of applying manure/compost at agronomic rates.

H Research into analysis and sampling protocols for liquid and solid manure at laboratory (commercial) and field scale.

I Can compost management result in reduced net GHG emissions?

J More research on quantifying the greenhouse gas mitigation benefits of different manure treatment systems.

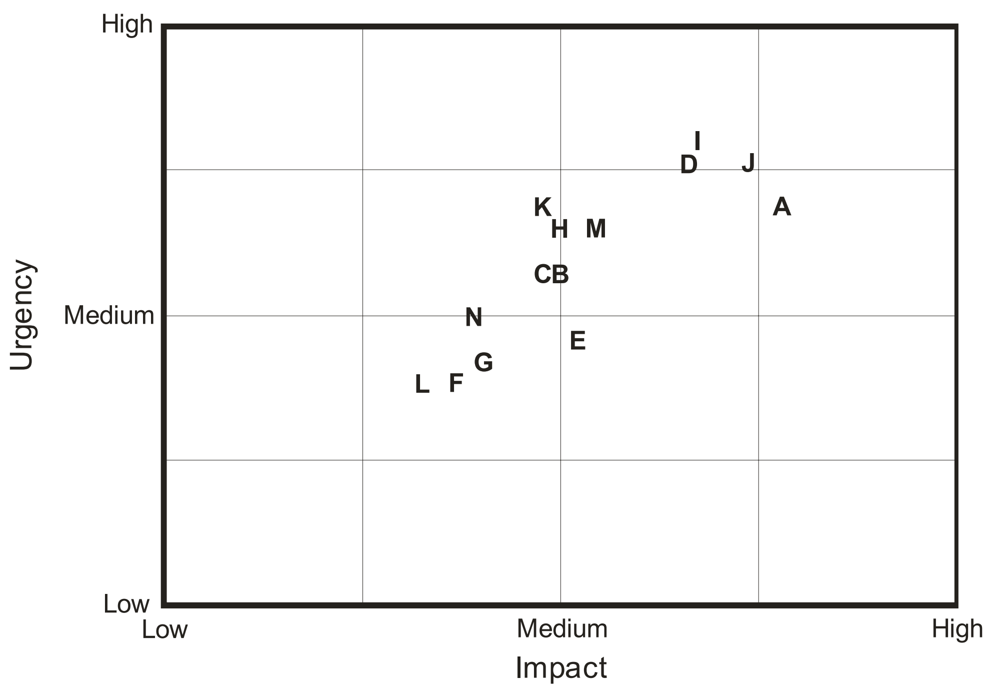
K More research is needed on placing manure in direct seeded and pasture systems.

L More research into economic distances for handling raw vs. processed manure in a GHG context.

M More research into the stability of carbon and nitrogen in composted manure.

N Constructing and evaluating constructed wetlands and vegetative filter strips for treating manure.

Figure 4. Impact/Urgency matrix for knowledge gaps and research priorities in manure management.



Livestock Management

A Long-term benefits of ionophore use in ruminant diets.

B Potential reduction of methane emissions using lipid additives in forage (i.e. pasture) based diets.

C Evaluation of diversified species/diets for methane emissions (elk, deer, bison, ostrich, horses, etc.).

D The effect of immunization against methanogenic rumen microbes on CH_4 emission.

E GHG emissions for beef and dairy cattle on backgrounding diets (i.e. low rates of gain).

F GHG emissions of various feedlot diets under western Canadian conditions.

G Simulation model development in forage beef production systems that integrate CH_4 emissions and manure production with economic sustainability.

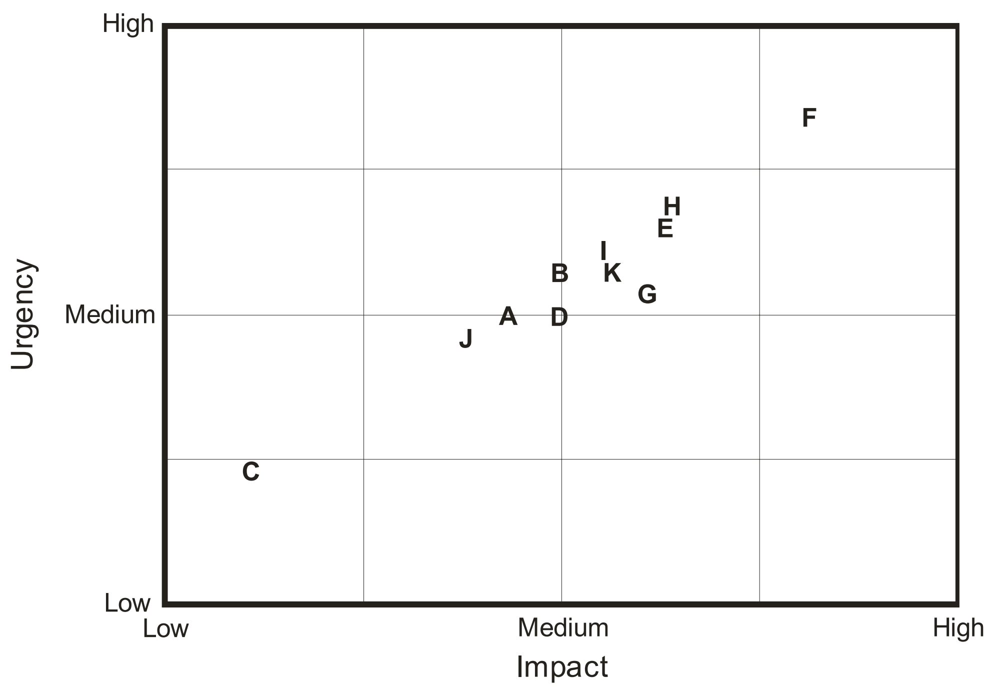
H Evaluation of western Canadian pasture systems for CH_4 emissions.

I Evaluate forage species for factors affecting methane emission and carbon sequestration (i.e. root and litter carbon).

J Impact of extending the grazing season on CH_4 emissions.

K The effect of genetic selection for feed efficiency on methane emissions and manure production.

Figure 5. Impact/ Urgency matrix for knowledge gaps and research priorities in livestock management.



Land Use and Energy

A Accurate and comprehensive inventory of wetlands and riparian areas.

B Research on the change in carbon stocks and GHGs (either positive of negative) with wetland destruction and restoration.

C Research on the change in carbon stocks and GHGs in the wetland as a result of different land management practices in the surrounding upland.

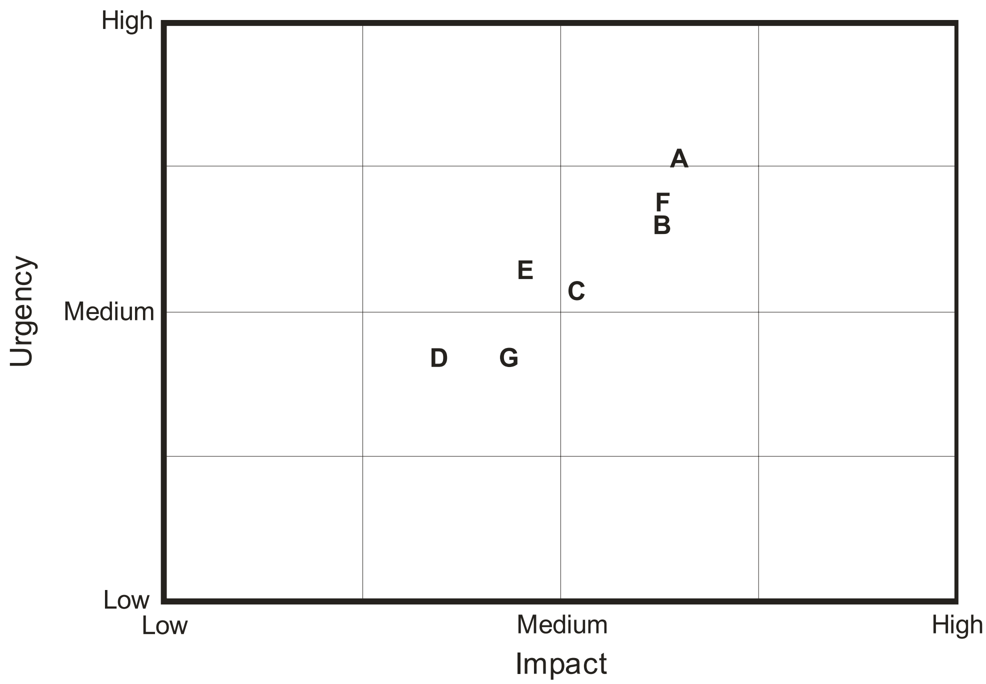
D Research of shelterbelts and woodlots emphasizing interactions with surrounding land (e.g. snow trapping leading to increase in spring GHG?, moisture/carbon competition with crops?, what is net GHG balance?).

E Research on carbon sequestration in woodlots, including consideration for soil carbon and wood products.

F Research into the feasibility of on-farm energy production (e.g. solar, wind, bio-fuels).

G Research into opportunities for improved infrastructure (buildings, the McLeod Harvester).

Figure 6. Impact/ Urgency matrix for knowledge gaps and research priorities in land use and energy.



Whole Farm Systems

A Systems analysis for net GHG production on the farm (on-farm practices and their interaction), including cost and value analysis.

B Effect of harvest method (silage vs. hay) on methane emission.

C Optimize GHG emission on a productivity and economic basis.

D Determine whether BMP for GHG impacts food health safety.

E Applying GIS to optimize whole farm production, carbon sequestration and nutrient flow by field, landscape and enterprise.

F With what certainty and with what error can we actually conduct on-farm GHG assessments?

G Linkage between GHG audits and agronomic management software.

H Linkage between GHG on-farm audit and the environmental farm plan.

I Research alternatives to synthetic nitrogen.

J Document applicability of Statistics Canada data and other existing databases to capture information on agricultural activities.

K Document the applicability of commercial/farm data management software to the GHG on-farm audit.

L Compare sum of GHG on-farm audits for Alberta to Environment Canada National GHG Inventory value for Alberta.

M Socio-economic research into the way producers make decisions with respect to changing economic conditions.

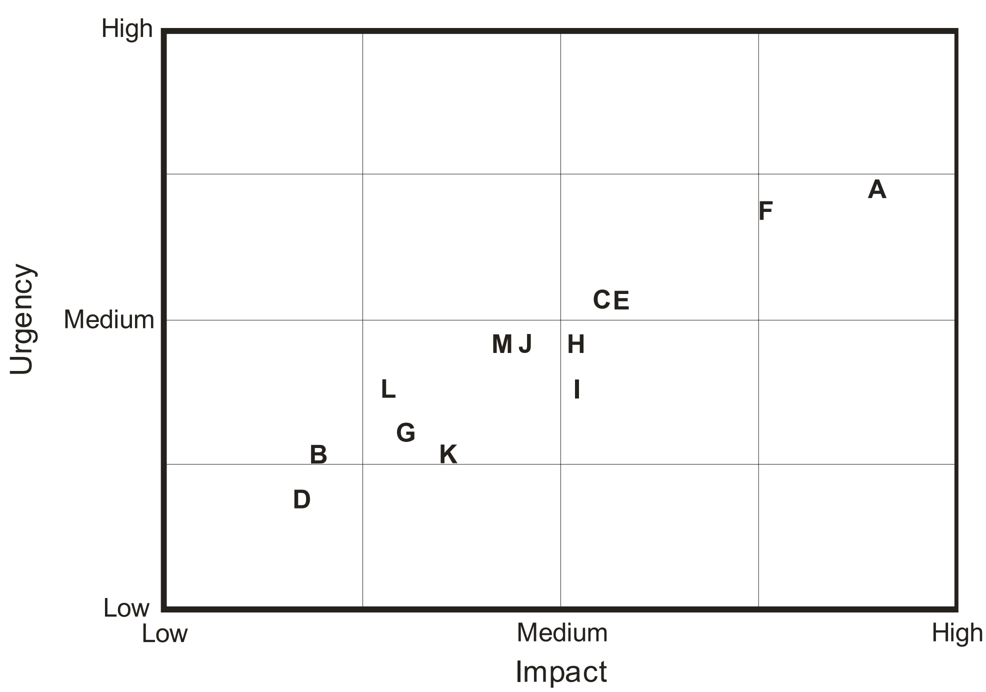


Figure 7. Impact/ Urgency matrix for knowledge gaps and research priorities in whole farm systems.

Conclusion and Recommendations

There is clearly some urgency required if Canada is to meet its Kyoto obligations by 2008-2012. Agriculture has the potential to make a significant contribution to GHG mitigation.

Based on assessments of their current GHG status, Alberta's primary agriculture industries provide a net sink for GHG —they sequester more than they emit. Through expanded application of sustainable crop and soil management practices, sequestration may be increased.

The beef cattle industry is Alberta's primary agricultural emitter of GHG, due to CH_4 production by rumen microbes along with CH_4 and N_2O losses from manure. Reduction of emissions from these two sources will result from the application of new feeding management programs and manure treatment technologies.

Although less significant than those suggested above, other opportunities also exist to mitigate emissions and promote sequestration of GHG in the agricultural landscape. Mitigation of emissions from other livestock and their manure will contribute to the achievement of Kyoto targets as will the application of management practices to increase carbon sequestration in riparian areas, wetlands and farm woodlots.

In the near term, it is recommended that research focus on acquiring the knowledge to more clearly evaluate GHG emissions from soils and cropping systems. The objective should be to further refine management practices that promote the net sequestration of carbon and nitrogen. In addition, research on methods to mitigate GHG emissions from ruminant livestock and animal manure should be emphasized. This research should include efforts to develop and refine economic manure treatment technologies applicable to livestock production facilities of all sizes.

Appendix A – Current Canadian GHG Research Projects, 2000-present

The following listing of current Canadian GHG research projects was extracted from a report entitled 'State of Knowledge of Agricultural Greenhouse Gases for the Prairie Region', published in May 2003 by the Alberta Agricultural Research Institute. The primary source of these citations was the Inventory of Canadian Agri-Food Research (ICAR) database which is maintained by the Canadian Agri-Food Research Council (CARC). Research scientists voluntarily submit project summaries to be listed in the ICAR database. Therefore, some current research projects may not be listed. However, this list can be used to assess whether the gaps identified in this Science Plan are currently being addressed.

Soil and Crop Management

1) Development of scientifically defensible estimates of N_2O emissions from agricultural ecosystems in Canada. R. Grant. 2000-2003
2) Fluxes of GHG from Prairie agricultural soils and improving N_2O emission estimates. B. Ellert and H. Janzen
3) AESA Soil Quality Monitoring Program. K. Cannon
4) Assessment of climate change and impacts on soil moisture and drought on the Prairies. S. McGinn
5) Soil and crop residue management effects on nitrogen cycling. Y.K Soon
6) Legume based conservation tillage systems. G. Clayton
7) Conservation of N during composting. J. Leonard
8) Identifying sources and sinks for atmospheric carbon. T. Goddard
9) Impact of soil erosion on the production and emission of GHG from soil within topographically complex, cultivated landscapes. D. Lobb and B. McConkey.

   This project will assess the impact of soil erosion on the production and emission of GHG from soil within cultivated, hilly landscapes. 2002-2006
10) Modeling spatial variability of GHG emissions in rangelands of Saskatchewan using GIS and linking GHG to plant species diversity production. Y.Bai, and B.McConkey.

Rangelands of both protected and heavily grazed areas in Saskatchewan will be studied for GHG emissions and GIS models linking GHG emissions and landscape elements, grazing, biophysical factors and vegetation will be developed. 2002-2006

11) Criteria to identify parts of the agricultural landscape least likely to sequester organic carbon under no-till. B. Kay and E. Gregorich

    This study will evaluate the use of organic content relative to a steady state OC as a criterion for identifying soils least likely to sequester C under no-till. 2002-2006

12) Isotopic tracing of CO_2 and N_2O emissions from soil as influenced by plant residues, livestock manure and inorganic fertilizer. B. Mayer and B. Ellert.

    This project will appraise the feasibility and potential of using stable isotopic tracers at natural abundance to assess the sources and biological processes contributing the GHG production in and emission from soil. 2002-2006

13) Quantifying N_2O emissions associated with N_2 fixation by pulse crops. L. Nelson and R. Lemke.

    This project proposes to quantify N_2O emissions associated with N_2 fixation by pulse crops as a function of soil moisture and N fertility under controlled conditions and to develop empirical algorithms relating N_2 fixation and N mineralization to N_2O emissions. 2002-2006

14) Reducing N_2O emissions through the use of fertilizer management technologies. D. Burton and C. Grant.

    To evaluate the influence of nitrogen source and placement on N_2O emissions from western Canadian soils and to examine the relationship between profile biological activity and nitrogen source placement in influencing the production, transport and emission of N_2O from agricultural soils. 2000-2004

15) Cycling of carbon and nitrogen in prairie agroecosystems: GHG emissions. H. Janzen.

    Identify management practices that enhance storage of carbon and minimize loss of nitrogen, thereby preserving soil productivity and environmental quality. 1999-2003

16) Nutrient BMPs for the reduction of GHG emissions. D. Burton

Develop soil nitrogen BMPs to include the assessment of GHG emissions. 2000-2004

17) Documenting impact of a reduction in tillage on the amount of C sequestered, the stability of the sequestered C and emission of N_2O under corn/cereal/soybean rotation in Ontario. B. Kay. 2000-2003

18) Development of scientifically defensible estimates of N2O emissions from agricultural ecosystems in Canada. T. Goddard.

Measure the sensitivity of N_2O emissions from agricultural ecosystems to different fertilizer products, rates, placements and timing. 2000-2003

19) Site-specific application of fertilizer N for reducing GHG emissions. G. Kachanoski

Quantify and evaluate site-specific fertilizer N application across a range of soils/climates in Canada. 2000-2002

20) Kinetics of denitrification and GHG emissions from agricultural soils. C. Drury.

Determine kinetic parameters and factors influencing the separate steps in denitrification and to evaluate agricultural management practices on GHG emissions from soils. 1986-2000

21) The effect of nitrogen fertilizer placement, timing and formulation on GHG emissions and agronomic performance. R. Lemke, G. Lafond, S. Brandt, S. Malhi, and G. Hultgreen.

Compare agronomic performance, GHG emissions, and total energy budgets of several fertilizer N management techniques (urea and anhydrous ammonia; side-banded or midrow-banded; spring banding or fall banding) on three test crops. One site was established in four of the agronomically important Chernozemic soil zones (Brown, Dark Brown, Black, and Dark Grey) in Saskatchewan. 2000-2003.

22) Assessing potential of split fertilizer N applications for economic and environmental risk management. F. Selles, and R. Lemke.

Compare N_2O emission from treatment receiving all N-fertilizer applications at spring seeding, to treatments that receive a baseline N-fertilizer at seeding following top-dress application later in the season if growing conditions warrant. 2003-2006.

23) Greenhouse gas implication of tilling long-term, no-till field plots. B. McConkey, R. Lemke, and H, Wang.

There are many questions that surround the permanency of carbon sequestered under no-till systems. This study compares CO_2 and N_2O losses from a continuously cropped no-till system to those from a long-term no-till system that has been recently converted to a conventionally tilled wheat fallow rotation. 2003-2006.

24) The impact of pasture crop species under managed intensive grazing (MIG) on greenhouse gas emissions. V. Baron, R. Lemke, et al.

This study will determine the environmental and productivity impacts of intensive pasture management practices (e.g. grazing, crop type, breaking, renovation with legumes) through measurement of carbon sequestration, liberation of mineral nitrogen, soil nitrous oxide and methane production, soil water availability and nutrient supply relative to old grass pastures. 2003-2005.

25) Carbon sequestration, methane production, and nitrous oxide emission from cattle grazing native prairie. A. Iwaasa, P. Jefferson, and R. Lemke.

Assess changes in soil quality and soil organic carbon concentration in native range grazed continuously season-long or in short duration rotational grazing management. In addition, it will evaluate the persistence of alfalfa/grass and sainfoin pastures under different grazing regimes, which will have implications for cattle performance and greenhouse gas production. (CH_4 and N_2O). 2003-2006.

26) Impact of termination method and species composition of short-term forages on agronomic performance and nitrous oxide emissions. P. Jefferson and R. Lemke.

This study is an assessment of agronomic performance and nitrous oxide emissions in the year following the termination of short-term forage stands. The forage stands had a variety of species mixes (alfalfa, grass, and alfalfa/grass combinations).

Chemical and tillage termination methods will be compared. 2002-2005.

27) Energy requirements of beef manure management systems in dry and moist ecozones of the Canadian Prairies. K. Buckley, F. Larney, X. Hao, P. McCaughey and B. Freeze. AAFC Lethbridge Research and Brandon Research Centres.

28) Greenhouse gas emission during cattle manure composting (effect of bedding materials and amendments addition). X. Hao, C. Chang, and F.J. Larney. AAFC Lethbridge Research Centre.

29) Effect of feed additive on manure characteristics of cattle manure and GHG emission. X. Hao and T. McAllister. AAFC Lethbridge Research Centre.

30) Identification of N_2O sources and sinks in shallow groundwater and soil zones in southern Alberta. K. Lorenz, M. Ryan, C. Chang, X. Hao, University of Calgary and AAFC Lethbridge Research.

Livestock

1) Reduction of GHG Emissions in Swine by Diet Manipulation. R.O. Ball and J.J. Leonard

   This project entails changing swine diets to decrease GHG and odour emissions by sows and finishing pigs. 2000-2003

2) Some long-term research on metabolic pathways of the rumen and mitigation strategies are presently being conducted by a partnership of researchers at the University of Alberta, Agriculture and Agri-food Canada and Alberta Agriculture, Food and Rural Development. (Specific authors not given.)

3) GHG and odour emissions from swine operations in Quebec and Saskatchewan: Benchmark assessments. C. Lague.

   Evaluate GHG and odour emissions for swine operations in two provinces under liquid manure management. 2001-2003

4) Feedlot GHG emissions: effect of diet and manure storage system. K. Buckley.

   Measure CH_4 emission associated with the feeding of feedlot rations differing in the ratio of forage to concentrate.

5) Evaluation of the effect of climate change on forage and livestock production and assessment of adaptation strategies on the Canadian Prairies. R. Cohen.

Determine economic consequences of climate change on forage/pasture and cattle production across the three Prairie provinces; determine management strategies for agriculture to adapt to climate change; determine need to develop new pasture cultivars to cope with climate change. 2000-2002

6) Reduction of GHG emissions from dairy production systems and poultry manure and its impact on agricultural sustainability. J. Shelford. 2000-2003

7) Vaccine development to reduce enteric methane emissions. (Australia)

8) Long-term effects of commonly used ionophores in rations containing various ratios of forage and concentrates. (University of Manitoba)

9) Effect of lipid use in feedlot rations on enteric emissions, manure pack emissions, and stockpiled or composted manure. (University of Manitoba and Agri-food and Agriculture Canada, Brandon)

10) Net greenhouse gas balance for conventional versus pasture based dairy production systems. (Truro, NS)

Manure and Bioenergy

1) Influence of method of application on N_2O emissions from animal manure. D. Burton. 1999-2001

2) Measurement of GHG emissions and odour from swine manure derived from standard and modified diets. J. Leonard.

   Compare GHG emissions from hog manure resulting from conventional and modified diets; quantify N_2O and CH_4 emissions from hog manure storage under Prairie conditions; and compare GHG emissions from conventional liquid manure storages with emissions from composted hog manure. 2001-2003

3) Greenhouse gas emissions from compost. J. Leonard

   Quantify emissions of GHG from composting at a commercial composting facility. 2001-2003

4) The use of phosphogypsum (PG) to conserve nitrogen in compost. J. Leonard.

5) Evaluate the levels of nitrogen retention that can be realized by PG addition to compost mix; determine the influence of C:N

ratio on nitrogen retention with PG; determine the influence of moisture content on nitrogen retention with PG; and determine the changes in rate of composting with PG addition. 2001-2002

6) Effect of different rates of hog manure application on N2O emission from soil. R. Farrell, M. Grevers, J. Knight, and G. Dauk

   To determine the effect of N_2O emission from soils amended with different rates of liquid hog manure. 1998-2003

7) Enhancing C sequestration and reduction of N_2O emissions in agriculture using tree-based agroecosystems. A. Gordon.

   Quantitatively measure sequestration in fast growing and slow growing tree species in an intercropped system. 2002-2006

8) Conservation of nitrogen during composting. University of Alberta until 2004. (Specific authors are not given)

   This project aims to determine a clear mechanism of how nitrogen may be lost in composting procedures. Objectives include formulation of practical guidelines for the operation of composting facilities to maximize nitrogen retention; confirmation of proven methods for enhancing the value of animal manure so that it can be utilized in an environmentally and economically sustainable manner; and reduction in manure odours attributable to ammonia volatilization.

9) Improved GHG emission estimates from manure storage systems. C. Wagner-Riddle

   Quantify N_2O and CH_4 emissions from manure storage systems in situ; to develop verification systems to assess source strength of confinement facilities; to incorporate finding into MCLONE. 2000-2003

10) Greenhouse gas emissions from constructed treatment wetlands. R. Gordon

    Evaluate GHG emissions (N_2O and CH_4) under a range of meteorological and physical conditions from on-farm constructed wetland treatment systems to identify their source/sink status. 2001-2003

11) Agriculture and Wetland Greenhouse Gas Initiative.

The focus of this initiative is to examine the functional linkages between prairie wetlands, riparian areas and their adjacent agricultural uplands in terms of carbon sequestration and GHG flux. Partners include: University of Saskatchewan, Agriculture and Agri-Foods Canada, University of Manitoba, University of Alberta, Alberta Agriculture, Food and Rural Development, Ducks Unlimited and Canadian Wildlife Service. There are five projects under this initiative. 2002-2005

12) Greenhouse gas dynamics in Prairie wetlands: The development of a landscape scale simulation model. K. Belcher

A process model focusing on the dynamics of greenhouse gases in prairie wetlands will be developed to organize existing information, identify important information gaps, and simulate and evaluate greenhouse gas dynamics in prairie wetlands at a range of scales.

13) Integrated catchment assessment of C sequestration and trace gas emissions: Saskatchewan. D. Pennock, R. Farrell and R. Lemke

This project will impose various land management strategies (e.g., conventional till, low-till, seeded perennial cover, restoration) on existing agricultural uplands and evaluate the effects on carbon storage and greenhouse gas emission along upland/riparian/wetland transects.

14) Integrated catchment assessment of C sequestration and trace gas emissions: Manitoba. D. Lobb and D. Burton

This project will impose various land management strategies (e.g., conventional till, low-till, seeded perennial cover, restoration) on existing agricultural uplands and evaluate the effects on carbon storage and greenhouse gas emission along upland/riparian/wetland transects.

15) C sequestration and GHG flux in selected Alberta catenas containing wetlands. L. Fuller and T. Goddard

This project will investigate carbon quantity and quality and greenhouse gas emission at four sites, under at least two different land management regimes. The inclusion of depressional areas of the landscape will strengthen landscape-scale estimates of C storage and GHG flux.

16) C sequestration and GHG Emission in restored Prairie wetlands R. McDougal, B. Clark and H. Murkin

This project will provide base-line information on the potential of restored wetlands and their associated riparian areas to function as net carbon sinks. The project will assess the effect on sink potential of (1) time since restoration; (2) soil zone; and (3) local site variables. In addition, the changes in soil organic carbon and GHG flux will be monitored before, during, and after the restoration process at selected sites.

Modeling

1) Influence of spatial and temporal variability of hydrological soil properties on the uncertainty of GHG model estimates. B. Si and G. Padbury.

This project will provide rigorous estimates of the effect of hydrological processes on GHG emissions and uncertainty estimates from major GH model; and develop reproducible protocols to facilitate comparisons with future landscape-scale studies conducted in other geographical locations. 2002-2006

2) Understanding intensity and spatial variability of N_2O emissions from fertilized agricultural fields. R. Grant and E. Pattey.

Test the ecosystem model ECOSYS at site and landscape scales with different fertilizer levels. 2002-2006

3) Landscape based GHG and climate change assessments. J. Brierley

To develop a National Carbon and GHG Accounting and Verification Systems (NCGAVS). 2002-2005

Miscellaneous

1) Influence of carbon amendment to distribution of denitrification activity in soil profiles and seasonal N_2O loss to the atmosphere and in tile drainage waters. Principal Investigators: D. Burton and J. MacLeod

This project will assess the potential for practices such as inclusion of animal manure and legumes in rotation either increase or decrease N_2O emissions from the soil surface and in tile drainage water. 2002-2006

2) Identification of N_2O sources and sinks in shallow groundwater and soil zones in Southern Alberta. C. Ryan and C. Chang.

   This project seeks to monitor vertical profiles of N_2O and related parameters in the unsaturated soil and groundwater zones over a year time period. 2002-2006