Please Select
- Index
- Restart

Agricultural Greenhouse Gases Methane and Nitrous Oxide

Faye Banham,
Consultant
Karen Haugen-Kozyra
Alberta Agriculture,
Food and Rural Development

Agricultural Greenhouse Gases Methane and Nitrous Oxide

Faye Banham, Consultant
and Karen Haugen-Kozyra
Alberta Agriculture,
Food and Rural Development

Science to Social Issues

Contents

1 Introduction 277
1.1 Methane Emissions 278
1.2 Nitrous Oxide Emissions 279

2 Mechanisms and Processes 279
2.1 Conditions for the Creation of Nitrous Oxide 280
2.2 Conditions for the Creation of Methane 281

3 Emissions of Nitrous Oxide and Methane 282
3.1 Calculated Emissions of Nitrous Oxide and Methane 282
3.2 Direct Measurement of Nitrous Oxide and Methane Emissions 284
3.2.1 Nitrous oxide emissions from animals and livestock buildings 285
3.2.2 Nitrous oxide emissions from manure management and land application 288
3.2.3 Mitigation techniques for nitrous oxide emissions 292
3.2.4 Methane emissions 293
3.2.5 Methane emissions from animals and livestock buildings 293
3.2.6 Methane emissions from manure management 296
3.2.7 Mitigation techniques for methane emissions 299

4 Challenges, Opportunities and Gaps 301
4.1 Challenges, Opportunities and Gaps of Calculated Emission Rates of Nitrous Oxide and Methane 302
4.2 Direct Measurements of Emissions of Nitrous Oxide and Methane from Livestock, Livestock Buildings, Manure Management and Land Application 303
4.3 Mitigation Techniques to Decrease Emissions of Nitrous Oxide and Methane 303

5 Beneficial Management Practices 305
5.1 BMPs for Reducing Greenhouse Gas Emissions 305
5.2 BMPs for Reducing Nitrous Oxide Emissions 307
5.3 BMPs for Reducing Methane Emissions 308

6 Resources and References 309

Introduction

The purpose of this literature review is to identify the scientific literature on agricultural greenhouse gas emissions from the following three aspects of animal production systems:

1. Livestock confinement
2. Manure storage and handling
3. Manure application

Appropriate management practices being used locally, within Canada and globally, are also identified in the Beneficial Management Practices section of this report. This literature review will focus upon two primary agricultural greenhouse gases – nitrous oxide gas (N_2O) and methane gas (CH_4).

In 1997 the Canadian government signed the Kyoto Protocol. Canada agreed to reduce its greenhouse gas (GHG) emissions to 6% below the 1990 emission levels. At present the Kyoto Protocol has finished parliamentary discussions and ratification is expected sometime in 2003. If Canada is to meet the agreed upon reductions, greenhouse gas emissions will have to be reduced by 240 Mt of carbon dioxide (CO_2) equivalents (AAFRD, 2001). Every sector of the Canadian economy will be expected to contribute to reductions in greenhouse gases.

Globally, agriculture contributes approximately 25% of the global carbon dioxide emissions (IPCC 2001). In Canada, the agricultural sector contributes approximately 10% of the total national anthropogenic greenhouse gas (GHG) emissions. Approximately 40% of the agricultural GHG emissions are from livestock production sources, and a third of those are associated with manure management (Lague et al., 2002). These authors also state that of Canada's primary agriculture emissions, N_2O and CH_4 contribute 61% and 38% of those emissions respectively. Canada's national inventory (1996) indicates that the primary agricultural sector in Canada was emitting about 64 000 kT of GHG expressed as CO_2-equivalent. The anthropogenic GHG emissions for 1996 totalled 671 000 kT CO_2-equivalents, where 1 kT is equal to 1000 tonnes. Primary agriculture was Canada's third largest source of GHG emissions after the transport industry, and the electricity and steam generation sector. It's important to note that 80 to 90% of the agriculture sector's emissions are not derived from fossil fuel combustion – solutions will need to be based on reducing N_2O and CH_4 or sequestering carbon in soils. Other sources of agricultural emissions also include fossil fuels and fertilizers. It is important to note that anthropogenic sources of GHG emissions should be of relative importance to the Canadian livestock industry for the following reasons:

1. Canada is responsible for contributing 2% of the global anthropogenic GHG emissions.
2. In Canada all agricultural related GHG emissions amount to approximately 15% of Canada's total anthropogenic GHG emissions or 0.3% of the global anthropogenic GHG emissions.
3. In Canada agricultural GHG emissions (methane and nitrous oxide) from livestock production are 42% or 6.3% of Canada's total GHG emissions equivalent to 0.13% of the anthropogenic GHG emissions (Lague et al., 2002).

Nitrous oxide and methane are part of a family of gases that persist in the atmosphere and have documented warming effects (i.e. greenhouse gases). The earth is surrounded with a layer called the atmosphere. The atmosphere acts like an insulating layer that surrounds the surface of the earth, much like the insulation between the walls of a house. In the atmosphere there are molecules of carbon dioxide and other greenhouse gases that react like glass in a greenhouse. When the sun's ultraviolet rays reach the earth's surface this warms the earth, and the earth radiates the infrared rays back into space. Long wavelength infrared rays are trapped by carbon dioxide and other gas molecules, resulting in some radiated heat to remain in the earth's atmosphere (Montgomery, 1997). This effect is known as the "Greenhouse Effect". Each of the greenhouse gases differs in its ability to absorb energy (heat), re-emit energy, and persist in the atmosphere. Together, these factors describe the "Global Warming Potential" of each gas (McNaughton, 2001). The global warming potential is established by the Inter-Governmental Panel on Climate Change (Table 1).

The Inter-Governmental Panel on Climate Change (IPCC), now operating under the United Nations Framework Convention on Climate Change (UNFCC), was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988 (IPCC website, 2002). The main objective of this group was to assess scientific, technical and social-economic information that was relevant to assist in the understanding of anthropogenic induced climate change, potential impacts of climate change and options for mitigation and adaptation. The Task Force on National Greenhouse Gas Inventories (TFI) was established by the IPCC in October 1998, to oversee the IPCC National Greenhouse Gas Inventories Programme (IPCC-NGGIP). The objectives of this group are:

- Develop and refine the internationally agreed methodology and software for the calculation and reporting of national GHG emissions and removals.
- Encourage the widespread use of this methodology by countries that are participating in the IPCC and by the signatories of the United Nations Framework Convention on Climate Change (UNFCCC).

The IPCC Guidelines for National Greenhouse Gas Inventories were approved internationally and developed from an international process that included the following:

- Dissemination of drafts and collection of comments from national experts
- Testing of methods from the development of preliminary inventories

Table 1. Major agricultural greenhouse gases and their global warming potential. *Source: IPCC (1966)*

Greenhouse Gas	Global Warming Potential in CO_2 Equivalents
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310

- Studies in countries which ensure that methods are tested in a wide range of national contexts
- Technical and regional workshops held around the world (Africa, Asia, Latin America, Central Europe and Western Europe)
- Meeting of informational expert groups that convened to recommend improvements on specific aspects of methodology

The IPCC Guidelines were first accepted in 1994 and published in 1995. The UNFCCC COP3 in 1997 in Kyoto reaffirmed that the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories should be used as the methodology for the estimation of anthropogenic emissions by sources and removals by sinks of greenhouse gases in calculation of the legally binding targets during the first commitment period of the Kyoto accord (IPCC website, 2003).

Over 80% of the greenhouse gas emissions from agriculture in Alberta are attributed to the livestock industry (methane emissions) and the fertilizer industry (nitrous oxide emissions). Alberta Agriculture, Food and Rural Development provided the breakdown shown in Table 2.

1.1 Methane Emissions

Methane emissions from the livestock industry are primarily produced from enteric fermentation from animals. Enteric fermentation is a process where microbes in the digestive system of ruminant animals such as cattle and sheep break down carbohydrates to produce energy and by-products. Methane is a by-product of this process and represents one of the losses of potential food energy to the animal. Methane escapes through respiration, belching or flatulence.

Table 2. 1996 Alberta emissions breakdown *Source: Alberta Agriculture, Food and Rural Development (1999)*

Industry or Sector	Emission Type and Amount	
Agri-Food Processing	Carbon Dioxide (CO_2)	3%
Manure Management	Nitrous Oxide (N_2O	7%
Soil (net source)	Carbon Dioxide (CO_2)	8%
Transportation	Carbon Dioxide (CO_2)	10%
Livestock	Methane (CH_4)	30%
Soil (Fertilizer)	Nitrous Oxide (N_2O)	42%

The majority of the methane comes from respiration and belching. Some non-ruminant animals such as pigs and horses can also produce methane but ruminant animals are the largest contributors since they are able to digest cellulose (over 90% of the production, Basarab et al.1999). The amount of methane that is produced and released by the animal is dependent on several factors such as: the type of animal; age; weight; quality and quantity of feed; and the energy use efficiency of each animal (IPCC, 1996 Guidelines).

Another source for methane emissions relates to manure management. Methane is produced during the decomposition process of manure under anaerobic conditions. Typically, anaerobic conditions can be attributed to areas of manure management where there are large numbers of animals, such as confined feeding operations, or when manure is stored in large piles or lagoons (IPCC, 1996 Guidelines).

1.2 Nitrous Oxide Emissions

Nitrous oxide emissions can also result from the storage of manure through the conversion of the nitrogen in the manure to nitrous oxide (N_2O) (IPCC, 1996 Guidelines). However the IPCC notes three major sources of nitrous oxide are:

1. Direct agricultural soil emissions
2. Direct soil emissions from animal production which includes livestock facility emissions
3. Nitrous oxide emissions indirectly induced from agricultural activities.

These three major sources are used in IPCC methodology for estimating N_2O emissions, but they also recognize several anthropogenic sources of nitrous oxide as inputs into agriculture operations such as: the use of synthetic fertilizers; animal manure/waste; nitrogen from increased biological nitrogen fixation; and nitrogen generated from the cultivation of mineral and organic soils resulting in increased organic matter mineralization (IPCC, 1996). Nitrous oxide may also be produced and emitted directly from agricultural fields, animal confinement areas, transported from agricultural systems into the ground or surface from leaching, surface water runoff, consumption by humans and introduced into sewage systems which transport the nitrogen into surface waters (IPCC, 1996). Other sources of nitrous oxide emissions come from ammonia and oxides of nitrogen that are emitted from agricultural systems. These can be transported off-site and used as fertilizer for other systems. This then leads to increased production of nitrous oxide (IPCC, 1996).

The IPCC recognizes two anthropogenic sources of nitrous oxide:

- Biogenic
- Abiogenic

Biogenic production of nitrous oxide in soil is primarily due to the nitrification and denitrification process that occurs within the soil matrix. Abiogenic production occurs when nitrous oxide is produced from the process of burning.

If Canada is to meet the agreed upon reduction targets outlined by Kyoto, all sectors of the Canadian industry must look at the mechanisms and processes responsible for the creation of emissions and at mitigation methods to reduce emissions. Once that is identified beneficial management practices must be developed that will ensure that the reduction of emissions can be achieved from a scientific and economic point of view.

2 Mechanisms and Processes

The mechanisms and processes responsible for the creation of nitrous oxide and methane are outlined by the IPCC:

Nitrous oxide:

- Soil nitrification
- Soil denitrification
- Manure management

Methane:

- Enteric fermentation from ruminant animals
- Storage and handling of large quantities of liquid manure under anaerobic conditions
- Emissions from agricultural soils

2.1 Conditions for the Creation of Nitrous Oxide

Nitrous oxide is primarily produced from two processes that occur within the soil. These two processes are:

A. Nitrification: process where ammonium (NH_4^+) in the soil is converted to nitrate (NO_3^-). This process occurs in two stages under aerobic conditions. First, ammonium (NH_4^+) is converted to nitrite (NO_2^-) and then the nitrite is further oxidized to nitrate (NO_3^-). This reaction is facilitated by the presence of autotrophic bacteria *(Nitrosomonas)*. Other autotrophic bacteria also include *Nitrosolobus*, *Nitrospira*, and *Nitrosovibrio* and to some extent heterotrophic bacteria can oxidize ammonium (NH_4^+) and reduce other nitrogen compounds such as amines to nitrite. The oxidation of nitrite (NO_2^-) occurs with autotrophic bacteria called Nitrobacter (Tisdale et al., 1999).

Factors Affecting Nitrification: Tisdale et al. (1999) indicates that there are several factors that can affect nitrification. Because nitrification is a microbial process the conditions within the soil environment can influence the rate of nitrification. Tisdale et al. (1999) notes six factors that affect nitrification in soil:

1. Amount of ammonium (NH_4^+) within the soil
2. Population of nitrifying organisms
3. pH of the soil
4. Amount of oxygen in the soil/soil aeration
5. Amount of moisture within the soil
6. Temperature within the soil

Amount of ammonium (NH_4^+): a supply of ammonium is the first requirement for the nitrification process. If the conditions within the soil do not favour mineralization of ammonium (i.e. release of NH_4^+ from organic substrates through bacterial decomposition) to occur then nitrification will not proceed. The nitrification process also requires that along with favourable amounts of ammonium there is a need for optimum temperature and moisture levels (Tisdale, et al., 1999), as noted below.

Population of nitrifying organisms: soils have varying abilities to nitrify ammonium under optimal temperature, moisture and ammonium content. The variation in the numbers of nitrifying bacteria within the soil will result in differences in the lag time between the addition of ammonium and the build up of nitrate (NO_3^-). Due to the fact that microbial populations are dependent upon an adequate supply of available carbon, the total amount of nitrification is not necessarily dependent upon the initial number of organisms present, provided that temperature and moisture conditions are favourable for sustaining the nitrification process (Tisdale et al., 1999).

Soil pH: the optimal pH range for nitrification to occur is a pH of 8.5; however, nitrification can occur from a pH range of 4.5 to 10. The nitrifying bacteria need an adequate amount of calcium (Ca^+), and phosphate sources ($H_2PO_4^-$) along with a balance of micronutrients (Tisdale et al., 1999).

Soil aeration: aerobic nitrifying bacteria require the presence of oxygen in order to produce NO_3^-. Maximum nitrification occurs at the same oxygen concentration in the ambient atmosphere. To ensure optimum aeration within the soil, it is important to ensure soil conditions that will allow rapid diffusion of gases into and out of the soil. Soils coarse in texture or with good structure will support rapid diffusion of gases and ensure that adequate amounts of oxygen are available within the soil for the nitrifying bacteria (Tisdale et al., 1999).

Soil moisture: nitrification rates are highest when soil moisture is at field capacity or 1/3 bar matrix suction (80% of total pore space). When the soil moisture content exceeds field capacity, nitrogen mineralization and therefore nitrification are reduced (Tisdale et al., 1999).

Temperature: the optimum temperature range for nitrification to occur is 25°C to 35°C (Tisdale et al., 1999).

B. Denitrification: When NO_3^- is formed in the soil, or is added into the soil by fertilizers, manure or wet/dry deposition, it may undergo reduction by microorganisms to gaseous oxides of N and N_2 under anaerobic conditions. Microbial reduction of NO_3^- to intermediates and then to gaseous NO, N_2O, and N_2 are lost to the atmosphere; this is noted as the process of denitrification (Paul and Clark, 1996). Bacteria responsible for denitrification belong to the heterotrophic genera *Pseudomonas, Bacillus*, and *Paracoccus*. There are also several autotrophs involved in the denitrification process: *Thiobacillus* *denitrificans* and *T. thioparaus* (Tisdale et al., 1999). Tisdale et al. (1999) summarized the main factors that affect the denitrification process:

1. Amount and nature of the organic material present
2. Soil moisture
3. Soil aeration
4. Soil pH
5. Soil temperature
6. Level and form of inorganic nitrogen such as: NO_3^- vs. NH_4^+

Amount and nature of the organic material present: the availability of readily decomposable organic matter or carbon will influence the denitrification process in the soil, i.e.: these sources will accelerate denitrification providing other conditions are favourable (Tisdale et al., 1999).

Soil moisture: moisture within the soil is one of the most important factors in the determination of denitrification losses. Oversaturation (waterlogging) of soils results in rapid denitrification due to the lack of oxygen available to the areas of microbial activity (Tisdale et al., 1999).

Soil aeration: the denitrification process only occurs when oxygen within the soil is too low to meet microbiological demands. Denitrification can still occur in well-aerated soils, but only in the anaerobic micro sites where the biological oxygen demand exceeds the supply (Tisdale et al., 1999).

Soil pH: the bacteria that are responsible for the denitrification process are sensitive to low pH. As a result, many acidic soils contain small microbial populations of denitrifiers. Denitrification is rarely found in soil with a pH below 5.0, but denitrification is high in soils with a high pH (Tisdale et al., 1999).

Soil temperature: the denitrification process is very sensitive to soil temperature. Denitrification will increase in the soil temperature range of 2°C to 25°C. At soil temperatures between 25°C to 60°C, the denitrification process will proceed at a slightly higher rate. Denitrification is inhibited when temperatures exceed 60°C. Increase of the denitrification process at higher temperatures indicates that thermophilic microorganisms play a role in the denitrification process (Tisdale et al., 1999).

Level and form of inorganic nitrogen such as NO_3^- vs. NH_4^+: there must be a supply of NO_3^- for the denitrification process to occur. High concentrations of NO_3^- result in increased activity of denitrification may increase (depending on the above conditions) the ratio of N_2O to N_2 released by this process (Tisdale et al., 1999).

C. Manure Management and Land Application: the IPCC (1996) notes that N_2O is formed when manure nitrogen is nitrified or denitrified, particularly once applied to soils. N_2O emissions can also occur during the storage or the handling of the manure (prior to land application). In the manure matrix, most of the conditions and processes outlined above for soils apply for manure. However, manure piles or lagoons can quickly form anaerobic conditions/pockets, limiting some of the requirements for the first stage of nitrification to occur. Generally speaking, the amounts of N_2O that are released are dependent upon the system and duration of the manure management system. A majority of N_2O emissions related to land application have been from the application of fertilizers. In Alberta approximately 42% of N_2O emissions are from the use of soil fertilizers (AAFRD Greenhouse Gas Team 1999).

2.2 Conditions for the Creation of Methane

The IPCC (1996) identified three major sources for methane production to guide countries in estimating rates of emissions.

A. Enteric fermentation from ruminant animals: enteric fermentation is the process where polysaccharides and other feed products undergo anaerobic fermentation in the gut of the animal. Examples of ruminant animals are cattle and sheep. The ruminant animals have an expanded gut known as the retrulo-rumen, most commonly called the rumen. The rumen is the area where feed is broken down by enteric fermentation prior to the feed being digested in the abomasum (AEA Technology Environment, 1998). During enteric fermentation methane is produced as a by-product in the rumen and typically released through belching (IPCC, 1996).

The amount of methane that is produced from this process is dependent primarily upon the type of digestive system and the feed intake (IPCC, 1996). Ruminant animals have the highest amount of methane emissions compared to ‘pseudo-ruminants’ such as horses, mules, asses and the monogastric animals such as swine (IPCC, 1996). The monogastric animals have lower methane emissions since fermentation occurs farther along in the digestive tract and they have no rumen (IPCC, 1996). For ruminants, higher intake of feed results in higher production of methane emissions. Feed intake is directly related to the animal's size, growth rate, and production (IPCC, 1996).

B. Storage and handling of large quantities of liquid manure under anaerobic conditions: animal manures are composed of organic compounds such as carbohydrates and proteins that are normally broken down by bacteria. Under aerobic conditions (oxygen is available) the breakdown of carbohydrates and proteins results in the conversion of carbon compounds into carbon dioxide. Under anaerobic conditions (when oxygen is not available) carbon compounds are incompletely digested resulting in several by-products, including methane. In terms of eco-efficiency, under aerobic conditions the conversion of the carbon compounds to carbon dioxide does not result in an overall increase in the global warming potential nor of carbon in the atmosphere. This is due to the fact that the carbon dioxide is a component of a natural cycle (plants capture the carbon dioxide from the air and use it in photosynthesis, the plant is then eaten by the livestock and then released (AEA Technology Environment, 1998). During an anaerobic reaction, some of the carbon is being converted into methane and released. Methane has a higher global warming potential than carbon dioxide (approximately 21 times), resulting in a contribution to the greenhouse effect (AEA Technology Environment, 1998) and no re-cycling of carbon into natural processes.

When livestock graze, the manure they release ends up being thinly spread on the ground, therefore, aerobic decomposition usually dominates (AEA Technology Environment, 1998). In the case of intensive livestock operations or confined feeding operations, amounts of manure are created and concentrated. For liquid type manure management systems (swine and dairy), manure is often stored in tanks for lagoons, resulting in anaerobic conditions and the creation of methane (AEA Technology Environment, 1998). In the case of solid manure management systems, the potential for methane emissions is much less, to the degree that the IPCC does not consider these as relevant.

C. Emissions from agricultural soils: emission of methane from agricultural soils can be a result of using of peat-based compost as a soil amendment, or from the burning of agricultural residues (IPCC, 1996). However, the practice of burning agricultural resides is more common in the developing countries (IPCC, 1996). Where it is used in the Prairies (Black soil zones), this practice should be discouraged.

3 Emissions of Nitrous Oxide and Methane

Currently there are no established, standardized ways to measure methane or nitrous oxide emissions from agricultural systems. This field is further complicated by the Kyoto-driven need for countries to report on their greenhouse gas emissions every couple of years. There is no consensus amongst the scientific community or the governing bodies of countries around the world on how to do this. However, most countries have used the Intergovernmental Panel on Climate Change's (IPCC) Guidelines for National Greenhouse Gas Inventories: Reference Manual (1996) as a guideline for the estimation of greenhouse gas emissions.

As a result of the global climate change reporting requirements, there are two approaches to describing emissions of N_2O and CH_4 from animal production systems: (1) calculated emissions (from IPCC guidelines or for reporting purposes) and (2) direct measurements (from independent research studies that will likely one day be used in IPCC calculations). This section is broken into these two fields of emissions measurement.

3.1 Calculated Emissions of Nitrous Oxide and Methane

The IPCC methodology uses emission coefficients derived from very broadly 'grouped' estimates from a variety of countries and as such, may not reflect the practices and conditions within each country, but they are 'agreed upon rates' that will stand up to scrutiny internationally. The IPCC has a two-tiered system for the estimation of emission rates.

Tier 1: relies on default emission factors that are collected from previous studies. This approach is deemed to be sufficient for most types of animals in most of the countries. However, because of the generalized nature of these factors, at a country-level, under- and/or over-estimations can occur. Large errors in the estimates are the typical case, particularly with nitrous oxide and methane emissions from animal production.

Tier 2: is more complex in the estimation of emission rates. The Tier 2 approach is country-specific with regards to information related to livestock characteristics and manure management practices. This type of approach is recommended when data being used in the development of default emission factors do not correspond with the country's livestock and manure/fertilizer management practices. Due to the variability of cattle characteristics from country to country, this approach is recommended when countries have large cattle populations in the estimation of methane emissions from cattle and manure. The Tier 2 approach is also recommended for countries with large swine and buffalo populations.

Although the IPCC reference manual is simply a guideline, most countries have used it in some capacity in the formulation of their default emission factors. The summary of the revised 1996 IPCC Guidelines for National Greenhouse Inventories affected three chapters of the Agricultural Greenhouse Gases section, the revisions involved were:

1. Methane emissions from rice cultivation (we will not discuss in this paper as rice production is not prominent in North America)
2. Nitrous oxide emissions from agricultural soils
3. Manure management

The calculation of estimated nitrous oxide emission and the default methods used under the revised 1996 IPCC guidelines are new along with new data.

In the revised 1996 IPCC Guidelines, a new default method is used in the calculation of national nitrous oxide emissions from agriculture. The new method is a revision of the 1995 IPCC methodology which encompasses more sources of nitrous oxide related to agricultural activities such as, application and use of nitrogen-based fertilizers to soil and the uptake of nitrogen through the food chain from plants to humans. The revised guidelines outline three major categories of nitrous oxide emission sources in the methodology:

1. Direct emissions generated from agricultural soils
2. Emissions from animal production
3. Indirect emissions created from agricultural activities

Due to the increased number of sources and pathways of nitrous oxide generation, the new methodology for calculating nitrous oxide emissions will affect a number of source sectors. Since nitrous oxide emissions are reported in several of the sections in the 1995 IPCC Guidelines (Manure Management Section 4.2, Agricultural Soils Section 4.5 and the Waste Section 6.3). There are also specific recommendations made in relation to nitrous oxide emission factors provided in the revised guidelines.

This new methodology does provide a more comprehensive description of nitrous oxide emissions from agricultural related activities as it takes into account previously omitted nitrous oxide sources. With this revised methodology it has been estimated that the global nitrous oxide emission estimates from agricultural production have likely been under-estimated in the past by as much as 70%.

Tier 2 Reporting Initiatives

In the United States, the United States Environmental Protection Agency (US EPA, or more commonly referred to as the EPA) recently asked a group of committees to address a number of concerns related to characterizing emissions from animal feeding operations (AFO's) including methane and nitrous oxide; however, it is unclear from the literature whether this approach is based upon the IPCC's 1996, Tier 1 or Tier 2 approach for the estimation of both methane and nitrous oxide emissions. A group of committees met and published an interim report titled "The Scientific Basis for Estimating Emissions from Animal Feeding Operations" in 2001. The main goal for the EPA was to develop a method to estimate emissions from an individual AFO level that would be reflective of the different types of animal production units that are commonly used in commercial-scale animal production facilities (US EPA, 2001).

In 1997 Okine et al. developed an Alberta-based Tier 2 approach called the Metabolic Energy (ME) approach. Okine's method uses experimental data to predict feed intake by the use of linear regression and mass balance of rumen efficiency digestion to assist in the calculation of emissions. This Alberta-based Tier 2 method incorporates the feeding of the subject animal with a diet containing a specific metabolizable energy concentration (MJ kg^{-1} dry matter). The animal is weighed weekly and monitored for weight gain over a period of a few weeks for its average daily weight gain and mid-test weight. The calculation of feed intake is done by taking daily energy intake of different rations consumed by the animal, providing the animal was fed more than one type of feed, then it was adjusted with the common energy intake of the two differing types of rations. This calculation is represented by the following equation:

> Feed conversion ration = dry matter intake (DMI)/ average daily weight gain of the animal.

The metabolic body weight is calculated as a mid test weight raised to the power 0.75, where the linear regression feed intake model is used for the prediction of mean average daily feed intake of animal populations. To calculate GHG emissions, metabolizable energy and metabolic energy intake measurements are required. Methane emissions produced on a daily basis are calculated from an equation that incorporates digestibility of feed expressed in percentage and the relative amount of feed intake need for animal maintenance. Methane created from enteric fermentation is expressed as a percentage of the gross energy intake of the animal (AGO, 2001). This method was originally created from the Blaxter and Clapperton equation (1965) (Jarvis and Pain, 1994; IPCC, 1996; Lassey et al., 1997; Basarab et al., 1999; AGO, 2001; Herd et al., 2001; IPCC, 2001; AAFRD Agriculture Air Issues Unit, in press).

Paul (1999) indicates that within Canada direct soil emissions account for slightly more than half of the total N_2O emissions from agriculture. Of the 50% N_2O emissions, half is from the use of fertilizer application and the other half is from manure application. Indirect emissions (such as releases from the soil after fertilizer application) account for a quarter of the N_2O emissions from agriculture.

Preliminary results on nitrous oxide emissions from soils, conducted by Agriculture and Agri-Food Canada in Saskatchewan, are providing evidence that using Tier 1 methodology to estimate N_2O production from soils may overestimate emissions by 4 to 5 times compared to direct measurements of nutrient application to soils using prairie application technology (Lemke et al., 2003). IPCC Tier 1 methodology assumes, using a default value, that 1.25% of applied N is lost directly as N_2O. But, the methodology does not take into account timing, placement and formulation of N being applied, nor the soil/environmental conditions that affect N_2O evolution. Use of these new emission coefficients for nitrous oxide would significantly alter Canada's agricultural emissions inventory (refer to Tables 3 and 4 for IPCC Tier 1 estimates for Canada's GHG emissions).

3.2 Direct Measurement of Nitrous Oxide and Methane Emissions

This literature review focuses on three broad categories for both nitrous oxide and methane when discussing research on greenhouse gas emissions:

1. Emissions from livestock buildings
2. Emissions from manure management and land application
3. Effects upon emissions from different treatment technologies

It should be noted that the science of measuring nitrous oxide and methane emissions is evolving, and although research papers on these subjects are scarce, the science is expected to increase in the next 3 to 5 years. The majority of the research to date on greenhouse gases and agriculture has focused on carbon sequestration from soils and N_2O emissions from soils after fertilization. About 20% of the research papers focus on livestock (AAFRD, Agriculture Air Issues Unit, in press), with the majority of those on CH_4 emissions (see Figure 1).

The following is a quote from AFFRD's State of Knowledge of Agricultural Greenhouse Gases in Alberta Towards a Systems Approach report (in press):

> "Livestock GHG research in western Canada is limited compared to many other countries. The western Canada focus is on the beef industry; cows and steers because this component dominates the industry. The studies are in controlled conditions without different production systems being considered. The majority of the research conducted in other sectors is in progress…"

Table 3. Methane emission estimates for Canada by the agricultural sector
Source: Environment Canada, Greenhouse Gas Division, June 2002

Methane Gas Emission Estimates for Canada, by the Agricultural Sector (1990 to 2000)
Methane CH_4 (kt) gas emissions

Greenhouse Gas Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Agriculture											
Enteric Fermentation	760	770	790	800	830	860	870	870	860	850	840
Manure Management	220	220	220	220	230	240	240	240	240	240	240
Agricultural Soils**	0	0	0	0	0	0	0	0	0	0	0
Yearly Totals	**980**	**990**	**1,010**	**1,020**	**1,060**	**1,100**	**1,110**	**1,110**	**1,100**	**1,090**	**1,080**
Ten Year Total from 1990-2000	**11,650**										

Methane Gas Emission Estimates for Canada, by Agricultural Sector (1990 to 2000)
Methane CH_4 gas emissions kt of CO_2 equivalents

Greenhouse Gas Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Agriculture											
Enteric Fermentation	16,000	16,000	17,000	17,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Manure Management	4,600	4,600	4,700	4,600	4,800	5,000	5,100	5,000	5,000	5,100	5,100
Agricultural Soils**	0	0	0	0	0	0	0	0	0	0	0
Yearly Totals	**20,600**	**20,600**	**21,700**	**21,600**	**22,800**	**23,000**	**23,100**	**23,000**	**23,000**	**23,100**	**23,100**
10 Year Total from 1990-2000	**245,600**										

*** Only one significant figure shown due to high uncertainty*

3.2.1 Nitrous oxide emissions from animals and livestock buildings

Lague (2002) notes that greenhouse gas emissions from swine production in Canada are estimated at 1835 kT of CO_2 equivalent per year, which is approximately 3% of the total agricultural emissions, or 0.3% of Canada's total anthropogenic greenhouse gas emissions. Lague (2000) cites Lindwall (2000) who estimates that 42% of Canada's agricultural emissions originate from livestock operations and a third of these are associated with manure management. It is important to note that anthropogenic sources of GHG emissions should be of relative importance to the Canadian livestock industry for the following reasons:

- Canada is responsible for contributing 2% of the global anthropogenic GHG emissions (ranked third in the world on a per capita reporting basis).
- In Canada all agricultural related GHG emissions amount to approximately 15% of Canada's total anthropogenic GHG emissions or 0.3% of the global anthropogenic GHG emissions.
- In Canada agricultural GHG emissions from livestock production is 42% or 6.3% of Canada's total GHG emissions equivalent to 0.13% of the anthropogenic GHG emissions (Lague et al 2002).

There are several methods being employed to sample N_2O fluxes in the field. These include chamber-based methods and micrometeorological techniques. Chamber methods provide more detailed process-based

Table 4. *Nitrous oxide emission estimates for Canada by the agricultural sector (1990-2000)*

Source: Environment Canada, Greenhouse Gas Division, June 2002

Nitrous Oxide Gas Emission Estimates for Canada, by Agricultural Sector (1990 to 2000)

Nitrous Oxide N_2O (kt) gas emissions

Greenhouse Gas Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Agriculture											
Enteric Fermentation	0	0	0	0	0	0	0	0	0	0	0
Manure Management	12	12	12	12	13	14	14	14	14	14	14
Agricultural Soils**	90	90	90	90	100	100	100	100	100	100	100
Yearly Totals	**102**	**102**	**102**	**102**	**113**	**114**	**114**	**114**	**114**	**114**	**114**
Ten Year Total from 1990-2000	**1,205**										

Nitrous Oxide Gas Emission Estimates for Canada, by Agricultural Sector (1990 to 2000)

Nitrous Oxide N_2O gas emissions in kt of CO_2 equivalents

Greenhouse Gas Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Agriculture											
Enteric Fermentation	0	0	0	0	0	0	0	0	0	0	0
Manure Management	3,700	3,700	3,800	3,900	4,100	4,200	4,300	4,300	4,300	4,300	4,300
Agricultural Soils**	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Yearly Totals	**33,700**	**33,700**	**33,800**	**33,900**	**34,100**	**34,200**	**34,300**	**34,300**	**34,300**	**34,300**	**34,300**

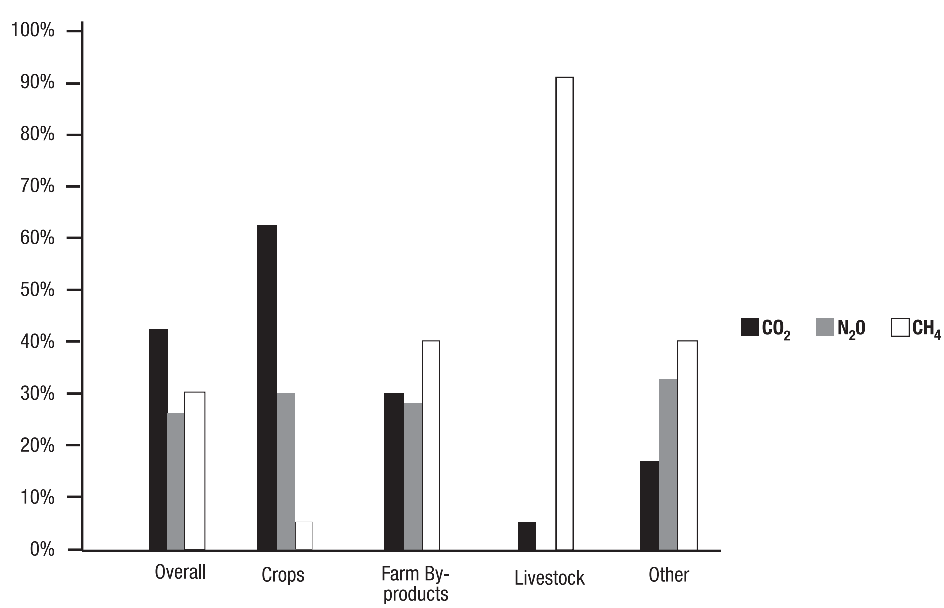

Figure 1. *Percentages of agricultural greenhouse gas emission studies for various research categories*

Source: AAFRD Agriculture Air Issues Unit, in press.

information. There are two kinds of chambers – steady state and non steady state. Steady state chambers are ideal for monitoring a site repeatedly over an extended period of time. Major disadvantages are the cost and maintenance of the equipment required to detect N_2O concentration. Non steady state chambers cost less and allow for higher minimum detection levels. For chamber methods, the integration over space and time remains problematic (Wagner-Riddle and Burton 1999).

Micrometeorological techniques integrate spatial variation and allow for the use of long-term monitoring to examine variations in N_2O emissions over time. Limitations of these techniques include possible errors in basic soil diffusion theories and the availability of instrumentation. High initial costs of buying the instrumentation are considered a disadvantage. To measure N_2O concentrations from these techniques, either gas chromatography, Fourier Transform Infrared Spectroscopy (FTIR) and/or tunable diode laser absorption spectroscopy (Wagner-Riddle and Burton 1999) has been used.

Table 5 displays the averages of gas and odour concentrations from two swine production buildings under liquid manure management systems (Lague 2002).

According to IPCC methodology estimates, approximately 10% of the N_2O created in Canada was from animal manure. Manure contains large varying amounts of carbon and nitrogen based on animal type and size. This in turn has an effect on nutrient content which impacts on N_2O emissions. It was found in most of the literature reviewed that dairy cattle produced the highest amount of N_2O emissions as their manure has a high nitrogen content, where poultry manure produced the least amount of N_2O emissions (Desjardins and Keng 1999).

Sneath et al. (1997) conducted a study titled "Long Term Measurements of Greenhouse Gas Emissions for UK Livestock Buildings" where the following conclusions were made:

1. The two methods that were used in obtaining ventilation rates, force-ventilation and naturally ventilated buildings, were found to have similar carbon dioxide emissions as indicated from literature on metabolic production rates of carbon dioxide from housed animals.
2. In his broiler house study there were no significant rates of methane or nitrous oxide emissions detected. This was possibly due to very dry litter resulting in the inhibition of the microbial processes that are required for the creation of nitrous oxide. Poultry does not produce methane or nitrous oxide as a by-product of their digestion.
3. High rates of methane emissions were noted at fattening piggery and a small but significant amount of nitrous oxide emissions. The researchers found it difficult to determine if the contributions of the total methane emissions were from enteric fermentation from the pigs or from the anaerobic degradation of the pig slurry stored beneath the partially slatted floor.

Table 5. Average gas and odour concentrations at ventilation inlets and outlets of different rooms in two swine production buildings under liquid manure management (shallow pit design).

Type of Room	Location	GHG Concentration Range (parts per million volume/ ppmv)		
		CO_2	CH_4	N_2O
Farrowing	Inlet	597-2827	2.8-98.8	0.3162-0.3641
	Outlet	2395-3179	21.2-79.7	0.3165-0.3871
Gestation	Inlet	596-814	2.4-11.9	0.2920-0.3343
	Outlet	2008-4819	10.7-170.2	0.3431-0.3891
Nursery	Inlet	644-1463	3.4-13.4	0.3044-0.3315
	Outlet	3274-3517	56.2-113.5	0.3324-0.3414
Grow-finish	Inlet	918	4.9	0.3092
Fully slatted	Outlet	2977	20.1	0.3160
Grow-finish	Inlet	533-596	1.7-2.2	0.3218-0.3436
Partly slatted	Outlet	2469-2702	14.9-15.6	0.2912-0.3589

4. They noted that the dairy cow housing had the highest emission rates for both methane and nitrous oxide per 500 kg liveweight housed. Also, when the cows were out grazing, the emission levels consistently fell to zero. Therefore, they concluded all of these emissions can be attributed to enteric fermentation and not to anaerobic degradation of any manure slurry within the building.

Sneath et al. (1997) stated that knowledge of nitrous oxide emissions is incomplete, and limited information exists on emissions from litter or bedding. The 24-hour observed average emission rates of N_2O are listed in Table 6.

Lague et al. (2002) identified that in the year 2000, the agricultural N_2O emissions accounted for 115 kT/year or 53% of all anthropogenic GHG emissions, and the swine sector contributed a total of 1.2 kT/year. Table 7 lists the concentrations of N_2O emissions from swine production buildings and the manure management systems. These researchers concluded that liquid manure management systems result in increased nitrogen losses as N_2O compared to solid manure management systems.

Increased emissions from liquid manure systems can be observed at all stages of the manure management system from collection, storage and land application. It was found that a change to a solid or hybrid, separate management of solid and liquid fractions of manure could result in the reduction of N_2O emissions (Lague, 2002). More detailed mitigation management options will be discussed in the following sub-section. According to Lague (2002) there were few sources of scientific literature that studied concentrations of N_2O emissions from manure storage facilities and/or barns. Most were from the swine industry (Table 7).

In Table 8, there are preliminary emission values from the Saskatchewan study conducted by Lague et al. (2002). These researchers caution that at the different piggery rooms, greenhouse gas concentrations have been reported but no emissions have been calculated yet. This is due to the early stages of this study; therefore, the author has made no conclusions. However, there is an indication that, with the exception of the farrowing room at the Floral Barn, nitrous oxide has been detected in most of the rooms, indicating that N_2O production is occurring.

3.2.2 Nitrous oxide emissions from manure management and land application

Three primary sources of nitrous oxide (N_2O) are emissions from agricultural soils, direct soil emissions from animal production including barn/feedlot emissions, and emissions indirectly induced from agricultural activities (IPCC, 1996 revised). In Australia, the National Greenhouse Gas Inventory stated that approximately 98% of the greenhouse gas emissions from livestock manure occurred as methane (CH_4) and only about 2% occurred as nitrous oxide (N_2O) (Hegarty 2001). Hegarty (2001) also notes that nitrous oxide from manure accounts for less than 0.1% of the total greenhouse gases from the Australian livestock sector.

In 1990 the calculated GHG emissions by Canadian pigs was 414 886 tonnes of CO_2 equivalent with the assumption that 0.5% of the excreted nitrogen is transformed to N_2O (Ball & Mohn, 2003). However these researchers noted that the published scientific literature used in the calculation of GHG emissions for swine that included methane production, nitrogen excretion and N_2O emissions from manure, excluded CO_2 production as it was assumed that

Table 6. Measured emission rates of nitrous oxide for various buildings

Source: Sneath et al. (1997), Long-Term Measurements of Greenhouse Gas Emissions from UK Livestock Buildings.

Building Type	24-hr average emission rate g N_20/day (500 kg liveweight)	Number of 24-hr periods of measurement on which reported value baed
Slurry-based fattening piggery	0.4	17
Broiler house	0	35
Slurry-based dairy cow house	0.8	12

CO_2 production from pigs could not be influenced. The current research that Ball and Mohn conducted indicates that this assumption is incorrect and that CO_2 can be manipulated. As a result previous literature values substantially underestimate the CH_4 production by pigs and consequently estimates for methane and nitrous oxide emission factors may be too high. For nitrous oxide this can be a higher value of up to 30% of the excreted nitrogen as potential N_2O emissions. This would then correct the calculated 1990 value of 11.6 million tonnes/year.

Chang et al. (1998) investigated nitrous oxide (N_2O) emissions from long-term manured soils in southern Alberta. Chang notes that annual N_2O emissions increased with manuring rate. Nitrous oxide emission rates for soils that received between 0 to 180 Mg manure per hectare for a number of years ranged from a low of 0.7 kg N/ha/yr to 56 kg N/ha/yr. Chang et al. (1998) notes that the "N_2O emission rate is not related to any single environmental factor, because the N_2O emission rate is controlled by rates of N_2O production and the rate of diffusion". Chang found that N_2O emission rates were highest in early spring but also noted significant fluxes of N_2O during the winter. Cumulative effects of soils manured year after year can generate rates of N_2O emissions that are much higher than soils receiving manure for the short term.

Paul (1999) notes that in manured soils there are several influencing factors for the creation of N_2O emissions from manure application. These are: type of manure being applied, rate of application, soil moisture content and soil temperature. The most important factor in the understanding of the creation of N_2O emissions is the nitrogen cycle and the processes of nitrification and denitrification as these are the two major processes that determine the rate at which N_2O emissions are created. Paul notes that N_2O can be emitted during both processes in manured soils.

Lague et al. (2002) studied emission factors of N_2O for manure storage facilities in Saskatchewan (Table 8). This study is still ongoing and further data will be collected in 2002 and 2003 to validate these values.

Lague et al. (2002) noted that the preliminary results on GHG emissions from liquid pig manure storage facilities in Saskatchewan indicate that N_2O emissions are, respectively, in the ranges of 0.002047 to 0.0394 g of gas per square meter of storage area per day during the spring to fall time period.

Table 7. Greenhouse gas emissions data for pig manure storage facilities.

Source: Lague (2002), Management Practices to Reduce Greenhouse Gas Emission from Swine Production Systems.

Source	Units	Greenhouse Gas			Comments
		CH_4	CO_2	N_2O	
Husted (1994)	G/day-m³	0.4-34.8	-	-	Liquid pig manure
		17.9-92.0	-	-	Solid pig manure
		11.6	-	-	Liquid pig manure
		28.3	-	-	Solid pig manure
	mg/m²-h	-	-	**25**	Liquid pig manure
Kuroda et al. (1996)	ppm	1430	-	**1400**	Swine feces compost
Osada et al. (1995)	kg/m³-day	-	-	**0.5**	Swine waste water
Peu et al. (1999)	mg/h-m³	-	-	**79 to 91**	Aerated liquid pig manure
Roger Phillips et al. (1997)	g/day- m³	0.014-0.39	-	-	Range over different types of manure storage facilities
Sommer & Moller (2000)	g/tonne	191	-	**58**	Deep litter manure system

Wagner-Riddle et al. (1997) investigated N_2O emissions from agricultural fields, 20 km north of Guelph, Ontario over a 28-month period. They noted the following range of N_2O emissions:

- Spring thaw emissions from fallow or ploughed plots measured from March 1993 to April 1995 ranged from 1.5 to 4.3 kg N/ha (0.00165 T N/ha to 0.004740 T N/ha).
- Lowest annual N_2O emissions were measured for second year alfalfa at 1 kg N/ha yr (0.0011 T N/ha yr) and bluegrass at 0 to 0.5 kg N/ha yr (0 to 0.000551 T N/ha yr).
- Higher annual N_2O emissions ranged from 2.5 to 4.0 kg N/ha yr (0.00275 to 0.00441 T N/ha yr) for corn, barley, canola, and fallow plots.
- The highest N_2O emissions were measured after the addition of animal manure to fallowed plots which ranged from 5.7 to 7.4 kg N/ha yr (0.00628 to 0.00815 T N/ha yr) and the alfalfa residue by fall ploughing at 6.1 kg N/ha yr (0.00672 T N/ha yr).

Wagner-Riddle et al. (1997) noted that plot management during the previous year had an effect on N_2O emissions, especially on the soybean plot where the N_2O emissions were 5.9 kg N/ha yr (0.00650 T N/ha yr). These researchers used the micrometeorological technique, which is described in detail in their paper, for this study. They found this technique to be somewhat successful in the monitoring of N_2O fluxes from several plots and useful in the detection of long-term effects of management, including manuring, on emissions rates.

In a two-year N fertilizer study conducted in Saskatchewan at four different locations, Lemke et al. (2003) studied the effect of source, timing, and placement of fertilizer N had on N_2O loss under western Canadian conditions (Table 9). They observed that management of N (anhydrous ammonia vs. urea, spring vs. fall fertilizers, and side row vs. banding) had very little influence on annual N_2O losses. However, there was little snow cover at most sites during the comparison, which may have minimized differences in the comparison. The most significant finding of the study was that the average estimate of N_2O loss was 0.3% of applied N – a factor several times lower than the default value of 1.25% recommended in Tier 1 IPCC guidelines (IPCC 1996). This suggests that the current factor needs to be modified for Alberta conditions. Lemke et al. (2003) caution that a single point was used for each flux estimate and linearity was assumed leading to a probable underestimation of 40%, and slope position was not taken into effect; however the % loss of fertilizer N would still be very low considering the current IPCC default values).

Coyne et al. (1994) measured the nitrous oxide (N_2O) flux from poultry-manured erosion plots and grass-filtered plots after simulated rain. They found that the grass filters used to control surface runoff from fields can also become an environment that is carbon-rich,

Table 8. Unit daytime greenhouse gas emissions (g_{GHG}/m^2 day) from pig production buildings and manure storage facilities: Methodology and preliminary results. Source: Lague et al. (2002). Greenhouse Gas and Odour Emissions from Pig Production Buildings and Manure Storage Facilities: Methodology and Preliminary Results.

Unit Daytime Greenhouse Gas Emissions (g_{GHG}/m^2 day)				
Gas	**Manure Storage Type**	**Morning Reading (g_{GHG}/m^2 day)**	**Mid-day Reading (g_{GHG}/m^2 day)**	**Afternoon Reading (g_{GHG}/m^2 day)**
N_2O	Uncovered Earthen Manure Storage (Aug, 2001 manure depth=3.0m)	-	0.002047	-
N_2O	Uncovered Tank (Oct, 2001 manure depth = 2.5m)	0.03735	0.004038	-
N_2O	Covered Earthen Manure Storage (Oct, 2001 manure depth = 2.0m)	0.0394	0.003696	-
N_2O	Uncovered Tank (May, 2002 manure depth = 2.8m)	-	-	-

Table 9. Percentage of Fertilizer-N lost as N_2O at Sites in Saskatchewan for the period May 2000 to April 2002.
Source: (Paul et al. 2001)

N form/Band Placement	Swift Current	Indian Head	Scott	Star City
	%, May 2000 to April 2001			
Urea side-row[1]	0.12	0.08	0.06	-0.59
Urea mid-row[2]	0.27	0.17	0.05	-0.16
Urea banded in fall	0.18	0.21	0.25	0.05
AA[3] side-row	0.03	0.19	0.04	-0.20
AA mid-row	0.30	0.11	0.14	0.16
AA banded in fall	0.12	0.17	0.18	-0.27
Mean	0.17	0.16	0.12	-0.17
N form/Band Placement	**Swift Current**	**Indian Head**	**Scott**	
	%, May 2001 to April 2002			
Urea side-row[1]	0.05	0.05	0.04	
Urea mid-row[2]	0.23	0.03	0.09	
Urea banded in fall	0.02	0.08	0.12	
AA[3] side-row	0.21	0.05	0.09	
AA mid-row	0.22	0.07	0.28	
AA banded in fall	0.06	0.05	0.17	
Mean	0.13	0.06	0.13	

1 side-row = fertilizer band placed to one side of the crop row
2 mid-row = fertilizer band placed midway between alternating crop rows
3 AA = anhydrous ammonia

favouring water infiltration and denitrification, which in turn promotes the generation of N_2O emissions. They found that the average N_2O flux of the three most dynamic erosion plots was 755 ug N_2O-N/m^2 hr.

Sommer et al. (1996) investigated nitrous oxide (N_2O) and methane emissions from pig slurry amended soils These researchers noted that the water content within the soil had a significant influence on N_2O emissions during the 16 day period. They found the following ranges:

- Moist Soil (240 g H_2O/kg): 300 g N_2O-N/ha (0. 33 Kg N_2O-N /ha)
- Dry Soil (100 g H_2O/kg): 100 g N_2O-N/ha (0. 11 Kg N_2O-N /ha)

They also suggested a trend that N_2O emissions were decreasing in the following order of manure application: lowest was injection, then surface application and the highest came from mixing into the surface. However, there were not statistically reported differences to support this observation.

A significant amount of nitrous oxide is emitted during the composting process; however, the magnitude is dependent on the type of compost process (Table 10). Generally speaking, the conditions for nitrous oxide emissions from soils, explained in Section 2.0 of this report, apply to the compost process as well.

3.2.3 Mitigation techniques for nitrous oxide emissions

As outlined earlier in section 3.0, the IPCC notes three areas identified as major sources of N_2O emissions:

1. Direct emissions from agricultural soils
2. Direct soil emissions from animal production (stable emissions as listed in the manure management section)
3. Indirect emissions resulting from agricultural activities

The literature identifies some main mitigation techniques:

- Increase N use efficiency of applied fertilisers
- Altering denitrification and nitrification processes
- Timing and rate of application
- Feeding strategies
- Slurry additives
- Switching manure management systems (wet to dry)

Oenema (1999) suggested two strategies in the management of these three areas to achieve decreased N_2O emissions. His strategies are:

1. Increase the N use efficiency concomitant with the lowering of total N input
2. Decrease the release of N_2O per unit of N from denitrification and nitrification

Oenema (1999) indicated that in order for this to be effective, the need to decrease N_2O emissions must be a management objective of the farm and management decisions must be based on this objective. Chang et al (1998) suggested that repeated long-term manure application to soils may generate rates of N_2O emissions that are much higher than predicted for soils receiving manure application for short periods of time. This suggests that it is important to use soil and manure testing as part of the farm management processes to control N_2O emissions.

Timing of application appears to be a major factor in reducing N_2O emissions from manure applied to soils. Paul (1999) indicated in his research that the application of fertilizer usually resulted in higher emissions of N_2O than that of manure. He noted that in Canada less than 50% of the manure produced is applied in the spring when there are suitable conditions for plants to utilize manure effectively. Fall application can lead to more N_2O emissions due to the winter/spring melt-thaw periods. This is probably due to the fact that producers do not have enough storage capacity to accommodate storage

Table 10. Estimates of nitrous oxide emissions from various research studies. Source: Paul et al. (2001)

Compost	Method	N_2O-N loss (% of Total N)
Yard waste	Turned windrow	0.5
Food and yard waste (80:20)	Windrow and agitated bed	0.2 – 0.4
Wastewater sludge	Aerated static pile	0.7
Cattle and horse manure	Turned windrow	0.5
Yard waste	Turned windrow	1.2
Horse manure & bedding	Turned windrow >60 days	2.2
Swine manure & cardboard	Aerated and turned in vessel	0.1
Animal manure	Heaps in containers	5.0
Cattle manure	Passively aerated windrows	0.11
Cattle manure	Turned windrow	0.19
Swine manure & straw	Passively aerated pile	0.8

of manure until spring application. Paul found that more than 40% of the manure produced in Canada is applied to the soil during the fall and the winter. In the cases of liquid manure lagoons in the prairies, there cannot be any spring application because often the lagoons are frozen so manure is usually applied in the fall after harvest.

Other methods to reduce N_2O emissions are the use of feed and slurry additives (Hornig et al., 1997). Horning et al. (1997) noted that the use of bentonite significantly reduced ammonia and odour emissions, but caused a higher ratio of ammonium to total nitrogen content of the slurry. Manure slurry acidified with lactic acid resulted in the prevention of ammonia, methane and N_2O emissions only at a pH value under 4.5. In order for lactic acid to work on cattle slurry, 4% by volume of cattle slurry was required. In the case of pig slurry the volume was slightly higher. The literature indicates that a reduction in ammonia emissions by improvement in diet may be proportional to a reduction in N excretion or it can be greater (Paul, 1999). Another method is to increase efficiency during animal production which results in less N excreted by the animal since N_2O emissions are relative to the amount of N excreted (Paul, 1999).

In terms of feeding strategies, Lague (2002) concluded that the most effective strategy for reducing N_2O emissions from manure is to minimize the nitrogen content of the urine and feces excreted from the animals. This can be managed through diet and water management practices, leading to increased nitrogen efficiency by the animals.

Another mitigation practice to decrease N_2O emissions from liquid manure systems is to change from a liquid management system to a solid or hybrid system where liquid is separated from the solid fractions. However, Lague (2003) noted that there needs to be careful management of these systems in order to generate any benefits. As well liquid manure management practices such as broadcast surface spreading can be used, as this is a more beneficial practice than banded application. Alternatively soil mixing with land-applied manure can also result in decreased N_2O emissions along with direct injection.

In Alberta there were two strategies in the reduction of N_2O emissions identified in Alberta Agriculture, Food and Rural Development's (AAFRD) Greenhouse Gas Emissions and Alberta's Livestock Industry June 2000 fact sheet. The first strategy was to avoid excessive manure application and the second strategy was to optimize timing of manure application. AAFRD notes that these practices will assist in the utilization of the most available nitrogen and decrease the risk of the loss of nutrients from runoff, greenhouse gases and leaching to surrounding water bodies.

3.2.4 Methane emissions

Table 11 summarizes the various direct measure methods used for the estimation of methane emissions from cattle.

3.2.5 Methane emissions from animals and livestock buildings

In Alberta, ruminant animals were the second largest contributors of greenhouse gas emissions for the agricultural and agri-food industry (AAFRD Greenhouse Gas Team 1999). Using IPCC Tier 2 methodologies, livestock in Alberta were responsible for contributing to methane emissions that accounted for 30% of total greenhouse gas emissions from Alberta's agriculture and agri-food processing sector for 1996. Between 1990 and 1996, there was a 15% increase in methane emissions nationally and an 18% increase in methane emissions provincially (Table 12). The reason for this increase was the increase in herd sizes. It was estimated that, by 2010, Alberta's livestock population will increase by 38.4% from 1990 values and 16.1% from 1996 values. This results in creation of 8.25 MT of CO_2 equivalents by 2010 from Alberta's livestock population (projected increases in feeder cattle, dairy cattle, hogs, poultry, bison, elk and deer populations). This report also noted that the methodology used to estimate methane production has been based on the estimation of herd size and the metabolic weight of individual animals. The Alberta Emissions Inventory estimates a ±5% error for Alberta methane emission calculations versus a ±30% error for the Canadian totals (which are based on IPCC guidelines).

In Alberta, methane (CH_4) emissions from the livestock industry have increased 18% from 1990 to 1996. There are projections of larger increases by more than 16.1% by the year 2010, while nitrous oxide (N_2O) from fertilizer has not increased since 1990 but there is an expected 5% decrease by the year 2010 (AAFRD Greenhouse Gas Team 1999). Table 12 displays the emission estimates for Alberta compared to the national emission estimates.

Dairy cows are considered to have a high rate of CH_4 emission per head compared to other cattle (105 to 165.2 kg CH_4 head^{-1} year^{-1}) (McCaughey et al., 1997; McAllister et al., 1998; Okine et al., 1998; Basarab et al., 1999; McCaughey et al., 1999; Kaharabata et al., 2000; Boadi and Wittenberg, 2001b). More recently CH_4 emissions were measured using the SF_6 tracer technique for feedlot dairy cattle in barns. The emissions ranged from 98.1 to 172 kg CH_4 cow^{-1} year^{-1} (McCaughey et al., 1999). Heifers were found to emit less CH_4 compared to non-lactating cows and steers (Boadi and Wittenberg, 2002; Boadi et al., 2002).

Methane emissions from wintering pasture and forage-fed cattle (mostly beef cows) are more difficult to obtain. Using the SF6 technique, McCaughey et al. (1999) obtained a range of emissions for lactating beef cows per day that took into account the date sampled and the type of pasture diet. The emissions ranged from 70.4 to 115 kg cow^{-1} year^{1} over four sampling dates between July 11 and August 15, 1994 on legume-grass pasture in Brandon, Manitoba and from 95.8 to 119 kg CH_4 cow^{-1} year^{-1} on the same dates in a grass-only pasture in the same vicinity (AAFRD in press).

In swine production systems methane is generated through anaerobic or oxygen-deficient microbial processes that decompose feed in the pig's large intestine. This is similar to the anaerobic biochemical decomposition of manure during collection, storage and land application or treatment that results in methane (CH_4) generation (Lague, 2002). Lague (2002) outlined the range of emissions data for pig production buildings reported by other researchers (Table 13).

Sneath et al. (1997) directly measured rates of methane emissions from different buildings listed in Table 14. These researchers noted that in the broiler house there was no significant increase in methane concentration between the inlet air and outlet air

Table 11. Summary of methods used for the direct measure of methane emissions (CH_4) from cattle sources.
Source: AAFRD, Agriculture Air Issues Unit (in press)

Authors	Method
Johnson and Johnson, 1995	Micrometerological technique
Khan et al., 1997; Harper et al., 1999	Mass balance technique
Johnson et al., 1994; Johnson and Johnson, 1995; Johnson & Westberg, 2001.	Non-radioactive, non-isotopic and isotopic tracer methods
Johnson & Johnson, 1995; Harper et al.,1999	Micrometerological measurements taken in a non-intrusive, open respirator chambers
Lockyer & Champion, 2001	Micrometerological measurements taken in non-intrusive, man made wind tunnels adjacent to grazing or feeding sites, stream of acetylene (C_2H_2) is passed over head space of chamber or tunnel. Samples are analyzed using gas chromatography for three greenhouse gases.
Johnson & Johnson, 1995; Harper et al.1999; Lockyer & Champion 2001.	Wind speed and direction are used to display the concentration over time
Holter & Young, 1992	Closed respiration chamber method, gas from animal was collected over a period of time (24 to 72 hrs) analyzed via gas chromatography
Johnson et al., 1994; Johnson & Johnson, 1995; McCaughey et al., 1997; McCaughey & Wittenberg, 1999; Boadi et al., 2001; Johnson & Westberg, 2001	Use of tracer techniques such as SF_6 to measure CH_4 concentrations from the animal rumen.
McAllister et al.,1996; Mathison et al.,1998; Lassey et al., 1997; Herd et al., 2001	Metabolic energy utilization method for annual emission rates of beef and dairy cattle.

Table 12. Emission estimates (MT CO_2 equivalents). Source: AAFRD Greenhouse Gas Team - May 7, 1999. Agriculture and Agri-Food Industry Greenhouse Gas Emissions in Alberta Summary Statement.

Emission Estimates (MT CO_2 Equivalents)						
Type of Emission	**Alberta**			**Canada**		
Carbon Dioxide (CO_2)	**1990**	**1996**	**2010**	**1990**	**1996**	**2010**
Soil (net source)	3.5	2.0	0(-2.5)	7.0	2.0	0(-10)
Farm Fuel	2.6	2.5	2.6	8.6	9.1	10.4
Agri-Food Processing	0.6	0.7	2.4	3.8	4.2	6.5
Methane (CH_4)						
Livestock/Manure Management	6.0	7.1	8.3	20.0	23.0	24.9
Nitrous Oxide (N_2O)						
Manure Management Systems	1.9	1.7	2.0	3.9	4.6	5.2
Soil Fertilizer	10.0	10.0	9.5	30.1	35.4	33.7
Total	24.6	24.0	24.8	73.4	78.3	80.7
Total (including soil carbon sinks)	24.6	24.0	22.3	73.4	78.3	70.7

Table 13. Greenhouse Gas Emissions Data for Pig Production Buildings

Source: Lague (2002), Management Practices to Reduce Greenhouse Gas Emission from Swine Production Systems.

Source	**Units**	**Greenhouse Gas**			**Comments**
		CH_4	**CO_2**	**N_2O**	
Gallman and Hartung (2000)	g/h-LU	0.5-1	3.8-5.5	-	Fattening pig
Groot,Koerkamp & Uenk (1997)	mg/h-animal	2406 445 1269	- - -	- - -	Sows Weaner pigs Finisher pigs
Hinz & Linke (1998a, b)	ppm kg/h 500kg live weight	- -	300-8000 0.64	- -	Fattening piggery
Jeppson (2000)	g/hm²	-	23.0-82.2	-	Grower-finisher pigs with space allowance of 1.1 m²/animal.
Ji-Qin et al. (2000)	g/hm²	-	0.8-118.4	-	Pig fattening building
Osada et al. (1998)	g/animal	302	5440	9.1	Total emissions from finisher pigs during an 8 week period.
Phillips et al. (1998)	ppm	-	1180-3765	-	Slurry-based sow unit monitored over 24 hr period in winter time.
Sneath et al. (1997)	g/day 500kg liveweight	85	-	0.4	Slurry-based fattening pig.

Table 14. Measured Emission Rates of Methane from UK Livestock Buildings

Source: Sneath et al. (1997). Long-Term Measurements of Greenhouse Gas Emissions from UK Livestock Buildings

Building Type	24 hr average emission rate g CH4/day (500 kg liveweight)	No. of 24 hr periods of measurement on which reported value based
Slurry-based fattening piggery	85	17
Broiler House	0	35
Slurry-based dairy cow house	320*	12

**corrected for any periods when cows were grazing, i.e. reported value as if the cattle were inside for 24 hrs of every day studied.*

that could be detected using gas chromatography. The reason for this was probably due to the very dry litter, which inhibits microbial processes from occurring within it, especially the anaerobic ones that create methane. However, for dairy cattle, they reported an average value of 320 g CH_4/day (500 kg liveweight) that is comparable to the upper end of the range of 170-330g CH_4/day (500 kg liveweight) reported by others.

The above researchers also noted that there were significant peaks in methane production that occurred within one to two hours after each feeding of the dairy cows, and a noted steady decline between feedings. They concluded that methane emissions are derived from enteric fermentation from the cows and not from the slurry deposited within the building.

Lague et al. (2002) reported the following concentrations of greenhouse gas emissions from their study conducted in Saskatchewan (Table 15). They concluded that due to the large variation in emissions data there is a need to better determine the contributions of the different stages of livestock production of greenhouse gases caused by the agricultural industry in Canada. These are preliminary concentrations, no emissions have been calculated and due to the early stages of this study the authors have made no conclusions. Lague et al. (2002) noted that with the exception of the farrowing room at the Floral Barn, preliminary results indicate that CH_4 production is occurring within each room.

Basarab et al. (2000) projected livestock emissions, based on direct measurements, for greenhouse gas emissions in CO_2 equivalents for 1990, 1996 and 2009 to 2012 (Table 16).

Table 16 shows that methane emissions from Alberta's livestock populations continued to grow by 19.5% from 1996 and are projected to increase a further 15.2% by 2008-2012. Beef cattle accounted for over 90% of Alberta's emitted methane from livestock, whereas hogs were the main emitters of nitrous oxide.

3.2.6 Methane emissions from manure management

Methane is a by-product of anaerobic microbiological decomposition and is influenced by the type of manure management practices used in manure collection, storage and handling (Lague, 2002). Using the IPCC methodology to evaluate CH_4 emissions for swine production systems in developed countries under cool climates, CH_4 emissions have been estimated at 1.5 and 10 kg per animal per year for enteric fermentation and manure management, respectively (Lague, 2002). Modern intensive livestock operations, or confined feeding operations, will result in manure concentrations being higher due to animal confinement (AEA Technology, 1998). This will usually result in the storage of manure in storage tanks or lagoons resulting in the creation of anaerobic conditions and setting the stage for the creation of methane. Methane emissions from manure depend
on the following factors:

1. Quantity of manure produced, which depends on the number of animals, feed intake and the type of feed, which will influence the digestibility by the animal.
2. Methane producing potential of manure, which depends on animal type and feed quality that is given to the animal.
3. Management of the manure, which depends on such factors as whether it is stored as a liquid or spread as a solid and climate, which will have an impact on biological activity and the conditions needed for methane production (AEA Technology, 1998).

Table 15. Average odour and greenhouse gas concentrations at inlets and outlets of different rooms at the Floral Barn and Elstow Barn, Dec 2001. Source: Lague et al. (2002), Greenhouse Gas and Odour Emissions from Pig Production Buildings and Manure Storage Facilities: Methodology and Preliminary Results.

Floral Barn Room	Location	Greenhouse Gas			Odour	
		CO_2 (ppmv)	CH_4 (ppmv)	N_2O (ppmv)	Odour concentration (OU/m^3)	Hedonic Tone
Farrowing	Inlet	2827	98.8	0.3162	-	-
	Outlet	3179	79.7	0.3165	430	-1.75
Gestation	Inlet	814	11.9	0.2920	-	-
	Outlet	4819	170.2	0.3891	680	-1.50
Nursery	Inlet	1463	13.4	0.3044	-	-
	Outlet	3274	113.5	0.3414	570	-2.65
Grow-finish	Inlet	533	1.7	0.3436	-	-
	Outlet	2469	15.6	0.2912	13	-1.00

Elstow Barn	Location	Greenhouse Gas			Odour	
		CO_2 (ppmv)	CH_4 (ppmv)	N_2O (ppmv)	Odour concentration (OU/m^3)	Hedonic Tone
Farrowing	Inlet	597	2.8	0.3641	-	-
	Outlet	2395	21.2	0.3871	290	-2.12
Gestation	Inlet	596	2.4	0.3343	-	-
	Outlet	2008	10.7	0.3431	330	-1.50
Nursery	Inlet	644	3.4	0.3315	-	-
	Outlet	3517	56.2	0.3324	360	-2.12
Grow-finish (Fully slatted)	Inlet	918	4.9	0.3092	-	-
	Outlet	2977	20.1	0.3160	270	-1.75
Grow-finish (Partially slatted)	Inlet	596	2.2	0.3218	-	-
	Outlet	2702	14.9	0.3589	230	-2.12

In Alberta the emission estimates for livestock and manure management for 1990 were 6.0 MT of CO_2 equivalents, 1996 is 7.1 MT of CO_2 equivalents and the projection for 2010 is 8.3 MT of CO_2 equivalents (AAFRD Greenhouse Team, 1999). Approximately 7% of Alberta's total agricultural and agri-food processing emissions in 1996 were from manure management. Methane emissions in Alberta for the livestock industry are increasing and expected to increase even more by the year 2010.

Lague et al. (2002) have released preliminary emissions results for manure storage facilities in Saskatchewan, listed in Table 17. These preliminary results from liquid pig manure storage facilities are in the ranges of 0.2088 to 50.40 g of gas per square meter of manure storage area per day during the spring and fall, respectively. More data from these experiments are expected in 2002 and 2003. Greenhouse gas emissions from pig manure storage facilities were reviewed from the literature as well. The large variability in emissions data found in the literature indicates that there needs

Table 16. *Greenhouse gas emissions in CO_2 equivalents from Alberta's livestock for 1990, 1996 and 2001.*
Source: Basarab et al. (1999)

Livestock type	1990, t/yr	1990, % of total	1996, t/yr	1996, % of total	2008-12, t/yr	2008-2012, % of total
1. Beef cattle	5,360,965	89.82	6,508,831	91.46	7,275,653	88.04
2. Dairy cattle	327,873	5.49	304,416	4.28	456,603	5.53
3. Hogs	127,771	2.14	128,499	1.81	256,998	3.11
4. Horses [y]	74,844	1.25	74,844	1.05	74,844	0.91
5. Sheep/lambs [y]	50,820	0.85	44,898	0.63	50,820	0.62
6. Poultry [y]	1134	0.02	1197	0.02	1575	0.02
7. Diversified species [y]	25,263	0.42	54,117	0.76	147,084	1.78
Total	5,968,670	100.0	7,116,802	100.0	8,263,577	100.0

[z] The livestock inventories and emissions in CO_2 equivalents are based on Tables 2 to 5 in Basarab et al. (2000).
[y] CO_2 equivalents includes methane produced directly from the animal plus methane emissions from manure times 21.

Table 17. *Unit daytime greenhouse gas emissions (g_{GHG}/m^2 day)* *Source: Lague et al. (2002). Greenhouse Gas and Odour Emissions from Pig Production Buildings and Manure Storage Facilities: Methodology and Preliminary Results.*

Gas	Manure Storage Type	Morning Reading (g_{GHG}/m^2 day)	Mid-day Reading (g_{GHG}/m^2 day)	Afternoon Reading (g_{GHG}/m^2 day)
CH_4	Uncovered Earthen Manure Storage (Aug, 2001 manure depth=3.0m)	-	-	0.2088
CH_4	Uncovered Tank (Oct, 2001 manure depth = 2.5m)	50.40	40.23	40.55
CH_4	Covered Earthen Manure Storage (Oct, 2001 manure depth = 2.0m)	5.424	0.8250	1.115
CH_4	Uncovered Tank (May, 2002 manure depth = 2.8m)	-	-	-

to be a consensus on how to determine emissions from manure management and the different stages of livestock production by the agricultural sector in Canada.

Hegarty (2001) indicated that 98% of methane emissions arise from livestock manure storage and handling, particularly with confined feeding operations, but this contributes to only 3% of the total methane emissions from the livestock sector. It is Hegarty's view that manure constitutes a small source of greenhouse gas emissions relative to enteric fermentation and that benefits to national (Australian) emissions from targeting these emissions is small. However there still can be management options to ensure that there are minimal emissions being created. In the case of manure this can be minimised by managing the needs of the animals. This means that the energy requirements of the animals are being met from the use of highly digestible feed and feeding at levels that are required for the desired performance of the animal. This approach can be achieved with the pig and poultry industries and to an extent the dairy industry as well.

Hilhorst et al. (2001) focused on strategies to reduce methane emissions from pigs and ruminants. They considered influencing factors. In terms of manure management, three key influencing factors are:

1. **Temperature:** Temperature is responsible for the growth rate of different types of methanogenic bacteria that create methane. It was noted by the study that below 20°C, methane production is positively affected by the growth rate of different types of methanogenic bacteria.
2. **Slurry at rest in a covered outdoor storage:** It was noted that as long as pig slurry is at rest, methane emissions are less than from agitated slurries. Covering the slurry storage reduces NH_3^+ emissions because of the thermodynamic equilibrium of NH_3^+ and ammonium in the liquid fraction of the slurry. As a side effect it results in lower methane emissions.
3. **Aeration:** Since methane production is an anaerobic process, the addition of oxygen via aeration in slurry can result in the reduction of methane emissions. However, this may increase nitrous oxide emissions depending on the circumstances.

Hilhorst et al. (2001) concluded that a number of manure management practices can assist in reductions of methane emissions. The reduction of indoor storage time combined with the use of a well-covered outdoor storage facility with the slurry at rest for cooler countries will assist in the decreased production of methane and a decrease in methane emissions. This is also a very cost-effective emission reduction option in the Netherlands. They indicated that this is much more effective for pigs than cattle.

Hilhorst et al. (2001) indicated that the storage temperature of manure has an effect upon methane emissions from manure of pigs and ruminants. They indicated that, from previous studies conducted by Sharpe & Harper (1999), temperatures below 20°C positively affected the production of methane due to the effect upon the growth rate of the different types of methanogenic bacteria. The covering of pig slurry at rest resulted in less methane emissions than from agitated slurry. The use of filters from housing and slurry storage facilities decreased the amount of methane released.

Although minimal information is available on the production of N_2O and CH_4 during the compost process, some studies from Agriculture and Agri-Food Canada in southern Alberta measured 6.3 g CH_4 kg^{-1} fresh manure and 0.11 g N_2O kg^{-1} fresh manure from passive composting systems, and 8.1 g CH_4 kg^{-1} fresh manure and 0.19 g N_2O kg^{-1} fresh manure from active composting systems (Larney et al., 1999; Hao et al., 2000). Currently there are a limited number of studies being conducted on greenhouse gas emissions and manure handling. However, a study currently being conducted at the Lethbridge Research station is examining passive composting and active composting. Passive composting is a process where the manure is piled on top of open ended perforated steel pipes. The preliminary results are showing that passive composting produced approximately a third less greenhouse gas emissions than active composting (manure was rotated six times over the course of three months). The preliminary results also indicated that during the passive composting process not all of the manure was completely composted; however there was some indication that carbon retention was twice as much. These preliminary finds suggest that the use of passive composting may be a management alternative to consider if the manure does not need to be completely composted (AAFRD 2001).

As a rule, methane emissions from composting are low, and aerating the compost creates even lower emissions. Hao et al. (2001) calculated 28% higher methane emissions during passively aerated composting than during turned windrow composting. Kuroda et al. (1996) studied methane emissions for one day only during composting of swine manure in forced aerated chambers. Once aeration was stopped, methane emissions increased. In general, methane emissions from most studies ranged from 0.2 to 2% of the carbon content of the manure. In most cases, aerating the compost will reduce methane emissions to negligible levels (Paul et al. 2001).

3.2.7 Mitigation techniques for methane emissions

In the literature reviewed, several suggestions for mitigating methane emissions were found. However there are several factors that need to be reviewed when looking at mitigation techniques for methane emissions generated from enteric fermentation and manure management (AEA Technology, 1998). In General, AEA Technology indicated that in Europe, emissions can be directly reduced by decreasing the amount of milk and meat produced – this is also linked to European Union's agricultural policy. However, in North America, the agriculture sector is continuously striving for increased production, and so policies differ in Canada. Alternatively, an indirect approach would be to improve upon animal productivity efficiencies such as increasing the amount of product produced per unit intake of feed. Another approach is to optimize rumen fermentation, but this requires an in-depth understanding of nutritional requirements of microbial populations and the effects of the use of chemical and physiological rumen modifiers. Unfortunately there is still little information available to date, even though we have made significant advances in the knowledge base of this area (AEA Technology, 1998).

In Alberta there are some studies looking at different mitigating techniques for methane emissions. Okine and Basarab (2000) indicated that the most promising methods they found for reducing methane emissions for beef cattle were:

1. Use of higher quality feeds with balanced rations for minerals, proteins and vitamins. This technique would reduce methane emissions in beef cow populations by 38% or approximately 54 416 T/year. This could represent up to 13.8% reduction in GHG emissions (CO_2 equivalents) from the livestock industry in Alberta.
2. The feeding of ionophores and ionophore rotations in grassed and feeder cattle using strategic rotations would see a reduction of methane emissions by 34 676 T/year or an 8.8% reduction in terms of CO_2 equivalents from the livestock industry in Alberta. Mathison et al. (1998) noted that the short-term use of ionophores reduced methane emissions by 18%, but there was an indication in this study that methanogens and other members of the microbial population can adapt to the presence of ionophores.
3. Use of lipids in feed for feedlot diets (4-7% DM) has the potential to reduce methane emissions by approximately 26 189 T/year or a 6.7% reduction in terms of CO_2 equivalents from the livestock industry in Alberta.
4. Increase the calf crop percentage. The current calf crop percentage in Alberta is estimated to be 84%. Making changes to management and feeding practices in the cow herd could increase the calf crop percentage to 88%. The increase in calf cropping means that more calves are being produced from fewer cows resulting in the decrease of methane emissions from the cow herd by approximately 4 439 T/year or a 1.1% reduction in terms of CO_2 equivalents from the livestock industry in Alberta.

Okine and Basarab (2000) indicated that the four general strategies they outlined could reduce CO_2 equivalents from Alberta's livestock industry by approximately 30%. This results in a reduction of greenhouse gas emissions in 2008-2012 to 6.2 MT/year, which is only a 3.4% increase above the baseline of 1990. These researchers also noted that the combination of pasture and livestock management strategies has a large impacting potential in the long-term sequestration of carbon, in that the pasture can sequester as much carbon as the animal is emitting. The authors noted that management of pastures and animals is vital to the amount of carbon being sequestered. They also indicated that more research is required in the areas of pasture-animal management and the sequestration of carbon, new products/delivery systems for anti-methanogenic compounds and for the reduction of protozoal numbers in rumen, and products that increase the nutritional quality of feeds.

Mathison et al. (1998) in their research also noted some other diet related products and management practices that resulted in the decrease production of methane.

1. **Defaunation:** resulted in the reduction of methane production by 20 to 50% depending upon the diet of the animal. This process eliminates the cilia of the protozoa from the rumen.
2. **Reduction of unsaturated fatty acids:** in the diet was found to inhibit methane production in the rumen.
3. **Modification of feeding practices by:**

   Diet type: the type of feed consumed can have a major effect upon the proportion of energy emitted as methane. It was noted that specific feeds affected methane production. Mature dried forages tend to increase methane production rates while ensiled forages decrease methane generation.

   Feeding frequency: lower feeding frequencies tend to increase propionate production and lower methane production.

Retention time of digesta in the rumen: when the mean residence time of the feed in the rumen is decreased, methane production is expected to decrease as well, due to competition occurring amongst methanogenic bacteria under a shorter residence time.

Feeding level: in general the higher the feed intake the increase in the passage rate of feed particles out of the rumen. The extent to which the microbes can access the substrate is decreased which will reduce the rate or extent of ruminal dietary fermentation resulting in a decrease in methane production.

4. **Increasing animal productivity level:** which is influenced by diet, feeding level and rate of passage.
5. **Selection of ruminant animals for their energy use efficiency:** based on phenotypic selection, considerable amounts of methane emissions can be reduced. This approach is currently being studied to determine quantities and animal characteristics (Basarab personal communication, 2003).

The other area of methane mitigation techniques is manure management. In Europe, AEA Technology Environment indicated that the following management practices can ensure methane reductions:

- Aerobic decomposition of manure.
- Livestock management, where livestock are kept on pastures or rangelands. This reduces the amount of manure concentrated in one area and manure will be spread thinly across the pasture resulting in mostly aerobic decomposition.
- Land application management, by avoiding anaerobic soil conditions, and by using nutrient analysis to match crop nutrient needs with manure application.
- Aerobic treatments of liquid manures by aeration and solid manures by composting.
- Conversion of manure to biogas (65% methane, 35% carbon dioxide, and other trace gases) through anaerobic digestion in a close vessel system. This can result in producing heat and electricity.
- Use of covered lagoons where liquid manure is stored in open pits or lagoons.

Some other strategies noted by Hilhorst et al. (2001) are:

- Creation of biogas production under controlled anaerobic digestion of slurry can reduce methane emissions from the slurry. Biogas can also be used as an alternative fuel source.
- Controlling of the acidity of the slurry. It is noted that the growth of micro-organisms and gaseous emission rates are a function of the acidity of the slurry. However, most studies do not promote the use of acidifying slurry as it is difficult to predict the complex chemical reactions that will occur due to the lack of homogeneity of the slurry. Because the slurry is not homogenous the addition of acids can result in the creation of dangerous gases that can be potentially harmful to human health.
- Adjustment of feed content, digestibility and the use of additives may be a low-cost method to reduce methane emissions.
- Since methane production is an anaerobic process, the addition of oxygen will reduce methane production. Manure slurries or composts can be mixed with oxygen by aeration; however the reduction of methane can result in the increased production of nitrous oxide emissions.
- Reduce the indoor storage time along with the use of a well-covered outdoor storage facility with minimal slurry agitation.
- Cooling of indoor stored pig slurry.
- Filtration of the ventilation air of the animal houses (still in the development stages).

4 Challenges, Opportunities and Gaps

This section will focus on the challenges, opportunities and gaps of:

1. Calculated emission rates of nitrous oxide (N_2O) and methane (CH_4).
2. Direct measurements of emissions of nitrous oxide (N_2O) and methane (CH_4) from animals, livestock, livestock buildings, manure management and land application.
3. Mitigation techniques to decrease emissions of nitrous oxide (N_2O) and methane (CH_4).

4.1 Challenges, Opportunities and Gaps of Calculated Emission Rates of Nitrous Oxide and Methane

Presently the preferred methodology used to calculate emissions rates (Tier 1 and Tier 2) are created by the Intergovernmental Panel on Climate Change (IPCC). However, there are limitations in the methodology, such as the absence/gap in collective scientific understanding of the processes involved in the creation of greenhouse gases (U.S. Department of Energy (US DOE), 1999). Other challenges are the limitations of the models. Like all models there are relevant and important parameters that cannot be incorporated in. This can at times have a significant impact upon the results of the model. Due to the variability of the emissions and the many knowledge gaps in the measurement, the estimates of agricultural GHG emissions results are highly variable (Agriculture and Agri-Food Canada, 2000).

The U.S. Department of Energy indicates a deficiency in usable baseline data for individual countries and where they do exist, there are issues of database accessibility. It also points out that the IPCC (1996) has indicated three areas of focus in the collection of baseline information. These areas are:

1. Bioenergy and biomaterials production from agricultural land
2. Carbon sequestration in agricultural systems
3. CH_4 and N_2O emissions from agricultural lands

1. Bioenergy and biomaterials production from agricultural land: will require research on improving the assessment of carbon dioxide mitigation with the use of biomasses such as: carbon sinks (forests, agroforestry and agricultural management); development of a database on energy inputs for value added products from plant based goods and chemicals; collection of data and the establishment of a database with information on land availability for bioenergy and biomaterials use, other factors that should be included with this are the cultural, social and political inputs that would have an effect of the use of land for this; the inclusion of economic analysis for use and efficiency of biofuels (US DOE, 1999).

2. Carbon sequestration in agricultural systems: assessing the sources of carbon stocks of the agricultural system by the use of a model-based system that could be used on a global basis. Currently there are a few models being used on a regional base level, however, there are gaps such as the lack of spatial databases that would incorporate parameters such as climate, soils, land use and management. The other gap is the reliability of these models and the how to verify the findings of the model. The opportunity exists for the creation of an international database for data on agricultural land use in which to create classifications and maps of agroecological management areas of the world. Other opportunities are to establish long-term agricultural studies in which to verify model predictions for the various management systems, soil and climatic conditions globally. Currently there are some long-term studies being conducted, however, they are still in their infancy stage (US DOE, 1999). The lack of consistent baseline establishment for sink activities remains a significant issue.

3. CH_4 and N_2O emissions from agricultural lands: there is a requirement for the existing data to be used to check and calibrate the process-based models that are being used. In many cases, the base biological and chemical processes at play in combinations of soils, climate and agricultural management are poorly understood. This leads to a lack of model or modelling ability that can estimate gas fluxes that will include parameters such as soils, cropping systems, climatic factors and fertilizer management practices. However, current field data collected for the estimation of gas fluxes have not been agreed upon by the scientific community. The opportunities for more research and gathering of data for various field collection methods for gas fluxes exist along with the creation of models that can allow for the input of more parameters (US DOE, 1999). The balance of all three greenhouse gases and tradeoffs in emissions for each management practice needs to be assessed (i.e. it takes one unit of nitrogen to sequester 10 units of carbon, so what is the balance between C sequestration and N_2O emissions?).

The challenges and gaps of calculated emissions for nitrous oxide and methane lie within the limitations of the data collected and being used (applicability due to temporal and spatial variability that exists on a worldwide basis, country-wide and locally). Limitations exist with the varying types of the models in the use of certain input parameters and a general consensus on the methodology of data collection and interpretation. However, the identification of these areas by the scientific community provides a stage for opportunities in the areas of research and development on equipment and methods of data collection. These opportunities can lead to the improvement of the current models used to create the emission estimate numbers.

4.2 Direct Measurements of Emissions of Nitrous Oxide and Methane from Livestock, Livestock Buildings, Manure Management and Land Application

From the literature reviewed, there is a limited amount of information for both nitrous oxide and methane emissions for direct measurements from livestock and livestock buildings. There appears to be no general consensus amongst the scientific community on the preferred methods for assessing the rates of emissions. Collection of direct measurements of methane and nitrous oxide is limited by the use of the technology (Agriculture and Agri-Food Canada, 2000).

Lague et al. (2002) note that variability exists within emissions data reported in the literature they reviewed. This gave a clear indication for a need to improve upon how to determine the relative contributions of the stages of livestock production and manure management with respect to the generation of GHG from the agricultural sector in Canada. Wagner-Riddle et al. (1999) point out that there exists a challenge in the understanding of the verification of values and the understanding of mitigation of emissions such as nitrous oxide in the field due to the temporal and spatial variability that exists in the soil, landscape, climate and land management practices. Currently there is a considerable error associated with the current estimates of GHG's associated with manure management (handling, storage and land application). The considerable error is due to the following: high efficiency of Canada's livestock production, difference in feed quality between various countries around the world; lack of baseline data on current use, handling, storage and land application facilities and associated equipment. The need of a credible database is important in helping target problematic areas of the livestock industry (Agriculture and Agri-Food Canada, 2000).

In general there appears to be a lack of understanding of the basic interactions of the carbon and nitrogen cycles and the complex relationships amongst soil, air, water, animals and plants. Improvements upon the knowledge of the interaction of these relationships could assist in the improvement of methodologies, technology and techniques being used in the buildings and field to improve on the gathering of data for all sources of direct emissions and improve upon our interpretations (Agriculture and Agri-Food Canada, 1999). Research on the use of a systems approach, analysing the balance of greenhouse gases and the impact of beneficial management practices on air, soil water and biodiversity in the entire animal-plant system is needed. For example, the practice of increasing digestibility of feedstocks to reduce methane production from enteric fermentation may increase C availability when manure is added to soils, resulting in increased N_2O production through denitrification.

4.3 Mitigation Techniques to Decrease Emissions of Nitrous Oxide and Methane

Grassland Management

Grasslands are considered to be an important carbon and methane sink. At present technology is available but the initial investments costs are high and the knowledge level of management skill of the producers needs to be improved (Agriculture and Agri-Food Canada, 2000).

Soil Management

Soil management practices have been understood, but the challenge is in understanding the effects and tradeoffs of nitrous oxide emissions. The present information is contrasting, but this is due to the lack of understanding of the processes involved in the production of nitrous oxide and also with availability and reliability of technology to measure emissions accurately (Agriculture and Agri-Food Canada 2000).

Soil Nutrient Management

The challenges of soil nutrient management begin with the understanding of the conditions that are ideal for nitrous oxide production and emissions from agricultural soils. Due to the spatial and temporal variability, one of the challenges is the ability to quantify nitrous oxide emissions. There are several models that are currently being used: DNDC (DeNitrification DeCompostion); CENTURY,Expert-N, and ECOSYS have been designed to look at the dynamics of nitrogen within Canadian soils. However, there is a need for more testing and validation before the data from these models can be accepted in the assessment of GHG emissions (Agriculture and Agri-Food Canada, 2000).

Livestock Feeding and Management

The major challenges that face livestock feeding and management are with the social issues such as housing and animal welfare. The use of any feeding management strategy for reducing GHG emissions will have a positive effect on GHG mitigation, social and environmental concerns. Other challenges involve the need to stay competitive such as: awareness by the industry of emerging issues; creation of a database that will accurately assess GHG emissions from livestock management system and the area in which it is based; and creation of incentives to promote existing technologies that will improve upon feed use for commercial readiness, such as the use of CH_4 inhibitors (ruminants) and diet formulation. There should also be a focus upon long-term issues: development of new technology such as biotechnology, improvement in the reproduction and genetic potential of animals, and improvement of plants for the purpose of feed (Agriculture and Agri-Food Canada, 2000).

Manure Management

The one significant challenge that has been observed by many scientists is the generation of considerable error in the current estimation practices of GHG emissions that are associated with manure storage, handling and land application. In Canada estimates are currently based on the IPCC (1996) guidelines that used little Canadian data. This results in large errors created for coefficients of methane and nitrous oxide emissions for manure management. One opportunity that can arise from this is the creation of a database that can identify or isolate a species or facility within the livestock sector and create coefficients specifically for those parameters.

Manure Application Practices

Current studies are being conducted with respect to the usage of different application practices of manure, such as broadcast or band spreading. A study conducted in 1999 by Ferm et al., found that when indirect emissions of nitrous oxide were included from NH_3 deposition outside the field it resulted in all manure application techniques (broadcast and band spreading) producing similar total N_2O emissions. However, Ferm et al. (1999), found that ammonia emissions were much lower when band spreading was used vs broadcasting. These researchers noted that the band spreading technique appears to result in decreased ammonia emissions, appearing to be the preferred method; however, this does warrant further investigation.

In conclusion the following challenges and gaps have been identified in all three areas discussed:

- Detailed database in which emission coefficients can reflect the true emission coefficients of a particular country.
- Lack of research in all areas of GHG emissions associated with the agricultural sector.
- Lack of research conducted on various measurement technologies, making it difficult to assess the relevance of values being reported.
- Need for testing of models that will incorporate more influential parameters such as climate, geography, soil type, etc.
- Creation of an international database in which data can be of general use.
- Research to create the knowledge base required to understand the basic processes and the complex biological relationships between soil, water, air and plants.

The AAFRD, Agriculture Air Issues Unit (in press) notes the following initiatives currently underway:

Current projects for livestock

More recent livestock and whole farm research studies are underway but are not finished projects. These research projects-in-progress in Alberta include:

1. Reduction of GHG Emissions in Swine by Diet Manipulation. This project entails changing swine diets to decrease GHG and odour emissions from manure. R.O. Ball and J.J. Leonard at the University of Alberta presently conduct the research study until 2003.
2. Conservation of Nitrogen During Composting. This project is to determine a clear mechanism of how nitrogen may be lost in composting procedures. Some of the objectives are formulating practical guidelines for the operation of composting facilities to maximize nitrogen retention, confirming proven methods for enhancing the value of animal manure so that it can be utilized in an environmentally and economically sustainable manner, and reducing manure odours attributable to ammonia volatilization. This study is in progress at the University of Alberta until 2004.
3. 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.

5 Beneficial Management Practices

The objective of beneficial management practices (BMPs) in the agricultural sector is to use management options that are environmentally sound, comply with existing regulations and are economically viable. For example, BMPs are used to reduce impacts from confined feeding operations (CFOs) upon resources such as the soil, air and water (Alberta Pork and AAFRD 2002, Alberta Cattle Feeders' Association and AAFRD 2002).

This section focuses on BMPs that relate to greenhouse gas emissions of methane and nitrous oxide. Many of the commonly accepted BMPs are as follows:

a. BMPs for reducing greenhouse gas emissions
b. BMPs for reducing nitrous oxide emissions
c. BMPs for reducing methane emissions

5.1 BMPs for Reducing Greenhouse Gas Emissions

Livestock operations (including housing, feedlots and buildings):

Approximately 40% of the agricultural GHG emissions in Canada are from livestock production sources, and a third of those are associated with manure management (Lague et al., 2002). The primary greenhouse gases that are produced from the livestock industry are methane (CH_4), which is created mostly from ruminant animals through enteric fermentation and a combination of both methane (CH_4) and nitrous oxide (N_2O) from manure (Agriculture and Agri-Food Canada, 1999. The breakdown of Alberta's emissions from livestock types, expressed as CO_2 equivalents, are shown in Figure 2.

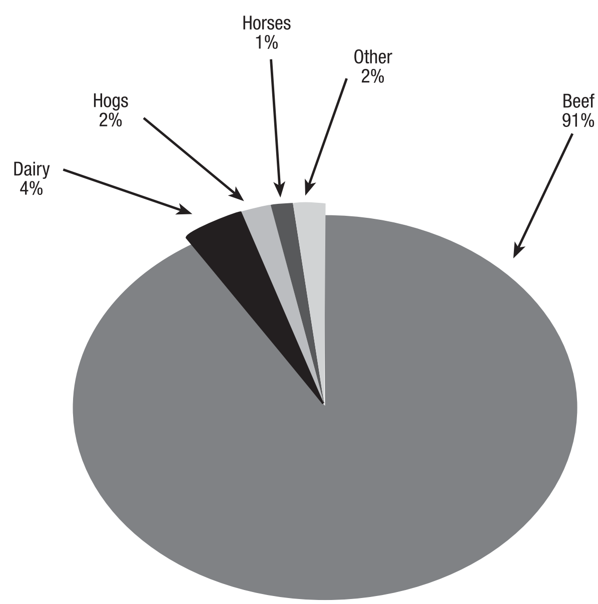

Figure 2. Alberta Livestock-Greenhouse Gas Emissions (CO_2 equivalents) Source: Basarab et al., 1999.

In Alberta the beef cattle industry contributes more than 90% of the greenhouse gases from the livestock sector. Methane is a by-product resulting from the animal's digestive process due to enteric fermentation. Cattle and other ruminant animals generate a lot of methane due to this digestive process. In every sector of the cattle industry the practice of efficiency and optimization in the use of resources will assist in the reduction of greenhouse gas emissions.

Some BMPs that can be applied to the cow calf sector of the beef cattle industry to reduce greenhouse gas emissions are (Okine and Basarab 2000; McNaughton 2001; Agriculture and Agri-Food Canada, 1998):

Improve upon grazing management practices:

To improve the ecosystem and increase yields, the usage of intensive grazing systems is the choice. However, the usage of intensive grazing systems requires a larger knowledge base and a longer period of time in which to implement management practices. There are two types of grazing systems:

Extensive: land base area may be large or small, animal stocking rate is low to allow animals to selectively graze over long periods of time with minimal stress on the forage stand. These areas have minimal cross-fencing and other developments on the land base.

Intensive: high management level is required, management practices determine where, when and what type of livestock will graze. Animals typically have higher stocking densities and shorter periods of time in each paddock. Pasture is divided into small units for grazing (using cross-fencing, electric fence, etc.) and livestock movements are based on rate of plant growth and forage availability.

Increasing calving percentage:

Increased calving percentage can be achieved by improving the efficiency per unit land area. This in turn will result in an increase in the amount of meat produced per acre. To achieve an increase in the amount of meat produced per acre, changes in management and feeding practices must be made. Management changes and changes to feeding practices can result in an increase of a calf crop to 88%. This results in more calves and fewer cows and possibly results in a one percent reduction in carbon dioxide equivalents in the livestock industry.

Cropping:

Due to the spatial variability of soil moisture, soil temperature, land management practices (such as surface residue, tillage, nutrient management, cropping systems, and slope aspect) and soil properties, it is a challenge to obtain accurate estimates of greenhouse gas emissions from cropping practices. However some general comments can be made:

- The major greenhouse gases emitted from cropping are nitrous oxide due to the use of fertilizer application and carbon dioxide c reated from the associated machinery.
- The most important component in the minimization of greenhouse gas emissions on croplands is to ensure a sufficient buildup of organic carbon within the soil. Sufficient levels of organic carbon within the soil will result in: increased soil fertility, consistent crop yields, soil resistance to severe and unseasonable weather events, decreased soil erosion, and increased soil tilth resulting in easier land management.

Carbon sinks are another important factor in minimising greenhouse gas emissions. Improving carbon storage can be achieved by implementing the following BMPs (McNaughton 2001; Agriculture and Agri-Food Canada 1998):

- Usage of reduced or zero tillage and the elimination of summer fallow.
- Nutrient management of the soil to ensure a proper match between crop needs and fertilizer application.
- Proper timing of fertilizer application.
- Proper method of fertilizer application.

Agroforestry:

Agroforestry is the incorporation of tree crops with agricultural crops or with domestic livestock. It includes woodlot management, shelterbelts, afforestation (planting of trees on open land) and pasturing on forested land (silvipasture). Some of the benefits of agroforestry include: moderation of rainfall intensity for improved absorption of water, decrease of wind and water movement which reduces soil erosion, absorption of potential toxins from the atmosphere, habitat for wildlife, and improved aesthetic value of the area. Trees also serve as a sink for the absorption of greenhouse gas emissions that a farm operation may create (McNaughton 2001).

5.2 BMPs for Reducing Nitrous Oxide Emissions

Reduce/eliminate cultivation on pasture and all other lands:

Cultivation of pasture or any land results in soil carbon loss. Perennial pastures have more root material than annual pastures, resulting in more carbon storage, and they are a better choice for pasture maintenance. Where pastures with annual crops require cultivation, pasture mixes of grasses and legumes are ideal for the creation of a balanced system. A pasture of legumes may result in the creation of excess nitrogen that, under favourable conditions can lead to nitrous oxide emissions (McNaughton 2001; Agriculture and Agri-Food Canada 1998).

Manure storage and handling:

Manure can be viewed as a valuable resource when it is applied properly to the soil to improve upon the soil conditions such as the soil tilth, structure, aeration and the water holding capacity. These improvements to the soil can then result in additional benefits such as increased crop yields. Manure consists mostly of carbon and nitrogen; when it decomposes, carbon dioxide, nitrous oxide and methane are emitted. The following strategies are commonly accepted ways of reducing GHG emissions (McNaughton 2001; Agriculture and Agri-Food Canada 1998).

Manure from grazing animals:

Manure from grazing animals can create nitrous oxide emissions from the dung and urine. One of the best methods to manage and decrease nitrous oxide emissions from grazing animals is to allocate proper grazing densities for the type of management you want to achieve. This will ensure that the manure is more evenly spread over the land base (McNaughton 2001; Agriculture and Agri-Food Canada 1998).

Manure management during winter feeding:

Manure management during the winter can be achieved by using a larger feeding area. This will ensure that the manure is not concentrated in a particular area allowing it to properly decompose and for the soil to incorporate the corresponding nutrients from it.

- Increasing the number of grazing animals and grazing into the late fall/winter and in the early spring will ensure that the manure will be spread over the field. Another method of grazing called swath grazing could be used. This practice spreads manure around the field and will decrease your feeding costs (McNaughton 2001; Agriculture and Agri-Food Canada 1998).
- The moving of bedding on a regular and frequent basis will spread the manure around the pasture.
- Feeding of animals on a level ground or areas with gentle slopes will prevent and minimize runoff and loss of nitrogen resulting in decreased production of nitrous oxide emissions.

Managing stored manure from feedlots and other manure concentrated areas:

BMPs for minimizing greenhouse gas emissions of stored manure are:

- Large quantities of stored manure can be composted which results in the creation of a more stable product. Composting if done correctly can reduce the volume of material, minimize odour, kill pathogens during the composting process, decrease weed potential and assist in the minimizing of flies. Compost can be viewed as a value added product that can generate extra revenue. Compost can also be used as a soil amendment adding nutrients into the soil.
- Composting of livestock manure can reduce greenhouse gas emissions since conventional stock piling of manure results in anaerobic decomposition and high emissions of methane. However, it can lead to increased nitrous oxide emissions – user beware.
- If raw manure is going to be spread, several factors must be considered before spreading. First, the manure and the soil should be analysed prior to application to assist in proper nutrient management, otherwise an over-application can

result in leaching into groundwater sources, unnecessary volatilization into the atmosphere causing preventable emissions and a waste of resources. Secondly, if there is to be an application in the spring, use of liquid manure is preferred along with cool conditions with no rain for 24 hours. Summer application should incorporate the use of solid manure so that it can be applied to fallowed fields and forages. In the case of forages, solid manure should be applied when rain is forecasted. Application of manure during hot and windy conditions will result in volatilization of nitrogen to the atmosphere and a waste of resources.

- In land base areas of zero-tillage or forage stands, manure should be applied by injection or incorporated immediately into the soil. No incorporation into the soil will result in nitrogen losses in the form of ammonia, which can be about 20% per day, and range from 50 to 80% per week.
- The spreading of manure onto frozen ground is not an encouraged practice. Since the manure cannot be incorporated, nitrogen losses to the atmosphere occur and the possibility of contamination to surrounding water bodies and courses during spring runoff exists.
- If swine manure is to be used as a fertilizer in pastures, broadcast application should allow for a time frame of 30 days for plant uptake and for pathogens to be killed free from grazing animals.

5.3 BMPs for Reducing Methane Emissions

Use of higher quality feeds and rations that are balanced for minerals, proteins and vitamins.

The higher quality feeds with balanced rations result in a lower production of methane and a greater feed efficiency. If straw is used as a portion of the feed, decreasing the size of the straw by chopping or grinding will make it easier to digest which can assist in better efficiency. On pastures, a high rate of grain or a higher production per cow will result in the lower production of methane per acre per unit of production.

Wintering backgrounders:

Some of the management practices that can be used are:

- Use of higher quality feeds with beef cows results in backgrounders producing less methane than the use of lower quality feeds. The higher quality feeds generally result in more efficient growth of the animal. The more balanced the diet with a higher quality of feed, the quicker it will be digested in the rumen of the animal resulting in less time for methane to be produced.
- If the use of higher quality feeds is not an option, then the chopping, grinding or pelleting of lower quality feed can reduce methane production and increase digestibility by the animal.
- Feeding ionophores (monensin, laslocid, tetranasin, and lysocellin) results in short-term reductions of methane emissions and increases the feed efficiency by 5 to 8%, depending upon the quality of the diet. The rotational use of different types of ionophores will decrease the chances of the bacteria becoming resistant and ensuring that optimal benefits from the use of ionophores are achieved.
- Selection of ruminant animals for feed use efficiency can result in significant reductions in methane emissions. Selection based on phenotypes could reduce methane emissions by 11 to 12%. Research is ongoing to determine how to select more feed efficient cattle (Basarab Personal Communication, 2003).
- In feedlots the usage of the same management strategies for backgrounder animals can be used. It is noted that feedlot animals produce less methane than beef cows due to their higher energy diets, higher quality of feed and the possible use of ionophores.

In order for any beneficial management practices to become effective in the decrease of greenhouse gas emissions, all stages of agricultural operations must be taken into consideration whether they are a direct or indirect result of agriculture or agricultural activities.

6 Resources and References

1. AAFRD, Alberta Agriculture, Food and Rural Development. 2001. *A Workbook on Greenhouse Gas Mitigation for Agricultural Managers, Version 1, April 2001.*

2. AAFRD, Alberta Agriculture, Food and Rural Development, Agriculture Air Issues Unit, Conservation and Development. In press. *State of Knowledge of Agricultural Greenhouse Gases in Alberta Towards a Systems Approach.*

3. AAFRD, Alberta Agriculture, Food and Rural Development Greenhouse Gas Team. 1999. Agriculture and Agri-Food Industry Greenhouse Gas Emissions In Alberta Summary *Statement-AAFRD Greenhouse Gas Team – May 7,1999.*

4. AEA Technology Environment. 1998. *Options to Reduce Methane Emissions (Final Report)*, A Report Produced for DGXI, Restricted-Commercial, AEAT-3773: Issue 3.

5. Agriculture and Agri-Food Canada.1998. *Health of Our Air*. Research Branch, Agriculture and Agri-Foods Canada, Sir John Carling Building, Room 777, Ottawa, Ontario.

6. Agriculture and Agri-Food Canada, Climate Change Table. 2000. *Options Report, Reducing Greenhouse Gas Emissions from Canadian Agriculture, January 2000*. Research Branch, Agriculture and Agri-Foods Canada, Sir John Carling Building, Room 777, Ottawa, Ontario.

7. Alberta Cattle Feeders' Association and AAFRD (Alberta Agriculture, Food and Rural Development). 2002. *Beneficial Management Practices-Environmental Manual for Feedlot Producers in Alberta*. Queens Printer, Edmonton, Alberta, Canada. http://www.agric.gov.ab.ca

8. Al-Masri, M.R. 2000. *Short Communication: Changes in biogas production due to different Ratios of some animal and agricultural wastes.* Bioresource Technology, **77**: 97-100.

9. Alberta Pork and AAFRD (Alberta Agriculture, Food and Rural Development). 2002. *Beneficial Management Practices-Environmental Manual for Hog Producers in Alberta*. Queens Printer, Edmonton, Alberta, Canada.

10. Australian Greenhouse Office. 1998. *Agriculture: Workbook for Livestock*. National Greenhouse Gas Inventory Committee, Workbook 6.1 with Supplements.

11. Ball, T. 2003. *The Lack of Science in Kyoto: A Solution for a Non-existent Problem*. Advances in Pork Production (2003) Vol (**14**) 1-12.

12. Ball, R.O. and S. Mohn. 2003. *Feeding Strategies to Reduce Greenhouse Gas Emissions from Pigs.* Advances in Pork Production (2003) Vol (**14**): 301-311.

13. Basarab, J.A.. Personal Communication, February 5, 2003.

14. Basarab, J.A., Okine, E.K., and Engstrom, D. 1999. GHG Emissions from Livsetock in Alberta: Past, Present and Future. Western Forage Group, Alberta Agriculture, Food and Rural Development, Lacombe Research Centre, Lacombe, AB.

15. Beline, F., J. Martinez, D. Chadwick, F. Guiziou and C.M. Coste. 1999. *Factors affecting nitrogen transformations and related nitrous oxide emissions from aerobically treated piggery slurry.* J. Agric. Engng Res., **73**: 235-243.

16. Cammell, S.B., D.J. Thomson, D.E. Beever, M.J. Haines, M.S. Dhanoa and M.C. Spooner. 1986. *The efficiency of energy utilization in growing cattle consuming fresh perrenial ryegrass (Lolim perenne cv. Melle) or white clover (Trifolium repens cv. Blanca)*. British Journal of Nutrition, **55**: 669-680.

17. Chadwick, D.R. and B.F. Pain. 1997. *Methane fluxes following slurry applications to grassland soils: laboratory experiments.* Agriculture, Ecosystems and Environment, **63**: 51-60.

18. Chang, C., C.M. Cho and H.H. Janzen. 1998. *Nitrous oxide emission from long-term manured soils.* Soil Science Society of America Journal, **62-3**: 677-682.

19. Chang, C. Personal Communication, Janurary 2003.

20. Chetner, S., A. Arendt, and G. Hoskinson. 2000. Annotated Literature Review of Greenhouse Gas Emissions from Composted Agricultural Products, July 19, 2000. Developed for the Alberta Environmentally Sustainable Agriculture (AESA) Council.

21. Cooper, J.M. and P.R. Warman. 1997. *Short Communication: Effects of three fertility amendments on soil dehydrogenase activity, organic C and pH.* Canadian Journal of Soil Science, **77**(**2**): 285-294.

22. Coyne, M.S., R.A. Gilfillen and R.L. Blevins. 1994. *Atmospheric Pollutants and Trace Gases: Nitrous oxide flux from poultry-manured erosion plots and grass filters after simulated rain.* J. Environ. Qual, **23**: 831-834.

23. Crutzen, P.J., I. Aselmann and W. Seiler. 1986. *Methane production by domestic animals,wild ruminants, other herbivorous fauna, and humans.* Tellus, **38B**: 271-284.

24. Desjardins, R.L. and J.C. Keng. 1999. *Nitrous Oxide Emissions from Agricultural Sources In Canada.* Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems, March 3-5, 1999, Banff, Alberta, Canada. Agriculture and Agric-Food Canada, Research Branch, Alberta Agriculture, Food and Rural Development, Conservation and Development Branch.

25. Dugba, P.N. and R. Zhang. 1999. *Treatment of dairy wastewater with two-stage anaerobic Sequencing batch reactor systems-thermophillic versus mesophillic operations.* Bioresource Technology, **68**: 225-233.

26. Environment Canada. 2001. *Canada's Greenhouse Gas Inventory 1990-1999, Emissions and Removal Estimation Practices and Methods, April 2001.* http://www.ec.gc.ca/climate/resources_reports-e.html

27. Environment Canada, Greenhouse Gas Division. 2002. *Canada's Greenhouse Gas Inventory, 1990-2000, Canada-Final Submission, June 2002.* http://www.ec.gc.ca/climate/resources_reports-e.html

28. Ferm, M, A. Kasimir-Klemdtsson, P. Weslien and L. Klemedtsson. 1999. *Emission of* NH_3 *and* N_2O *after spreading of pig slurry by broadcasting or band spreading.* Soil and Use Management, **15**:27-33.

29. Fleischner, T.L. 1994. *Ecological Costs of Livestock Grazing in Western North America.* Conservation Biology, **8**(**3**): 629-644.

30. Gavala, H.N., H. Kopsinis, I.V. Skiadas, K. Stamatelatou and G. Lyberatos. 1998. *Treatment of Dairy Wastewater Using and Upflow Anaerobic Sludge Blanket Reactor.* Journal of Agricultural Engineering Research, **73**: 59-63.

31. Goldstein, Jerome. 2000. *Anaerobic Digestion Advances.* Biocycle: 30-32.

32. Gonzalez, E. and L.G. Ruiz-Suarez. 1995. Methane Emissions from Cattle in Mexico: Methodology and Mitigation Issues. Interciencia, **20**(**6**): 370-372.

33. Hao, X., C. Chang, F.J. Larney, and G.R. Travis.2001. Greenhouse Gas Emissions During Cattle Feedlot Manure Composting. Journal of Environmental Quality, **30**:376-386.

34. Hegarty, R. 2001. *Greenhouse Gas Emissions from the Australian Livestock Sector.* Australian Greenhouse Office, The Lead Commonwealth Agency on Greenhouse Gas Matters, 2001. http://www.greehouse.gov.au/land/agriculture/pubs/livestock/chatpters3_8.htm

35. Henson, J. Michael, P.H. Smith, and D.C. White. 1985. *Examination of Thermophillic Methane-Producing Digesters by Analysis of Bacterial Lipids.* Applied and Environmental Microbiology, **50(6)**: 1428-1433.

36. Herd, R.M., P.F. Arthur, R.S. Hegarty and J.A. Archer. *Potential to Reduce Greenhouse Gas Emissions from Beef Production by Selection for Reduced Residual Feed Intake.* Paper from: NSW Agriculture, Beef Industry Centre, University of New England, Armidale, NSW 2351, NSW Agriculture, Agricultural Research Centre, Trangie, NSW 2823, Australia.

37. Hilhorst, M.A., H.C. Willers, C.M. Groenestein and G.J. Monteny. 2001. *Effective Strategies to Reduce Methane Emissions from Livestock.* Paper from an ASAE Meeting (Society for engineering in agricultural, food, and biological systems), **Paper Number: 01-4070**.

38. Hill, D.T. and J.P. Bolte. 1992. *Bio-retentive properties of synthetic media for anaerobic digestion of animal waste.* American Society of Agricultural Engineers, **35(2)**: 711-715.

39. Hironaka, R., G.W. Mathison, B.K. Kerrigan and I. Vlach. 1996. The effect of pelleting of alfalfa hay on methane production and digestibility by steers. The Science of the Total Environment, **180**: 221-227.

40. Hornig, G., W. Berg and M. Turk. 1997. *Harmful Gas and Odor Emissions Under Use of Feed and Slurry Additives.* Livestock Environment V, Volume I, Proceedings of The Fifth International Symposium. Hotel Sofitel Minneapolis, Bloomington, Minnesota, May 29-31, 1997. American Society of Agricultural Engineers.

41. Howden, S. M. and P.J. Reyenga. 1999. *Methane emissions from Australian livestock: implications of the Kyoto Protocol.* Australian Journal of Agricultural Research, **50**: 1285-1291.

42. Howden, S.M., D.H. White and P.J. Bowman. 1996. *Managing sheep grazing systems i*n *southern Australia to minimise greenhouse gas emissions: adaptation of an existing simulation model.* Ecological Modelling, **86**: 201-206.

43. Huque, K.S. and S.A. Chowdhury. 1996. *Study on Supplementing Effects or Feeding Systems of Molasses and Urea on Methane and Microbial Nitrogen Production In the Rumen and Growth Performances of Bulls Fed a Straw Diet.* AJAS, **10(1)**: 35-46.

44. Immig, I. 1996. *The Rumen and Hindgut as a Source of Ruminant Methanogenesis.* Environmental Monitoring and Assessment, **42**: 57-72.

45. IPCC (Intergovernmental Panel on Climate Change). 1996. *IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual.* http://www.ipcc.ch (December. 2002).

46. IPCC (Intergovernmental Panel on Climate Change). 2002. Website Guideline page. http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

47. Itodo, I.N. and J.O. Awulu. 1999. *Technical Notes: Effects of Total Solids Concentrations of Poultry, Cattle and Piggery Waste Slurries on Biogas Yield.* American Society of Agricultural Engineers, **42(6)**: 1853-1855.

48. Jarvis, S.C. and B.F. Pain. 1994. *Greenhouse Gas Emissions from Intensive Livestock Systems: Their Estimation and Technologies for Reduction.* Climatic Change, **27**: 27-38.

49. Johnson, D.E., G.M. Ward and G. Bernal. 1997. *Biotechnology Mitigating the Environmental Effects of Dairying: Greenhouse Gas Emissions.* Milk composition, Production and Biotechnology, CAB International, 1997. 497-510.

50. Johnson, K., M. Huyler, H. Westberg, B. Lamb and P. Zimmerman. 1994. *Communications: Measurement of Methane Emissions from Ruminant Livestock Using a* SF_6 *Tracer Technique.* Environ. Sci. Technol., **28**: 359-362.

51. Jouany, J.P. 1994. *Methods of Manipulating the Microbial Metabolism in the Rumen.* Ann Zootech, **43**: 49-62.

52. Kaharabata, S.K. and P.H. Schuepp. 2000. *Estimating Methane Emissions from Dairy CattleHoused in Barn and Feedlot Using an Atmospheric Tracer*. Environmental Science and Technology, **34**: 3296-3302.

53. Kaharabata, S.K. and P.H. Schuepp. 1998. *Methane emissions from aboveground open Manure slurry tanks.* Global Biogeochemical Cycles, **12**(**3**): 545-554.

54. Kennelly, J.J., L. Doepel and K.Lien. No Date. Ionophores-Mode of Action and Effects on Milk Yield and Milk Composition. Paper from: Department of Agriculture, Food and Nutritional Science, University of Alberta, Edmonton, AB, Canada.

55. Kowalenko, G. 1999. *Assessing Nitrous Oxide Emissions from Farming Practices.* Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems, March 3-5, 1999, Banff, Alberta, Canada. Agriculture and Agric-Food Canada, Research Branch, Alberta Agriculture, Food and Rural Development, Conservation and Development Branch.

56. Kumar, R., M.K. Gupta and S.S. Kanwar. 1999. *Fate of bacterial pathogens in cattle dung Slurry subjected to anaerobic digestion.* World Journal of Microbiology & Biotechnology, **15**: 335-338.

57. Kuroda, Kazutaka, T. Osada, M. Yonaga, A. Kanematu, T. Nitta, S. Mouri and T. Kojima. 1996. *Emissions from malodorous compounds and greenhouse gases from composting swine feces.* Bioresource Technology, **56**: 265-271.

58. Lague, C. 2002. *Management Practices to Reduce Greenhouse Gas Emissions from Swine Production Systems.* Advances in Pork Production (2003), Vol (**14**): 287-299.

59. Lague, C., S.P. Lemay, T.A. Fonstad, L. Chenard, E. Gaudet and R. Fengler. 2002. *Greenhouse Gas and Odour Emissions from Pig Production Buildings, and Manure Storage Facilities: Methodology and Preliminary Results.* AIC 2002 Meeting, CSAE/SCGR Program, **Paper No. 02-604.**

60. Lassey, K.R., M.J. Ulyatt, R.J. Martin, C.F. Walker and I.D. Shelton. 1997. *Methane Emissions measured directly from grazing livestock in New Zealand.* Atmospheric Environment, **30**(**18**): 2905-2914.

61. Lemke, R., H.H. Janzen and P. Rochette. 1999. *Processes of Nitrous Oxide Emissions from Canadian Agroecosystems.* Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems, March 3-5, 1999, Banff, Alberta, Canada. Agriculture and Agric-Food Canada, Research Branch, Alberta Agriculture, Food and Rural Development, Conservation and Development Branch.

62. Lemke, R.L., Lafond, G., Brandt, S., Malhi, S.S. and R. Farrell. 2003. Nitrogen fertilizers and N_2O Emissions. In: Twentieth Proceedings of the ManDak Zero Tillage Society Meetings. Published by the Manitoba-North Dakota Zero Tillage Farmer's Association, Box 40. Isabella, MB R0M 0Y0.

63. Lessard, R., P. Rochette, E.G. Gregorich, R.L. Desjardins and E. Pattey. 1997. *CH_4 fluxfrom a soil amended with dairy cattle manure and ammonia nitrate.* Canadian Journal of Soil Science, **77**(**2**): 179-186.

64. Liao, Chung-Min and Dwaine S. Bundy. 1994. *Bacteria additives to the changes in gaseousmass transfer from stored swine manure.* J. Environ. Sci. Health, **B29**(**6**): 1219-1249.

65. Lockyer, D.R. 1997. *Methane emissions from grazing sheep and calves.* Agriculture, Ecosystems and Environment, **66**: 11-18.

66. Marantz, D, C. Kohut and L. Haderlein. 1999. *Controlled Release Fertilizers and NitrousOxide Emissions.* Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems, March 3-5, 1999, Banff, Alberta, Canada. Agriculture and Agric-Food Canada, Research Branch, Alberta Agriculture, Food and Rural Development, Conservation and Development Branch.

67. Mathison, G.W. and D.F. Engstrom. 1995. *Ad libitum versus restricted feeding of barley and corn-based feedlot diets*. Canadian Journal of Animal Science, 637-340.

68. Mathison, G.W., E.K. Okine, T.A. McAllister, Y. Dong, J. Galbraith and O.I.N. Dmytruk. 1998. Reducing Methane Emissions from Ruminant Animals. J. Appl. Anim. Res. **14**: 1-28.

69. Mathison, G.W., R. Soofi-Siawash and M. Worsley. 1994. *The Potential of isobutyraldehyde monourea (propanal, 2-methyl-monourea) as a nonprotein nitrogen source for ruminant animals*. Canadian Journal of Animal Science, 665-674.

70. McAllister, T.A., E.K. Okine, G.W. Mathison and K.J. Cheng. 1996. *Dietary, environmentaland microbiological aspects of methane production in ruminants*. Canadian Journal of Animal Science, 231-243.

71. McCaughey, W.P., K. Wittenberg and D. Corrigan. 1999. *Impact of pasture type on methane production by lactating beef cows*. Canadian Journal of Animal Science, 221-226.

72. McCaughey, W.P., K. Wittenberg and D. Corrigan. 1997. *Methane production by steers on pasture*. Canadian Journal of Animal Science, 519-524.

73. McCrabb, G.J., K.T. Berger, T. Magner, C. May and R.A. Hunter. 1997. *Inhibiting Methane production in Brahman cattle by dietary supplementation with a novel compound and the effects on growth*. Aust. J. Agric. Res., **48**: 323-329.

74. McNaughton, N. 2001. Alberta Agriculture, Food and Rural Development, *A Workbook on Greenhouse Gas Mitigation for Agricultural Managers, Version 1, April 2001*.

75. Minami, K. and K. Takata. 1997. *Atmospheric Methane: Sources, Sinks, and Stategies ForReducing Agricultural Emissions*. Wat. Sci. Tech., **36**(**6-7**): 509-516.

76. Mladenovska, Z. and B.K. Ahring. 2000. *Growth kinetics of thermophillic Methanosarcina spp. isolated from full-scale biogas plants treating animal manures*. FFMS Microbiology Ecology, **31**: 225-229.

77. Mosier, A. and C. Kroeze. 1999. *Contribution of Agroecosystems to the GlobalAtmospheric N_2O Budget*. Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems, March 3-5, 1999, Banff, Alberta, Canada. Agriculture and Agric-Food Canada, Research Branch, Alberta Agriculture, Food and Rural Development, Conservation and Development Branch.

78. Montgomery, C.W. 1997. *Environmental Geology*, Fifth Edition. WCB/McGraw-Hill, Boston, Massachusetts, USA: 211-216.

79. Moss, A.R., J.P. Jouany and J. Newbold. 2000. *Methane production by ruminants: its contribution to global warming*. Ann. Zootech., **49**: 231-253.

80. Moser, M.A., R.P. Mattocks, Dr. Stacy Gettier and K. Roos. 1998. *Benefits, Costs and Operating Experience at Seven New Agricultural Anaerobic Digesters*. Paper presented at: BioEnergy '98, Expanding Bioenergy Partnerships, Madison, Wisconsin, October 4-8, 1998.

81. National Academy of Sciences and U.S. Environmental Protection Agency. 2002. Interim Report: The Scientific Basis for Estimating Emissions from Animal Feeding Operations. National Academy Press, Washington, D.C. http://www.nap.edu

82. Oenema, O. 1999. *Strategies for Decreasing Nitrous Oxide Emissions from Agricultural Sources*. Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems, March 3-5, 1999, Banff, Alberta, Canada. Agriculture and Agric-Food Canada, Research Branch, Alberta Agriculture, Food and Rural Development, Conservation and Development Branch.

83. Okine, E.K. and J.A. Basarab. No date given. *Strategies for Reducing Methane Emissionsfrom Ruminants*. Western Forage Group, Alberta Agriculture, Food and Rural Development, Lacombe Research Centre, Lacombe, AB.

84. Okine, E.K.,J.A. Basarab, V. Baron and M.A Price. 2000. *Net Feed Efficiency in Young Growing cattle: III. Relationship to methane and manure production*. Western Forage Beef Group, Alberta Agriculture, Food and Rural Development, Fact Sheet.

85. Ong, H.K., P.C. Pullammanappallil and P.F. Greenfield. 2000. *Physical, Chemical and Biomethanation Characteristics of Stratified Cattle-Manure Slurry.* Paper from: Advanced Wastewater Management Centre, Department of Chemical Engineering, The University of Queensland, Brisbane, St. Lucia, QLD 4072, Australia.

86. Paul, J. 1999. *Nitrous Oxide Emissions Resulting from Animal Manure Management.* Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems, March 3-5, 1999, Banff, Alberta, Canada. Agriculture and Agric-Food Canada, Research Branch, Alberta Agriculture, Food And Rural Development, Conservation and Development Branch.

87. Paul, J.W., Wagner-Riddle, C., Thompson, A., R. Fleming and M. MacAlpine. 2001. *Composting as a Strategy to Reduce Greenhouse Gas Emissions.* Conference Proceedings, Climate Change 2: Canadian Technology Development Conference, October 3-5, 2001, Toronto, Ontario, Canada. Canadian Nuclear Society.

88. Paul, E.A. and F.E. Clark. 1996. *Soil Microbiology and Biochemistry*, 2nd Edition. Academic Press, Inc. 525 B Street, Suite 1900, San Diego, California 92101-4495, USA.

89. Riddle-Wagner, C. and D. Burton. 1999. *Measuring Nitrous Oxide Emissions in the Field.* Proceedings of the International Workshop on Reducing Nitrous Oxide Emissions from Agroecosystems, March 3-5, 1999, Banff, Alberta, Canada. Agriculture and Agric-Food Canada, Research Branch, Alberta Agriculture, Food and Rural Development, Conservation and Development Branch.

90. Riddle-Wagner, C., G.W. Thurtell, G.K. Kidd, E.G. Beauchamp and R. Sweetman. 1997. *Estimates of nitrous oxide emissions from agricultural fields over 28 months.* Canadian Journal of Soil Science, **77**: 135-144.

91. Rochette, P. and D. Cote. 1999. *CH_4 fluxes and soil CH_4 concentration following Application of pig slurry for the 19th consecutive year.* Canadian Journal of Soil Science, **80**(**2**): 387-390.

92. Ruiz-Suarez, L.G. and E. Gonzalez-Avalos. 1997. *Modeling Methane emissions from cattle in Mexico.* The Science of the Total Environment, **206**: 177-186.

93. Ruz-Jerez, B.E., R.E. White and P.R. Ball. 1994. *Long-term Measurement of denitrification in three contrasting pastures grazed by sheep.* Soil. Biol. Biochem., **26**(**1**): 29-39.

94. Shibata, M, F. Terada, M. Kurihara, T. Nashida and K. Iwasaki. 1992. *Estimation of Methane Production in Ruminants.* Anim. Sci. Technol. (Jpn), **64**(**8**): 790-796.

95. Sneath, R.W., Phillips, V.R., Demmers, T.G.M., Burgess, L.R., J.L. Short and S.K. Welch. 1997. *Long-Term Measurements of Greenhouse Gas Emissions from UK Livestock Buildings.* Livestock Environment V, Volume I. Proceedings of the Fifth International Symposium, Hotel Sofitel Minneapolis, Bloomington, Minnesota, May 29-31,1997. Society of Agricultural Engineers.

96. Sommer, S.G., R.R. Sherlock and R.Z. Khan. 1996. *Short Communication: Nitrous oxide and methane emissions from pig slurry and amended soils.* Soil. Biol. Biochem., **28**(**10/11**): 1541-1544.

97. Sterling Jr, M.C., R.E. Lacey, C.R. Engler and S.C. Ricke. 2000. *Effects of ammonia nitrogen on* H_2 *and* CH_4 *production during anaerobic digestion of dairy cattle manure.* Bioresource Technology, **77**: 9-18.

98. Suleiman, A., E.K. Okine, L.A. Goonewardene, P. A. Day, B. Yaremcio and G. Recinos-Diaz. 1999. Yield and Feeding of Prairie Grasses in east-central Alberta. J. Range Manage., **52**:75-82.

99. Tisdale, S.L., J.L. Havlin, J.D. Beaton and W.L. Nelson. 1999. *Soil Fertility and Fertilizers*: *An introduction to nutrient management*/ Samuel L. Tisdale, et al., 6th edition. Prentice-Hall, Inc. Simon & Schuster/ A Viacom Company, Upper Saddle River, New Jersey, USA.

100. Tiquia, S.M., T.L. Richard and M.S. Honeyman. 2002. *Carbon, nutrient, and mass loss during composting.* Nutrient Cycling in Agroecosystems, **62**:15-24.

101. Thompson, A.G., C. Wagner-Riddle, R. Fleming and M. MacAlpine. 2000. *Emissions of nitrous oxide and methane from composting liquid swine manure.* Research paper from the Land Resource Science, University of Guelph, Ridgetown College of Agricultural Technology, University of Guelph, Ontario, Canada.

102. US DOE, U.S. Department of Energy. 1999. Emissions and Reduction of Greenhouse Gases from Agriculture and Food Manufacturing, A Summary White Paper, December 1999. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of Industrial Technologies.

103. US EPA, U.S. Environmental Protection Agency, Office of Air and Radiation and Office of Air Quality Planning and Standards.1985. Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources. Research Triangle Park, North Carolina, USA. Report AP-42, Fourth Edition, September 1985.

104. Whitelaw, F.G., J.M. Eadie, L.A. Bruce and W.J. Shand. 1984. *Methane formation in faunated and ciliate-free cattle and its relationship with rumen volatile fatty acid proportions*. British Journal of Nutrition, 52: 261-275.

105. Xu, C., M.J. Schaffer and M. Al-kaisi. 1998. *Simulating the Impact of Management Practices on Nitrous Oxide Emissions.* Soil Sci. Soc. Am. J., **62**: 736-742.

106. Yamulki, S., S.C. Jarvis and P. Owen. 1998. *Nitrous oxide emissions from excreta applied in simulated grazing pattern.* Soil Biol. Biochem., **30**(**4**): 431-500.

107. Yang, P.Y. and Z. Wang. 1999. *Integrating an intermittent aerator in swine wastewater treatment system for land-limited conditions.* Bioresource Technology, **69**: 191-198.