GREENHOUSE GAS EMISSIONS
FROM CANADIAN AGRICULTURE
NARROWING THE KNOWLEDGE GAPS

FINAL PROGRAM AND RESEARCH REPORT

for the

CLIMATE CHANGE FUNDING INITIATIVE IN AGRICULTURE
(CCFIA)

April 2005
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APRIL 2005
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PREFACE

In February 2000 the Canadian Agri-Food Research Council (CARC) accepted an invitation from Agriculture and Agri-Food Canada to deliver the Climate Change Funding Initiative in Agriculture (CCFIA). At that time, climate change research was still a relatively new area, particularly for agriculture. In the four years since, research activities in all areas have grown exponentially, with added urgency given as a result of Canada’s commitment to the Kyoto Protocol to the United Nations Framework Convention on Climate Change.

Through its Canadian Adaptation and Rural Development (CARD) II program, Agriculture and Agri-Food Canada provided funding of $4 million over four years to CARC for the CCFIA. The funding was used to support development of human resources, for research projects, and for communications activities. CARC’s Canada Committees initiated activities to coordinate climate change activities in Canadian agriculture, including the development of three major position papers, as well as a process to identify research and development needs that are not being currently addressed or that require increased attention.

The dedication of researchers, the agriculture industry, and federal and provincial governments to contribute to reduction of agricultural greenhouse gas emissions is notable. We believe the CCFIA program was instrumental in developing and promoting this interest and collaboration.

CARC is grateful to Les Haley, Chair of the CCFIA Committee, for his leadership, and to the members of the Committee for providing their considerable expertise to the program for the past five years. We were fortunate to have such an exceptional team working with us.

We deeply appreciate the participation in the CCFIA program of Agriculture and Agri-Food Canada scientists throughout Canada who contributed to many of the research projects, made presentations at the CCFIA workshops, and prepared the summary reports by research area on progress and knowledge gaps for this report.

The individual research project summaries in this report were prepared by four graduate students from the Nova Scotia Agricultural College: Vimy Glass, Rob Michitsch, Manasah Mkhabela and Erin Smith. Our sincere thanks to them, and to their supervisory team of Robert Gordon and David Burton of the NSAC.

John Vanderstoep
Chairman
Canadian Agri-Food Research Council
PROGRAM OVERVIEW

INTRODUCTION

The Climate Change Funding Initiative in Agriculture (CCFIA) was announced by the Minister of Agriculture and Agri-Food Canada in February 2000 in response to recommendations contained in the Agriculture and Agri-Food Climate Change Table options report, *Reducing Greenhouse Gas Emissions from Canadian Agriculture*.

The Climate Change Table found there were many knowledge gaps in the measurement and understanding of agricultural Greenhouse Gas emissions. The Table identified the need for basic research activities for net Greenhouse Gas reduction in the areas of crop nutrient management, livestock nutrient management, manure management, carbon sequestration and biofuels, and a need for refinement of national inventory, measurement and verification systems for net Greenhouse Gas emission and to reflect improvements in technology.

The Canadian Agri-Food Research Council (CARC) was responsible for delivering the CCFIA program. The AAFC Canadian Adaption and Rural Development (CARD) II Fund provided $4 million over four years for the CCFIA program in support of its four goals:

- Increased Canadian human resource research capacity and expertise in climate change issues in agriculture.
- Research on knowledge gaps in agricultural greenhouse gas emissions.
- Development of industry best practices and technology to reduce agricultural greenhouse gas emission and increase carbon sequestration potential of agricultural soils.
- Enhanced awareness and improved communication on climate change.

These goals were met through the four components of the CCFIA:

| Component 1 | Developing Canadian Human Resources |
| Components 2 and 3 | Science Networks for Climate Change in Agriculture and Industry Matching for Climate Change in Agriculture |
| Component 4 | Communications |

A CCFIA Committee (Appendix A) comprising representatives from the AAF Table, CARC, Agriculture and Agri-Food Canada Research Branch, Environment Canada and industry, was appointed to evaluate and make funding decisions on research project proposals for Components 1, 2 and 3. The Committee approved funding to eight universities for Component 1, human resource development in agricultural climate change. The Committee selected 16 research projects for funding under Components 2 and 3, research on knowledge gaps and development of industry best practices and technology. These projects addressed the areas of focus identified by the AAF Table report, and included all regions of Canada, widely divergent climatic conditions, and a variety of crops and...
livestock.

CARC coordinated Component 4, the communications elements of the CCFIA and activities within CARC to ensure continuity in climate change research over time.

Component 1 projects were completed March 31, 2003 and Component 2 and 3 projects were completed by September 30, 2003. Research results were presented at the CCFIA final workshop, held in Winnipeg, January 19-20, 2004.
Component 1 of the CCFIA provided funding of $100,000 over three years (2000-2003) to Canada’s eight agricultural universities/colleges to increase the number and expertise of researchers in agricultural climate change. Six of the universities funded under Component 1 appointed graduate or post-graduate students who were trained and participated in research projects related to one or more of the priority areas identified in the Agriculture and Agri-Food Table Options report. McGill University created a new position of Assistant Professor in Micrometeorology and the Nova Scotia Agricultural College created a new Climate Change Research Chair. A total of 27 graduate students, postdoctoral fellows and research associates, plus the two research chairs, participated in training and research under the CCFIA program. This represents a significant increase in Canada’s expertise on climate change and agriculture.

The University of British Columbia supported five graduate students. A Ph.D. student conducted research aimed at increasing the rumen undegradable protein of forage grass (for lactating dairy cattle) by managing nitrogen fertilization rates and harvest dates. A Masters student was involved in research on reduction of greenhouse gas and odour emissions from composting of poultry manure. Three graduate students assisted with research to examine the role of environmental and management factors on the process of soil respiration in agricultural fields in Agassiz, BC and in forests on Vancouver Island, and to predict the consequences of management, land-use change and climate variability on regional and global carbon budget.

The University of Alberta provided training to three graduate students. One conducted research for a Ph.D. thesis in 3-D modeling of spatial variability in N₂O emissions from agricultural fields. A second Ph.D. student was involved in a research project relating to reduction of greenhouse gas emissions in swine by diet manipulation. The third student studied identification, quantification and comparison of greenhouse gas emissions from two different manure management systems - composting and conventional spreading.

The University of Saskatchewan trained six students under the CCFIA program. The research undertaken by the students encompasses climate change research in the areas of agroforestry, nitrous oxide emissions measurement, the effect of conversion of land from forest to agricultural land on carbon storage capability of soil, and the effect of climate change on forage and livestock production on the Canadian prairies.

The University of Manitoba supported five graduate students and two post-doctoral fellows through the CCFIA program. Students were trained in techniques for measurement of enteric methane emissions, including field experience in use of static chambers to quantify methane and nitrous oxide emissions from soils or manure packs; and effects of mitigation strategies. All students conducted research as part of multi-disciplinary or multi-institutional research teams. A post-doctoral research associate refined the university’s analytical capability for the measurement of greenhouse gas emissions from agricultural systems. This capacity was used to provide analytical support to a range of
studies examining agricultural management practices in Manitoba.

The University of Guelph provided training to three graduate students and one research associate. Research included nitrous oxide emissions from a corn/soybean/wheat rotation under best management versus conventional practices; greenhouse gas emissions from stored manure and during composting; and soil physical and chemical conditions in comparison to field N₂O emissions measured using micrometeorological methods during spring thaw. The research associate is compiling published greenhouse gas emission factors for manure storage in a database, and converting the University of Guelph research results to emission factors comparable to published studies.

The Assistant Professor of Micrometeorology at McGill University, Ian Strachan, has used the CCFIA funding to support graduate students and other highly qualified personnel to increase research output on the effects of climate change on agricultural productivity in a range of sites. Seven graduate and undergraduate students have trained with Dr. Strachan in field data collection and analysis in micrometeorological research related to climate change.

Two graduate students were trained at Laval University, one working on characterization of greenhouse gas emissions from solid and liquid manure treatment and management processes, and the other undertaking modeling work on greenhouse gas emissions from cattle and swine production.

The Climate Change Research Chair at the Nova Scotia Agricultural College, David Burton, has established a well-respected research and outreach program, and has become a key climate change resource person in Atlantic Canada. He has made numerous presentations to producer organizations in the Atlantic provinces.

CCFIA COMPONENTS 2 AND 3

SCIENCE NETWORKS FOR CLIMATE CHANGE IN AGRICULTURE AND INDUSTRY MATCHING FOR CLIMATE CHANGE IN AGRICULTURE

Components 2 and 3 of the CCFIA funded 16 projects to a total of $2,734,456 in the period 2000-2004.

The research was aimed at improving knowledge and understanding in one or more of the priority areas identified by the AAF Table and several projects addressed more than one area. Three projects were in the area of crop nutrient management; five in livestock nutrient management (dairy, beef and swine); five in manure management; two in carbon sequestration, and three in measurement and verification systems.

Summaries of each research project, and a summary by area, can be found in the following section of this report.
CCFIA COMPONENT 4
COMMUNICATIONS

WORKSHOPS

The CCFIA mid-program review meeting was held March 21-22, 2002 in Winnipeg. CCFIA funded researchers and graduate students participated in the workshop, which featured presentations by AAFC experts and updates on each of the CCFIA research projects.

The CCFIA final workshop took place January 19-20, 2004 in Winnipeg. The workshop featured presentations by the CCFIA investigators on their research project results. Agriculture and Agri-Food Canada scientists provided synthesis reports, by research area, highlighting the progress that was made through the CCFIA program, as well as remaining knowledge gaps. Graduate students trained under the CCFIA program made poster presentations at the workshop. The workshop also featured presentations on the three position papers developed under the CCFIA program. A total of 119 people attended the workshop, from industry, academia, government and non-government organizations.

COORDINATION OF ONGOING CLIMATE CHANGE RESEARCH ACTIVITIES WITHIN CARC

The Canadian Agri-Food Research Council initiated coordination of climate change activities within CARC by holding a climate change workshop for its Canada and Expert Committee members in Ottawa, April 28-29, 2001. Proceedings were published.

The Canadian Agri-Food Research Council’s Expert Committee on Greenhouse Gases and Carbon Sequestration has established a process to identify research and development needs that are not being currently addressed or that require increased attention. The Committee reviews research reports, workshops on greenhouse gas mitigation and carbon sequestration in agriculture, and reports produced by other organizations. The Greenhouse Gas Mitigation and Carbon Sequestration Research Needs and Priorities for Agriculture (Appendix E) will be updated by the Committee each year, and will be posted on the CARC website.
CLIMATE CHANGE POSITION PAPERS

In 2002-2003 CARC Canada/Expert Committees coordinated the development of three major climate change position papers, as well as continuing work on a database on sustainable development programs across Canada. The three position papers are:

- *Beneficial Management Practices to Reduce Emissions and Increase Carbon Sinks in Canadian Agriculture*;
- *An Assessment of the Economics of Adopting Stewardship Practices in Livestock Production in Response to Environmental and Societal Concerns*;
- *An Assessment of the Opportunities and Challenges of a Bio-based Economy for Agriculture and Food Research in Canada*.

The latter two papers were presented at the Bio-Logical Futures Conference in Saskatoon, June 14-15, 2003. Two of the position papers have been posted on the CARC website. Fact sheets are being developed as part of the third paper, *Beneficial Management Practices to Reduce Emissions and Increase Carbon Sinks in Canadian Agriculture*. 
CCFIA Research Projects

List of Abbreviations

- C: Carbon
- CH₄: Methane
- CO₂: Carbon dioxide
- CP: Crude protein
- CT: Conventional tillage
- GHG: Greenhouse gases
- GPS: Global positioning system
- ha: hectare
- IPCC: Intergovernmental Panel on Climate Change
- LCO: Lipo-chitooligosaccharides
- MIG: Management intensive grazing
- N: Nitrogen
- NBL: Nocturnal boundary layer
- NH₃: Ammonia
- NH₄NO₃: Ammonium nitrate
- NO₃⁻N: Nitrate-Nitrogen
- N₂O: Nitrous oxide
- N₂O-N: Nitrous oxide-nitrogen
- NT: No-tillage
- REA: Relaxed eddy accumulation
- SF₆: Sulphur hexafluoride
- SOC: Soil organic carbon
- TMR: Total mixed ration
- TSS: Total suspended solids
DEVELOPMENT OF SCIENTIFICALLY DEFENSIBLE ESTIMATES OF N₂O EMISSIONS FROM AGRICULTURAL ECOSYSTEMS IN CANADA

PROJECT LEADER:
Robert Grant
University of Alberta

CCFIA GRANT:
$225,000

Field measurements of N₂O emissions are variable and often confined to a limited number of sites defined by soil, climate, and disturbance history. These emissions are controlled by complex interactions among microbial and physical processes in the soil.

This study had two components. The first measured N₂O fluxes using surface chambers over field plots. Different fertilizer, tillage, residue management and manure treatments were examined. The second component focused on the measurement of N₂O fluxes using the eddy correlation method over entire fields for different fertility treatments.

STUDY SUMMARY

In April 2001, surface flux chambers were installed in 72 field plots in Alberta for two years of monitoring. Soil samples were taken at three depths, and the weather was monitored continuously.

A quarter of the 72 chambers were installed at locations that had either not been fertilized previously or since 1984. Low rainfall during the 2001 and 2002 growing seasons resulted in minimal N₂O emissions for both fertilizer systems, indicating emissions from fertilizer applications are negligible in dry years. Fifteen of the chambers were established on plots where fertilizer trials had been conducted since 1984. In general, residual N from earlier applications was shown to contribute to emissions following current application, even during dry years. Twenty-four of the plots were planted in peas in 2001 and received no N applications. In 2002, barley was planted and fertilizer was applied. Both seasons were dry and N₂O emissions were negligible, regardless of tillage or residue management. The remaining fifteen chambers were situated on cattle or pig manure application plots. Large N₂O emissions were observed from plots treated with hog manure, regardless of the dry conditions. No significant emissions were measured from plots treated with cattle manure.

The landscape-scale experiments were conducted on a 30-ha corn field at the Greenbelt Farm, near Ottawa. In addition to meteorological data, soil moisture and leaf area index data were collected. Eddy covariance data was collected continuously throughout the growing season. The 2001 study examined N₂O emissions from plots receiving anhydrous ammonia applications. Cool temperatures and frequent rainfall reduced accumulation of corn heat units and resulted in lower than average leaf area index. For all treatments, large N₂O emissions followed rainfall events and the plots receiving higher fertilizer rates exhibited larger N₂O emissions. In 2003, the impact on GHG emissions using slow-release...
urea fertilizer rather than conventional urea was examined. Little difference was observed in the N₂O emissions between slow release and conventional urea.

In general, residual N from previous years can contribute to current year emissions, even during dry years. This is important when considering emission factors, especially in higher rainfall areas where emissions factors should be larger.
MULTI-SCALE ESTIMATION OF N₂O FLUX FROM AGROECOSYSTEMS

PROJECT LEADER:
Daniel Pennock
University of Saskatchewan

CCFIA GRANT:
$200,000

Measurement, verification, and refinements of the national N₂O emissions inventory from agriculture were identified by the Agriculture and Agri-Food Climate Change Table as part of a national strategy to reduce GHG emissions. Nitrous oxide is a difficult gas to measure due to its low concentrations and highly variable release over time and space. Currently, small chambers are typically used for estimating N₂O emissions, however, this causes problems when validating large-scale models. In general, most regional N₂O estimates have used a simple measure and multiply approach. Measurements are taken using a chamber-based approach then scaled up to calculate the annual emissions. This study focused on verifying integrated chamber-based point N₂O measurements with aircraft-based measurements.

STUDY SUMMARY

The study area was in Saskatchewan. The majority of the fields were in small grains, followed by canola, pulse crops (mainly field peas), and forages. Manure was added to two fields adjacent to two livestock operations. These fields had been used for manure spreading since the early 1900’s.

Twelve positions were chosen for soil sampling and chamber-based gas measurement. Of these, four had pulse residues, four had small grain residues, and four had canola residues. Three of the grain sites and the canola sites received N fertilizer. The remaining grain site received manure. The pulse sites received starter N at the time of seeding only.

Up-scaling the chamber measurements to the township as a whole was performed by multiplying the total flux measured by a given class (i.e., pulse, grain, canola) by the area of the class. In addition to the chamber measurements taken at each field, undisturbed soil samples were used to determine N₂O emissions at optimum water and controlled temperature conditions in a laboratory setting. Using the National Research Council Twin Otter atmospheric research aircraft, a total of thirteen project flights in conjunction with the chamber measurements were conducted to gain insight on the magnitude of N₂O emissions during spring thaw in 2002.

Precipitation was below normal from January 2001 through March 2002. Early in April 2002, an increase in air temperature caused a widespread loss of snow cover. The area was essentially clear of snow within a three-day period. It was during this period that the highest N₂O emissions were observed. The estimated cumulative emission for the chamber-based measurements was approximately 20% higher than the aircraft measurements. The
The largest mean N₂O flux measured with the aircraft was only a fifth of that measured in Eastern Ontario, a direct result of the lower amount of fertilizer used in Western Canada and the substantially drier soil conditions.

The controlled environment study with the soil cores was intended to provide direct correlations between the characteristics of a site and anticipated emissions. This was not achieved as the three crop types showed opposite responses in the field and the controlled environment study. Canola displayed the highest emissions in the laboratory and lowest emissions in the field.

Day-to-day agreement between the chamber averages from the twelve sites and the aircraft-based sensors was low. The small area sampled, coupled with the different temporal patterns of emissions, meant the likelihood of daily emissions from the chambers being consistently similar to the whole-township average from the aircraft is very small.

The cumulative agreement between the chamber-based and aircraft based measurements was very close when scaling up. However, landscape-scale estimates of emissions are much more robust than are point-specific results as these aircraft based measurements provide an area-average.
WHAT ARE THE ISSUES FOR MEASURING DIFFUSE SOURCES OF N₂O?

Nitrous oxide is a trace gas, for which high resolution instrumentation is required to quantify the fluxes at field scale or regional scale. Since the instrumentation is expensive and the learning curve is quite steep, most of the N₂O emissions studies are presently carried out by a network of research scientists using in situ soil chambers to compare treatments in various environmental conditions. However, the equipment cost is not that different (about 20%) between a gas chromatograph equipped with a autosampler and a tunable diode laser analyser (~ $100,000). The chamber information is limited to less than 1 m² and to discontinuous and short periods. Chambers often provide relative comparisons, since the uncertainty becomes large when extrapolating over time and space. They are very useful as a preliminary assessment of the management practices and environmental conditions using factorial experimental design except for quantifying snowmelt N₂O emissions under wet soil conditions. They are used, in conjunction with ancillary data, to implement new processes in mathematical models.

Another key issue is that N₂O fluxes are intermittent and highly variable over space. The question is how to integrate this variability to derive sound emission estimates for various management practices, knowing that none of the available measuring techniques allow measurement simultaneously of large spatial domains over time. Tower-based flux measurements provide integration up to the field scale on a continuous time series of half hourly or hourly fluxes. They are especially suitable for covering nitrous oxide emissions associated with snowmelt. They can be associated with given management practices. A bias is introduced as more flux data are rejected at night when stable atmospheric conditions prevail. Beyond the field scale, two options can be considered: either 1) using tall towers, which are expensive to set up and run, but allow collection of continuous N₂O fluxes over several fields at a fixed location, or, 2) using snapshot approaches such as aircraft-based turbulent techniques (i.e. the relaxed eddy accumulation) or the nocturnal boundary-layer budget, which can cover various locations. Specific aspects of mathematical models can be verified using the observations from the various micrometeorological techniques. The tower-based flux time series allows verification of the model dynamic, while airborne measuring systems permit evaluation of integration schemes using model estimates. The quality of the input descriptors is critical in the performance of the model. Mathematical models become the critical link between the time and space domains.
**Research Progress**

The following two projects were funded by CCFIA in support of GHG measurement and verification systems:

1) *Development of Scientifically Defensible Estimates of N₂O Emissions from Agricultural Ecosystems in Canada* led by Dr. Robert Grant, and

2) *Multi-scale Estimation of N₂O Flux from Agroecosystems* led by Dr. Dan Pennock.

The objectives and a summary of each project were:

1) **Development of Scientifically Defensible Estimates of N₂O Emissions from Agricultural Ecosystems in Canada**

N₂O fluxes were measured using flux chambers in field plots at several agricultural sites in Alberta in order to establish the effects of N management practices (band vs. broadcast application, fall vs. spring application, slow vs. fast release products, low vs. high rates of application) on N₂O emissions from agricultural ecosystems. N₂O fluxes were also measured using a tunable diode laser almost continuously during the growing season at an agricultural site near Ottawa to evaluate the use of new technology for measuring the effects of N management practices (low vs. high rates of application) on N₂O emissions at a field scale.

All these measurements are used to test predictions of N₂O emissions from a mathematical model of agricultural ecosystems in order to establish how well we understand the processes by which N₂O emissions are controlled. Model development and testing during this project are used to establish confidence in the model as a method for making scientifically defensible estimates of land management effects on N₂O emissions from agricultural ecosystems.

2) **Multi-scale Estimation of N₂O Flux from Agroecosystems**

Measurement, verification, and refinements of the national N₂O emissions inventory from agriculture were identified by the Agriculture and Agri-Food Climate Change Table (AACCT) as a key part of a national strategy to reduce greenhouse gas emissions. It is widely recognized that measurement and verification must proceed at several scales - from the individual farmer’s field to regional scale assessments. The problem to date is that models of nitrous oxide emissions for large areas have been difficult to validate because the “scale” of collaborating measurements have been very local - normally, a small chamber. However, recent developments in aircraft monitoring techniques of nitrous oxide emissions make it possible to validate these model results for much larger areas. The project, which was intended to build on past research and development, focussed on providing integrated N₂O flux measurements from the major agroecosystems in Saskatchewan and in Ontario using a combination of chamber-based point measurements and aircraft-based flux measurements.
The project had two major stages. In the first, sampling strategies for large area estimates of N\textsubscript{2}O emissions was developed and applied in Ontario for the aircraft methods and in Saskatchewan for the chamber-based methods during 2001. These measurements provided separate estimates for N\textsubscript{2}O emissions for these regions. In 2002, both methods were used to measure the emissions from major agroecosystems in Saskatchewan during the snow melt period.

**OBJECTIVES OF EACH STUDY**

*Derive scientifically defensible emission factors*
1. To measure the sensitivity of N\textsubscript{2}O emissions from agricultural ecosystems to different fertilizer products, rates, placements and timing.
2. To develop and test a scientifically defensible technique (in the form of a mathematical model) for estimating N\textsubscript{2}O emissions from agricultural soil under any combination of climate, soil type and land management (fertilizer, irrigation, rotation, tillage, harvesting).
3. To use this technique in later studies for estimating regional N\textsubscript{2}O emissions as affected by postulated changes in climate and land management as a way to predict the impacts of climate and land management policy on these emissions.

*Multi-scale Estimation of N\textsubscript{2}O Flux from Agroecosystems*
1. To develop techniques for large area measurements of N\textsubscript{2}O emissions using chamber and aircraft-based methods.
2. To measure N\textsubscript{2}O emissions during spring melt from major agricultural landscapes in Ontario using tower and aircraft methods and in Saskatchewan using chamber and aircraft methods.
3. To test and improve the usefulness of the main N\textsubscript{2}O models for predicting N\textsubscript{2}O fluxes at large area scales as well as reflecting the improvements in technology.
4. To refine the estimates from the agricultural sector in the national inventory.

**RESULTS**

*Derive scientifically defensible emission factors*

The comparison on various fertilizer rate and formulation treatments could not be performed for one of the experimental sites, which had low mineral N, as all N\textsubscript{2}O emissions were small in relation to rainfall deficit. This indicates that N\textsubscript{2}O emissions from dry soil are negligible, regardless of tillage or residue management. Large N\textsubscript{2}O emissions were recorded from two hog manure treatments for three weeks after the onset of a rain period in early June 2001 as well as in the repetition of the experiment in 2002. These large emissions may be attributed to the large ammonium concentration of hog manure which was manifested as higher NO\textsubscript{3}-N concentration in the soil (20 – 30 ug N g\textsuperscript{-1}). No significant emissions were recorded in 2001 and 2002 from the cattle manure which has a lower ammonium concentration and lower soil mineral N concentrations.

All the experiments in Ottawa were carried out in a clay loam field. The field was split into three sections and a management practice under evaluation was applied in the middle...
section, while the sections on the side had the conventional management practice. Two pairs of eddy covariance and flux gradient towers were installed at the boundary of the middle area. The 2000 growing season featured above average rainfall in May and June, and below average rainfall in July and August. Anhydrous ammonia was applied at the recommended rates of 170 kg N ha\(^{-1}\) and at a suboptimal rate of 107 kg N ha\(^{-1}\). In almost all cases the efflux from the 170N was larger than the corresponding flux from the 107N tower. Total \(\text{N}_2\text{O}\) emissions during the period of measurement were 3.7 kg \(\text{N}_2\text{O}\cdot\text{N ha}^{-1}\) for the recommended rate and more than 50% lower for the suboptimal rate. The larger response of \(\text{N}_2\text{O}\) emissions to fertilizer at the Ontario site than at the Alberta site indicates that emission factors for N fertilizer should be larger in higher rainfall areas. In 2001, the field was planted with spring wheat and fertilized with ammonium nitrate at 68 and 41 kg N ha\(^{-1}\). Cumulative \(\text{N}_2\text{O}\) emissions reached 1.1 kg \(\text{N}_2\text{O}\cdot\text{N ha}^{-1}\) for the recommended N rate and were 25% lower for the suboptimal N rate. In 2002, the experiment was carried out to evaluate the impact on corn growth and GHG emissions of using slow-release urea fertilizer rather than conventional urea. The entire field received the same application rate of 155 kg N ha\(^{-1}\). The \(\text{N}_2\text{O}\) emissions during this period were similar for conventional and slow release urea.

All the datasets will be used for model testing in 2004. These tests will greatly contribute to the confidence with which Ecosys can be used for predicting \(\text{N}_2\text{O}\) emissions in national GHG programs.

**Multi-scale Estimation on \(\text{N}_2\text{O}\) Flux from Agroecosystems**

The objective of the study was to estimate \(\text{N}_2\text{O}\) emissions during snowmelt in 2002 for a township (approximately 92 km\(^2\)) near Laird, Saskatchewan. Chamber measurements were made at twelve sites in the township: four fields with canola (*Brassica napus* L.) residues, four with pea (*Pisum sativum* L.) residues, three with wheat (*Triticum aestivum* L.) residues, and one field that received cattle manure. Ten sampling chambers were used at each site, and \(\text{N}_2\text{O}\) samples were made on seven days during the snowmelt period (from April 3 to April 17, 2002). Cumulative \(\text{N}_2\text{O}\) emissions during the 14 days of the snowmelt period differed between crop residue types: cumulative emissions from sites with wheat residues were 0.1 kg \(\text{N}_2\text{O}\cdot\text{N ha}^{-1}\) and were significantly higher \((P<0.1)\) than those from fields with pea and canola residues (0.08 kg \(\text{N}_2\text{O}\cdot\text{N ha}^{-1}\)). The single manured site assessed had the highest cumulative emissions of 0.3 kg \(\text{N}_2\text{O}\cdot\text{N ha}^{-1}\). The crop-specific emissions from the chamber-based measurements were multiplied by the area of each crop type in the township to calculate an area-weighted value for emissions. Cumulative emissions were 0.09 kg \(\text{N}_2\text{O}\cdot\text{N ha}^{-1}\) for the chamber-based measurements. Water-filled pore space and soil temperature were not significantly correlated with cumulative emissions. The emissions for the Laird township were well below the emissions calculated for most other studies in the Prairies and in central Canada. The lower emissions are probably due to low soil water contents and soil nitrate levels in the fall of 2001 and below normal snowfall in the winter of 2001-2002. This reinforces the importance of antecedent moisture conditions and soil N levels for modelling of emissions at snowmelt.

The aircraft \(\text{N}_2\text{O}\) flux system, which is based on the relaxed-eddy accumulation technique, provides fluxes of \(\text{N}_2\text{O}\) for areas of about 100 km\(^2\) with a resolution better than 5 ng \(\text{N}_2\text{O}\).
The N₂O emissions observed during the 2002 field campaigns were extremely small. The maximum observed flux was at least 5 times smaller than the maximum observed in Eastern Canada. The small emissions during this campaign were not unexpected, considering that the soil was extremely dry during the measuring period. The peak emission was closely synchronized with soil thawing. The comparison between aircraft results and N₂O spring emissions predicted by the DNDC model indicates that DNDC estimates are likely overestimated at times in Western Canada. These results will undoubtedly provide valuable information to test and improve N₂O models.

**ACHIEVEMENTS**

- Several measuring tools (i.e. chambers, towers, aircraft) are operational for measuring N₂O fluxes.
- Optimized sampling strategies according to the specificity of each measuring tool were developed.
- Solid measurement databases were assembled. We are at the stage where we can integrate the information provided by the different measuring tools for verifying the process-based models and the GHG inventories.
- The *Ecosys* model is incorporating the major processes for estimating N₂O emissions.

**RESEARCH GAPS AND FUTURE AREAS OF RESEARCH**

Linkage between space and time cannot be carried out with a unique measuring tool. An immediate challenge is to derive temporal integration schemes for instantaneous N₂O flux measurements collected using either chamber or aircraft. As previously noted, the first study had more emphasis on the time domain while the second study emphasized the spatial integration. It requires an interdisciplinary approach combining both modelling and measurement at various levels for the determination of environmental conditions and the verification of the GHG exchange between agroecosystems and the atmosphere. How do we define the best strategy for integrating space and time in a region to derive regional N₂O estimates? What resolution, over space and time, is required for the driving variables, to estimate GHG emissions? What is the resolution required for policy decision-making and implementation? Are they compatible?

Models need additional refinements to establish the linkages between space and time and describe their impact on N₂O emission variability.

When considering the trade-off between net Carbon change and N₂O emissions, the scale difference in the temporal dynamic between both GHGs is still an issue for defining beneficial management practices.

Emissions of N₂O during snowmelt are not fully understood and their magnitude in relation to environmental conditions and management practices should be further studied.

Determine and verify, using models, the impact of weather conditions on spring N₂O emissions in relation to given management practices. What is the impact of heavy rainfall on the magnitude of N₂O emissions?
Not much is known about indirect N$_2$O emissions. For example, what are N$_2$O emissions from the area on which short-range deposition of ammonia is occurring?

We need to have more researchers trained in micrometeorology as well as for using tunable diode laser technology in agriculture.

**A Few Recommendations**

The period of annual N$_2$O emissions from diffuse sources related to a given management practice should be defined in Canada as starting from the preparation of the seeding bed and finishing after the following snowmelt.

An infrastructure is needed to deliver more rapidly field scaled N$_2$O emissions in relation to management (rotation, tillage, fertilization, etc.) and environment (soil, climate). This might be achieved by expanding Fluxnet-Canada (an initiative of the BIOCAP Canada Foundation) to include a few agricultural flux towers equipped with tunable diode lasers.

Fortunately, a 3-D model, *Ecosys* (University of Alberta), now exists at the field scale, which allows characterizing within field variability. The next step is to verify its sensitivity to contrasting conditions. The goal will be to implement optimized N application rate for homogeneous soil zones in order to evaluate the reduction of N$_2$O emissions associated with this BMP.

More pilot studies, involving chamber, tower, tethered blimp, aircraft flux measurements as well as detailed environmental conditions derived from existing databases and remote sensing would be helpful for verifying the performance of models at the regional scale as well as the precision of our Canadian inventories. Setting up a tall tower in an agricultural environment (as is being done in the US), would complement regional scale studies.
REDUCTION OF GREENHOUSE GAS EMISSIONS IN SWINE BY DIET MANIPULATION

PROJECT LEADER:
Ron Ball
University of Alberta

CCFIA GRANT:
$175,000

Concern exists as to the amount of GHG emissions being generated from swine production in Canada. The objective of this study was to determine the effect of reducing dietary protein in relation to CO$_2$ and CH$_4$ emissions by pigs. In addition, the excretion of nutrients from pigs following a lowered dietary protein intake was evaluated.

STUDY SUMMARY

Carbon dioxide and CH$_4$ emissions from swine were measured using an open circuit respiration system. Emissions were obtained from four groups of pigs including non-pregnant, gestating, lactating, and finisher pigs. Non-pregnant pigs were offered diets based on lower protein (barley-canola) or higher protein (corn-soybean) content meals. Gestating and lactating pigs were allowed either a high protein conventional diet or a low protein, amino acid supplemented diet depending on body condition. Finisher pigs were fed either a wheat-barley-canola or a corn-soybean diet.

Emission measurements demonstrated that reducing protein content in feed lowered CO$_2$ emissions by 2.5 to 6%. Reducing the protein in diets however, had no effect on CO$_2$ production when the corn diet was used. Methane production was reduced with the low protein barley diet. Within the non-pregnant pigs, the protein level in the corn-soybean diet did not affect emissions. When fed low protein diets, N and C excretion were reduced 20 and 6%, respectively.

Reduction of dietary protein content decreased CO$_2$ production and also decreased CH$_4$ emissions for wheat-barley-canola based diets. However, reductions were not observed for the corn-soybean diet. In general, diet manipulation reduced GHG emissions as well as the nutrient content in manure.
MEASUREMENT OF GREENHOUSE GAS EMISSIONS AND ODOUR FROM SWINE MANURE DERIVED FROM STANDARD AND MODIFIED DIETS

PROJECT LEADER:
Jerry Leonard
University of Alberta

CCFIA GRANT:
$75,000

Both methane and N₂O are substantially higher from manure storage systems than from manure that is stockpiled or composted. Diet manipulation is speculated to reduce these emissions, however limited research has been conducted in this area. The objective of this study was to quantify and compare GHG emissions and odour from swine barns, manure storages and manure compost under Prairie conditions.

STUDY SUMMARY

Throughout 2001 and 2002 trials were conducted where animals were fed either a conventional high-protein diet or a low-protein diet. Odour emissions from the barn and the manure storage were quantified using an olfactometer. Effects of manure management on GHG’s were evaluated using a wind tunnel from the surface of three storage tanks that were managed as undisturbed, periodically agitated, or liquid-only.

Protein content had no effect on GHG emissions from swine. Diet also had no effect on CH₄ production from manure storage tanks but CH₄ emissions were 10× higher during the first few minutes of agitation. Carbon dioxide emissions from the undisturbed and agitated tanks were lower for the low protein diet. The CO₂ production however, was an order of magnitude higher during agitation compared to the undisturbed tank. There were no differences in emissions from composting due to diet. Low CH₄ emissions however, were observed during the composting process. Odour emissions were higher from the storage tanks compared to the barn, but diet had no effect on these emissions.

Overall, diet had no effect on GHG production from the swine, or when composting was performed. Methane production from the storage tanks was not affected by diet, however CO₂ emissions were lower for the low protein diet. Methane emissions were higher during agitation. Low CH₄ emissions and high CO₂ emissions were observed during composting, possibly due to the aerobic (oxygen-rich) process and the microbial activity. Results suggested that both diet manipulation and composting did not reduce odour emissions.
GREENHOUSE GAS EMISSIONS FROM SWINE OPERATIONS IN QUÉBEC AND SASKATCHEWAN: BENCHMARK ASSESSMENTS AND SELECTIVE MITIGATION PROCESSES

PROJECT LEADERS:
Claude Laguë  
University of Saskatchewan

Alfred Marquis  
Laval University

CCFIA GRANT:
$150,000

A major portion of the agriculturally produced GHG emissions originates from livestock production. A need exists to better quantify the contribution of each stage of animal production on these emissions. Although carbon dioxide emissions are generally not accounted for when evaluating net GHG emissions from agricultural operations, CO₂ emissions were evaluated in this project from a site-specific perspective. The objective of this study was to quantify CH₄, CO₂ and N₂O emissions for swine operations under liquid manure management systems. Specifically, GHG emissions from different swine production buildings and floor designs, manure storage facilities (covered and uncovered), and manure treatment systems were assessed.

STUDY SUMMARY

The study was conducted in Quebec and Saskatchewan, from January 2001 through September 2003. Open chambers constantly exchanging air were used for samples from the manure storage facilities, while samples from buildings were collected at air inlet and exhaust fans using a pulmonary pump. Samples were analysed using gas chromatography.

Carbon dioxide was by far the largest contributor (up to 99.9%) of GHG emissions from buildings, followed by CH₄. The N₂O emissions were negligible. The highest CO₂ emissions occurred in grower-finisher rooms, while the lowest occurred in gestation rooms. The floor design had no effect on CO₂ emissions, however, fully slatted floors resulted in 2× the CH₄ emissions compared with partially slatted floors.

Methane emissions from storage facilities comprised 66 to 92% of the GHG emissions. The remaining emissions were contributed by CO₂, while N₂O was negligible. The uncovered earthen manure basin and concrete tank manure storages produced similar GHG emissions. Compared to uncovered storages, the addition of straw cover resulted in a five-fold reduction of GHG emissions. The depth of manure in the storage structure had no impact on GHG emissions.

Greenhouse gas emissions from aerobic-anoxic (oxygen rich-oxygen limited) manure treatment systems consisted of 71% from CO₂, 19% from CH₄, and 10% from N₂O. Carbon dioxide emissions were more dominant during the aerobic stage, while CH₄ and N₂O were more dominant during the anaerobic stage. As a result of higher temperatures during the summer, 10× more CH₄ and 5× more CO₂ emissions were measured compared to the fall.
The bio-filter system was effective in reducing CH₄, but had an opposite effect on N₂O emissions.

Most of the GHG emissions originated from pig production buildings, thus buildings should be the primary targets for reducing emissions. Both aerobic-anoxic and bio-filter manure treatment systems have potential to reduce CH₄ emissions from pig production, but may increase N₂O emissions. Covering manure storage facilities with straw is a viable strategy for reducing GHG emissions, in particular CH₄.
REDUCTION OF GREENHOUSE GAS EMISSIONS FROM DAIRY PRODUCTION SYSTEMS AND POULTRY MANURE AND ITS IMPACT ON AGRICULTURAL SUSTAINABILITY

PROJECT LEADER:
Jim Thompson
University of British Columbia

CCFIA GRANT:
$250,000

Agriculture production accounts for approximately 9.5% of Canadian GHG emissions. Farmers are consistently facing challenges with regard to land application of manure and subsequent GHG emissions on their farms. This study examined potential manure management strategies in relation to GHG emissions.

STUDY SUMMARY

From 2001 through 2003 manure management practices from two composting systems were investigated to determine operating conditions where GHG emissions can be minimized. Poultry manure, yard trimmings and bio-solids were used to examine the effect of adding a biocatalyst (main ingredients were zeolite and yeast) to the composting process during two different stages (active and curing). Methane emissions were lower under all treatments where a biocatalyst was used. Although N₂O emissions were variable, the addition of a biocatalyst generally reduced emissions during composting. Drying the manure prior to composting had no effect.

Regulations limiting land application during the winter months requires applying manure in the spring to bare corn land, which accounts for 25% of farm land as opposed to the 75% in perennial grass. The uptake of N by corn is half that of grass, leaving a high level of N that can potentially be lost as N₂O. In 2001 and 2002, vented chambers using a gas filter correlation N₂O analyzer were used to assess N₂O emissions from manure that was applied on grass instead of bare corn land. Only a small quantity of the total N loss can be attributed to N₂O emissions. However, from a GHG perspective N₂O losses were up to 40× higher on the bare soil.

Beginning in 1994, CO₂ emissions from different levels of cattle manure applied to pasture were determined. Carbon dioxide emissions were measured from soil using a portable CO₂ analyzer following dairy manure application. Treatments included surface application of manure or inorganic fertilizer, four times a year. Carbon dioxide released from manure was found to be higher than the control and fertilized plots, especially in the first two weeks after application and in particular when soil temperature and moisture were favourable. A CO₂ efflux model was developed to determine soil temperature and water content effects on emissions. The model indicated that CO₂ emissions were more sensitive to soil temperature than to soil moisture and increased with higher temperatures.

The effect of sand or sawdust as a bedding type on GHG emissions was evaluated. Closed
chambers were used to measure GHG emissions from bedding materials in a dairy barn. Results indicated that sand was better for reducing CO₂ emissions. Sawdust however, produced lower N₂O emissions. Similar CH₄ emissions were found for both.

This study provided useful information for developing on-farm management strategies to reduce GHG emissions. The use of a biocatalyst during composting, spreading manure to grassland, and using sand or sawdust as a bedding material, will aid in reducing GHG emissions.
Diet formulations for animals influence the amount of C and N excreted in manure, and are speculated to influence CH$_4$ released from manure. The addition of fats to increase the energy of high forage grain diets has shown lowered CH$_4$ emissions. The objectives of this study were to assess CH$_4$ emissions from beef steers fed diets with two ratios of forage:grain by including sunflower seeds as a fat nutrient source, and to quantify GHG emissions from bedded manure in pens of the same feedlot steers.

**STUDY SUMMARY**

Experiments using 112 steers were conducted in Manitoba beginning October 2001. Animals were placed in eight pens. Half were fed an 84% barley grain diet (low forage:grain), while the remaining animals were fed a 42% barley grain diet along with 14% as whole sunflower seeds (high forage:grain). Methane, CO$_2$ and N$_2$O were measured over the 126 day course of the feeding trial using vented static chambers.

Steers fed the low forage:grain diet consumed more feed and gained more weight than steers fed the high forage:grain diet. Steers fed a low forage:grain diet produced 42% more CH$_4$ than steers fed a high forage:grain diet that contained sunflower seeds. Higher CH$_4$ and CO$_2$ emissions occurred with chambers located deeper in the manure packs where the temperature was also higher. There was no effect of diet however, on manure pack temperature. The addition of sunflower seeds in the high forage:grain diet resulted in even lower total daily emissions of CH$_4$ and N$_2$O. Overall, the addition of sunflower seeds as a dietary fat in a high forage grain diet substantially reduced CH$_4$ and N$_2$O emissions.
ENVIRONMENTAL PERFORMANCE OF ALTERNATIVE DAIRY PRODUCTION SYSTEMS

PROJECT LEADER:
Alan Fredeen
Nova Scotia Agricultural College

CCFIA GRANT:
$116,440

Management intensive grazing strategies aim to keep pasture forage near its optimal growth stage, improve forage quality, reduce grain requirements and reduce GHG emissions. If grazing is feasible, adoption of MIG strategies can help mitigate environmental degradation and reduce production costs compared to intensive (silage-based) confinement production systems. The overall objectives of this study were to evaluate GHG emissions from pasture-based and silage-based dairy production systems as well as evaluate two different CH4 measurement techniques.

STUDY SUMMARY

Using the Atlantic Dairy Sustainability Model, the impact of milk production on CH4 emissions and feed requirements were evaluated. For similar milk yield levels, CH4 emissions were 40 to 50% lower in grazing cows. Although 10 to 20% fewer cows are required to achieve similar milk production levels, more CH4 will be produced from stockpiled manure in confinement systems. In addition, more energy is required to produce grain for silage-based confinement systems, thus increasing GHG emissions.

The impact of feed source (pasture vs. silage) on CH4 emissions of lactating cows was determined. During the fall of 2001, cows fed freshly cut pasture with less concentrate produced 20% less CH4 compared to cows fed silage-based TMR diets. During spring and fall 2002, CH4 emissions were 14 and 3% lower for pasture and TMR diets, respectively. Milk yield and quality were similar for both systems. Milk revenue per cow was $1 higher for pasture-based systems during spring 2002, but similar during fall 2002.

A comparison of chamber and SF6 methods for measuring CH4 emissions was performed. When the chamber and SF6 CH4 measurement techniques were simultaneously compared, the chamber method estimated 26% more CH4 emissions. That translates into 32% more CH4 emissions per liter of milk produced. The chamber method was less variable and easier to use than the SF6 technique.

The impact of dietary CP on GHG emissions of dairy cows was assessed. Milk urea N from cows fed the higher CP diet exceeded requirements. Methane emissions were similar for both diets, while N2O emissions were higher from cows fed the higher CP diet.

Where grazing is possible, cows under MIG systems can be as productive as those under silage-based confinement systems with reduced environmental degradation, lower GHG
emissions and lower overall costs. High N rate and/or legume concentration in pasture however, will increase pasture's CP content, and thus increase N₂O emissions.
EXAMINATION OF ENVIRONMENTALLY AND ECONOMICALLY SUSTAINABLE MANAGEMENT PRACTICES IN FORAGE-BASED BEEF PRODUCTION SYSTEMS

PROJECT LEADER:
Kim Ominski
University of Manitoba

CCFIA GRANT:
$61,445

Livestock production contributes 58% of the total GHG emissions from agriculture, of which 28% is associated with ruminant digestion and 30% with manure storage and handling. A significant proportion of the beef cattle in Canada, particularly in the Prairies, are fed low-quality high-forage diets consisting of hay/round bale silage and natural pasture. Limited studies have been conducted to quantify CH$_4$ emissions from these forage-based beef production systems. This study evaluated the impact of forage quality on performance and CH$_4$ production by steers during overwintering and pasture phases of production.

STUDY SUMMARY

The study was conducted in Manitoba, from February 2001 through September 2003, using a total of 144 steers. The steers were divided into four groups and fed four qualities of round bale silage during the overwintering phase. Following the overwintering phase, steers were placed in either seeded or native grass-based pasture. Methane emissions were measured using the SF$_6$ technique.

Steers fed the lowest quality diet had the lowest average daily weight gain, and in general weighed 5% less than those fed higher quality diets. Regardless of diet quality, CH$_4$ emissions were similar for all groups of steers, indicating that forage quality had no effect on CH$_4$ production.

After eight weeks on pasture diets, all groups had similar average body weight implying that steers fed the lowest quality diet during the overwintering phase were able to recover. On average, CH$_4$ emissions were 11% lower for steers in native pasture compared to those in seeded pasture.

Steers can be fed low quality forage during the overwintering phase without negatively affecting final pasture weight. Rumen CH$_4$ emissions from steers fed low-quality forage-based diets are comparable to emissions from steers fed high-quality forage-based diets.
IMPROVED GREENHOUSE GAS EMISSION ESTIMATES FROM MANURE STORAGE SYSTEMS

PROJECT LEADER:
Claudia Wagner-Riddle
University of Guelph

CCFIA GRANT:
$200,000

Livestock production continues to increase, resulting in greater manure volumes being generated. This study focused on improving GHG emission estimates from outdoor swine and dairy manure storage systems, as well as from swine barns. Emissions were compared to existing IPCC and European emission factors.

STUDY SUMMARY

Year-round emissions (N$_2$O and CH$_4$) from outdoor manure storage systems were estimated from three swine farms (Arkell, Guelph, and Jarvis) and two dairy farms (Bright, Embro) in Ontario using the mass balance micrometeorology technique. In addition, two swine barns (Guelph and Wartburg) were also investigated to examine emissions from livestock confinement facilities and test an air dispersion model, AGMOD.

Nitrous oxide emissions from manure at the Arkell farm were not detectable, while CH$_4$ emissions at this site were highly variable with increased emissions during manure addition and removal. During the summer of 2001, Jarvis and Guelph differed in N$_2$O emissions; Jarvis resulted in a positive flux (source) while Guelph was a negative flux (sink). Nitrous oxide and CH$_4$ emissions were also highly variable at the Bright and Embro site. This may be attributed to the composition of the manure, the surface area of the manure storage tank and the number of animals contributing to the manure tank. Methane emissions were highly variable and linked to several factors including manure properties, temperature, wind, and manure disturbance (i.e. agitation of the manure).

Methane and N$_2$O emissions in the swine barns at Guelph and Wartburg were directly related to barn temperature, with higher emissions observed during mid-day. This finding will aid in estimating emissions in Ontario from mechanically ventilated swine confinement barns. At the Guelph site there were strong correlations between CH$_4$ and N$_2$O emissions. Average emissions (CH$_4$ and N$_2$O) were higher in the spring at both the Guelph and Wartburg site. Methane emissions measured at Wartburg were used as model inputs to validate the modified AGMOD model. The modified model predicted emissions better than the original model. Further work however, is needed to validate this model so that it can be used for other facilities.

Results indicated that the IPCC and European emission factors for CH$_4$ and N$_2$O were not representative of emissions under Canadian conditions. In general European emission factors overestimated CH$_4$ by 2× to 5× for swine manure (at Arkell, Guelph, and Jarvis). For dairy, emission factors overestimated (5×) the measured emission factor from Bright
and underestimated the measured emission factor from Embro. Nitrous oxide was also overestimated by up to 98×, depending on the animal type. The data collected in this study will aid with the development of Agriculture and Agri-Food Canada’s Model Farm initiative.
This summary report was prepared by reviewing CCFIA project reports and emphasizing the major findings of each project. As with any research, investigation into one area often leads to more questions than answers. The present group of projects make a significant contribution to our knowledge on the impact of animal nutrient management on greenhouse gas emissions. There are never enough resources (i.e., personnel, time, equipment) to conduct all of the measurements that one would like to in any one single experiment. Consequently, the fact that there are still knowledge gaps after this series of projects has been completed is not surprising and only emphasizes the need for continued research in this area.

**FEEDLOT PRODUCTION SYSTEMS**

**A. Enteric Emissions**

IPCC proposes that cattle fed high concentrate diets lose about 4% of Gross Energy Intake (GEI) as methane. This figure was derived mainly on work conducted using corn-based finishing diets. Work in Canada using barley-grain diets has estimated that from 4.4 - 5.8% of GEI is lost as methane (Mathison et al. 1997). Methane losses from more typical 90% barley-based finishing diets have been reported to be 6.6% of GEI (Delfino et al. 1988). Logically, one could hypothesize that the higher fiber and lower oil content of barley would result in a higher methane production per unit GEI than corn. This relationship was supported by work that showed that methane emissions were 15% higher from cattle fed finishing diets containing 77% barley vs 77% corn (Zinn et al. 1996).

In CCFIA work, methane production as a % of GEI ranged from 0.9 to 6.9% for feedlot cattle fed a typical 85% barley-based concentrate diet. Inclusion of sunflower seeds in a forage-based diet resulted in a range of methane production of 0.7 to 4.9% of GEI. Sunflower seeds were effective at reducing methane production, but the exact mechanism whereby this response occurs remains unclear. Sunflower oil is known to inhibit ruminal protozoa, and the unsaturated fatty acids can act as a sink for hydrogen (Ivan et al. 2004). A reduction in protozoa can lead to an inhibition of fiber digestion as ruminal protozoa can be responsible for up to 30 to 40% of the fiber digestion in the rumen. Consequently, it is important that steps be taken to ensure that sunflower seeds are achieving a reduction in methane production as %GEI without causing a corresponding reduction in diet digestibility or the growth performance of animals.
KNOWLEDGE GAPS - ENTERIC EMISSIONS

- Need further studies that relate dietary changes in methane production to stoichiometric changes in fermentation acids as ultimately redirection of hydrogen from methane should be accounted for by other possible hydrogen sinks.
- Need to develop further studies that separate alterations in total nutrient utilization from reduction in methane emissions. Ultimate objective is to get a reduction in methane emissions with a corresponding improvement in feed efficiency and animal performance.
- Need to carefully consider implications of intake level and diet digestibility as these two parameters can have major implications on relative methane emissions from ruminant animals (Blaxter and Clapperton 1965).
- Need to further examine other possible mitigation strategies that may have implications in feedlot systems.
  - Optimize fat or oil levels in diet with consideration for both digestibility and economic parameters.
  - Assess the effect of altered forage levels in concentrate-based diets on methane emissions.

B. Manure Emissions

CH$_4$, CO$_2$ and N$_2$O emissions from bedding packs were not influenced by the nature of the diet fed in the CCFIA study. Manure pack was deeper in pens of cattle that were fed the high forage: low grain diet, a result that suggests that the digestibility of this diet may have been lower than the low forage: high grain diet. Emissions from bedding packs may be related to the degree of surface exposure and are likely to be of a highly seasonable nature. Diet also did not influence greenhouse gas emissions from either stock piled or windrow manure piles. Stockpiling of the manure created conditions that were favorable to the establishment of methanogens and therefore resulted in greater methane production.

KNOWLEDGE GAPS - MANURE EMISSIONS

- Need to determine the effects of season on greenhouse gas emissions from the manure pack.
- Need to do projects on whole system analysis on the emissions from manure with consideration for manure handling (e.g., stock pile vs compost), hauling and method of land application.
- More detailed measurements are required to develop models that can be used to determine under which conditions composting can be considered a BMP for reduced emissions, with special emphasis placed upon N$_2$O emissions.
FORAGE BASED BEEF PRODUCTION SYSTEMS

Previous work in Canada has suggested that CH$_4$ emissions were lower in cows grazing alfalfa-grass (7.1% GEI) pastures as compared to cows grazing grass-only (9.5% GEI) pastures (McCaughey et al. 1999). In contrast, feeding a variety of forages of differing quality did not influence the amount of CH$_4$ produced as a %GEI in beef or dairy heifers (Boadi and Wittenberg 2002). In the CCFIA study, CH$_4$ as a %GEI ranged from 5.1 to 5.9% of GEI in cattle fed forages in confinement and did not differ among forages that ranged in ADF from 35.6% to 46.4%. Under grazing conditions, CH$_4$ as %GEI ranged from 7.1 to 11.3% in steers on improved pastures and from 6.9 to 9.4% in steers on unimproved pastures. The high production of CH$_4$ as %GEI on the improved pasture is attributed to a reduction in forage quality. However, it is not clear why similar differences in CH$_4$ as %GEI were not observed despite the wide variety in the quality of the forages employed in the backgrounding phase of the study.

KNOWLEDGE GAPS - FORAGE BASED BEEF PRODUCTION SYSTEMS

- Additional studies are required to determine the relationship between forage quality and methane emissions. Theoretically, crops with higher starch or soluble carbohydrate content should result in lower methane emissions than crops with higher structural carbohydrate contents. Further work that confirms or refutes the legume-related reduction described by McCaughey is warranted.
- Estimation of intake continues to be a major source of error in the estimate of CH$_4$ emissions from cattle under grazing production systems. Although this source of error has been widely recognized it has not been adequately quantified. As with feedlot production, estimation of nutrient intake and digestibility are integral to drawing meaningful conclusions with regard to the impact of diets on greenhouse gas emissions.

DAIRY CATTLE - PASTURE BASED DAIRY PRODUCTION SYSTEMS

Pasture-based and TMR based production systems for dairy cows produced similar levels of enteric methane of 14.8 and 15.1 g kg$^{-1}$ milk, respectively. This work suggests that where appropriate, pasture based production systems could result in similar or even lower levels of methane emissions per unit of milk produced than confinement production systems. However, to give a true reflection of total reduction the model would have to take into consideration the varying lengths of grazing season at locations across the country. Forage quality and grazing management may also influence the relative amount of emissions that occur for such a system.
KNOWLEDGE GAPS - PASTURE BASED DAIRY PRODUCTION SYSTEMS

- Pasture-based systems should be considered with regard to the various climatic conditions across Canada.
- Pasture-based systems should also consider the larger land-base that would be associated from such an operation and the advantages that this may impose by allowing manure to be spread over a wider area in a less concentrated manner.
- Success of the system is heavily dependent on maintaining forage in a high-quality state for the majority of the grazing season. To meet this goal, different forage systems may have to be defined for different regions of the country.
- Should be resources to establish stronger linkage with countries (e.g., New Zealand) that have a long history with regard to the use of forage-based production systems.

Soil CO₂ Flux with Dairy Cattle Manure

Application of dairy cattle manure resulted in a dramatic increase in CO₂ efflux (85 μmol⁻² s⁻¹ vs 3 μmol⁻² s⁻¹) from plots as compared to control plots or plots fertilized with conventional fertilizer. In a second study using modified equipment CO₂ efflux was 21 and 14 μmol⁻² s⁻¹ from high and low manure application plots as compared to 9 μmol⁻² s⁻¹ for fertilized and control plots. CO₂ fluxes from manured plots fell to levels that were comparable to those in the control plots after 19 days. Additional work demonstrated that CO₂ efflux is much more sensitive to soil temperature than to soil water content. CO₂ efflux was mainly influenced by the rate of production in the soil and not by its degree of migration through the soil profile.

KNOWLEDGE GAPS - SOIL CO₂ FLUX WITH DAIRY CATTLE MANURE

- Need for multi-year projects to monitor long term implications of manure application on soil CO₂ efflux, to track changes in soil carbon under various agricultural practices.
- Need to monitor effect of various manure application methods, (e.g., surface, surface - incorporation, direct injection) under various soil conditions (i.e., temperature and moisture).

COMPOSTING SYSTEM FOR POULTRY MANURE

CH₄ emissions were found to be low, whereas N₂O levels were highly variable from biosolids and poultry manure compost. In general, higher N₂O emissions were recorded for compost that had a higher moisture content. A lower initial moisture content appeared to reduce the extent of N₂O emissions. A biocatalyst consisting of zeolite and a yeast was unable to reduce N₂O emissions throughout the active phase period. Predrying the manure prior to composting did not appear to offer any advantage in mitigating N₂O emissions.

KNOWLEDGE GAPS - COMPOSTING SYSTEM FOR POULTRY MANURE

- What conditions during the composting process contribute to the anaerobic shifts that are responsible for the emissions of CH₄ and N₂O. For example, number of times the pile is turned, moisture level, forced vs passive aeration etc.
Do changes in diet result in changes in manure composition that in turn have an impact on emissions during the composting process.

Need to recognize composting as a dynamic process and to develop predictive models that take this fact into consideration.

**Swine Production Systems**

**Sows**

Reducing protein content in barley or corn diets fed to sows at maintenance tended to increase CO₂ emissions. Lowering the protein content in barley-based diets reduced CH₄ emissions, but a similar response was not observed in sows fed low protein, corn-based diets. Overall, CO₂ equivalents were reduced by about 16% as a result of reducing dietary protein levels. Piglet birth weight and weaning did tend to also be lower with the low-protein than the high-protein diet. Consequently, such a management option would have to be carefully monitored to ensure that the kg of piglets weaned per sow were not reduced to a point that overall emissions per unit of piglet weaned was increased due to a reduction in the kg of piglets weaned per sow. Perhaps the most significant reduction in emissions was associated with a 20% reduction in the nitrogen excretion in the sow as a result of feeding low-protein diets. The majority of this reduction was associated with a decline in urinary excretion and consequently may have the greatest impact on reducing the volatile emissions of ammonia from manure.

**Finishing Pigs**

Unlike with sows, reducing the dietary protein content of wheat-barley-canola meal or corn-soybean meal diets reduces CO₂ emissions from finishing pigs. As with the sows, a reduction in protein level reduced CH₄ production from wheat-barley-canola meal based diets, but did not alter CH₄ production from corn based diets. Emissions of CO₂ equivalents were reduced by about 16.4% in finishing pigs fed wheat-barley-canola based diets.

**Knowledge Gaps - Swine Production Systems**

- Need to determine if enteric production of CH₄ occurs in the greater swine population.
- Need to determine to what extent fiber content in the diet impacts enteric production of CH₄ in swine.
- Determine if fibrolytic enzymes can be used to improve nutrient utilization and reduce CH₄ emissions from swine.
- Determine the impact of oil or lipid content on CH₄ and N₂O emissions from swine (i.e., does this account for the differences seen between cereal and corn-based diets in the present CCFIA study.)
OVERALL KNOWLEDGE GAPS

Microbial ecology

With the exception of respiratory CO$_2$, all of the greenhouse gases whether of enteric or manure origin arise as a result of microbial activity. However, our understanding of the nature of the microbial communities that participate in these processes is at best rudimentary. Perhaps, our greatest knowledge base in this area lies in rumen ecology, but even in this instance DNA-based evidence has shown that there are methanogens in the rumen that have yet to be cultured or characterized. Understanding the microbial ecology in manure systems and the soil biosphere is critical to predicting potential greenhouse gas emissions. It is this lack of knowledge that has impeded scientists’ ability to answer relatively simple questions such as can composting be recommended as a best management practice with regard to greenhouse gas emissions?

Stoichiometric Gap

The first law of thermodynamics states that energy can not be destroyed or created, but only transformed from one form to another. Reductions in CH$_4$ production in the rumen must be accompanied with the provision of alternative electron acceptors or fermentation and ultimately production efficiency will be compromised. There are numerous instances where large decreases in ruminal CH$_4$ production have been reported without identifying the nature of the alternative electron acceptor that accounts for this decrease. The first law of thermodynamics is the premier test for the accuracy and meaningfulness of developed greenhouse gas mitigation strategies. Ultimately, assessing the value of mitigation strategies on this basis may identify additional knowledge gaps or further illustrate the inherent limitations of the techniques presently employed to estimate emissions from biological systems.

Whole farm model systems

For the most part, greenhouse emissions are presently estimated on individual farm components without an appreciation for the whole farm system. Consequently, recommendations that reduce emissions from one component in the system, may in fact lead to an increase in emissions from another point in the system. For example, conservation and concentration of nitrogen in manure by composting may lead to an increase in N$_2$O release from soil when this material is applied to the land. Ultimately, the extent of greenhouse gas emissions should be determined by estimation of mass balance within the whole farm system. The growing volume of data with regard to emissions within specific components of the farming system now makes it possible to develop sophisticated, integrated whole farm models for the prediction of mass balance within farming systems.
REFERENCES


This report was written based on the information presented by the authors of the CCFIA projects in their final reports and at the CCFIA Final Workshop. Our objective was to highlight the main scientific outcomes of the projects and to identify questions that remain to be addressed regarding emissions of greenhouse gases associated with manure management. In addition to specific comments on each project, we also propose a list of more general knowledge gaps relative to greenhouse gas production and emissions from livestock housing and manure (storage and land application).

Measurement of Greenhouse Gas Emissions and Odour from Swine Manure Derived from Standard and Modified Diets

Objective
The principal objective of this project was to quantify and compare GHG emissions (N₂O, CH₄ and CO₂) from pigs, their manure, and manure compost under Prairie conditions, where the animals were fed either a high-protein (conventional) or low-protein diet. The effect of management practices on GHG emissions from the manure storage units was also evaluated.

Research Progress

Slurry
- There were no measurable N₂O emissions from the production room or from the manure storage tanks.
- Diet treatments had little effect on CH₄ emissions.
- Emissions were greatest during agitation of the slurry.
- This study measured GHG emissions at several stages of a manure handling system (building, storage, composting). Such studies provide a more thorough assessment of the GHG emissions than when only one component of the system is investigated.

Compost
- Protein level in the diet had little effect on N₂O emissions during composting.
- Emissions of CH₄ were low during composting (this is expected in such a small compost pile, with a well aerated non compacted material).
- Adds to the scarce information on GHG emissions during composting.
Knowledge Gaps

Slurry

- Interestingly, CH₄ emissions were ≤0 at 5 of the 10 sampling dates. The small size of the tunnels, the short sampling period and low sampling frequency (once a week) may not be appropriate to capture adequately the spatial and temporal random nature of the CH₄ emissions. These results raise the question regarding how chambers should be deployed to measure GHG emissions from manure storage.

- Slurry depth is often reported as having a large influence on methane production and emission during storage. The absence of response of methane dynamics to slurry depth (0.8 to 3 m) in this study might be explained by the simultaneous influence of confounding factors such as temperature and pH.

- All measurement dates but one had CH₄ emissions ≤5 g C m⁻² d⁻¹. These data are about 10 times smaller than most emission rates from storage facilities in Southern Ontario reported by Wagner-Riddle et al. (CCFIA final report). Reasons for this difference might be explained by lower TSS contents in this study.

Compost

- Use of smaller-scale composting containers is needed to make inter-comparison between composting management practices. However, it is not clear whether conditions in small containers are representative of typical compost piles. It is difficult to reproduce in a 60 kg compost pile conditions found in a large commercial compost pile. For example, the density of material changes substantially with depth in a large compost pile. This increasing density with depth may in turn result in differences in N₂O and CH₄ dynamics.

- During scientific experiments, it is never easy to reproduce conditions representative of commercial farms. In this study, manure in tank A, B and C likely differed from the raw manure evacuated from the swine barn because part of the liquid fraction of tanks A and B were pumped in tank C. This has most probably resulted in more concentrated manure in tanks A and B and more diluted manure in tank C. Manure properties during trial 2 (high-protein) and 3 (low-protein) were substantially different. For example, TSS ranged between 0.6 to 26 g/L in trial 2 and between 2.3 and 40.7 g/L in trial 3. It is difficult to separate the contribution of diets to these differences from that of other factors such as climatic (summer vs fall) influence water consumption. Low TSS slurry contents such as in trial 2 are not often found on commercial farms.

- N₂O emissions from compost were 0.6 and 1.0 g N m⁻² d⁻¹. It would be most interesting to express emissions in fraction of total N lost as N₂O. If we assume that the vessel was a cube, then each face = 0.3 m². Losses of N₂O-N were 0.2 to 0.33 g N d⁻¹ per vessel or 6 to 10 g N per vessel during the composting period (30 d). There was 60 kg of compost at 0.3% N for 0.18 kg N per vessel; 6 gN₂O-N/180 g total N and 10 g N₂O-N/180 g total N = 3.3 and 5.5% loss respectively. These values are in the high range of N₂O losses reported during composting (0.1 to 5%). There is a need to identify composting methodologies that minimise N₂O production.

- Can it be ruled out that differences in temperature during storage of manure from low- and high-protein rations may have influenced GHG emissions?
**Improved Greenhouse Gas Emission Estimates from Manure Storage Systems**  
*Claudia Wagner-Riddle et al., University of Guelph*

**Objectives**
- To quantify N$_2$O and CH$_4$ emissions from manure storage systems in situ;
- To examine the feasibility of using an air dispersion model (AGMOD) to obtain greenhouse gas emissions from livestock confinement facilities;
- To convert measured greenhouse gas emissions to emission factors and compare these with IPCC emission factor estimates.

**Research Progress**
- Abundant information was provided on CH$_4$ emissions from the five farms. The continuous monitoring of the emissions over several seasons allowed researchers to quantify the effect of slurry temperature on CH$_4$ production. The effects of other slurry driving variables on fermentation rates were also studied. The possible impact of the presence of a crust at the surface of the slurry on CH$_4$ oxidation was particularly interesting.
- It is concluded that IPCC default emissions coefficients overestimated CH$_4$ emissions from swine manure as stored under Southern Ontario conditions. N$_2$O emissions were also overestimated using IPCC coefficients.
- The mass balance method was used at two swine barns to measure N$_2$O and CH$_4$ emissions from these buildings.
- The assumption of well-mixed conditions inside the barns was confirmed by tests.
- In addition to providing GHG emission rates per animal during production, this study has yielded interesting observations:
  - A strong diurnal pattern in the emission rates of the two gases, with CH$_4$ lagging behind N$_2$O.
  - These two observations suggest that both gases are largely controlled by the same or correlated variables. A more in-depth discussion of the possible sources of these gases (animal vs. manure + bedding) would add to the value of this report.
- Gas flux measurements were used to validate flux estimates obtained using an air dispersion model at one of the two sites. Results were inconclusive but have helped at identifying critical factors that will require improvement in future tests.

**Knowledge Gaps**
- Most N$_2$O emissions were not significantly different from zero, with a few relatively large positive and negative fluxes. Apparently many of these upward and downward emissions appeared during the same periods (almost successively). More explanation is needed about how the conditions in the manure could change so rapidly regarding N$_2$O dynamics.
- More discussion is needed about how CH$_4$ oxidation in the crust could be high enough to result in a net downward flux as reported at the Bright site in 2003. One could argue that since methane tends to come out in a large gas bubble, a thin wet crust should not oxidise much methane.
- Several factors govern methane production and emission from slurry during storage. In this study, effects attributed to slurry temperature on CH$_4$ dynamics may also include confounding effects by other parameters such as depth and composition of manure, pH,
etc.

- Does the increase in CH$_4$ emissions observed at the time of slurry agitation consist of a real increase in CH$_4$ production or just a temporal increase in emissions that would be compensated for by a subsequent temporary decrease after agitation has stopped?
- Relationship between emission and ventilation rates. Is it meant here that total gas emissions from the barn over an extended period is proportional to ventilation or that only instantaneous fluxes are? Correlation with long-term emissions would mean that ventilation affects gas production rates while correlation with instantaneous fluxes would be much less useful as a predictive variable. Explanation of the effects of ventilation rates on the temporal pattern of emission rates is straightforward but effects of ventilation on gas production would require more discussion.
- Why would CH$_4$ emissions from slurry be related to wind speed? Methane is largely produced by fermentation occurring in the sediment layer at the bottom of the tank. Would wind affect methane emission by agitating the slurry?
- Comparison of CH$_4$ emissions from different sites is difficult because several governing variables may be different at each site. Methane emissions are the result of complex interactions between manure composition, depth and temperature. More information about these variables at each site would help interpret the CH$_4$ data. The expression of methane emission per unit volume (mg/m$^3$-s) rather than by unit area (mg/m$^2$-s) would also help, taking into account the differences in depth between sites.
- There are several situations when imperfect mixing of air inside animal housing should be expected. For example, dense cold winter air entering a livestock building tends to move toward the floor and displaces warm and moist air toward the ceiling. For this reason, a gas concentration gradient may be observed during the cold period of the year. Year-round monitoring of spatial patterns of GHG concentration inside buildings may be necessary to confirm that the assumption of well-mixed conditions inside barns is valid throughout the year.

**Effect of Diet on Enteric and Manure Pack Greenhouse Gas Emissions from a Feedlot**

*K. M. Wittenberg et al., University of Manitoba*

**Objective**

*Quantify GHG emissions from bedded manure packs in pens of feedlot steers fed isocaloric diets with two ratios of forage : grain over a 126 d feeding period.*

**Research progress**

- Emissions of GHG emissions from bedded manure are potentially high. This study provided information about a source of GHG for which very little is known.
- Diets had no impact on either manure C and N or GHG emissions.
- GHG fluxes and temperature of the manure pack varied along a transect across the manure packs.
- Total emissions of N$_2$O-N during the three periods were 180 g N per pen or approximately 11 g N per animal.
- Emissions from the manure pack in this study corresponded to approximately 50% of the emissions estimated by IPCC (Tier 1).
Knowledge Gaps
- Information on temporal variations within periods are required. A greater number of sampling dates with random location of the chamber would also provide information on small-scale variability of GHG fluxes from the manure pack.
- Conditions in large commercial feedlots likely differ from those of a smaller experimental pen. Estimation of GHG emissions from large feedlots will more likely be based on mathematical relationships between governing variables such as temperature, aeration, moisture and surface to volume ratio, than from direct extrapolation of gaseous emissions measurements made in small-scale experimental units.

Reduction of GHG Emissions from Dairy Production Systems and Poultry Manure and its Impact on Agricultural Sustainability

Part 1, Composting
Anthony Lau et al., University of British Columbia

Objective
To investigate greenhouse gas emissions from composting facilities and determine the operating conditions under which GHG emissions can be minimised.

Research Progress
- N$_2$O losses during composting were highly variable, confirming the high sensitivity of the gas producing processes to methodology and raw materials.
- Water content and use of an additive had no consistent impact on N$_2$O losses during composting.
- Authors developed and used a new lab-scale apparatus for studying the impacts of several variables on gas production and emission during composting.

Knowledge Gaps
- It is not clear why negative aeration resulted in much greater N$_2$O emissions than positive aeration.
- A full accounting of N$_2$O-N losses during composting will require monitoring during the full length of the process, including curing phase.
- Reporting cumulated N$_2$O losses during composting in % of the manure N would make comparison with other manure management options easier. Expression of N$_2$O emissions per unit of volume (m$^3$) of compost would also help. Interpretation of emissions per unit area (m$^2$) is difficult because compost piles have different geometry and surface to volume ratio.
- Monitoring changes in manure N and C during composting is necessary to understand effects of composting on gaseous emissions.
- When testing the effect of moisture on GHG emissions during composting, compaction or compost density should also be taken into account.
- Microbial processes that produce GHG in the composting pile are governed by complex interactions of several factors. Information on several variables including geometry, density, level of aeration, nature and amounts in C and N of both the manure and the added materials, and change in moisture content of compost piles during the process.
would be useful to compare results with data from other studies and to extrapolate results to commercial conditions.

**Part 2, Conserving Manure Nutrients – What Does it Do to Greenhouse Gas Emissions?**
*S. Bittman et al., AAFC Agassiz and University of British Columbia*

**Objective**
*To assess the impact of spring application of manure on grass, compared to standard application on bare corn land, on emissions of N₂O.*

**Research Progress**
- Results showed that spring application of slurry to grass reduced N₂O emissions by about 2 kg N ha⁻¹ compared to the standard application on bare corn land.
- Application to grass also decreases volatilisation of NH₃, making this option not only more acceptable for the environment but also an option to increase in manure N-use efficiency by the crops.

**Knowledge Gaps**
- Slurry was applied to the corn land several weeks before planting. It would be interesting to test if a later application of slurry when corn could uptake nitrogen more rapidly might also decrease N₂O emissions compared to the early spring application.
- Farmers apparently apply slurry to corn fields because of concerns about damage to grass and soil compaction. Adoption of this mitigation practice (early-spring application on grass) is therefore linked to the development of application methodology that would avoid these adverse effects on crops and soil.

**Reduction of Greenhouse Gas Emissions in Swine by Diet Manipulation**
*R.O. Ball et al., University of Alberta*

**Objective**
The objectives of these experiments were to determine the effect of reducing dietary protein on the gas emissions by sows and finishing pigs and on the excretion of nutrients. The latter was to serve as a basis for the calculation of greenhouse gas emissions from manure.

**Research progress**
- Mode efficient feeding strategies resulted in reduced excreted N at no extra cost compared to conventional practices.
- This mitigation practice is especially attractive to reduce greenhouse gas emissions as it offers advantages on both profitability and environmental impacts.

**Research Gaps**
- Feed carbon that is oxidised by farm animals and emitted as carbon dioxide was originally atmospheric CO₂ that had been fixed by crop photosynthesis. Respiration by animals is therefore just a recycling of atmospheric CO₂ and for this reason, is not included in the global greenhouse gas budget in agriculture.
- Reduced N excretion results in lower N$_2$O emissions downstream from the animal (storage, field). However, reductions in N$_2$O emissions should be estimated using IPCC emission factors for manure storage (nearly 0 for liquid and 2% for solid manure) rather than the extreme factors used by the authors (5 to 30%).

- Reduction in slurry volume is an important aspect for the producers. It reduces cost by decreasing manure storage capacity and volumes to haul and spread on land. Low-protein diets usually reduce the total volume of manure slurry produced. Studies in Europe have shown a significant reduction (25%) in manure volume. Report of the volume reduction obtained in this study would complement the information related to GHG emissions.

**GENERAL LIST OF KNOWLEDGE GAPS RELATIVE TO GHG PRODUCTION AND EMISSIONS FROM LIVESTOCK HOUSING AND MANURE (STORAGE AND LAND APPLICATION)**

- **Need to standardise measuring methodologies.** Understanding processes that govern GHG production and emission from manure is a challenging exercise that starts with reliable field measurements. Many of the measuring methods that are currently used are under development and rigorous assessment of their accuracy is often lacking.

- **Need to measure emissions over a wider range of situations.** GHG emissions from livestock confinement and manure storage are among the sources that have been least documented. Moreover, the large range in combinations of animal production types, housing, manure management, climate, feeding rations, etc. increases variability in GHG source intensity.

- The body of empirical measurements is greater for cattle, intermediate for pigs and least for poultry.

- We have more information on CH$_4$ than on N$_2$O emissions.

- GHG emissions from liquid manure have been more often studied than from solid manure and from pasture (dung and urine).

- Most manure treatments are not proposed solely for reduction in GHG emissions. We need to quantify emissions from emerging new treatment methodologies (including composting).

- We know the processes that produced GHG from manure and the variables that control their intensity. We need to go beyond conceptual models and develop operational models that will permit quantification of the emissions with a minimum dataset of input variables.

- Ideally, studies should consider all aspects of manure management (feed to field including farm operations + costs).
• A closer coupling between measurement and modelling efforts is required to develop better models (multi-disciplinary teams of scientists). Researchers must know the needs of modellers to include all relevant variables in their protocols; and modellers must be aware of the value and limitations of the experimental data when building their models.

• Reduction in GHG emissions should not be done at the expense of increasing another environmental issue. \( \text{NH}_3 \) losses should be included in GHG studies.
NUTRIENT BEST MANAGEMENT PRACTICES FOR THE REDUCTION OF GREENHOUSE GAS EMISSIONS

PROJECT LEADER:
David Burton
University of Manitoba and Nova Scotia Agricultural College

CCFIA GRANT:
$200,000

Developing N delivery strategies that support increased levels of productivity while reducing N\textsubscript{2}O emissions is a key objective in achieving national economic and environmental goals for the Canadian agricultural sector. This research determined the GHG impact of common nutrient and cropping management practices in five independent studies by measuring GHG emissions under different scenarios using vented static chambers.

STUDY SUMMARY

In Western Canada, many farmers prefer to apply N fertilizer in the fall rather than in the spring, however, moist soils increase the risk of loss of fall-applied N due to leaching and denitrification. The first study examined the interaction of factors influencing the efficiency of fall-banded N fertilizer. Field experiments were conducted in fall 2000 and 2001. Landscape position and fertilization treatment were examined, and N\textsubscript{2}O emissions measured. Delaying the banding of urea to late fall resulted in N use efficiencies equivalent to those from spring applications, while efficiencies at other times were reduced. Cumulative emissions of N\textsubscript{2}O also decreased. Overall, delayed fall-banding of N showed the potential to reduce N\textsubscript{2}O emissions, and increase fertilizer use efficiency and grain yields.

Excessive cereal crop residue (particularly oats) is an impediment to crop production due to its adverse effects on equipment and crop performance. As such, these residues are typically burned as a management practice. The objectives of the second study were to assess the potential of manure application and tillage practices to manage excessive crop residues, and how these methods influence GHG (N\textsubscript{2}O, CO\textsubscript{2}) emissions. Manure applied by a variety of techniques were examined in the fall and spring, and rates of soil respiration and N\textsubscript{2}O emissions were measured. Yield reductions associated with retaining residues on the surface were not observed. Greenhouse gas production from soil was stimulated by manure application but not tillage method. These results are in contrast to other studies that have observed higher N\textsubscript{2}O emissions following injection. Rates of N\textsubscript{2}O production were 3 to 4× higher in 2001, indicating the episodic nature and difficulty in measuring N\textsubscript{2}O emissions over a limited time period.

In a third study N\textsubscript{2}O emissions associated with the use of composted manure compared to inorganic fertilizer or liquid swine manure were evaluated. Flax, durum wheat and hulless barley were examined in rotation, and treated with liquid hog manure, chemical fertilizer or composted cattle manure (with or without side-banded urea). All N amendments
resulted in increased N₂O emissions, however observations were widely different between years. Emissions from the composted manure treatment were significantly lower than just manure or composted manure + urea, indicating that composting may provide a lower N₂O emitting nutrient source.

Potato production is one of the major agricultural activities in Atlantic Canada, receiving large amounts of N fertilizer. Elevated levels of NO₃-N in groundwater are therefore a major concern in the region. A fourth study examined split applications of N (as banded NH₄NO₃) to improve N use efficiency and to quantify N₂O emissions from potato production. Emissions of N₂O were lower than IPCC predicted levels and similarly episodic, observed to be higher early in the growing season but not at time of fertilization. Split N applications tended to result in lower emissions. Nitrous oxide emissions occurred primarily from potato hills while denitrification was greatest in furrows.

The fifth study examined potato production, but included solid or liquid swine manure as treatments in comparison to inorganic fertilizer (as banded NH₄NO₃). Late spring and early summer periods were observed to be the times of greatest N₂O fluxes. Solid manure resulted in lower N₂O emissions, coinciding with lower NO₃ levels in the manure source. Higher N₂O emissions were associated with treatments and times when soil NO₃ concentrations were elevated, therefore cropping systems that limit NO₃ accumulation will result in reduced N₂O emissions.

In general, N₂O emissions were shown to be variable from one year to the next and lower than the IPCC predicted levels. Time of year, landscape position, and wetter conditions influenced N₂O emissions. The variability in determining N₂O emissions from short-term studies was apparent.
PROJECT LEADER:
Donald L. Smith
McGill University

CCFIA GRANT:
$175,000

Removal of CO₂ from the atmosphere occurs mainly through photosynthesis. Experimentation with LCO’s has been shown to increase bacteria-to-plant signaling causing higher rates of photosynthesis, leading to increased biomass production. Coupled with this increase in plant material, deposition of this biomass in soils causes C to be sequestered from the atmosphere. Soil and cropping best management practices, such as no-tillage farming, also increase C sequestration, yet the associated soil moisture increase may enhance GHG emissions. From 2000 through 2003, this study examined the effects of N fertility rates and tillage practices on N₂O and CO₂ production, and C sequestration, in soil and plant systems in Eastern Canada. Three sites were studied: a multi-crop site growing soybean, corn, sorghum, red clover and timothy; a switchgrass site; and a long-term corn site. The first two sites were extensively studied for all parameters, while the long-term site was mainly examined for changes in C over the past 12 years. Estimating the amounts of biomass for biofuel production and establishing a research expert group in Eastern Canada, were secondary goals.

STUDY SUMMARY

The use of LCO’s on soybean rarely affected the photosynthetic rate when comparing different tillage systems. However, under conventional tillage, LCO use resulted in greater yields. Higher N₂O fluxes were observed in soybean under conventional tillage, yet tillage system did not significantly affect CO₂ flux in any year. Nitrous oxide flux was greatest for corn at the multi-crop site at the recommended N fertilization rate, and in 2003 under the no-tillage system until July. A similar trend was observed for CO₂ flux under the no-tillage system, however CO₂ emissions were lower at the recommended fertilizer rate. The only difference in yield occurred for sorghum and corn under no-tillage, presumably due to enhanced soil moisture. This improved N efficiency would remove excessive N as a potential source for N₂O emissions. Due to greater exposure to C inputs (e.g. rhizodepositions and root turnover), higher levels of soil biological activity and a lack of annual tillage, the perennial crops exhibited higher C sequestered soil amounts.

Data for the long-term corn site were limited to 2003 due to drought conditions in previous years. Both N₂O and CO₂ fluxes were higher under conventional tillage. However, N₂O fluxes were higher and CO₂ fluxes were lower where crop residues were removed. Further results regarding soil C sequestration were not reported.

This research endeavour supports the adoption of cropping best management practices in
an Eastern Canadian context. In general, LCO use, maximizing N use efficiency, retaining crop residues on field surfaces and adopting reduced tillage practices, will help to limit the emission of GHG’s. Carbon sequestration in plant biomass and soil was also exhibited, but should be examined on a system wide basis, since it is reflective of both quantity and quality of crop residues and their effects on C sequestration, organic matter levels and GHG emissions.
QUANTIFYING N₂O FLUXES ASSOCIATED WITH AGRICULTURAL PRACTICES IN NON-LEVEL PRAIRIE LANDSCAPES

PROJECT LEADER:
Richard Farrell
University of Saskatchewan

CCFIA GRANT:
$177,000

National estimates of GHG emissions in Canada are based on the IPCC assumption that 1.25% of the N fertilizer used in agriculture is released as N₂O. This is debatable as extrapolation of N₂O flux estimates derived from level and homogenous landscapes to non-level landscapes are unreliable. Landscape-scale studies of N₂O production and emissions use spatial sampling designs based on large-scale factors, such as topography, successional plant communities, soil texture and drainage, vegetation and land-use practices. This study examined the effect of topography, hummocky Prairie terrain in particular, on N₂O emission following application of liquid swine manure or conventional N-fertilizer (as urea), in conventional or no-tillage systems and forage or pasture systems.

STUDY SUMMARY

Fertility treatments were applied at 1× or 2× the recommended rate before seeding alfalfa in rotation with oat. Nitrous oxide fluxes were collected from non-steady state, vented chambers. Results were up-scaled using a ‘measure and multiply’ approach to estimate total N₂O-N flux as well as N₂O emission factors for both liquid swine manure and urea fertilizer.

The N₂O emissions were lower than anticipated, attributed to an extreme drought experienced in Western Canada from late summer 2000 through 2003. In 2001 and 2002, precipitation received during the month following seeding resulted in low crop yields and soil moisture conditions insufficient to stimulate N₂O emissions. In 2003, improved moisture and temperature conditions were experienced but data were not obtained for the entire growing season, and therefore cannot be compared to the other years.

Several trends were apparent even though conditions were very dry. Fluxes of N₂O exhibited a high degree of spatial and temporal variability. Highest fluxes corresponded to lower slope areas. Due to higher precipitation amounts, overall fluxes were much higher in 2002 compared to 2001. Also, emissions were higher in late spring/early summer and decreased as the growing season progressed. Higher emissions of N₂O were observed for conventional versus no-tillage plots, and for cropped (wheat, barley) versus pasture/forage plots. Two-year average N₂O fluxes from conventional tillage were more than double those from the pasture/forage plots. Observed trends were more evident in lower slope areas.

Fluxes of N₂O increased with increasing rates of applied N, but not N source. These observed flux trends were consistent both within and between years, and effects were
similarly more pronounced in lower slope areas. Calculated emission factors for both N sources were independent of N application rate, yet still low in comparison to the standard IPCC value of 1.25%. This suggests the need to modify the fertilizer N emission factors currently being applied to Western Canadian agriculture.
SITE-SPECIFIC APPLICATION OF FERTILIZER N FOR REDUCING GREENHOUSE GAS EMISSIONS

PROJECT LEADER:
Gary Kachanoski
University of Alberta

CCFIA GRANT:
$225,000

Crop requirements for N fertilizer vary significantly within agriculture fields, yet a constant rate of N is typically applied. Using satellite GPS, digital fertilizer requirement maps and computer controlled variable rate fertilizer applicators, N can be applied precisely within a field. The study determined the influence of site-specific application of N fertilizer on GHG emissions from fields in Alberta, Ontario and Quebec. Results were combined with ongoing soil and crop measurements at each site to validate working GHG flux models. All data were used to develop and test a stochastic spatial scale model and the hypothesis that crop yield response coefficients are related to cumulative N$_2$O gas flux coefficients as changes in applied N occur.

STUDY SUMMARY

In 2000, a potato site in Alberta with soil clay contents up to 50% was used. Greenhouse gas flux measurements were sampled using closed, vented, surface flux chambers. The site was seeded to wheat in 2001 and N fertilizer was applied at 0, 0.5, 1.0, 1.5 and 2.0× the recommended rate. Throughout the study, half of the plots received supplemental irrigation. Soil moisture, meteorological data and soil samples (for textural, N and C analysis) were obtained from each sampling location. Cumulative GHG flux was calculated and crop yields were obtained.

Surface soil properties, in particular texture, displayed significant spatial variation. This influenced distribution of crop yield and N$_2$O flux response to applied N fertilizer, suggesting site-specific application of fertilizer N would result in significant agronomic benefits. In addition, application of fertilizer in the fall can significantly increase the amount of early spring N$_2$O flux. Crop yield response increased with applied N, while N$_2$O flux increased exponentially, mainly after fertilization or irrigation events. Measurements of CO$_2$ flux showed no trend with N fertilizer application rates, timing or after irrigation events. Additional irrigation had no significant effect on either N$_2$O or CO$_2$ gas fluxes.

Cumulative N$_2$O flux increased as the soil N availability to crops increased attributed to nitrification. Excessive application of N above crop requirements resulted in greater N$_2$O fluxes in areas with initially high soil N tests. Evaluation of the stochastic model mimicked the measured data, indicating its flexibility and power to predict any scenario.

In Ontario in 2000, a corn site was similarly used to study the effect of slope position and fertilizer N rate on the emissions of N$_2$O and CO$_2$. Greater values of soil organic C,
moisture, and soil NO₃ were observed in lower slope positions. However, N₂O flux patterns were not detectable. In the following years, very dry growing conditions led to highly variable yields. Slope position affected the CO₂ flux from the soil. For N₂O, both slope position and N fertilization rate affected fluxes, with some erratic results.

A second corn site was established in 2002. Greatest yields were obtained from lower slope positions and higher rates of applied N. Total N₂O emissions mimicked this trend. This indicates the potential benefit of reducing N applications, though this may be a function of growing season conditions rather than soil/site conditions.

A Quebec corn site was also examined in 2000 and 2002. The availability of N did not appear to be the rate-limiting factor of N₂O production, since high overall N₂O fluxes were measured. Highest fluxes of N₂O were observed after precipitation events, supporting the observation that denitrification is not limited by N availability or soil type. These results indicate the need for multi-year flux monitoring to adequately assess results.

A significant outcome of the Alberta study was a spatial correlation between crop response to applied fertilizer N and cumulative N₂O flux, allowing development of a stochastic model. The model predicted that site-specific application of N would reduce N₂O flux from field locations with lower soil fertility, yet increase flux from more fertile locations. Model predictions at the Ontario and Quebec sites were unclear. Highest fluxes of N₂O occurred in early summer following N application at all sites, as opposed to the spring. Year to year weather variability significantly affected flux emissions. Soil CO₂ flux rates were not related to applied N, yet were related to slope position and other soil properties. Overall, knowledge of just the field average soil N test is not sufficient to make an accurate fertilizer recommendation, especially for fields with high spatial variability.
The following summary report is based on the final reports of Burton et al., Smith et al., Farrell et al. and Kachanoski et al., which were submitted to the CCFIA. All submissions reported on results of field-based nitrous oxide flux (N\textsubscript{2}O) measurements in relation to some aspect of crop production. Although other research topics were also addressed in some reports, only the N\textsubscript{2}O components will be considered here. A very brief synopsis of the results from each project is provided followed by a short discussion.

**Synopsis of Reports**

Burton et al. reported on 5 separate field experiments. The first three studies were located in southern Manitoba, and included a study that compared fertilizer use efficiency (FUE) and N\textsubscript{2}O emissions from spring applied N to fertilizer N applied in early, mid and late fall on low and high landscape positions. Results from the two site years presented suggest a trend for FUE to increase and for N\textsubscript{2}O emissions to decrease with the later fall application dates – particularly in lower landscape positions. Nitrous oxide emissions from N applied on the late fall date did not differ from the check. They also studied the influence of fall tillage and manure applications on fall and spring soil respiration and N\textsubscript{2}O production. Manure applications increased both respiration and N\textsubscript{2}O emissions compared to inorganic N applications, but there were few significant differences between tillage systems. Of particular note was the lack of difference between injected and surface applied hog manure. A third study compared spring applied liquid hog manure, composted cattle manure, urea, a composted cattle manure-urea combination, and a check (no N). In general, N\textsubscript{2}O emissions were highest from the liquid hog manure and the composted cattle manure plus urea treatments, although the differences were often not statistically significant.

The final two studies considered potato production in Atlantic Canada. One study quantified N\textsubscript{2}O emissions from two different N management methods. The results indicate that emissions from potato production are low – considerably lower than the 1.25% loss coefficient currently used in national inventory calculations. Neither banding N at seeding time, or splitting the N applications significantly reduced N\textsubscript{2}O emissions compared to broadcasting N at seeding. The final study compared N\textsubscript{2}O emissions from potato and barley crops fertilized with inorganic N, liquid and solid hog manure applied in spring as well as solid hog manure applied in the fall. Emissions were lower during the barley compared to the potato phase, and N\textsubscript{2}O emissions were similar or lower from plots receiving solid manure compared to liquid hog manure and inorganic N.

Farrell et al. reported results of two years of measurements at a site located on hummocky terrain in central Saskatchewan. Treatments included two rates of urea and injected liquid...
hog manure on conventional (CT) and minimum tillage (MT) systems, and fertilized and unfertilized (inoculated) alfalfa. Urea and manure were applied at 1x and 2x the recommended rate. All treatment combinations were overlaid on upper, mid and lower slope positions so that the influence of topography could be considered. In general, N\textsubscript{2}O emissions from CT > MT > Forage with CT being significantly different from MT and forage. In terms of N source, N\textsubscript{2}O emissions were greatest from the 2x urea treatment, similar for the 1x urea and both manure treatments, and generally lowest from the inoculated alfalfa (N supplied by biological N-fixation). Emissions were lowest on the upper slope positions. Emissions from the mid-slope position were either similar or lower than on the lower slope positions. The influence of management on N\textsubscript{2}O emissions was more clearly expressed on the lower slope positions.

Smith et al. reported on N\textsubscript{2}O and CO\textsubscript{2} measurements taken on two sites in Quebec, referred to as the multi-crop and long-term sites, as well as soil organic carbon measurements at the multi-crop site. The authors note that soil organic carbon (SOC) levels under perennial systems (red clover and timothy) were higher compared to annual systems in 2003. This is indeed true, however this reader also notes that initial SOC status on the corn phase was significantly lower than the perennial systems, and that the relative change in SOC status between 2001 and 2003 for the corn treatment appears comparable to the change in the perennial systems. Inferences based on measured SOC status over a three year interval need to be viewed with great caution.

At the multi-crop site, the authors report a significant increase in N\textsubscript{2}O emissions due to fertilizer application, and a trend for emissions to be higher on NT compared to CT under corn, but emissions were higher on CT compared to NT for soybean. This reader also notes that soybean systems appear to have lower emissions compared to corn. At the long-term site N\textsubscript{2}O emissions were significantly higher on CT compared to NT systems. Emissions were reduced when residues were retained rather than removed.

Kachanoski et al. reported on studies in Ontario, Quebec and Alberta. The Ontario study investigated the influence of slope and fertilizer N rate. In 2001, N\textsubscript{2}O losses tended to increase from mid-slope to knoll to depression, but the only significant difference was between the mid-slope and the depression. In general, increasing fertilizer N rates increased estimated N\textsubscript{2}O losses, although the trend had some reversals. There was no significant slope by N-rate interaction. Nitrous oxide emissions were not affected by either fertilizer N-rate or slope position during the 2002 growing season. Conversely, N\textsubscript{2}O emissions were significantly affected by fertilizer N rate and slope position at a second site included in 2002. There was a significant interaction between slope and N-rate in that N\textsubscript{2}O emissions increased linearly as fertilizer N-rate increased from 0, through 50, 100, 150 and 200 kg N ha\textsuperscript{-1} on both the mid-slope and depression, but emissions leveled off after 100 kg N on the knoll.

The Quebec study quantified N\textsubscript{2}O emissions on corn fields with three different textures (sandy loam, clay loam and clay) and two rates (150 & 250 kg N ha\textsuperscript{-1}) of anhydrous ammonia (AA). Emissions tended to be higher on treatments receiving 250 compared to 150 kg of fertilizer N; however the difference was not statistically significant. Soil type significantly influenced N\textsubscript{2}O emissions before but not after fertilizer N application.
Emissions measured after rainfall events appeared to be unusually high, and the authors speculate that AA may produce higher losses of N₂O than other forms of fertilizer N.

The experimental design at the Alberta site allowed investigators to explore crop yield and N₂O emissions response to fertilizer N rate (0, 40, 80, 120, 160 kg ha⁻¹) and soil characteristics such as water content, texture, total N, total C, and spring and fall nitrate (NO₃-N) status. This information was then utilized to develop a stochastic spatial averaging model to predict N₂O emissions as a function of fertilizer N application and spring soil test NO₃-N.

Several extremely interesting observations were reported in this work. Firstly, sampling locations within the field could be classified according to very specific yield response behavior. High baseline yields with low yield response, low baseline yields with high yield response, intermediate baseline yield with either intermediate yield response or no response. Nitrous oxide emissions response closely paralleled yield response patterns. The authors concluded that response patterns of yield and N₂O emissions were a reflection of inherent differences in soil fertility status (N availability). Assuming a similar management history across this study site, then these differences must be related to soil characteristics. It would be of great interest to see if similar differences may also exist between fields as a result of contrasting management histories.

**DISCUSSION**

National estimates of N₂O loss from agricultural activities are calculated assuming that 1.25% of fertilizer N applied is lost directly as N₂O (Neitzert et al. 1999). Table 1 shows percent loss estimates that were constructed from data presented in the Kachanoski et al., Burton et al., and Farrell et al. reports. These loss estimates have a very wide range that brackets the 1.25% value, but for the P.E.I. and Saskatchewan sites percent loss estimates fall well below the 1.25 value. Values from the latter site are in close agreement with recently completed work from Manitoba and Saskatchewan comparing N₂O emissions from differing combinations of fertilizer N placement, timing and formulation (Burton et al. 2003; Lemke et al. 2003). Percent loss estimates in these studies ranged from 0.1 to 1.0%, but the preponderance of values were at or below 0.5%. For example, selected results from the Saskatchewan study are presented in Table 2. In the semi-arid areas of western Canada it appears that the 1.25% loss coefficient may be an over-estimate, however the reverse appears to be true for many other parts of the country.

A simple comparison of cumulative N₂O loss versus fertilizer N input levels presented in Table 1 suggests that factors other than N input level strongly govern cumulative N₂O loss. There appears to be a general concurrence between N₂O emissions and growing season precipitation levels. Highest emissions reported occurred at the irrigated site in Alberta, while many of the lowest were reported from the Saskatchewan site. It would have been useful if all studies had provided an indication of actual growing season precipitation. For example, both Kachanoski et al. (Ontario location) and Farrell et al. (Saskatchewan location) indicate that drought conditions were encountered in 2001. About 230 mm of rainfall was received at the Ontario site while only about 89 mm of rainfall was received at the Saskatchewan site. While “drought” is a legitimate term in both instances (relative to
long-term means), actual rainfall values help the reader put the N$_2$O losses reported into a clearer context. Considering the actual rainfall levels, it is no great surprise that emissions were lower at the Saskatchewan compared to the Ontario location.

**Table 1.** Estimated percentage of fertilizer N lost as N$_2$O from studies reported to the CCFIA program. Estimates were constructed from data presented in the reports.

<table>
<thead>
<tr>
<th>Report</th>
<th>Location</th>
<th>Crop</th>
<th>Fertilizer N (kg ha$^{-1}$)</th>
<th>N$_2$O-N (kg ha$^{-1}$)</th>
<th>% loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burton</td>
<td>PEI</td>
<td>Potato</td>
<td>120</td>
<td>0.61</td>
<td>&lt;0.5  *</td>
</tr>
<tr>
<td>Burton</td>
<td>PEI</td>
<td>Potato</td>
<td>120</td>
<td>1.23</td>
<td>1.0</td>
</tr>
<tr>
<td>Burton</td>
<td>PEI</td>
<td>Barley</td>
<td>120</td>
<td>0.12</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Burton</td>
<td>Brandon</td>
<td>Durum</td>
<td>110</td>
<td>3.67</td>
<td>1.3</td>
</tr>
<tr>
<td>Burton</td>
<td>Brandon</td>
<td>Barley</td>
<td>75</td>
<td>1.30</td>
<td>1.1</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Alberta</td>
<td>Wheat</td>
<td>40</td>
<td>1.72</td>
<td>-1.1</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Alberta</td>
<td>Wheat</td>
<td>80</td>
<td>3.55</td>
<td>1.8</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Alberta</td>
<td>Wheat</td>
<td>120</td>
<td>4.60</td>
<td>2.0</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Alberta</td>
<td>Wheat</td>
<td>160</td>
<td>11.96</td>
<td>6.1</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Ontario</td>
<td>Corn</td>
<td>37</td>
<td>1.28</td>
<td>&lt;3.5</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Ontario</td>
<td>Corn</td>
<td>71</td>
<td>1.64</td>
<td>&lt;2.3</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Ontario</td>
<td>Corn</td>
<td>104</td>
<td>1.28</td>
<td>&lt;1.2</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Ontario</td>
<td>Corn</td>
<td>185</td>
<td>1.94</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Quebec</td>
<td>Corn</td>
<td>150</td>
<td>4.9</td>
<td>&lt;3.3</td>
</tr>
<tr>
<td>Kachanoski</td>
<td>Quebec</td>
<td>Corn</td>
<td>250</td>
<td>6.1</td>
<td>&lt;2.4</td>
</tr>
<tr>
<td>Farrell</td>
<td>Saskatchewan</td>
<td>Wheat</td>
<td>60</td>
<td>0.08</td>
<td>0.1</td>
</tr>
<tr>
<td>Farrell</td>
<td>Saskatchewan</td>
<td>Wheat</td>
<td>120</td>
<td>0.38</td>
<td>0.3</td>
</tr>
<tr>
<td>Farrell</td>
<td>Saskatchewan</td>
<td>Barley</td>
<td>60</td>
<td>0.14</td>
<td>0.2</td>
</tr>
<tr>
<td>Farrell</td>
<td>Saskatchewan</td>
<td>Barley</td>
<td>120</td>
<td>0.32</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* values designated with a “<” indicate that no control (no N applied) treatment was present and all emissions were attributed to the N application. This undoubtedly overestimates the true percent of fertilizer-N lost as N$_2$O.
Based on the relatively high N$_2$O emissions observed at the Quebec location, Kachanoski et al. speculated that emissions may be higher from anhydrous ammonia (AA) compared to other sources of fertilizer-N. However, the percent loss estimates (constructed from data presented in the report) do not appear out of range with values presented for the Alberta or Ontario locations in the same study, although the authors do note that emissions were very high on the final sampling day, therefore flux estimates were almost certainly understated. Inspection of Table 2 reveals no apparent difference in N$_2$O loss from anhydrous ammonia compared to urea reported by Lemke et al. (2003). In addition to lower rainfall regimes, the latter study had a maximum N application rate of 120 kg ha$^{-1}$. It is possible that N$_2$O loss increases for AA at higher rates. Certainly more study regarding relative N$_2$O loss from various fertilizer N sources is warranted.

Currently, a similar N$_2$O emission is assumed for all nitrogen sources whether the N is applied as commercial (inorganic) fertilizer, livestock manures, N in crop residues or fixed biologically by legume crops. Table 3 presents percent loss estimates that were either reported or have been constructed from data presented in the Burton et al. and Farrell et al. reports. Inventory calculations assume that 20% of the total N applied in manure is lost as volatilization, and that 1.25% of the remaining 80% of total N is lost as N$_2$O in the first year. Burton et al. assumed that only 15% of the N contained in compost would be available to the crop in the first year. Thus, in order to supply 110 kg N the total amount of N applied must have been about 733 kg. Using the inventory calculation, this would have resulted in an estimated direct N$_2$O-N loss of 7.3 kg. This compares to an actual measured loss of 0.5 and 1.1 kg N$_2$O-N lost for 2000 and 2001, respectively. The impact that this compost addition will have on future year emissions, the possible impact of consecutive applications and, the N$_2$O loss during the composting operation needs to be given careful consideration before any conclusions can be drawn. However, this data certainly indicates that assumptions made for inventory calculations to estimate N$_2$O from manure applications needs much more evaluation.

Table 2. Percent of fertilizer N lost as N$_2$O loss (mean of 3 years) from selected treatments at four Saskatchewan sites. (Source: Lemke et al. 2003)

<table>
<thead>
<tr>
<th>N management</th>
<th>Swift Current</th>
<th>Scott</th>
<th>Star City</th>
<th>Indian Head</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anhydrous Ammonia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall banded</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Mid-row (spring)</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Urea</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall band</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Mid-row (spring)</td>
<td>0.3</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Overall Mean</strong></td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Inventory calculations also currently assume two separate emissions associated with legume crops. One is based on the N content of legume residues returned to the soil, and a second is based on the amount of N “fixed” by the leguminous crops. Several observations reported in the current studies speak to the latter point. Farrell et al. reported significantly higher N\textsubscript{2}O emissions from plots seeded to alfalfa and fertilized with urea or liquid hog manure applied at recommended rates compared to plots where alfalfa had been inoculated (no N applied). Smith et al. noted a similar trend where N\textsubscript{2}O emissions tended to be higher from corn (fertilizer-N) compared to soybean (biologically fixed-N). Assuming that the amount of N fixed biologically was similar to the N applied, then these observations imply that N\textsubscript{2}O emissions related to biologically fixed N (if they occur) may be less than from inorganic N applications. However, reductions realized by growing legumes could quickly be outweighed by increased N\textsubscript{2}O loss associated with the decomposition of the legume residues in subsequent years. The entire cropping system must be assessed before any firm conclusions can be drawn, however this data does suggest that current N\textsubscript{2}O estimates for legume crops may be overestimated.

Smith et al. observed that “treatments with the crop residues left on the field generally had lower rates of N\textsubscript{2}O emissions than those with the crop residues removed”. This observation is consistent with results of Hao et al. (2001), who observed higher N\textsubscript{2}O emissions from field plots with cereal crop residues removed compared to plots with residues retained. These observations run contrary to current inventory calculations which treat the N in crop residues as a source of N\textsubscript{2}O, i.e. crop residues would increase N\textsubscript{2}O emissions. Assuming that cereal crop residues are an additional source of N\textsubscript{2}O may result in an over-estimate of N\textsubscript{2}O loss for many situations.

Helgason et al. (2003) recently completed a review of available Canadian data comparing tillage systems. Their data set contained 87 comparisons. Emissions from no-tilled (NT) soils were less than those under conventional tillage in about half of the observations (56%), while the opposite was true for 39% of the comparisons. For western Canadian sites, about 63% of comparisons showed NT to have lower emissions than tillage based systems, while in eastern Canada, about 66% of the comparisons showed NT to have higher emissions. They concluded that “…tillage does have an influence, but the magnitude and sign of that effect is highly inconsistent, depending on interacting influences....” In the current studies, Farrell et al. observed that N\textsubscript{2}O emissions on conventional till treatments were higher than on reduced till treatments. Similarly, Smith et al. observed that N\textsubscript{2}O emissions were higher on conventional compared to NT treatments on both the Multi-Crop and Long-Term sites, although some reversals were also noted. Evidence suggesting similar or lower N\textsubscript{2}O emissions from NT systems in western Canada continues to accumulate, but the evidence points to a real need to understand the “interacting influences” before we can claim any degree of confidence in predicting the influence of tillage on N\textsubscript{2}O emissions.
Table 3. Estimated percentage of manure N lost as N\textsubscript{2}O from studies reported to the CCFIA program. Estimates were constructed from data presented in the reports.

<table>
<thead>
<tr>
<th>Report</th>
<th>Location</th>
<th>Crop</th>
<th>Manure Type</th>
<th>N applied (kg ha(^{-1}))</th>
<th>N\textsubscript{2}O-N (kg ha(^{-1}))</th>
<th>% N lost as N\textsubscript{2}O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burton</td>
<td>P.E.I.</td>
<td>Potato</td>
<td>solid hog</td>
<td>120</td>
<td>0.42</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>Burton</td>
<td>P.E.I.</td>
<td>Potato</td>
<td>liquid hog</td>
<td>120</td>
<td>0.61</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Burton</td>
<td>P.E.I.</td>
<td>Barley</td>
<td>solid hog</td>
<td>120</td>
<td>0.15</td>
<td>&lt;0.1</td>
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<tr>
<td>Burton</td>
<td>P.E.I.</td>
<td>Barley</td>
<td>liquid hog</td>
<td>120</td>
<td>0.20</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Burton</td>
<td>Manitoba</td>
<td>Durum</td>
<td>liquid hog</td>
<td>110</td>
<td>3.49</td>
<td>2.4</td>
</tr>
<tr>
<td>Burton</td>
<td>Manitoba</td>
<td>Durum</td>
<td>compost + urea</td>
<td>110</td>
<td>2.34</td>
<td>1.4</td>
</tr>
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<td>Manitoba</td>
<td>Durum</td>
<td>compost</td>
<td>110</td>
<td>1.35</td>
<td>0.5</td>
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<td>Barley</td>
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<td>75</td>
<td>2.59</td>
<td>1.2</td>
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<td>Burton</td>
<td>Manitoba</td>
<td>Barley</td>
<td>compost + urea</td>
<td>75</td>
<td>1.37</td>
<td>2.8</td>
</tr>
<tr>
<td>Burton</td>
<td>Manitoba</td>
<td>Barley</td>
<td>compost</td>
<td>75</td>
<td>1.30</td>
<td>1.2</td>
</tr>
<tr>
<td>Farrell</td>
<td>Saskatchewan</td>
<td>Wheat</td>
<td>liquid hog</td>
<td>60</td>
<td>0.04</td>
<td>0.0</td>
</tr>
<tr>
<td>Farrell</td>
<td>Saskatchewan</td>
<td>Wheat</td>
<td>liquid hog</td>
<td>120</td>
<td>0.05</td>
<td>0.0</td>
</tr>
<tr>
<td>Farrell</td>
<td>Saskatchewan</td>
<td>Barley</td>
<td>liquid hog</td>
<td>60</td>
<td>0.13</td>
<td>0.1</td>
</tr>
<tr>
<td>Farrell</td>
<td>Saskatchewan</td>
<td>Barley</td>
<td>liquid hog</td>
<td>120</td>
<td>0.35</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Previous work [e.g. Corre et al., (1996)] has pointed to the importance of topography on N\textsubscript{2}O emissions. Work reported herein has extended this by providing data collected from topographic positions under a broader range of cropping-climate-soil combinations. Based on observations reported from the current studies and other recent work, a few consistent trends can be noted. Upper slope positions generally have the lowest N\textsubscript{2}O emissions and lower slope positions often have the highest. Mid-slope positions, however, show a complex response. Emissions from the mid-slope can be higher or similar to upper slope positions, and lower, similar or in some cases higher than the lower slope positions. In general, treatment effects (e.g. fertilizer N rates) tend to be expressed more strongly on the lower slope positions. Thus the risk of increased N\textsubscript{2}O loss due to poorly managed N applications appears to be greater for lower slope positions.

Lastly, Kachanoski et al. have clearly shown that the influence of site-specific or variable rate fertilizer N applications on N\textsubscript{2}O emissions is complex. Under the conditions of their experiment, N\textsubscript{2}O emissions increased markedly when fertilizer-N application rates exceeded local crop requirements – reinforcing the notion that to minimize N\textsubscript{2}O emissions
fertilizer-N application must be carefully matched to crop needs. However, the authors concluded that site-specific N application could modestly reduce N\textsubscript{2}O compared to field average application on fields with low to moderate soil fertility, but could significantly increase N\textsubscript{2}O emissions on fields with high soil fertility. Clearly the question of how to minimize N\textsubscript{2}O emissions while at the same time maximizing crop production is not straightforward, and will require considerable additional investigation.

Relatively uniform methodologies (vented non-steady state) were employed at most sites. This allowed across site comparisons of flux values with reasonable confidence. Kachanoski et al. utilized a photo-acoustic gas monitor at their Alberta location. Although not without its limitations, this recent technology appears to have much promise for process level N\textsubscript{2}O studies. It would be desirable to determine (verify?) the comparability of the photo-acoustic and chamber-GC methods.

Currently, linear interpretation between sampling dates is used to estimate cumulative N\textsubscript{2}O loss over a season or year. Choices regarding sampling density (number of sampling days per season) and the temporal distribution (e.g. sampling schedule that is “event triggered” vs. fixed routine) of those sampling days likely has a substantial impact on the cumulative estimate generated. While quantifying the impact of these scheduling choices remains to be determined, it is still helpful for the reader to be provided with details of the sampling schedule employed, particularly when comparing across sites and/or studies. Clearly, N\textsubscript{2}O sampling technology that provides continuous measurement on a scale small enough to be applied to process level studies would advance the science tremendously.

**Summary**

The four reports discussed in this summary have provided additional evidence in support of some established, but still preliminary, conclusions. Firstly, at least for western Canada, N\textsubscript{2}O emissions tend to remain similar or lower when tillage intensity is reduced. Secondly, N\textsubscript{2}O loss coefficients from fertilizer-N use in western Canada appear to be lower than the coefficient currently used in inventory calculations, although emissions may be underestimated for more humid regions. Thirdly, fall application of fertilizer N can increase the risk of “spring” N\textsubscript{2}O loss, but application very close to soil freeze-up might reduce or even eliminate this risk. Fourthly, N\textsubscript{2}O emissions tend to be lower from crops that “fix” their own N (legumes) compared to those receiving fertilizer-N or manure applications. Lastly, topography strongly influences N\textsubscript{2}O loss. Emissions tend to be lowest from upper (convex) positions and highest from lower (concave) positions. The work also demonstrated that emissions patterns from mid-slope positions are complex, and that the factors controlling these emissions are poorly understood.

Results presented in these reports tended to confirm that fertilizer-N applications applied in excess of crop needs increases the risk of enhanced N\textsubscript{2}O emissions. However, the work also demonstrated the complexity of N\textsubscript{2}O emission response to fertilizer-N application. No clear picture has yet emerged as to how best to determine the optimal rate of fertilizer-N in regard to both crop production and N\textsubscript{2}O emissions.
REFERENCES


DOCUMENTING THE IMPACT OF A REDUCTION IN TILLAGE ON THE AMOUNT OF C SEQUESTERED, THE STABILITY OF SEQUESTERED C AND EMISSIONS OF N\textsubscript{2}O UNDER CORN/CEREAL/SOYBEAN ROTATIONS IN ONTARIO

**PROJECT LEADER:**
Bev Kay
University of Guelph

**CCFIA GRANT:**
$350,000

Studies focused on C sequestration have been limited to the effect of CT versus NT practices. This study examined the extent of C sequestration on long-term NT soils of different textures and landscape positions. In addition, the ease with which C is lost to the atmosphere once tillage is reintroduced, as well as the amount of N\textsubscript{2}O that is emitted from a fine textured soil under NT, were examined.

**STUDY SUMMARY**

Eight sites in Ontario that represented a range of soil and landscape conditions, and on which corn had been growing using NT, were studied. Soil samples were collected from the top 60 cm of the profile.

Tillage had no effect on total corn stover C production during the 11-year study. No-tillage plots had more soil organic C in the upper layers (0 to 15 cm), while no differences were noted in the lower layers. The effect of tillage treatment on SOC distribution varied. The amount of C sequestered was strongly dependent on initial SOC content.

The rate of loss of C when NT sites were reverted to CT for one year was determined. Two of the sites were used for this study. A significant decrease of SOC was observed in the top 5 cm of the soil profile. This loss of SOC in a NT area with a single tillage event raises concerns about accurately assessing the effects of soil management at broad regional, provincial, and national levels. Early in the season, fluxes of CO\textsubscript{2} were higher in the plowed soils. These increased emissions however were short-lived (<60 days). Nitrous oxide fluxes were similar in both tillage systems.

Tillage sites established in 1983 were split in half in 1996. This was done to determine the CO\textsubscript{2} and N\textsubscript{2}O fluxes from new tillage treatments (5 to 6 years) or established (18 to 19 years) NT or CT treatments. In both years there were drought periods, which influenced CO\textsubscript{2} and N\textsubscript{2}O emissions. Nitrous oxide emissions were fairly low (<50g N\textsubscript{2}O ha\textsuperscript{-1} d\textsuperscript{-1}) for all treatments from April through the middle of the growing season, due to dry conditions. In general, N\textsubscript{2}O emissions were 10 to 15% lower in NT plots. Carbon dioxide emissions were similar for all treatments, except CT following Kentucky bluegrass.

The sequestration of C under NT was strongly dependent on initial SOC content. The impact of plowing NT soils was not consistent among soils. Results of this study raise
questions regarding the validity of national inventories of the potential of soil to sequester soil C that ignore the variable amount of redistribution of soil that has occurred in the agricultural landscape.
GREENHOUSE GAS EMISSIONS FROM CONSTRUCTED AND NATURAL WETLAND SYSTEMS

PROJECT LEADER:
Robert Gordon
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CCFIA GRANT:
$135,000

Constructed wetland systems pose an economical and low maintenance approach to wastewater treatment. The purpose of constructed wetlands in an agricultural context has involved their performance in relation to water quality management. Their role as either GHG ‘sinks’ or possible ‘sources’ has largely been unaddressed. An additional difficulty with many previous studies is that they have attempted to quantify only a single GHG. Few studies have attempted to quantify each of the major agricultural GHG’s with high precision. The goal of this study was to quantify GHG emissions from constructed wetlands treating dairy wastewater in an effort to evaluate their GHG ‘source’ or ‘sink’ status.

STUDY SUMMARY

Six pilot scale operational wetlands were established in Nova Scotia. These wetlands include both shallow and deep zones, similar to large-scale operational wetlands. Each wetland was constructed as a partially closed system with removable covers. The wetlands were automatically loaded with dairy wastewater (i.e. dairy parlour washwater and manure runoff) from a single storage tank to ensure a consistent influent. Four of the wetlands were planted with aquatic vegetation (cattail, Typha sp.) in the fall of 2003, while the remaining systems were free of vegetation. Typical wastewater loading rates were maintained for three wetlands and double the loading rate for the remainder. Water samples were taken on a weekly basis from the influent and effluent. Carbon dioxide, CH$_4$, and N$_2$O were simultaneously measured within each wetland using a tunable diode laser trace gas analyzer system.

Water quality analyses showed decreases in the wastewater parameters measured at the outlet. The age of the wetlands limited their ability to treat the wastewater to the extent necessary to meet typical discharge guidelines. The wetlands loaded at the conventional rate and containing aquatic vegetation (plant cover approximately 100%) showed consistent CO$_2$ fluxes with each other (typically within 5%). Both wetlands were considerable overall CO$_2$ ‘sinks’. During the sampling period, the average CH$_4$ flux from these wetlands was approximately half the flux observed in the others. This indicates a strong link between CH$_4$ emissions, vegetation and wastewater strength. The wetland loaded at a conventional rate without vegetation consistently had net positive CO$_2$ emissions. All wetlands loaded at the high wastewater rate exhibited little variation in CO$_2$ flux. Nitrous oxide emissions were negligible for all wetlands.

In general, the benefits of a well established plant canopy within the wetlands provided a net ‘sinks’ of greenhouse gases. However, the results of this study were collected during a
warm part of the growing season. Data are still being collected and will help to develop a better perspective of the real source-sink relationships during warm and cool periods. Results from the first season of monitoring have shown promising results regarding the efficiency and 'sinks' possibilities of constructed wetlands. A dependence on both loading rate and vegetative cover however, is apparent in the emissions estimates.
As reported in the mid-program review of the CCFIA, relatively little research on carbon sequestration was funded by CCFIA. This is justified by our better knowledge of agricultural soil carbon change compared with that of N\textsubscript{2}O and CH\textsubscript{4} emissions. The two projects C sequestration involved situations for which our knowledge is limited. A few other projects under CCFIA funding also included C sequestration. These projects have been reviewed in the “Soil Nutrient Management” section.

The first major project which was led by Dr. Bev Kay of the University of Guelph, investigated the impact of reduction in tillage on carbon sequestration and N\textsubscript{2}O emissions under corn/cereal/soybean rotations in Ontario. This comprehensive project involved documenting rates of C sequestration, persistence of C sequestration, tillage systems effects on N\textsubscript{2}O emissions, and modelling of C dynamics. The study made excellent use of existing long-term tillage studies in Ontario. The research has shown that no-till (NT) has resulted in higher C contents in the 0-5 cm than in conventional tillage (CT) but did not lead to significantly higher C storage to a depth of 40 cm. This was attributed to increased variability in soil C contents below the plow layer. In two soils, there was also more C at depth (~10-20 cm) in the CT soil that in the NT soil. The sequestration of C under NT on variable landscape was dependent on initial C contents with higher potential on parts of the landscapes which have been eroded (lowest C contents). The impact of plowing NT soils was variable with only one soil out of four showing a reduction in C content 15 months after plowing. Measurements of N\textsubscript{2}O emissions in long-term tillage plots showed that N\textsubscript{2}O emissions were about 10 to 15% lower for NT than CT systems. Finally, data was presented showing that the Century model can be modified to better take into account the light fraction organic matter which is very sensitive to tillage practices.

The other major project involving C sequestration under the CCFIA funding was led by Dr. Rob Gordon from the Nova Scotia Agricultural College in Truro. The project addressed C sequestration potential of constructed wetlands used for treating wastewater from on-farm dairy operations. The study included the measurement of CO\textsubscript{2}, N\textsubscript{2}O and CH\textsubscript{4} using micrometeorological methods. Considering the net equivalent greenhouse gas emissions, results showed that these constructed wetlands may provide a partial “sink” under typical loading rates and dense vegetation. However, treatment wetlands which are receiving higher strength wastewater may be a net “source” of greenhouse gases.
KNOWLEDGE GAPS

The various presentations and informal discussions during the course of the workshop provided opportunities to identify knowledge gaps in the area of C sequestration in agricultural soils. This is not a complete list and probably reflects the author’s own bias.

In terms of management effects on C sequestration, the following questions remain:

- The interactive effects of various management factors such as tillage, crop type, manure/fertilizer application, irrigation etc. need to be considered. Most research so far has focused on the effects of isolated factors.
- As grasslands and forage lands represent a very large area in the Canadian agricultural landscape, a better understanding of the potential of these systems to sequester C is required.
- Drainage of agricultural lands is still occurring in many parts of Canada but its effects on net GHG emissions is still poorly known.

There are also many fundamental questions regarding the whole area of soil C sequestration and C cycling that are still poorly understood:

- We are accumulating much information on the rate of accumulation of C in soil but we still have little data on the persistence of sequestered C and the duration over which C sequestration occurs.
- There have been several reports on possible accumulation (sequestration) of C at depth in some agricultural soils. The occurrence and nature of C sequestration at depth needs further research.
- The high spatial variability of soil C stocks in the landscape represents a major challenge in our efforts to develop sampling schemes and inventory/verification systems for international reporting and C trading. More studies on spatial variability of C are required and we need to develop standard sampling/analytical methods.
- Erosion by water, wind or tillage can displace significant amounts of C in the landscape. More information is needed on the fate of C eroded offsite in order to close the C cycle.
- Carbon sequestering management systems have been identified for various parts of the country. There is concern that in some areas some of these practices may increase N₂O emissions. A total accounting of other GHG emissions as well as other environmental impacts of these practices needs to be undertaken.
SOME REFLECTIONS ON CCFIA RESEARCH

HENRY JANZEN, PH.D., RESEARCH SCIENTIST
AGRICULTURE AND AGRI-FOOD CANADA, LETHBRIDGE

This summary was prepared by Vimy Glass from a transcript of Dr. Janzen’s presentation (the full transcript, in English, is attached as Appendix D).

The GHG issue is relevant to Canada and has been researched for about 10 years in agricultural science. It became evident early on that policies were being forged and solidified, and decisions were being made by governments. As scientists, we thought we could contribute to some of those policies as they were being made.

Greenhouse gas science is really about following carbon and nitrogen atoms...from plants, to soils, to air, to water, to trees. In fact, 30 years ago the physicist Freeman Dyson, came up with the idea: can we control the CO₂ in the atmosphere? He was talking about carbon sequestration. Researchers in Canada latched onto that idea quite quickly, because we knew there would be far-reaching benefits.

One of the first research topics studied extensively was no-till. A lot of data were gathered, but the inherent variability soon became apparent. Some of the CCFIA research is still looking at this variability by examining the site-tillage interaction. While no-till was in effect the poster child of carbon sequestration, it was only one aspect. Whole systems were being examined, recognizing that carbon and nitrogen flows are inextricably bound together, and, as such we need to look at them together. Soils at different places in the topography are very, very different, and the factors that drive the exchange of greenhouse gases at the different points on the landscape are just beginning to be understood.

Carbon dioxide is only one small piece of the GHG puzzle. In fact, the big ones are not CO₂ at all, but N₂O and CH₄. Much of the research that has been implemented recently has focused on this aspect: trying to fill in the picture, not only for CO₂, but for other GHG’s. The result of that has been many emission estimates for a wide range of variables. This has helped to populate the tables of co-efficients; the estimates of emissions as a function of various parameters and variables.

Much of the research is conducted in small plots, sometimes in small chambers, and sometimes in parts of fields, but those values do not have a lot of meaning unless they can be applied to a farm. This means taking into account the material that leaves the farm, ends up somewhere else, and creates greenhouse gas emissions.

If you measure emissions from two systems in any one year, you will get the wrong answers. It somehow needs to be done over the long term. Many of the practices may actually have only long term effects. So, a practice adopted right now may not be visible in increased GHG emissions for many years to come. This introduces what ecologists call “the long now,” meaning that now is not just the slice of time, but includes many years beforehand. To put it another way, the GHG emissions measured from a field today are a
function not only of what happened this spring, but what happened ten years ago, and what happened in your grandfather’s time. And the GHG emissions that happen 50 years from now are to some extent influenced by what we do today. That’s the idea of “the long now,” and somehow that has to start entering the models.

The status of Canadian research is progressing well. Through the CCFIA, the biggest contributions were the net greenhouse gas effects, counting all the gases together, and starting to look at offsets. Also, the issue of scaling up - there has been improved understanding of the origins. Now is not the time for a whole new flurry of more measurements. Now is the time for synthesis, going beyond just measurements to understanding. And the scale of understanding - it’s a matter of understanding at each level and synthesizing and tying together, and building from that understanding, all the way up to regional and national levels.

One of the most important items that could be categorized as a legacy for the CCFIA comes from the idea of training and enthusing new people in this science. And the idea of working together - it’s not often that soil scientists work with micrometeorologists, or an animal scientist thinks about manure and subsequent effects, or a plant scientist thinks about soils, or someone doing N₂O thinks about plant yields. This has been a real opportunity for us to build those bridges and those collaborations, and teamwork will persist.

Freeman Dyson, physicist, maybe says it best. He says, don’t be surprised if some of the things I say are wrong, in science it is better to be wrong than to be vague. That is why it is fun to be a scientist, you don’t need to be afraid of being wrong. So one way or the other, though we may enjoy the mysterious, we are going to have to look for ways of quantitatively or qualitatively describing what we know, the confidence with which we know it, and sometimes admitting that we do not know something. That is as important to the decision-makers as telling them what we do know.
PLenary Discussion - ‘The Road Ahead’

The following is a summary of issues discussed during a plenary session at the end of the workshop.

The Kyoto Protocol is structured into a timeframe and was initially engineered to focus on fossil fuels. As negotiations proceeded, scientists reminded the collaborators there are a lot of terrestrial contributions that need to be considered. Agricultural results may take decades before there is confidence in what is being concluded and recommended. Kyoto should be viewed as more of a starting point for thinking of the steps to take to reduce greenhouse gas emissions.

Research needs to satisfy three sectors: producers, policy makers, and consumers. The producers must farm and function under changing conditions, and research needs to consider whether the results are in agreement with making their production systems more efficient to compete in international marketplaces. The policy makers have an agenda to satisfy the political masters. Finally, the consumers want clean air and water, and to feel comfortable with the agricultural products they consume.

Research presented suggested emission factors for Canada are actually lower than what IPCC proposed. IPCC encourages countries to use country-specific data. It was clarified that IPCC makes allowances for this, but that the group relies on published data from which to draw their estimates. In reality, the quicker the presented research is published, the better the chances are that the IPCC will have a more realistic representation of the factors. Included in this is the need to include as much information as possible when characterizing the sites where the emissions are represented (temperature, where was redox measured, percent dry matter, beneficial management practice utilized, etc). Researchers need to include as much data as possible to provide a more complete story for others trying to compare numbers.

Has the issue of greenhouse gas emissions high-jacked the agricultural research agenda in Canada? Or is it simply driving the systems and in turn causing us to become more environmentally aware? We need to look at what the research funded by CARD has accomplished.

The research funded by CARD was multidisciplinary and included both temporal and spatial integrations. Before disseminating results to the producers, we need to agree on what units to use when expressing greenhouse gas emissions from farms. There was much discussion during the meeting regarding units - perhaps a sheet of conversions to shift between the varied units is needed. This will aid the researchers and provide a much simpler way to compare results. Also, taking into account the varied agriculture in Canada, it is necessary to determine a way of measuring efficiency and greenhouse gas emissions so that it is obvious when a good practice is developed. Summarizing needs to start now, while data collection needs to take the back burner. There is ample information available to take back to commodity groups. It is time to start disseminating the information.
In future, CARC needs to promote GHG research focusing on the field crop sector. We need to prioritize what the producers view as research needs. We can make lots of lists of what needs to be looked at but we have never ranked what is highest priority or the ‘most bang for your buck.’ When this is completed, we need to advocate the federal government to allocate money into mitigating greenhouse gases, while continuing research based on the fundamental understanding of the science behind greenhouse gas emissions.

CCFIA was a very successful program where we were able to bring together networks of researchers across all sectors - university, industry, and government.
Appendix A

CARC CLIMATE CHANGE FUNDING INITIATIVE IN AGRICULTURE COMMITTEE

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Appendix B

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Reduction of Greenhouse Gas Emissions in Swine by Diet Manipulation

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Quantifying N₂O Fluxes Associated with Agricultural Practices in Non-level Prairie Landscapes

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Environmental Performance of Alternative Dairy Production Systems

Alan Fredeen, Department of Plant and Animal Sciences, Nova Scotia Agricultural College, Truro
Mike Main, Department of Plant and Animal Sciences, Nova Scotia Agricultural College
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Greenhouse Gas Emissions from Constructed and Natural Wetland Systems

Robert Gordon, Department of Engineering, Nova Scotia Agricultural College, Truro
Vimy Glass, Graduate Student, Department of Land Resource Science, University of Guelph, Guelph
Development of Scientifically Defensible Estimates of N₂O Emissions from Agricultural Ecosystems in Canada

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Tom Goddard, Alberta Agriculture, Food and Rural Development, Edmonton
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Site-Specific Application of Fertilizer N for Reducing Greenhouse Gas Emissions

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Philippe Rochette, Agriculture and Agri-Food Canada, Sainte-Foy
Regis Simard (deceased 2002), Agriculture and Agri-Food Canada, Sainte-Foy

Documenting the Impact of a Reduction in Tillage on the Amount of C Sequestered, the Stability of Sequestered C and Emissions of N₂O under Corn/Cereal/Soybean Rotations in Ontario

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Greenhouse Gas Emissions from Swine Operations in Québec and Saskatchewan: Benchmark Assessments and Selective Mitigation Processes

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Robert Fengler, Prairie Swine Centre Inc.
Éric Gaudet, Undergraduate Research Assistant, University of Saskatchewan
Measurement of Greenhouse Gas Emissions and Odour from Swine Manure Derived From Standard and Modified Diets

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Brent Morin, Department of Agricultural, Food and Nutritional Science, University of Alberta
Ike Edeogu, Agricultural Engineering Branch, Alberta Agriculture, Food and Rural Development

Examination of Environmentally and Economically Sustainable Management Practices in Forage-Based Beef Production Systems

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Karin Wittenberg, Department of Animal Science, University of Manitoba

Multi-Scale Estimation of N₂O Flux from Agroecosystems

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Reduction of Greenhouse Gas Emissions from Dairy Production Systems and Poultry Manure and its Impact on Agricultural Sustainability

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Network on Crop Production Practices to Reduce Agricultural Greenhouse Gas Emissions in Eastern Canada

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Chandra Madramootoo, McGill University
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Improved Greenhouse Gas Emission Estimates from Manure Storage Systems

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Michèle Marinier, Research Assistant, Department of Land Resource Science, University of Guelph
Jim Whitehouse, Producer
Harry Stam, Producer
Leo Donker, Producer
Myron Gerber, Producer
Fred Groenestege, Producer

Feedlot Greenhouse Gas Emissions: Effect of Diet and Manure Storage

Karin Wittenberg, Department of Animal Science, University of Manitoba, Winnipeg
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## CCFIA Matching Funding

**As Reported to AAFC CARD II**

### 1999 - 2004

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I want to reflect on where CCFIA research has been, but I want to do that in the context of some longer term questions. Clearly there’s not a way that I can capture all that we’ve heard and seen in the last two days, let alone in the last number of years in CCFIA research. So instead of trying to do that I have tried to put together a bit of a story line using what I’ve called the evolving questions.

I’ve tried to go back over the last 10 years or so, where some of us have been grappling with the greenhouse gas issue, and I’m going to present a number of questions as they seem to have occurred to us, not only over the last 10 years, but today and perhaps also into tomorrow. And then, using those evolving questions as the story line, as the thread, I’ll try to place the CCFIA science into that context. I have a series of eight questions. They’re not necessarily discreet, they overlap some, and they’re certainly not comprehensive. But I hope they give at least some glimpses of where we have been, where we’re at now, and if we’re lucky, maybe also where we are going.

1. IS THE GHG ISSUE RELEVANT?

The first question is perhaps the most basic. And it’s one that we probably started wrestling with about 10 years ago in Canadian agricultural science. Is the greenhouse gas issue really relevant to us? Is it worth devoting a lot of resources and intellectual effort and creativity to this question, or should we divert our resources elsewhere?

I think we decided fairly early on that it is worthy of our scientific expertise, for several reasons. First of all, because the atmosphere is changing. There’s still a huge amount of uncertainty about what that means. We don’t know, at least I don’t pretend to know, what’s going to happen to this climate exactly, what’s going to happen to temperature, to precipitation. But we do know the atmosphere is changing and it’s changing abruptly.

Secondly, no less important, we saw quite early on that policies were being forged, policies were being solidified, decisions were being made - far-reaching decisions - and we thought maybe we could contribute just a little bit to some of those policies as they were being made.
The third reason, not the least important, is that we realized from the outset that the science we do is applicable in many arenas. Greenhouse gas science is really following carbon and nitrogen atoms...from plants, to soils, to air, to water, to trees. And it doesn’t hurt us to know a little more about the carbon cycle. For many reasons. It doesn’t hurt to know a little bit more about the nitrogen cycle, nitrogen use efficiency, improved feeding efficiency, and so on.

So we decided yes, it was worthy of some scientific effort. And the first big question we latched onto, I think, was can we absorb excess CO₂ - the whole question of carbon sequestration. And I think that came out of the big picture analyses, which looked at the global carbon cycle, where we know that about 6 billion tonnes of carbon are being spewed annually into the air, about half of which stays behind. And then we got quite excited by the size of these pools. These are very large pools of carbon in plants, mostly trees, and in soil. In fact 30 years ago, Freeman Dyson, the physicist, came up with the idea: can we control the carbon dioxide in the atmosphere? He was talking about carbon sequestration, realizing that if we could just expand these pools a little bit, that would draw down atmospheric CO₂. And we latched onto that idea in Canada quite quickly, because we knew that we had lost a lot of carbon, probably a thousand million tonnes of soil carbon or more since cultivation began. And we thought, if we can return some of that lost carbon, thereby pulling out CO₂ from the air, that has many far-reaching benefits.

One of the first things we looked at was no-till, in conjunction often with enhanced intensity of cropping systems. We gathered a lot of data, and very soon we came up with some rough values of about a third of a tonne of carbon per hectare per year, but soon realized that they vary. Rates that apply to Swift Current do not necessarily apply to Sainte-Foy, and so on. And so we increasingly had to look at, and are still looking at, and some of the CCFIA research is still looking at, this site-by-tillage interaction. We should probably include in there site-by-tillage-by-climate, by a number of interactions: trying to find the rate of carbon gain as a function of the landscape, the climate, the crop, the other cropping practices, and so on.

While no-till was in effect the poster child of carbon sequestration, and it deserved to be that, we soon realized that’s only one aspect. And here again, CCFIA has come to the fore and started looking at other aspects: forages, grasslands and grazing systems. I think we still have a lot of work to do there. We still only have very weak understanding across Canada for some of those treatments. And other crops. And what about trees? There are a lot of trees on agricultural land. There are a lot of trees on the periphery of agricultural land. Where do they fit into this carbon sequestration business? And of course the wetlands. CCFIA has done some work in that area, which we heard about today. Probably there’s a little bit more work needed there.
2. Can we absorb excess CO$_2$?

It wasn’t long before we got a bit nervous about carbon sequestration. We looked at our agro-ecosystems and realized that CO$_2$ is only one small piece of the greenhouse gas puzzle. In fact, the biggies are not CO$_2$ at all, but N$_2$O and methane. Those are estimates for 2001. We don’t know exactly how much carbon we can sequester, I think we saw some estimates earlier this morning, I think the value was something like 10. Is it 10 million tonnes of CO$_2$ equivalent, is it 15, is it 20? In any case, it is dwarfed by these. And nitrous oxide and methane emissions apparently are increasing, so we can’t forget about the others.

So a lot of research has been implemented recently, also in CCFIA, and in fact much of what we have seen here in the last two days has focused on this aspect: trying to fill in the picture, not only CO$_2$, but these other greenhouse gases. So we’ve looked at a whole range of environments, often starting initially with looking at better methods. How do we do this? How do we go out to the field and capture N$_2$O emissions from the field? Or in a barn?

The result of that has been a whole lot of emission estimates for a wide range of variables, which we’ve seen over the last two days. And what that has done is helped us populate the tables of co-efficients, the estimates of emissions of a function of various parameters, various variables. So that we can devise equations or models, or whatever the case may be, where we can predict N$_2$O as a function of soil type, fertilizer rates, precipitation and so on.
3. But what are the net effects?

The next step though, the third question - what are the net effects - was the recognition that we cannot look at each of these separately and individually. They are completely, hopelessly, interconnected. Any one of these is a function of the parameters that also exist in the other equations. So we’ve started looking at whole systems, recognizing that carbon, nitrogen flows are inextricably bound together. We realize that we have to look at them together.

One of the first questions that came up, and we’re still wrestling with it, we’ve seen data a number of times over the course of the last two days, is this one: do we need to worry about increased N$_2$O emissions in our efforts to sequester carbon in soils? I think much of the world would say you do have to worry about increased N$_2$O emissions. There are assumptions many places that say that if you adopt no-till you may get higher N$_2$O fluxes. We’re collecting quite a lot of data, and we’ve seen quite a lot of reassuring data, which says in fact under our conditions, no, N$_2$O fluxes do not necessarily increase. In fact in some cases they’re going down. There seems to be a site-by-treatment effect interaction. But overall I think these findings are fairly optimistic.

We just heard a marvelous presentation on this issue of biofuels and other bioproducts. Again, it’s systems analysis that has come to the fore, and I think Ewen [Coxworth] mentioned it already, biofuel is a marvelous opportunity for reducing greenhouse gas emissions. There’s a lot of excitement in Canada and globally looking at this as a mitigation tool. Because while it’s still generates CO$_2$, you’re still burning something to generate CO$_2$, it is recycled CO$_2$. You are reducing the amount of old, old fossil carbon that goes into the system. But at the same time, we want to be careful. We have to account for the fact that there may be nitrous oxide emissions associated with the production of that biofuel. There may be energy use in the production of that biofuel. There may be a worry that if we are taking more plant photosynthate out of the system, soil carbon will be depleted. And if this is depleted, then we have to count that offset against the benefits from the biofuel. Overall, probably this is still a very sound practice and there’s a lot of justified optimism, but we need to look at all these effects.
Here is a third example of interactions, and this is one that many of you have looked at (and it’s been gratifying to see that we are thinking well beyond individual pieces), suppose we want to change the feeding rations, and suppose we find that a ration reduces methane emissions. That of course changes, or might change, the composition of the manure. And change greenhouse gas emissions from the manure. And that goes further, because when we apply that manure to the field, it may have different nutritive benefits, which changes the amount of fertilizer, and the type of fertilizer that is applied, which has ramifications for $N_2O$ emissions, which has ramifications for energy use for fertilizer production. And all of these may affect crop yields, which affects $CO_2$ drawdown, and so it goes on and on and on. It works the other way too. If we change the ration, that probably means somewhere down the road somebody is changing cropping systems to make that new ration. And so, it doesn’t take long before we’re swimming in all of these interactions. And it’s going to take us a while to understand them all. But it’s been very reassuring, and I think there’s been a lot of progress in CCFIA, where people are not just looking at the cow. They’re looking also at the manure. And they’re not only looking at feeding practices, they’re recognizing that there are ramifications and implications and spreading ripples all the way through the system. So I think we’ve made a lot of progress. A little bit of work still to do, but the progress I think has been magnificent in that regard.

Finally, I do want to very timidly suggest that maybe what we need most now is not necessarily a whole new flurry of more measurements. Maybe what we need most is more synthesis. Maybe it is not these little pieces that we need to study most, but the connections. And I think we’re moving toward that, I think many people have started saying that, and I think that is a great step forward.
Fourth question. This has occupied us a lot the last two years and has also been a big, big factor in CCFIA activities. And that is the whole question, can we estimate emissions on a farm scale? Much of our work is done in small plots, sometimes in small chambers, sometimes in parts of fields, but somehow or another those values do not have a lot of meaning unless we can apply them to a farm. And farms are not always as simple as that. Sometimes there’s topography, and buildings, and all kinds of combinations of animals, and weird field shapes, and different biotypes and ecotypes within the same farm. How do we do this? This is a tough question. And so again, this has been a predominant objective in CCFIA research that we’ve seen many times in the posters and the presentations.

We’ve seen, for example, studies looking at topography. We recognize the soils at different places in the topography are very, very different. Maybe I’m exaggerating to say that if you go to a field, the soil here and there, the difference may be as great as the difference between Swift Current and Ottawa. Maybe that’s an exaggeration, but not that much. Huge differences. And we’re beginning to understand the exchange of greenhouse gases at the different points on the landscape, understanding what’s driving it. And then is the factor that was mentioned earlier today, erosion. Erosion of course moves materials and nutrients and soil and carbon around the landscape, changing it enormously, both at the site where the soil was removed and at the site where the soil was deposited. So how does that change N₂O and CO₂ emissions here, how does it change it in the newly deposited material, what happens to the material that is now buried? We heard about some of that earlier.

And so there is a lot of progress being made, but probably we don’t have the full picture yet. And it raises some practical questions. I think in Gary [Kachanoski’s] talk, he asked the question, can we reduce emissions by site specific farming? Can we do better by farming each of these pieces a little bit differently? And I think his answer was, if I understood it correctly, that at least for greenhouse gases, it does make a difference, you can reduce emissions, but maybe only by a little bit.

And sometimes the variability is not even related to any noticeable topographical feature. I think those of you who are doing N₂O emissions estimates using chambers sometimes get peculiar
looking data, where you have a couple of chambers not that far apart, where one gives a very low emission rate, another one a very high emission rate. What is that? Where does that come from? And do we understand why that happens, and how do we take that kind of variability and develop any kind of an estimate of a farm level emission?

When we think about the farm scale, we have to take into account the material that leaves the farm, ends up somewhere else, and creates greenhouse gas emissions. How much do we know about ammonia emissions - we’ve heard that question. Some of you are wrestling with that. And when it is deposited, how much of it becomes N₂O? Or the nitrate. How much of that becomes N₂O, and of course the same can be said about carbon. What happens to the organic carbon that leaching, how much of it becomes CO₂?

So what we are looking at then, is extending our understanding, sometimes from small areas, to the full farm ecosystem level and of course going beyond. And there is still another level below that. And that is the process level. And some of the work we’ve seen the last two days is also there.

5. **DO WE KNOW THE ORIGIN OF EMISSIONS?**

And that brings me to the fifth question, and that is, do we really understand and know at the cellular and molecular enzymatic levels where these greenhouse gases are coming from? Do we really know the origins? And maybe we need to go beyond just measurements to understanding, and in fact I’m sure that is what’s happening. And I think Tim [McAllister] mentioned yesterday, the idea of understanding the rumen microflora more effectively, looking at the ecology, the microbial ecology. Do we really know what’s happening inside a compost heap? Or in the plant soil carbon flows? Somebody mentioned charcoal this morning. Do we understand how that behaves in terms of carbon storage and potential carbon re-release? Nitrous oxide still remains, at least in my view, a little bit of a mystery. Do we know exactly what processes are generating the N₂O at the various times and the various places and the various management practices? Someone mentioned earlier today the potential of abiotic processes: do we understand that, and do we need to spend a little more time at this scale as well.

And it is not only biology where we have still, I think, some uncertainties, it is also sometimes even in physics. Those of you who have been looking at soil profiles, and nitrous oxide, sometimes
get trends like this - high concentrations at depth, declining as you get nearer the surface, which suggests that way down here there is some N₂O and it may be bubbling up and do we know about that, do we know where it’s coming from, do our models know about that and where it’s coming from. So there’s an enormous opportunity I think still here to go to the origins, and even though I’m definitely not a biologist, I would suggest that biology may be the greatest opportunity. There is a whole new array of biological techniques that are available to us, for understanding these processes, for understanding the cells and the enzymes that contribute to greenhouse gas emissions. Do we understand them and are we taking advantage of that?

And so it comes again to building upon the levels of understanding. And the scale of understanding. And it’s not a question of one or the other, it’s not test tubes versus towers at all. It’s a matter of understanding at each level and synthesizing and tying together, building from that understanding, all the way up to regional and national levels. The question is, do we really want to scale up numbers, or do we want to scale up understanding? And so I’ve said here, partly facetiously, part of the answer to scaling up may in fact lie in scaling down.

6. CAN WE PROJECT FUTURE EMISSIONS AND SINKS?

Question 6. Can we project future emissions and sinks? In other words, what I’m suggesting is do we spend enough time thinking about time? We’ve expended quite a lot of resources trying to extrapolate across space. And maybe we need to also spend as much time extrapolating across time. Many of these studies in CCFIA are already doing that to some extent. Certainly time is implicit in many of them, if not explicitly expressed. For example, how long does soil organic carbon continue to increase after you adopt a new practice? Do we know that? And it’s very, very critical. Certainly under net-net accounting, if we start leveling off, for example in the first commitment period, that makes quite a significant impact on our net calculated gain. So that is one question, how long does the soil organic carbon gain continue?

Looking at another example, and here let me propose a little thought experiment. Suppose you take two heaps of manure, two piles of manure, one of which you compost, one of which you immediately take out to the field and apply onto a
wheat stubble. And you start measuring nitrous oxide emissions from those two piles. Probably initially you will find, I'm guessing, higher greenhouse gas emissions from the composting process itself than from the pile that you applied and spread on the fields. But as time goes on, I suspect the converse will be true, that the composted materials will have much lower emissions over the long term than will the applied fresh manure. And if you look at cumulative greenhouse gas emissions over time, you might get a shape like that - I have no idea what that shape looks like, maybe some of you have data. But the point is, if you measure emissions from these two systems at any one year slice, you're going to get the wrong answers. We have to do it over the long term, somehow. That's a hard thing to do, I'm not sure if we can do it measurement-wise, or models, whatever the case might be, but we have to start increasingly thinking not in terms of growing seasons, but of years, and maybe beyond years.

Another example that's been alluded to: that many of the practices may actually have only long term effect, long term accumulation, on nitrogen available and in the soil. So that a practice that you adopt right now may not be visible in increased greenhouse gas emissions for many years to come. And that brings up this whole idea of what ecologists call “the long now.” Meaning that now is not just the slice of time, but now includes many years beforehand. To put it another way, the greenhouse gas emissions coming off a field today are a function not only of what happened this spring, but what happened ten years ago, and what happened in your grandfather's time. And the greenhouse gas emissions that happen 50 years from now are to some extent influenced by what you do today. That's the idea of “the long now” and somehow that has to start entering our models. And of course it only gets more difficult because the future is a little bit dim. There may be agronomic disruptions. We heard about one of those earlier today, from Bev Kay, practices are evolving. Our current
“best practices” today are likely obsolete 10 or 20 years from now. There may be future droughts and so on, and it increases ever faster in the coming years.

There are those who say that the next number of decades will see the final period of rapidly expanding global human environmental impacts from agricultural practices. I think they may be right. There is a whole deluge of changes coming into our agroecosystems. Climate change, who knows how much that will happen. Atmospheric CO₂ certainly will change, it’s going to double, at least. Nutrients - I think someone has written that the amount of nitrogen fertilizer produced from 1960 to 1995 has increased seven-fold and there are probably some more increases coming - new energy sources, new technologies. Our plants may not look the same ten years from now as they do now. Social perspectives, population pressures. In another 50 years there’s likely to be another three billion of us. What does that do to food pressures, what does that do to landscapes, what does that do to greenhouse gas emissions? It comes back. And so there are lots of things that will keep us entertained when you think about future emissions.

7. CAN WE GIVE ANSWERS THAT ARE USEFUL (BUT HONEST)?

Number 7. Two questions to go. This is one I am a bit uneasy about presenting, but maybe I thought I would present it as a discussion point if nothing else. And the question is, can we give answers that are useful, but honest. I think as scientist we enjoy the mysterious. We like the uncertainty. It is in fact to the area of darkness that we go, because that’s where the most progress can be made. Freeman Dyson, physicist, maybe says it best. He says, don’t be surprised if some of the things I say are wrong, in science it is better to be wrong than to be vague. That is why it is fun to be a scientist, you don’t need to be afraid of being wrong. I think most scientists would applaud that, but, decision-makers need specific, definitive answers. And they are right in asking for those. So one way or the other, though we may enjoy the mysterious, we are going to have to look for ways of quantitatively or qualitatively describing what we know, the confidence with which we know it, and sometimes admitting that we do not know something, because that is as important to the decision-makers as telling them what we do know. And so, with great trepidation, and I won’t leave this slide up too long, but I have put down my estimates of
uncertainty of our ability to estimate or predict emissions from these various sources. And I don’t believe them. But I put this up merely to emphasize that maybe we need to do some of these things collectively. For example, I would argue that animal methane, we know reasonably well, relative to off-site nitrous oxide emissions where there’s a huge uncertainty...better move on.

But it comes down to these practical questions. Can we put error bars on our estimates of current emissions? Can we put error bars on our projections of future emissions? Can we put error bars on our estimates of the effectiveness of proposed practices? For example, if a new practice is adopted were to reduce emissions by 10%, would we see it? Would we be able to verify it? Or an even more scary question, what is the chance that a BMP [Best Management Practice] that we recommend turns out, after we do more research, to be a poor management practice? I would suggest sometimes that is not a trivial risk. We may need to find ways of acknowledging that.

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8. CAN WE TIE GHG SCIENCE TO OTHER RELATED QUESTIONS?

Last question. A little bit safer one. Can we tie greenhouse gas science to other related questions? We said at the outset that one of the reasons we’re doing this greenhouse gas science, one of the reasons we’re so excited about it, is that it is universally applicable. It has ramifications and scientific importance in many regions. And when we look at what we ask our farmlands to do...yes, we can look at ways to reduce greenhouse gas emissions, but also our farmlands are a source of livelihood, they’re our source of food, our timber, our fuel, they filter our air and our water, and so on down the list. Reducing greenhouse gases is not the highest priority. It’s an important one, but not nearly the highest. And so it doesn’t hurt us, once in while, it doesn’t hurt me, as a greenhouse gas researcher, to remind myself that this is only one of many, many other services that we expect of farmlands. The good thing, as we’ve said before, is that many of these processes, the understanding that we derive from studying them, have implications for virtually all of these - for economics, for water quality, for so-called permanence or soil conservation, and we can go on down the list. And so in one way, maybe greenhouse gas emissions are in part also a measure, a signal, of how well we are doing.

CONCLUDING THOUGHTS

Concluding thoughts. I’ve been reflecting a little bit. Let me try, again very carefully, to put some quantitative markers on these reflections. What I’ve done here is listed the 8 questions. And in this [left] column are what I very roughly perceive to be the research status of Canadian science generally - where that [left] point would be complete stupidity, that [right] point would be complete wisdom, full knowledge. And I would say that for some of these generally we’re doing OK, others we have a lot of opportunity. Basically, orange is the colour of opportunity. So let me now, very quickly, suggest at least my impressions of where I think CCFIA research has made the biggest contributions.
And I would suggest it looks like that. I would say there has been enormous progress, especially in these two areas: the net greenhouse gas effects, counting all of the gases together, and starting to do the offsets. Also, the issue of scaling up; there has been improved understanding of the origins. And we could point to other bits and pieces that have emerged. It’s been gratifying again to see how many of the studies point to the other benefits, and to the other interactions. But there are still some ways to go.

So if we look at a program like this and think about its legacy, beyond just greenhouse gas science, how would a person a generation from now assess it? I suspect that one of the most important items that could be categorized as a legacy, comes from the idea of training and enthusing new people in this science. And the idea of working together. It’s not often that we see soil scientists working with micrometeorologists, and an animal scientist thinking about manure and subsequent effects, or a plant scientist thinking about soils, or someone doing nitrous oxide thinking about plant yields. And I think this has been a real opportunity for us to build those bridges and I am quite confident that those bridges and those collaborations and that learning and teamwork will persist.

One last question and then I’m done. And this is truly a contemplative question. Let me ask this one - twenty years from now, will we still be doing greenhouse gas research? Will it still be a high priority? I’m not sure about that. I would not be surprised if 20 years from now there’s a workshop like this, we will be focusing on some other more urgent issue. Knowing how one issue leads to the next. How one way leads to the next. I expect that we may well have moved on to something else. But that doesn’t discount the fact, it emphasizes, as Carpenter would say, that scientific knowledge is part of the endowment we leave to future generations. Much of the research, much of the science that has been done in this program, will benefit scientists a generation from now.

And so it may be that while we applaud, and I certainly applaud, CCFIA, and its researchers for all of the magnificent progress and the great strides that have been made in greenhouse gas research, I suspect that it may be that its enduring legacy may be its answers to questions we have not even thought of yet. And that gets me excited. And with that, I thank you for your attention.
Greenhouse Gas Mitigation and Carbon Sequestration
Research Needs and Priorities for Agriculture

It is the mandate of the CARC Expert Committee on Greenhouse Gases and Carbon Sequestration to identify research and development needs that are not being currently addressed or that require increased attention. The following is a compilation of research priorities identified by the Expert Committee in consideration of several recent Canadian reports and workshops examining GHG mitigation and Carbon sequestration in agriculture. The discussion papers considered include:

- Development of a Farm-Level Greenhouse Gas Assessment: Identification of Knowledge Gaps and Development of a Science Plan, commissioned by the Alberta government;
- Beneficial Management Practices to Reduce Greenhouse Gas Emissions and Increase Carbon Sinks in Canadian Agriculture, commissioned by CARC, BIOCAP Canada foundation and Agriculture and Agri-Food Canada;
- An Assessment of the Economics of Adopting Stewardship Practices in Livestock Production in Response to Environmental and Societal Concerns, commissioned by CARC and Agriculture and Agri-Food Canada;
- Manure Management and Greenhouse Gas Mitigation Techniques: A Comparative Analysis, commissioned by Climate Change Central; and
- An Assessment of the Opportunities and Challenges of a Bio-Based Economy for Agriculture and Food Research in Canada, commissioned by CARC and BIOCAP Canada Foundation.

Links for each of the papers are listed at the end of this document. This document has also been shaped by two workshops, the GHG Research Priorities Workshop hosted by CARC in Ottawa in December 2003 and the CCFIA final workshop held in Winnipeg in January 2004.

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Crosscutting Issues

One of the strong messages heard by the Committee was the need for greater multidisciplinary research efforts, particularly projects that address crosscutting issues. There is a need to more fully integrate socioeconomic assessment as part of biophysical research programs as well as greater support for socioeconomic research in its own right.

The following research priorities in these general areas were identified:

Economic analysis

Policy options must incorporate impact analysis of adoption of mitigation practices at the farm, regional, national and local levels on competitiveness. Economic analysis should include sensitivity analysis, analysis of issues associated with early adoption, or with not taking action. The role of government incentives and regulation in encouraging adoption needs to be studied.

In this area it was difficult to separate knowledge gaps from policy gaps. The following gaps in one or both of these areas were articulated:

a. Domestic Emissions Trading (DET) System - There is a clear need to develop a DET system addressing issues such as:
   • The clear definition of accepted baseline (e.g., types of methods, methods used in a base year).
   • The time frame over which emission reductions and removals be eligible for incentives or trading?
   • Recognition of early action - How do farmers who have already reduced or removed greenhouse gas (GHG) and plan to continue before 2008 get rewarded?
   • Recognition of ownership and permanence need to be resolved to reduce farmer risk.
   • Identification of those practices which will be rewarded by incentives and which are open for credit trading?
   • There is a need for pilot scale tracing to learn how the process could work. It is time to try it.
   • There needs to be consideration of institutional design, trading mechanisms (e.g., emissions trading), and the role of regulation in facilitating the adoption of these difference practices.

b. There is a need to clearly identify and disseminate the financial co-benefits (e.g., improved production efficiency, improved water quality) of the adoption of Beneficial Management Practices (BMPs) encouraged for reducing or removing GHGs.

c. There is a need to identify the barriers to adoption of current BMPs, particularly those that offer improved production efficiency, and where these barriers are weather- and financially-related (initial investment costs). There is a need for more work on BMP valuation, costing and non-market or externalities.

d. There is a need to identify where incentives will be needed to offset the costs of those BMPs which do not offer improved production efficiency, and possibly for those BMPs
which have a significant initial investment cost in hardware to upgrading of management skills.

e. Programs are needed to ensure that farm leaders who are early adopters (after 1990 and prior to 2008) are rewarded for their innovation and leadership. Incentives will be needed to encourage them to be ambassadors, helping their peers adopt the same BMPs in the future.

f. Benefit-cost analysis - Estimation and analysis of the economic and environmental costs and benefits of livestock production remains to be done on a comprehensive and systematic basis for Canada.

g. There is a need to integrate risk (probability and outcome), with uncertainty (outcome, no probability) and ignorance (neither probability nor outcome).

**Full-life cycle considerations in food and fiber production**

There is a need to consider the impacts of GHG mitigation technologies and of alternate or new products on carbon sequestration, GHG emission reduction, and energy balance along the whole system of food and fiber production and processing. This should include all sectors from the manufacturing and distribution of inputs to primary production, processing, distribution, transportation, retail and the consumer.

Technologies considered should include zero-tillage, fertilizer placement and efficiency, irrigation, biofuels, waste utilization, natural resources conservation, food processing, and vegetable oil extraction. Consideration should also be given to on-farm production of bioproducts, wood and other forms of bioenergy. Opportunities for the use of system processes based on renewable energy sources and increasing the efficiency of existing fossil-energy based processes to reduce total net GHG emissions should be examined.

The interactions between and among the suites of GHG mitigation practices being proposed for the farm need to be examined. This should include a more detailed examination of GHG emissions from the interactions of crop rotation, animal feeding systems, irrigation, agricultural residue management, and rangeland/pasture management. This should also include consideration of impacts GHG mitigation practices have on GHG emissions from surrounding lands (woodlots, wetlands, and riparian areas).

The need for “crosscutting” research was also expressed within areas of biophysical research, stressing the need for more integrated investigations.

Research has to start looking at the whole process as a function of marketing: if you know the product you are going to sell, you can link the research to the market. The opportunity for marketing of GHG friendly practices/products should be explored.
Integration of carbon (C) nitrogen (N) and phosphorous (P) cycles in nutrient management and GHG mitigation

Improve the understanding of the effect of GHG mitigation options on the C, N and P cycles (components, interconnections, and interactions). Consider the impact of fertilizer and manure management and cropping systems on maintaining a responsible balance of phosphorous and other important nutrients in soils. Consider the refinement of the role of soil testing procedures for nutrient management in long-term carbon sequestering systems such as reduced tillage crop production.

Research examining whole farm systems and associated watersheds

There is a need for research examining GHG emissions and carbon sequestration on a whole farm and watershed basis. This research should include:

a. Consideration of animal production system modeling (e.g., intensive livestock operations and manure and biosolids handling, treatment and utilization) for the reliable estimation of impacts of recommended mitigation strategies on GHG emissions is needed. Measurement and verification needs and responsibilities require re-evaluation and refinement.

b. There is a need for research on shelterbelts and woodlots emphasizing interactions with surrounding land (e.g., snow trapping leading to increase in spring GHG? Moisture/carbon competition with crops? What is net GHG balance?).

c. An accurate and comprehensive inventory of wetlands, streams, and riparian areas must be conducted. The proportion of wetlands, streams, and on-farm riparian areas or riparian areas directly impacted by farms, must be determined. Research is needed on the change of carbon stocks (including GHG emissions and sinks) resulting from wetland destruction and restoration and on the change in net GHG emissions (including change in carbon storage) as a result of management practices on surrounding uplands.

d. The influences of GHG mitigation on bio-diversity (i.e., species, habitats) natural resources (i.e., contaminant filtration, nutrient cycling, odour) need to be scientifically and economically assessed.

Identify co-benefits for whole farm systems and associated watersheds

Continue to identify and develop socially acceptable and economically efficient food and biomass production and processing systems with the lowest energy intensity, GHG emissions, and increased carbon sequestration on whole farm as well as watershed bases.

a. Consideration needs to be given to animal production system modeling (e.g., intensive livestock operations and manure and biosolids handling, treatment and utilization) for the reliable estimation of impacts of recommended mitigation strategies on GHG emissions.
b. Measurement of the physical impacts of manure management options on environmental goods. There is a need for more accurate data on nutrient and organic matter retention rates, surface and groundwater leaching rates, and other impacts on off-farm economics.

c. Economic valuation of damages (benefits) of environmental goods - Valuation of resource services, particularly as applied to the livestock industry, should build on existing livestock density and geographical identification work such as that done by Statistics Canada.

Adaptation

Impacts and adaptation

The issue of impacts and adaptation of agriculture to climate change extends beyond the mandate of this Expert Committee. C-CIARN Agriculture (www.c-ciarn.uoguelph.ca) has developed a position paper on climate change, impacts, and adaptation in Canadian agriculture. The Executive Summary is attached as Schedule A. The Committee commended C-CIARN Agriculture on its efforts and wished to reiterate the importance of developing and evaluating agriculture management options for adapting to climate change.

Increasingly participants stress the need to consider mitigation and adaptation concurrently. There are a number of areas where efforts to mitigate GHG emissions and/or sequester carbon in agricultural landscapes may contribute to efforts to adapt to climate change. There is merit in the coordination of research efforts in these areas. The following areas were identified by the Expert Committee as research gaps and/or needs:

a. Drought - There is a pressing need to develop improved cropping systems for dealing with drought conditions. These might involve integration of tillage systems (such as zero till), crops with higher resistance to heat or drought (such as *Brassica carinata*) and, possibly, new techniques such as the use of selected endophytic fungi which give plants greater resistance to heat or drought.

b. Plant pests - Pathogens, insects and weeds influence plant biomass production. The interactions between these factors and the C, N, and P cycles may have an influence on C sinks especially under conditions of climate change. Some eco-regions may be more affected by pests than others.

c. Atmospheric CO₂ fertilization - Opportunities to capitalize on the increase in the CO₂ content of the atmosphere to realize improved plant growth should be explored.

d. Identify the anticipated impacts of climate change on the social and economic well-being of rural communities. Identify and prepare adaptation strategies and plans to minimize potential adverse effects and to take advantage of positive impacts of climate change on the sector.
Measurement, verification and validation

Measurement techniques

There is a need for protocols for the measurement of GHG emissions and carbon sequestration to be established and widely disseminated. The protocols should address quality assurance/quality control issues associated with sampling and analysis, data requirements in support of modeling and/or scaling up exercises and reporting requirements (including recommended units). Methods to document and reduce the level of error associated with scaling up from microplot to field scale should be included in the standard protocol.

a. Farm-level measurement tools - Greenhouse gas emissions observed in laboratory and microplot-level experiments are well understood, but farm-level observations are not. There is a need to develop measurement/accounting tools that permit farm scales GHG emission estimates.

b. Animal production systems - There is a need to develop methods for the measurement of GHG emissions from various animal production systems including losses associated with manure management.

National accounting and verification

Establishment of a national accounting and verification systems for C-stocks and GHG emissions requires transparent and standardized methods and protocols. The AAFC program is called the National Carbon and GHG Accounting Verification System (NCGAVS). Establishing the NCGAVS needs to consider inherent seasonal and regional variability in soil distribution of C-stocks, scaling-up protocols (i.e., plots to landscapes to regions), the spatial resolution of soil and databases of agricultural activity, and the uncertainties or associated errors of estimates need improved quantification. Development of an accounting system will further the acceptance of sinks under the Kyoto Protocol and provide a solid basis for GHG emission trading schemes.

The following issues have been identified and need to be addressed in the development of a national accounting and verification system:

a. Databases of Agricultural Activities - In general there is concern that current databases of agricultural activities in Canada may not be sufficient to meet accounting and verification requirements. A study is needed to assess the comprehensiveness and suitability of Statistics Canada data and other existing databases to capture information on agricultural activities. Development of databases that contain land management data (such as land management change data) is needed for more comprehensive modeling to be successful. These efforts should be coordinated with existing initiatives in the sector.

b. There is a need to develop a baseline profile for the livestock industry and manure handling, storage and application options. This baseline data should identify links/relationships between livestock production and water quality at the watershed scale at selected sites based on Statistics Canada data (areas of livestock concentration, areas of vulnerability). These surveys should also attempt to identify problems faced
with the use of particular storage systems, their effectiveness on various types and sizes of farms and farm information needs. These efforts should be coordinated with existing initiatives in the sector.

c. The accounting systems must have the ability to express greenhouse gas emissions per unit of production (per litre, per unit live weight gain, per tonne grain yield, etc.) and support a full life-cycle analysis of GHG production (see research need above).

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

e. There is a need to clarify the process for updating IPCC coefficients to better reflect emissions under Canadian climatic conditions and management systems.

**Monitoring sources and sinks**

In general the need to obtain better estimates of GHG emissions and carbon sinks was identified. This can be achieved by establishing new, and/or utilizing existing, benchmark sites to create a national network of model farms representing most common production systems in watersheds and major agro-ecoregions of Canada to monitor changes in soil C (sinks) and GHG emissions. These “learning farms” could be used to demonstrate current BMPs for reducing GHG emissions, collect baseline data on emission reductions, improve the understanding of the impacts of GHG mitigation on the carbon and nitrogen cycles and examine the socio-economic implications and consequences of mitigation strategies. The “learning farms” could also serve as pilots for GHG emissions measurement and verification as well as the documentation of GHG emissions reduction trading systems.

**Ecological models**

Quantitative models help identify the effects of human activity on GHG emissions and C sequestration across the scales of time and space. Models are also essential tools for determining national and global carbon budgets. Enhancing scientific knowledge of the C, N and P cycles is a key requirement for improving models that help policy makers implement and adopt effective policies, and help land managers use best management systems for reducing global warming and minimizing costs. The interactions and feedback between terrestrial-ecological and atmospheric circulation models still need to be evaluated.

The following research needs in support of ecological modeling have been identified:

a. The adoption and dissemination of a single process-based ecological model and associated documentation would provide greater focus for the research community. The development and refinement of the model following an “open source” concept could serve as a forum for the discussion and evaluation of fundamental processes.

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

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

d. Validation of models is required using measured data that takes into account all temporal and spatial situations.

The Mitigation of Agricultural GHG Emissions

Animal production

Livestock Management

Research is needed examining the implications of livestock management on GHG emissions at the level of the food system, the whole farm and the animal. These areas should include:

Genetics - An examination of the implications of genetic selection for feed efficiency of GHG emissions is needed. This should include assessment of direct emissions from the animal and emissions associated with manure handling, storage, and land application. There is a need to better characterize the degree of variation in emissions among animals.

Feeding systems - The implication of feed additives and feeding strategies being utilized for monogastric animal to increase average weight gain and to reduce the nutrient content of manure needs to be assessed from a GHG mitigation standpoint. This should include a full-life cycle assessment of GHG emissions intensity and efficiencies realized in the reduction of manure volumes/nutrient contents produced.

Further research is needed on the potential for ionophores to reduce CH₄ emissions for both beef and dairy cattle. The sustainability and long-term potential for reductions in CH₄ emissions need to be evaluated. In particular, the potential for methanogens in the rumen to develop immunity needs to be assessed. Research is needed to identify alternatives that will achieve equivalent or better GHG reductions while maintaining economic production and the quality of other aspects of the environment.

Research is needed examining the opportunities for feeding strategies to reduce GHG emission intensity in ruminants. This should include an examination of feed additives (e.g., lipids), grazing strategies/pasture management (e.g., rotational grazing, pasture fertilization) and a comparison of the relative efficiencies of current feeding practices on the GHG emission intensity (e.g., total mixed ration vs. grazing systems).

Animal Shelter Management - Research should be undertaken to examine the implications of management options relating to other aspects of livestock management including housing, comfort and general well-being of the animal on GHG emissions. Practices
such as providing shelter from wind and cold require research to determine the relationship between the resultant improved daily rate of gain and GHG emissions. Minimizing livestock confinement time and/or providing timely removal of manure from confinement areas appear to provide promising options to reduce GHG emissions; however, research measurements are required to verify this suggestion and to optimize the management practices.

There is limited information available on GHG emissions associated with poultry production.

**Soils and crops, including nutrient management and carbon sequestration**

**Key soil processes and components**

Many abiotic (i.e., clay minerals, temperature) and biotic (i.e., enzymes, microbial and plant biomass, and ecology) factors are involved in the terrestrial C and N cycles. Improvement of simulation models of GHG sources and sinks requires scientific understanding of key components and processes such as controlling release of C into the soil, including microbial soil ecosystems, root exudation and respiration, the humification and oxidation of carbon and nitrogen,-complexation of organic matter with minerals, and N\textsubscript{2}O emissions. The availability and supply of C, N, and P sources in terrestrial ecosystems regulate the C, N and P cycles and this process needs greater attention. Enhancement of basic knowledge is essential for the successful manipulation of food and biomass production and processing systems and for improvement of prediction/simulation models.

Specific knowledge gaps include:

a. The need for basic research on the production and consumption of N\textsubscript{2}O in soil and specifically factors controlling the N\textsubscript{2}O/N\textsubscript{2} ratio in different spatial and temporal scales.

b. There is a need to elucidate the role of carbon availability in influencing N\textsubscript{2}O emissions from soil. Further examination of N\textsubscript{2}O emissions in agricultural soils where carbon is being sequestered (reduced-till or no-till systems) is needed to determine net GHG balance for semi-arid and sub-humid ecosystems.

c. Research is required to confirm the levels of carbon sequestered by region and to identify the new equilibrium level of soil organic carbon as well as the management conditions which must be maintained to sustain the new level. This research is particularly needed for management practices that involve a major change in land use (e.g., conversion to permanent grass or trees or wetlands).

d. Methane production and consumption - There is a need for more research examining the mechanisms and rates of methane consumption and production in agricultural landscapes.

e. Nitrogen management - With nutrient management, a number of options have been suggested which will lower the requirement for added nitrogen. Research is generally required to confirm the premise on which lower requirements are based (e.g., soil test base for crop nitrogen requirements will result in a lowering of N use, etc.).
Observations need to be extended to a wider range of crops over a greater area of the country. Research is also required to quantify the relationship among total N use, plant yield response, and GHG emissions.

f. Atmospheric CO₂ fertilization - The effects of increased atmospheric CO₂ content on the stabilization, retention and oxidation of soil C and N, and on biochemical processes of N₂O emissions, are largely unknown and need to be ascertained.

g. Carbonate pools - Soil carbonates represent an important C pool in terrestrial ecosystems. The magnitudes of their pool sizes are uncertain, and this needs to be considered during the preparation of national and global C budgets. The influences of soil and crop management, land use changes, erosion, and weathering on soil, stream and lake carbonates are largely unknown. The dynamics of carbonates need to be included in models of soil carbon.

h. The potential for genetic manipulation of crop plants - There is a need to examine the potential for the genetic manipulation of crop plants to reduce GHG emissions or to enhance C sequestration. The expression of novel genes in plants and the ability to alter the chemical composition of roots, and other novel plant traits offer the promise of the use of agricultural crops to reduce emissions or increase the removal of GHG from the atmosphere.

I. Improved soil testing - There is a need to develop improved soil testing methods to measure soil quality, the nutrient supplying capacity of soils (especially soils that have been under reduced tillage for extended periods of time).

**Grasslands, organic soils, and irrigated land**

To date the majority of agricultural GHG research has focused on annually cropped land. The role of grasslands in mitigating emissions must not be neglected. Grasslands include 20.1 million hectares (about one third of all agricultural land). Better understanding of the C, N and P cycles and proper management in grasslands can help reduce GHG emissions and enhance C sequestration.

Similarly, there needs to be greater research examining GHG emissions and C sequestration from organic soils and irrigated land and the potential for land management to influence these processes.
Manure management

Manure Management

Animal manure represents a significant source of GHG emissions from the agricultural sector and an area of considerable interest in other areas of farm management. Opportunities exist to address GHG emission issues in concert with initiatives directed at nutrient management, odour management and energy management on the farm. There is a need to evaluate N₂O, CH₄ and NH₃ emissions associated with currently emerging manure handling, storage and land application technologies. Better data is needed on GHG emissions from each phase of manure management for all regions of the country. Specific needs include:

a. Manure application - There is a need for information relating to the influence of the rate of application, type of manure, composition of manure, time of year and location of placement. The development of improved manure application techniques for direct seeding (no-till) systems is needed.

b. Composting - Composting is becoming an increasingly popular means of processing animal manures. There is a need to examine and optimize the management of manure composting systems from a GHG emissions perspective. This includes better baseline data on GHG emissions from all phases of the composting operation (composting, maturation/curing, and land application) and an assessment of the potential for compost management to influence GHG emissions. The potential for composting in colder regions of the country should also be assessed. The opportunity to use composting as a means of enhancing carbon storage in soil needs to be further evaluated.

c. On-farm manure treatment options - The potential for solids separation and other manure treatment systems to reduce GHG emissions needs to be evaluated.

d. Anaerobic digestion - Anaerobic digestion is an emerging technology for manure treatment. This technology has potential as an on-farm source of energy as well as a means of generating land amendment of high nutrient value. Additional studies need to be performed to assess the practicality of on-farm anaerobic digestion of manures, particularly in colder climates. Better estimates are needed of the potential reduction in GHG emissions associated with CH₄ capture and N₂O emissions associated with the land application of digester sludge.

e. Storage systems - Better data is needed on the GHG emissions from manure storages reflecting Canadian conditions. The ability of manure storage covers to reduce GHG emissions and reduce energy use associated with the land application of manure should be further explored. There is a need for better information on GHG emissions and management options for sold pack/bedding systems.
Bio-fuels and bio-products

Research on primary production aimed specifically at products for use in industrial applications

Research examining the potential for agriculture to produce bioproducts and biofuels that could be substituted for other carbon-based feedstocks should be promoted. Products considered should include the production of biodiesel, ethanol, methanol, biolubricants, biocomposites, bioplastics, platform chemicals (e.g., methyl esters) and adhesives. This research should include an examination of the agronomics of production, improving the quality and quantity of raw materials for industrial application, and the impacts on total net GHG emissions. This research should be conducted in collaboration with research in the industrial sector on the use of these materials in industrial processes. Research should be undertaken to consider opportunities and/or constraints to on-farm energy production (e.g., solar, wind, biofuels, biodigestors).

a. There is an opportunity for increased sustainability and utilization of animal and plant by-products (bio-energy and bio-fertilizers) on farm.

b. There is an opportunity for compositional analysis of product and by-product streams for high value components (need market research and business sense built in).

c. Standards are needed for the industrial use of products (e.g., flax fiber) and by-products (e.g., manure for use as fertilizer). Producers can use standards to begin to establish targets.

d. Case studies will help us to learn from previous failures (e.g., wheat fractionation). We need to know what went wrong and then apply lessons learned.

e. There is an opportunity to look at utilization of failed crops and diseased animals.

f. There is a need to examine the human dimensions of this issue. How do we link farmers, industry and economic development organizations?
   • Identify skills needs.
   • How to bring different communities with different orientations together and produce useful results - e.g., Ontario regional cluster development?

Research capacity, coordination, support and communication

National research networks

Collaboration between scientists, producers, government agencies, industry and NGOs at the national and regional levels fosters scientific and technological advances and helps inform and educate citizens. Organizing and coordinating scientific research networks nationally and regionally will help Canada to set the environmental science basis for sustainable development and fulfill its international commitments. Linkage of a national climate change network with international science networks will contribute to communicating scientific progress, accessing emerging technologies, and advancing Canada’s position on agricultural sinks in all forums.
Research networks need to have both the scientific capacity and the financial support to fulfill their mandates.

The following specific needs/opportunities were identified:

   a. Improved integration could be achieved by having projects co-chaired by universities and producer groups. Creative funding programs that support life-cycle analysis for specific commodities. This would encourage people to work together. Also look at the end point and focus on coming up with a variety of production processes that would minimize emissions per unit of product. Instead of having reporting only at the end of research projects, have regular and routine communication with both commodity and producer groups.

   b. We need better integration of funding objectives across federal and provincial government departments. Currently there are different proposals for different programs, at different stages, resulting in a duplication of effort for researchers and in some cases multiple projects addressing the same issue. Tripartite (federal government, provincial government, university) research collaboration structures need to be developed and integrated with producer advisory mechanisms.

**Long-term commitment to the underpinning sciences**

Climate change science is complex, requires a multi-disciplinary approach, and needs a long-term commitment by society. Minimizing the impact of global warming through basic and applied research requires long-term support from governments and industry to create necessary and adequate infrastructures, maintain programs, and develop effective policies to support producers in implementing mitigation measures.

**Communication, public outreach, and transparency**

Scientific and technological progress, methodologies and protocols used in accounting and verification systems for carbon stocks and GHG emissions needs to be published and made available to the scientific community and the public on a timely and ongoing basis.

Specific initiatives were identified:

   a. The potential linkages between GHG audits and environmental farm planning, nutrient management planning, agronomic management software, and commercial/farm data management software should be explored.

   b. There should be a concerted technology transfer initiative incorporating existing knowledge with the new research results, producing practical working solutions for the farmer.

   c. There is a need for a clearinghouse to transfer knowledge to farmers, act as a resource for researchers, and to assist in targeting gaps in research knowledge.

   d. Community-based energy co-ops are a new concept that offer great possibilities. Involve the community in the exploration of solutions rather than being confrontational.
**Cross-sectoral opportunities**

Cross-sectoral opportunities to reduce GHG emissions, particularly those that represent economic opportunities (e.g., strawboard, biochemical, biofuels, carbon trading, agroforestry) need to be identified and promoted. Climate change is a cross-sectoral issue that will present opportunities. The focus should not be restricted to sectoral issues, rather, expanded to understand the economic implications and resulting cross-sectoral opportunities. Involving regulatory agencies in the early stages of project development might be useful.

**Technology transfer**

Technology transfer has been identified an integral element of the realization of reduced GHG emissions from the sector. Specific initiatives identified include:

a. Evaluation of the economic impact of technologies on a “whole-farm” type analysis, including Best Management Practices, must directly involve produce groups.

b. Technology transfer to producers must be regionally targeted and integrated with suggested production and management practices, indicating clearly the benefits to accrue from technology adoption.

c. There is a need to enhance government capacity for extension activities, and to receive feedback.

d. There is a need to develop a calculator similar to that developed by the Canadian Cattlemen’s Association for the determination of GHG emissions and C sequestration on a wide range of farming systems to show relative changes in GHG since 1990.
References


Preface

Climate and weather conditions are important factors for agricultural production. Variations in climate conditions, especially drought and extreme temperatures, frequently pose significant challenges to agricultural operations, and to related businesses and communities. With climate change, it is expected that many of these weather conditions will be altered. Indications are that climate change is already having an effect on farming in several Canadian regions.

Producers view climate and weather risks as one of several factors to be included in their operating strategies related to production practices and financial management. Policy makers are charged with developing programs and legislation that enhance the agri-food sector’s ability to manage climate risks and take advantage of opportunities, while researchers seek to improve our understanding of the implications of climate change for the agri-food sector and to provide a sound basis for decisions on adaptive strategies. Representatives from these three groups (industry, policy, and research) work actively in C-CIARN Agriculture (Canadian Climate Impacts and Adaptation Research Network for Agriculture) and have requested an overview of the state of knowledge regarding the implications of climate change for agriculture and the prospects for adaptation in the agri-food sector.

This position paper reviews and summarizes the current state of knowledge about climate change risks and opportunities for the Canadian agri-food sector with a focus on adaptation strategies. The document also identifies research gaps and issues that need to be addressed if policy and programs for agricultural adaptation to climate change are to be timely and effective.

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Climate change, manifested through climate variability and weather, will pose significant challenges and some opportunities for the Canadian agri-food sector. Extended droughts and increases in temperature appear to be the conditions causing the most concern while longer growing seasons offer potential increases in yield and diversity of crops grown. Climate and weather impacts vary widely according to region and farming system.

Many strategies exist for adapting to climate change and weather conditions. Adaptation involves government, industry, and farm level actions. Because producers adapt to climate change in conjunction with other business risk management strategies, it is important to use a “whole-farm” approach for understanding adaptation issues. Likewise, adaptation policy will be more effective if it is integrated into existing programs.

Research and policy initiatives for adaptation to climate change are relatively undeveloped for a number of reasons, including the tendency for climate change to be equated only with greenhouse gas emission reduction rather than acknowledging the need for understanding adaptation to altering conditions. Also relevant is the fact that impacts research relies mostly on “top-down” scenario-based approaches where adaptation tends to be assumed and removed from producers’ lived experience.

There is need for policy-relevant research that examines producers’ capacity to deal with climate and weather risks. To date, there has been little government support for research approaches focusing on capacity. However, leading non-governmental organizations such as the IPCC, the World Economic Forum and the World Food Programme are moving in that direction with their adoption of a “vulnerability perspective”. This perspective features what is “known” and can accommodate diversity; it incorporates producer-based experience and knowledge, encourages integration, and builds on existing capacity.

Government ministries working for a stronger agri-food sector could enhance their capacity to develop effective climate change adaptation programs and policies by supporting research that uses the vulnerability approach.
Recommendations

Based on the information presented in this position paper, a number of gaps relevant to the Canadian agri-food sector have been identified in climate change adaptation research approach and support as well as government policy. Recommendations for addressing these gaps include:

**Research Approach and Support**

- Employ the vulnerability approach for climate change adaptation research:
  - Enhance knowledge of producer’ experiences with climate and weather risks and how these affect adaptation choices.
  - Incorporate knowledge of farm production practices and management so that linkages to existing (and future) programs and policies can be identified and acted on.
  - Ensure that climate scenarios and related models include agro-climatic conditions identified as relevant by the agri-food sector.
  - Encourage climate change related research projects to incorporate whole farm perspectives.

- Support research that enhances the adaptive capacity of Canadian agriculture and results in reliable products for managing climate risk and uncertainty.

**Government Policy**

- Assess current and future policies including the Agricultural Policy Framework in light of agri-food sector requirements for climate change adaptation.

- Improve existing climate and weather data collection and services related to them.

- Make climate change adaptation research a funding priority.
Executive Summary

This position paper summarizes the current state of knowledge about climate change risks and opportunities for the Canadian agri-food sector, and provides recommendations based on an assessment of the outstanding research gaps and issues. Following an introduction to the main issues, literature is reviewed and presented according to three broad topics: Scenario-based Impact Assessments, Climate Risk Management and Adaptation Opportunities, and Vulnerability and Adaptive Capacity. The paper concludes with recommendations regarding future research and policy directions. The main points from each section of the position paper are presented in this executive summary.

1. INTRODUCTION

The phrase “climate change” is associated with the analysis, policy, and action related to increased greenhouse gas emissions and subsequent global warming. Significant human and financial resources have been devoted to implementing policy and programs related to the Kyoto Protocol. Efforts are aimed at reducing or mitigating greenhouse gas emissions to address one dimension of the climate change issue, namely the need to slow down or stabilize climate change. Concurrent with this mitigation objective is another goal, to develop and promote adaptation strategies that will reduce the adverse effects of climate change itself and moderate the risks while capturing opportunities associated with changing climate and weather conditions. However, for a number of reasons, adaptation research has often been neglected.

2. SCENARIO-BASED IMPACT ASSESSMENT

Most research into climate change impacts on agriculture and how to adapt to them is based on climate change scenarios (i.e. plausible future climate conditions), which in turn derive from General Circulation Models (GCMs). Climate scenarios represent a “top-down” view of climate change. Such studies begin with some assumed future climate, usually focused on changes in temperature (i.e. global warming). They can be used to generate estimates of future climate conditions, mainly temperature norms and some moisture attributes, at a rather coarse spatial scale. Researchers then downscale the climate model outputs to estimate future local climate and to predict agricultural impacts.

Scenario based climate projections suggest there will be both positive and negative impacts on agro-climatic properties, crop and livestock production, farming systems, and regional economies. With climate change, most regions in Canada are expected to experience warmer conditions, longer frost-free seasons, and increased evapotranspiration rates. However, projected climate conditions and associated predicted impacts vary widely across regions and farm type. Some crop yields may increase due to longer growing seasons but uncertainties exist related to accompanying moisture levels and indirect impacts from pests and diseases. Projected impacts on livestock remain largely unknown although concerns exist about increased heat stress, pest infestations, and disease rates. It is noted that future changes in climate and weather conditions have the potential to produce profound effects on soil erosion and runoff from cropland. As well, there may be potential for already sensitive agricultural ecosystems to be damaged unless they are managed even more carefully.
Scenario-based impacts on farming systems and regional economies vary widely depending on levels of adaptation among producers and other factors. Many studies assume the technology, knowledge, and capacity to adapt will be in place for future agricultural production. Little to no attention has been directed to how climate and weather risks will merge with other risk factors for the sector (e.g. economic and environmental conditions).

3. CLIMATE RISK MANAGEMENT AND ADAPTATION OPTIONS

Focusing on risk management and adaptation broadens the context for the discussion and provides insights into how climate and weather risk management are integrated into on-farm decision-making processes. Producers rarely deal with risks as isolated phenomena given the highly integrated nature of farming systems. Climate and weather risks are closely linked to management decisions regarding yield, input costs, and environmental factors.

Even though they may not explicitly acknowledge climate and weather conditions as an important element of their risk management strategy, producers employ adaptation strategies that lessen the risk of negative impacts. Examples include: crop and enterprise diversification, land and water resource management, alterations to livestock management, altering timing of planting, and adopting new technology (e.g. irrigation systems if/when water resources are available), among many others. Adaptation options such as these have been categorized according to temporal scale (long and short term measures) and according to type (technological, government program, production practices, and farm financial management).

Some researchers incorporate adaptation options into scenario based impact assessments while others feature producer perspectives on those actions. In all cases, adaptation options for climate and weather related risks form part of a business risk management strategy and vary according to farm types and locations. Understanding what adaptation is and the implications various options carry with them is an increasingly important dimension of climate change research.

There are several ways governments (often in partnership with the larger agri-food industry) can provide support for climate and weather risk management, including sponsoring programs and subsidies for action, providing information for climate and weather impact reduction, supporting research programs, and participating in crop insurance and income stabilization programs.

Issues, and therefore research, related to climate risk management and related adaptation options are wide-ranging. They often link to data and information gathered for other topics of concern, further supporting the fact that climate and weather risk management cannot be understood as an isolated component in farm decision-making, policy development, and research. A great deal remains unknown about how producers perceive climate risk and make decisions regarding adaptation strategies. As well, many existing programs and policies are relevant for adaptation strategies yet little has been done to identify opportunities for integration and mainstreaming.
4. VULNERABILITY AND ADAPTIVE CAPACITY

The IPCC notes that vulnerability to climate change is a function not only of the system’s sensitivity but its ability to adapt to new climatic conditions. Generally, vulnerability increases with sensitivity and decreases with adaptive capacity, which is defined for climate change as “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.”

The application of a vulnerability perspective to climate change impacts and adaptation research is still in its infancy and has the following characteristics:

- It considers a variety of stresses, both climatic and non-climatic.
- It considers not just the “what?” (the hazard) but the “on what?” (the conditions of the system exposed to the hazard).
- It is time and place specific, but with a recognition of what came before and the larger environment within which a place exists.
- It involves stakeholders.
- It takes an “inverse” approach, which starts with the system (farm/community/sector/region) under consideration rather than a particular hazard.

Pursuing the vulnerability perspective requires closer integration of researchers from the social sciences with climate modelers and natural scientists. In scenario-based research, work begins with modeling and the role of human agency is only considered after future climate and impacts have been predicted. Research which employs the vulnerability perspective incorporates human agency at the outset, and what is relevant and potentially problematic for farmers and their capacity to deal with stresses is a key input into modeling exercises. Thus research into producer perspectives and actions (traditionally done by social scientists) receives earlier and more prominent consideration than it does in scenario-based approaches.
5. CONCLUSIONS: RESEARCH GAPS AND RECOMMENDATIONS

Based on the information presented in this position paper, a number of gaps relevant to the Canadian agri-food sector have been identified in climate change adaptation research approach and support as well as government policy. Recommendations for addressing these gaps include:

**Research Approach and Support**

- Employ the vulnerability approach for climate change adaptation research:
  - Enhance knowledge of producer’ experiences with climate and weather risks and how these affect adaptation choices.
  - Incorporate knowledge of farm production practices and management so that linkages to existing (and future) programs and policies can be identified and acted on.
  - Ensure that climate scenarios and related models include agro-climatic conditions identified as relevant by the agri-food sector.
  - Encourage climate change related research projects to incorporate whole farm perspectives.

- Support research that enhances the adaptive capacity of Canadian agriculture and results in reliable products for managing climate risk and uncertainty.

**Government Policy**

- Assess current and future policies including the Agricultural Policy Framework in light of agri-food sector requirements for climate change adaptation.

- Improve existing climate and weather data collection and services related to them.

- Make climate change adaptation research a funding priority.