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MINISTRY MANAGEMENT PRACTICES AND THEIR EFFECT ON GHG EMISSIONS IN THE ONTARIO AGRICULTURAL SECTOR:

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for

ONTARIO MINISTRY OF AGRICULTURE, FOOD AND RURAL AFFAIRS

by

SRG

SOIL RESOURCE GROUP
503 Imperial Road, North
Guelph, Ontario
N1H 6T9
Tel: 519 837 1600
Fax: 519 837 1242
gwall@agtest.com

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1 Executive Summary

Greenhouse gas (GHG) emissions from the agricultural and agri-food sectors result from the combined losses of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) to the atmosphere. Best management practices (BMPs) have been promoted as a means to remediate soil erosion, sedimentation and the on and offsite environmental problems associated with soil degradation. While BMPs were developed and implemented to address soil and water issues, their widespread implementation also has the potential to effect both the emission and sequestration of GHG. This study was initiated to determine the potential reduction in emission of GHG from agricultural land use through adoption of BMPs. The specific study objectives were as follows:

- Measure and project the effect of agricultural management practices (BMPs) on GHG emissions for the period 1990 to 2012
- Identify and recommend technical measures to improve the efficiency and effectiveness of BMP practices to reduce GHG emissions and project these measures over the period 2000 to 2012.
- Identify the provisions that the Ministry would need to consider in order to achieve GHG reduction scenarios of 2, 4, and 6% (based on 1990 emission estimates) with the listed BMPs or any other feasible BMP practice for the period 2008 to 2012.

The study approach can be summarized into 4 separate components as follows: a) the identification of specific best management practices for analysis, b) the development of a provincial, regional and county level data base reflecting the implementation and rates of adoption of best management practices to 2012, c) the development of GHG emission coefficients for all of the best management practices identified that reflect the climate and agricultural management practices of Ontario, and d) projections of agricultural GHG emissions as best management practices are implemented through the period 1990 to 2012.

Under the categories of soil management, nutrient management, manure storage and handling, and farm forestry management about 15 best management practices were selected for analysis. For each BMP studied, the pre-BMP conditions were described as well as the conditions associated with the use of the BMP for the soil and water conservation or GHG emission reduction. The pre-BMP condition was generally considered “conventional” agricultural practices prior to concern for soil and water quality. The soil and water BMPs are those practices promoted by OMAFRA for soil and water conservation and described in the agricultural best management practices booklets. Greenhouse gas (GHG) best management practices were conceptualized as modifications to current BMPs to better address emissions from production processes. Factors or conditions that were important in the development of GHG BMPs were as follows:

- Practices that control conditions such as temperature or oxygen status that affect GHG emissions
- Practices that sequester or reduce Carbon emissions
- Practices that improve N use efficiency for crop production
- Practices that reduce residual N levels in soils after the growing season
- Practices that reduce direct (N_2O) and indirect losses (NH_3 to the atmosphere) of GHG

The baseline, soil and water and greenhouse gas BMPs studied are shown in the accompanying Table with a brief description of the practice. All of the BMPs studied could contribute to the reduction of GHG emissions while maintaining the benefits for soil and water conservation. Implementation of BMPs on rural land has been facilitated with the use of a range of publicly funded incentive programs. These incentive programs have included approaches ranging from education/extension efforts, grants and subsidies, taxation credits, cross compliance with other programs, to regulation/legislation. Most often these programs have been available to all landowners willing to participate. Recently, some more cost effective targeted programs have been used to foster BMP adoption. These programs are only available to landowners in specific locations or with specific problems (e.g. Only landowners with livestock in floodplain locations qualify).

Provincial, regional and county data for the use of BMPs, cropland area and livestock numbers were obtained from a number of data bases including the Census of Agriculture 1991,1996; Statistics Canada census projections for Ontario, 1998; Farm Inputs Management Survey, 1995; Permanent Cover Program 2 (1991-1993). A forestry management questionnaire was sent to all Provincial conservation authorities to collect past and current adoption information not available from census data. Preliminary BMP adoption rates were obtained from the census and program data over several time periods (1991,1996,1998). Focus group meetings (8) were conducted to use expert opinion to collect missing BMP data on practices, current and potential BMP adoption rates and the role of policy instruments in fostering adoption. The Ontario Soil and Crop Improvement Association (OSCIA) set up the meetings in the 5 agricultural regions of the Province with participation from members of their organization. The database for BMP implementation and rates of adoption were modified to reflect the expert opinion obtained from the focus group meetings and Ministry extension personnel. Incremental increases in cropland numbers obtained from census data were modified to calculate cropland data to year 2000 and beyond and to back calculate cropland data to 1990. Livestock numbers (1998 Census) were kept constant to 2012.

A three-stage approach was used to arrive at GHG emission coefficients for the selected BMPs studied. First, default values for the GHG emission coefficients were obtained from estimates by the Intergovernmental Panel on Climate Change (IPCC, 1996) and the Canadian Economic and Emissions Model for Agriculture (CEEMA, 1999). Secondly, an extensive literature review was undertaken to find published emissions coefficients applicable to the selected BMPs for Ontario. Measured coefficients from long-term field data were used for studies deemed representative of Ontario agricultural management and climate. Where published coefficients or relevant field data were not available, IPCC formulas were used to calculate coefficients, using Ontario base data. Thirdly, expert consultation was sought from Ontario researchers who provided further information and validation of coefficients used in calculations. The final Ontario coefficients are not a mean or median of the reported range but represent the most likely annual emission rate from both direct and indirect sources. Rates are reported on a carbon dioxide equivalent basis (kg per hectare or livestock head) using a 100-year timeline and conversion factors of 21 CO_2 equivalents for every molecule of CH_4, and 310 CO_2 equivalents for every molecule of N_2O emitted. Each BMP tended to have a dominant GHG of concern and the emission coefficients presented reflect the impact of the BMP on the relative emission of at least this gas.

Greenhouse gas emission projections for the regions and counties of Ontario were made for the period 1990-2012 using current estimated rates of adoption of soil and water BMPs. Similar projections for the period of 2000-2012 were made using the same rates of adoption but implementing GHG BMPs. Several additional scenarios were evaluated for the 5-year period of 2008-2012 to see if accelerated rates of BMP adoption or implementation of GHG BMPs would result in the reduction of GHG emissions by 2 to 6% of 1990 emission levels.

The extent of implementation of BMP in the counties (48) and agricultural regions (5) of Ontario rose steadily through the mid 1990's in association with a number of soil and water conservation incentive programs. By the turn of the century, BMP implementation slowed dramatically as resources for incentive programs terminated. Projected BMP implementation through 2012 is expected to be slow without the creation of new incentive programs. Soil management BMPs that achieved significant levels of adoption through year 2000 included crop rotations and reduced tillage. Crop rotations were improved with increased use of soybeans and wheat in corn-based rotations while the adoption of no and reduced tillage systems increased to levels >20% across the Province. Nutrient management BMPs such as soil and manure testing showed only slight increases (about 10%) in adoption leaving much room for improvement. Banded application of fertilizer was relatively constant across the Province at about 50% but did indicate some significant increases in specific counties and regions. Progress has been made in the implementation of BMPs for livestock and poultry waste management. Run-off containment and covering of solid manures has increased in both the dairy and beef sectors. The storage and covering of liquid manure in concrete storages has increased to levels of 40 to 50% in the swine and dairy industries. Shelterbelts and riparian buffers have not been widely adopted (<5%) in the Province and do not occupy a large land base.

The GHG emission coefficients for the BMPs developed in this study are the most likely annual emission rates for Ontario that reflect both local agricultural management practices and regional climatic conditions. The emission coefficients are an improvement on generalized international values published by the IPCC or the Canadian values reported by CEEMA. The current study developed emission coefficients for a number of BMPs (buffer strips, cover crops, individual crops as opposed to crop rotations, fertilizer application type, manure testing, timing and incorporation of manure, agro-forestry) that were not considered by the IPCC or CEEMA. For the fertilizer and manure use BMPs, the GHG emission coefficients were developed from the IPCC formula but using Ontario fertilizer recommendations as described in Publication 296. Tillage emission coefficients were based on N_2O losses rather than carbon values used by IPCC and CEEMA. Soil testing and residue management coefficients were 10 to 30% lower than coefficients used by IPCC. Manure storage coefficients tended to be higher than IPCC values but lower than values used in the CEEMA model.

Estimates of 1990 GHG emissions from the agricultural sector range from about 10,000 (CEEMA) to 12,000 kt (Greenhouse Gas Emission and Economic Model for Ontario, GEEMO). Therefore, in order to achieve annual GHG reduction scenarios of 2, 4, and 6% of 1990 emission levels, then GHG load reductions of 200-300 kt, 400-500 kt, and 600-700 kt are required respectively.

For the period 1990 to 2012, the observed implementation of BMPs to year 2000 and the projected implementation of BMPs through the year 2012 would result in a 360 kt reduction in GHG emissions. Greatest reduction would occur in the southern and eastern regions with residue management (spring rather than fall tillage) and nutrient management BMPs making the greatest impacts. The implementation of GHG BMPs from 2000 to 2012 using the same adoption rates as the previous example would result in a GHG reduction of 665 kt. The southern, eastern and central regions contributed significantly to the observed reduction. Several BMP implementation scenarios were evaluated for the period 2008 to 2012. Increasing the adoption rates of BMPs from 2008 –2012 to levels observed in the mid 90’s would result in a 675 kt reduction in GHG emissions. A 5% increase in adoption of all GHG BMPs in the 2008-2012 period would reduce GHG emission by 1090 kt. Residue management, manure management and application were identified as potential BMPs to make significant reductions in GHG emissions. Accelerated implementation of these practices to 20% in the 2008 to 2012 period would result in GHG reductions of 682 kt.

The study databases were used to predict the effect of changing several management practices on GHG emission reduction. The following management practices were assessed for potential emission reductions:

Best Management Practices and their Potential Effect of GHG Mitigation

MANAGEMENT PRACTICE		**GHG REDUCTION (CO_2 equivalent kt/yr)**
Reduce Recommended N Use On Corn		
	By 5%	46
	By 15%	140
Grow No-Till Corn On Clay Soils		
	50% Adoption	47
Use N Soil Test		
	100% Adoption	288
Use PSNT Soil Test		
	100% Adoption	468
Use All Available Manure N for Crop Production		650

The preceding examples show the effect of potential adoption rates and selected management practices on annual GHG emissions within a single year of adoption. Reducing recommended N application rates on corn by 5 to 15% (which might be reasonable with site-specific N management and a revised N response curve) affects all corn producers and reduces annual emissions by 46 to 140 kt. The use of no-tillage practices on corn crops grown on clay-textured soils affect fewer producers yet reduces GHG emissions by 47 kt. Assuming a 100% adoption of the N or PSNT soil test by regulatory methods results in annual reductions of emission by 288 to 468 kt respectively. Crediting 50% of available manure N produced in the Province for crop production gives an annual emission reduction of 650 kt.

The study results show that the implementation of BMPs can lead to the reduction of greenhouse gas emissions from the agricultural sector. While some reduction in emissions of carbon dioxide and methane were associated with BMP implementation, the most significant reduction in GHG emissions in the Ontario agricultural sector was attributed to the reduction of N_2O emissions associated with crop production and livestock waste management practices. The study concludes that the adoption of agricultural BMP in Ontario could lead to reductions of GHG emissions in the order of 600 to 700 kt over the period 1990-2012.

Best Management Practices (BMPs) for Soil and Water GHG Mitigation

PRACTICE	PRE-BMP	SOIL & WATER BMP	GREENHOUSE GAS BMP	GHG FACTORS
Soil Management				
Buffer Strips	None	Grass along field border	Riparian along field border	Reduce indirect N losses, C sequestration
Cover Crops	None Fall plough	Rye cover crop	On 'High Use' N crops	Minimize residual N
Crops	Monoculture	Crop rotations; use of cereals	Legume N credit	Minimize residual N
Tillage	Conventional	Reduced-till	No-till	Reduce indirect N losses; C sequestration
Residue Management	Fall primary tillage	Reduced-till	Spring primary tillage	Reduce spring / winter denitrification
Nutrient Management				
Soil Testing	None for N	Spring N test	Pre-sidedress N test	Minimize residual soil N
Manure Testing	None	Manure N credits	Manure testing	Minimize residual soil N
Inorganic N	Pre-plant, broadcast	Banding	Pre-plant, broadcast <1-day incorporation,	Reduce direct/indirect N losses
Organic N	Fall/winter application, no incorporation	Spring application, 1 day incorporation	Increase spring application	Reduce direct/indirect N losses
Livestock and Poultry Waste Management				
Solid Handling	Cleanout once a week	Cleanout 2-3 times a week	Transfer daily	Minimize NH_3 losses
Liquid Handling	Scrape floor to storage	Wide or partial slatting	Full slats on pit, flushing	Minimize NH_3 losses and decomposition
Solid Storage	Uncovered, on ground	Uncovered with runoff containment	Covered storage, dried	Reduce anaerobic conditions and runoff / leaching
Liquid Storage	Earthen storage	Concrete storage	Minimal summer storage	Reduce surface area and NH_3 losses
Farm Forestry and Habitat Management				
Field windbreak, Building shelterbelt	None	Present	Increase	Not fertilized, C sequestration
Riparian buffers	None	Present	Increase	Not fertilized, C sequestration, reduced indirect N losses

2 Introduction

Greenhouse Gas (GHG) emissions from the agricultural and agri-food sectors result from the combined losses of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) to the atmosphere. Implementing practices and management techniques that reduce the source of the gas or create conditions unfavourable for the production of the gases can reduce GHG emissions from agricultural productions systems.

This study is being conducted to establish the effect of agricultural "Best Management Practices" (BMPs) on the emission of GHG. BMPs are practical, feasible solutions that are beneficial for the environment and for the farming operation. The BMPs as identified by OMAFRA were those recommended or used by farmers, researchers and extension personnel. Farmers were encouraged to adopt BMPs as a means by which to remediate soil erosion and sedimentation, and the associated on and offsite environmental problems associated with soil degradation. While BMPs were developed and implemented to address soil and water conservation issues, their widespread implementation has the potential to effect both the emission and sequestration of GHG.

This study was initiated to determine the potential reduction in emission of GHG from agricultural land use through adoption of BMPs. BMPs that have the capability to reduce the emissions of GHG will be identified and potential reductions in emissions of GHG will be calculated for current and accelerated rates of adoption.

2.1 Study Objectives

In response to OMAFRA's request for studies on the effect of ministry management practices on GHG emissions in Ontario's agricultural sector, the following study objectives were developed:

- Measure and project the effect of the documented Ministry practices (BMPs) on GHG emissions for the period 1990-2012 (Objective # 1)
- Identify and recommend technical measures to improve the efficiency and effectiveness of BMP practices to reduce GHG emissions and project these measures over the period 2000-2012 (Objective # 2)
- Identify the provisions that the Ministry would need to consider in order to achieve GHG reduction scenarios of 2, 4 and 6 % (based on 1990 emission estimates) with the listed BMPs or any other feasible BMP practice for the period 2008-2012 (Objective # 3).

3 Background Literature Review

3.1 GHG Processes and Controlling Factors

To evaluate the impact of BMPs on GHG production and to suggest modifications to practices that further reduce GHG emissions, an understanding of the processes that control GHG emissions must be established. How farming practices may impact these processes can then be evaluated. The following sections describe the greenhouse gases identified in this study – N_2O, CH_4 and CO_2 – in regards to processes, controlling factors and the BMPs that could affect these processes.

3.1.1 Nitrous Oxide (N_2O)

The microbial processes of nitrification (ammonium to nitrate, NH_4 to NO_3) and denitrification (nitrate to nitrogen gas, NO_3 to N_2) are the major sources of N_2O production in agricultural soils (Beauchamp 1997). Other processes, such as chemodenitrification or heterotrophic nitrification, are generally considered to play very minor roles in N_2O production in agricultural soils. Nitrification is a microbial process dependent on oxygen and NH_4 supply. Denitrification is an anaerobic process, requiring the exclusion of oxygen, and is dependent on a carbon (C) energy source and a concentration of NO_3 (or other N oxides). Nitrous oxide is normally a minor, intermediary product of theses processes but the product ratios (N_2O: NO_3 or N_2O: N_2) can increase as physical and chemical conditions vary. Both processes can be occurring simultaneously in the same soil due to the spatial and temporal variability of anaerobic microsites and available carbon sources (Chantigny et al. 1998).

N_2O is more completely reduced to N_2 under wet or saturated conditions, resulting from the reduced diffusion rate of gases in the liquid phase, which creates greater opportunity for microbial reduction of N_2O to N_2. Denitrification potential is reduced under aerobic conditions and complete reduction of NO_3 to N_2 is less likely to occur. Higher rates of N_2O emissions in upland soils are assumed to be the result of the gas entering the soil atmosphere more rapidly where diffusion rates are much higher. N_2O production from denitrification tends to maximally occur between 60 and 90% water filled pore space (WFPS) and at water contents above field capacity for nitrification (Linn and Doran 1984).

The relationship between N_2O emission rates and pH is complex. Both nitrification and denitrification rates increase when pH increases from acidic (pH 3 – 5) to neutral or slightly alkaline conditions. However, the ratio of N_2O: N_2 from denitrification falls at pH levels greater than 5 or 6, while nitrification rates show no corresponding trends at these pH levels (Granli and Bockman 1994).

Farming practices affect the evolution of N_2O primarily through influences on oxygen content, nitrate or ammonium content and carbon content of the soil (Kowalenko 1999). In most agricultural soils, the formation of N_2O is enhanced by an increase in available N that, in turn increases nitrification and denitrification through which N_2O is produced (Mosier and Kroeze 1999). Nitrogen additions to soil from inorganic or manure N amendments or biologically fixed N result in additional N_2O formation in the field in which the N is applied.

The return of crop residues and manure to soil supplies both N and a carbon energy source for the biological processes responsible for N_2O production. Manures tend to have higher N_2O emission rates than fertilizer applied to soils because they provide C, block soil pores and increase soil moisture content, all of which increase the denitrification potential hence, increased N_2O emission potential (Loro et al. 1997; Paul 1999).

Nitrous oxide losses are more dependent on the total amount of unused N after the crop-growing season than on the total amount of N applied to the crop (Chantigny et al. 1998). Under Ontario conditions, 45 to 60% of the annual N_2O emissions in the field occur during the spring thaw period (Mar.-Apr.) when there is not a living crop present (Wagner-Riddle et al.1994 in Beauchamp 1997). Wagner-Riddle and Thurtell (1998) found the October to April emission of N_2O to be correlated to the nitrate concentration measured during the previous fall. Conditions for N_2O production from denitrification are particularly favoured during spring thaw because there is no plant growth competition for mineral N, there are many opportunities for anaerobic conditions due to thaw and rainfall events, and denitrifying microbes are not reducing NO_3 to N_2 completely because of low temperature conditions. The key to reducing N_2O emission in the field, therefore, is to minimize the concentration of NO_3 in the soil over winter and during the spring thaw (MacDonald and Thomsen 1999).

In addition to these direct losses of applied N as N_2O, indirect formation of N_2O by the same processes of nitrification and denitrification may occur from N lost from soil in runoff or leaching or as a gas (NH_3) to the atmosphere (Mosier and Kroeze, 1999). Farming practices can also affect N_2O production indirectly by impacting the efficiency of the denitrification/nitrification processes. Compaction, tillage, irrigation and drainage affect soil structure and water content that control the rate of diffusion of oxygen into the soil.

BMPs Related to Nitrous Oxide Production

Management practices such as soil testing, manure testing, cover crops, crop rotations, buffer strips, riparian zones, manure handling and storage, manure and fertilizer application type and timing have a role in the emission or mitigation of GHG.

3.1.2 Methane (CH_4)

Approximately 80% (405 Tg yr^{-1}) of the total global CH_4 emissions evolve from biogenic sources, of which ruminant animals represent approximately 20% (80 Tg yr^{-1}) and the rest comes from landfills, rice fields, natural wetlands, biomass burning, oceans and insects (Crutzen, 1991). Most CH_4 emissions from agriculture originate from the livestock industry. Ruminant livestock such as cattle and manure storage facilities that become anaerobic are the most important sources.

Gastric methane production by ruminants is a large source of global methane emissions: 65-100Tg per annum. Methane is the final product of anaerobic fermentation of complex plant carbohydrates ingested by ruminants. The less digestible the feed intake is (i.e. higher roughage), the greater the methane production by the ruminant micro flora. Mitigation measures that alter ruminant diet and feed efficiency have proven beneficial in reducing CH_4 emissions. Generally, upgrading low-quality forages will decrease the amount of methane produced per unit of animal weight (Milich 1998). Decreasing the amount of hydrogen available in the feed will reduce methane production. For example, forages with high-solubility carbohydrates limit methane production (Moss 1992). Corn or sorghum starch, compared to wheat and barley, is more rumen-resistant and promotes movement of feed to the small intestine without methane production.

Animal waste accounts for 20-30% of the annual global methane budget (Kreileman and Bouwman, 1994). In manure management, methane production will increase with anaerobic conditions, with organic matter content, with pH levels of 7-8, and with increasing temperatures. Liquid storage of manures in earthen manure storages and storage tanks promotes the anaerobic conditions required for high methane emissions, and the natural pH of manures lies within the optimum production range. Milich (1998) reported that, in manure cesspits, wet manure produces seven times more methane as dry manure.

Temperature can be a major factor in emission rates. In Ontario, naturally cool conditions for a significant portion of the year, will reduce, and for some months practically eliminate GHG emissions. Husted (1993) showed that a 1.8 ^{o}C increase in temperature resulted in a 13.1% increase in CH_4 emissions; therefore, storage in summer months should be avoided. Furthermore installing underground concrete manure storages, or banking aboveground tanks will further reduce temperatures in the warmer months.

Reducing losses of CH_4 from manure involves slowing the rate of decomposition, providing better aeration and reducing the length of storage.

Methane (CH_4) is also part of the soil carbon cycle. It is released to the atmosphere during the decay of organic materials under anaerobic conditions. Methane is produced through the reduction of CO_2 and through transmethylation of acetic acid or methyl alcohol by methane-producing bacteria, known as methanogens (Milich 1998).

Soil oxidation of methane recaptures about 5% of the global emissions (Kreileman and Bouwman, 1994). This methane consumption occurs in soils through two main bacterial groups: methanotrophs and nitrifiers. Oxidation of methane by these groups is primarily dependent on moisture. Saturation of the soil will halt consumption and produce more methane. Temperature and fertility levels have been shown to affect the rate of soil moisture-dependant consumption of methane, with high fertility and temperatures of –5 to 10 degrees Celsius favouring oxidation on aerobic forested sites (Milich 1998).

Changing management practices may significantly alter the amount of methane consumed in the soil. It is now generally accepted that ammonium fertilizer can suppress methane uptake via competitive inhibition (Hutsch, 1996, 1998). Castro et al. (1995) suggest that methane uptake is related to soil-N turnover, soil-N content and changes in microbial communities. Methanotrophs dominate unfertilized soils while nitrifiers dominate fertilized regimes. In relation to nitrous oxide fluxes, both methane consumption and nitrous oxide production are low at prolonged high soil moisture levels. N_20 levels peak after precipitation, then rapidly falls, while methane consumption drops to almost nil (or production rises) after rainfall, followed by an increase in consumption (Milich 1998). Management practices that reduce the biological activity in the soil will also reduce the amount of methane consumed.

Under most conditions typical of agriculture and forestry in southern Ontario, methane emissions are negligible to negative (soil environment is a net sink for CH_4). Methane emissions may be an issue in poorly and very poorly drained soil conditions. However, the BMPs discussed here are unlikely to have a significant effect on methane emissions. For instance, the recommended BMP for wildlife habitat improvement is appropriate to lowland areas not suitable for agricultural production (i.e. wetlands); however, these practices will have no measurable effect on GHG emissions.

BMPs Related to Methane Production

Manure handling and storage, riparian zones and buffer strips are BMPs that can impact GHG emissions and mitigation.

3.1.3 Carbon dioxide (CO_2)

CO_2 is currently increasing in the atmosphere at a rate of about 1ppm per annum, largely because of the use of fossil fuels for energy. Primary producers, plants and microorganisms through photosynthesis in the production of organic matter, consume atmospheric CO_2. Methanogenic microorganisms will also use CO_2, but their product is CH_4, so from a greenhouse perspective, their net effect is negative. CO_2 is returned to the atmosphere during respiration by animals (especially ruminants), plants, insects etc. and microorganisms, and decomposition (by microorganisms) of the organic matter. The amount of CO_2 released from organic matter is a function of the % carbohydrate, % lignin and the C: N ratio in that organic matter. The net CO_2 effect of agriculture will depend on the balance between the photosynthetic use of CO_2 and its release from decomposition of organic matter in fields and in manure storage, and the use of fossil fuels in production processes.

In manure storage, CO_2 losses are of greater concern in aerobic systems, where CO_2 is the primary carbon gas of concern, than in anaerobic systems, where CO_2 represents about 10 to 20% of the gaseous C losses (Safley & Westermann, 1988, 1989). Covering manure stores, solid or liquid, will reduce gaseous losses in the order of 80% (Beauchamp, personal communication.). As with all biological reactions, CO_2 production is greatly affected by temperature, and so losses will be much smaller in the winter than in the summer, therefore summer storage should be avoided.

Agricultural crop production is an important source and sink for carbon dioxide (CO_2). On every hectare of cropland, many tonnes of C are removed from the atmosphere annually and changed to organic materials through photosynthesis. At the same time, the decomposition of organic matter and the burning of fossil fuels release roughly equivalent amounts of CO_2 back into the air. Generally, amounts of carbon, released from agricultural systems as CO_2, are relatively equal to amounts of carbon sequestered, resulting in a negligible net emission of CO_2. As a result, there are two main ways of reducing emissions: one is to increase the amount of stored C in soil; the second is to burn less fossil fuel.

Farmers can increase soil C levels by using higher yielding crops with high levels of nutrient and water management and by using cropping systems that keep actively growing plants on the land as long as possible. Increased levels of soil C can only be maintained if a large proportion of the crop residues are returned to the soil. Within any given climatic and soil zone there is a maximum amount of carbon which can be sequestered until soil decomposition is balanced (in equilibrium once again) with plant/animal residue inputs.

The potential for farm forestry to sequester carbon is related to the growth phase of the trees. Trees do not grow in a linear fashion. During the early growth phase, relatively little biomass is accumulated. After some number of years, growth enters what is known as the exponential phase. It is during this phase that carbon is rapidly sequestered into the woody biomass. There are many factors that affect the development of a tree and will influence the timing of the onset and conclusion of this rapid growth phase. Some of these factors include the biotic potential of the site (including moisture and nutrient availability, frost free period, limits to root growth and many more factors), tree genetics (seed source, cultivar selection), and pest damage. Thevathasan and Gordon (1999) have estimated that a fast growing fibre tree species (in this case hybrid poplar) can fix approximately 36 t ha^{-1} C (144 t ha^{-1} CO_2) over a 40 year period at a planting density of 111 trees ha^{-1}. This is about 1/10th of the stocking of a typical plantation. The authors have also estimated that Norway spruce, a slower growing species, will sequester carbon at a rate approximately 25% of the fast growing species. These values reflect the tree biomass only.

Carbon sequestration is balanced by increased soil respiration (CO_2 emission) under tree cover. Data provided by Thevathasan (1998) estimates that CO_2 emissions in a tree row are approximately double that found in the crop. This is attributable to enhanced biotic potential in the relatively undisturbed tree row. Under a temperate intercropping system utilizing poplar and a cereal crop, Thevathasan (1998) showed that CO_2 evolution from the soil rapidly decreases as distance fro the tree row increased. This decrease is related to soil temperature changes away from the tree row. Increased canopy cover will decrease the amount of radiative heating of the soil surface. As such, shelterbelts will create an environment towards the interior that more closely resemble a forest. The environment along the edges of the shelterbelt will be similar to a windbreak. Some estimates of CO_2 emissions from temperate forests are an order of magnitude less than that observed in the single row plantings described by Thevathasan (Bowden et al. 1998, 2000).

BMPs Related to Carbon Dioxide Production

Manure handling and storage, tillage, residue management, buffer strips, riparian zones, reforestation, woodlot management, and intercropping / agroforestry are BMPs that can impact GHG emissions and mitigation.

Agricultural Management Practices Affecting GHG Emission and Mitigation

Ministerial agricultural management practices that are the focus of this study have been grouped into 5 management categories (soil, nutrients, livestock and poultry waste, farm forestry and habitat). In the following sections, the role of specific management practices in controlling GHG emissions and mitigation will be discussed.

3.1.4 Soil Management

Buffer strips

Land use change from a disturbed/cultivated site to a permanent cover will reduce GHG emissions over time due to the improved potential for permanent vegetation (trees, grasses > legumes) to reduce excess atmospheric, surface and subsurface (leachate) nitrogen (N). Increases in CO_2 emissions are more than balanced by the increased levels of soil organic matter (SOM) and the increase in carbon resources, with the extent of carbon sequestration dependant on biomass production. The addition of any permanent vegetation area, such as a buffer strip, provides an additional carbon sink much greater than any sequestration contributions that can be made through a cropping system.

Nitrogen that is leached from agricultural areas into groundwater can re-enter the surface water system through drainage outlets, and denitrify off-site to release N_20. Vegetation in the buffer strips can intercept both surface and groundwater flows and scavenge excess NO_3 and NH_4, thereby reducing the water content N and future N_20 production potential.

Heathewaite et al. (1998) has indicated that a 10 m grass buffer strip is adequate to reduce N export via surface transport from upland areas / adjacent fields by 75% (below cropland on which cattle manure slurry was applied) to 94% (solid manure). This width was not sufficient to provide substantial reductions for other nutrients (e.g. phosphorus P). Nitrogen (N) export from inorganically- fertilized areas decreased by 5- to 10-fold, once runoff passed through the buffer strip. NH_4 was readily trapped, NO_3 less so. Losses of total N were greatest for inorganic fertilizer > solid manure > slurry, with most of the manure N losses in organic form. The 10 m buffer width appeared to be adequate for N reduction (not so for P reduction), although losses are also incurred through subsurface pathways.

Inclusion of fast-growing tree species in conversions from grass to riparian buffers can result in the following GHG benefits: greater biomass and therefore higher sequestration potential (which compensates for the increase in CO_2 emissions from trees); erosion/runoff reductions; and removal of N in leachate from adjacent cropland. Estimates of leachate NO_3 reduction range from 50% to 70%, trapped by 5 to 10 m width riparian buffers, respectively (Thevathasan, personal communication). In permanently water-covered riparian fens, denitrification serves as a sink for both dissolved N_2O in groundwater recharging the fen and N_2O produced in the system (Bilcher-Mathieson and Hoffman 1999).

Modifications to the buffer BMP to improve GHG emission reduction are as follows:

- Enhancement of the existing grass buffer, through: increases in width; addition of high N-use, deep-rooting grass species; increase in overall quality and coverage; protection of banks and outlet flow areas; inclusion of filter species (bulrushes) in watercourses; retain permanent cover on all areas throughout the year

- Conversion to riparian (treed) system from grasses using: greater biomass growth; inclusion of high N-use species (e.g. fast-growing poplars)

Crop rotations

High N-use crops will uptake applied N and reduce denitrification. Plants do not produce N_20 but act as a conduit. The type of crop chosen will affect the amount of N uptake (Kowalenko 1999). As an example, corn demands a high supply of N throughout its growing season and after harvest, the residual stalks will contain a high amount of N and C relative to that retained in other crop residues. Nitrogen losses to the soil throughout the growing season will be a result of residual NO_3, which remains unavailable to the crop or is leached before it can be used – losses will not be emitted from the crop itself. Fan et al. (1997) have found a greater release of N_20 during the growing season for some crops (corn > soybeans) but this relates more to the amount of fertilizer applied than to the actual crop.

Biomass production is crop-dependent. Crops with greater biomass usually return a greater quantity of carbon to the soil via crop residues. High C: N ratios can reduce N_2O production. Recent increases have been observed in overall Ontario crop yields which can be related to improved varieties and better pest management practices (Swanton et al. 1996). Choosing higher yielding, hardier varieties in rotation provide some scope for mitigation of GHGs. Although higher crop production can be associated with higher CO_2 emissions, this is more than offset by the potential for carbon sequestration and implications for improved soil quality.

Kowalenko (1999) advocates growing crops in such a way that residual inorganic N is kept at a minimum. The use of crop rotations, a recommended Soil and Water BMP, compared to continuous high-N use crops, serves this purpose. Further nutrient use efficiency / reduction in excess N to mitigate GHG emissions could be achieved with prudent crop choice, and the sequencing of these crops in rotation. The amount of NO_3 available in the soil can be reduced by alternating high N-producing / releasing N-crops (alfalfa) with high N-use crops (corn). The following crop can use residual N released into the soil via decomposition and mineralization of previous crop residues. By accounting for the residual N from previous crops and incorporating these organic N credits into crop requirements, inorganic fertilizer additions can be minimized. Mackenzie et al. (1997) recommends using legumes in rotation and making use of the legume N credits to reduce NO_3 / NH_4 use.

O’Hara (1998) advocates a shift in balance from fertilizer-based N to biological source to meet crop N requirements through: optimization of the N-fixing potential of current systems; introduction and expansion of N-fixing crops to new systems; and the development of new crops with the capability to fix their own N (a long-term goal). Symbiotic biological N fixation – with direct inputs of atmospheric N – has two primary benefits: reduced crop disease pressure through legume inclusion (reduction of chemical/fungicidal dependence), and improved pest management e.g. through nutrient management (potential reduction in N fertilizer costs). The amount of N supplied by grain legumes, such as beans, for growth and subsequent crops varied by: available soil moisture, supply of P and K, soil acidity, nutrient competition, crop management (sowing date, cultivar varieties). Herridge and Danso (1995) report limited success in producing grain-legume types that show enhanced nitrogen production.

Corn rotations with soybeans can emit less N_2O than corn rotations with legumes such as alfalfa (Mackenzie et al. 1997). Improvements in N-fixing rotational systems might have the most impact in areas where there is a need to overcome environmental stresses such as acidity, water stress, and nutrient deficiencies (Giller and Cadisch 1995).

Biologically fixed N sources remain as organic-N until mineralized and nitrified and as such are not prone to denitrification, whereas chemical fertilizer is readily denitrified if not taken up by plants or leached. Therefore, bio-N should contribute less to global atmospheric N loading than chemically fixed N (Beauchamp 1997).

The type and timing of operations will further affect N and C availability. Fall ploughed residues, particularly legumes, will make NO_3 and C available for spring GHG fluxes, and potentially less available when the nutrients are required in the growing season. Supplies of NO_3 and O_2 could be reduced by planting the next crop as soon as possible after spring tillage, (Wagner-Riddle et al. 1998) or, preferably, applying herbicides to kill forages (Tenuta and Beauchamp 1995).

Crop and rotational choices can affect methane production indirectly. In poorly drained soils, application of N fertilizers to soils frequently inhibits methane oxidation but presumably can increase N_20 emissions (Hansen et al. 1993). Lowering the water table can convert a wetland area or very poorly drained site (i.e. through drainage) from a methane source to an atmospheric methane sink (Topp and Pattey 1997).

Modifications to the crop rotation BMP to reduce GHG emissions are as follows:

- Follow high N-production crops with high N-use crops
- Maximize all sources of N, limit additions of inorganic fertilizer to required amount
- Use biologically-fixed N sources as part of the fertilizer requirements for the following crop, use N credits
- Interseed high N-use crops
- Choose varieties of crops that will efficiently use N
- Delay kill of legume forage crops until spring, just prior to planting
- Time operations to limit fluxes, leaching of N

Cover crops

Emissions of N_20 during spring thaw in Ontario have been found to be substantial. These should be considered in nitrogen budgets (Wagner-Riddle 1998). Over-wintering cover crops have potential to mitigate the flux of N_2O in the spring-thaw period. Soil $N0_3$ or NH_4 concentrations can be lowered by growing cover crops when the main crop is not growing or after harvest (Boran and Smith 1995, Beauchamp 1997). Wagner-Riddle et al. (1996, 1998) found negligible emissions in spring if plants were present (alfalfa, grass); however, fall incorporation of legumes contributed to the spring N_20 flux.

Intercropping of legumes and rye grass into grain corn can cause a reduction of nitrate residues and in fertilizer requirements for a following crop. While Zhou (1996) noted a yield reduction (15-20%) in an interseeded corn crop during a dry year, Ball-Coelho and Roy (1997) overseeded cereal rye into corn with equally promising leachate / soil NO_3 reductions, but without the yield penalty. In dry years on coarse-textured soils, the reduction of NO_3 leaching was most pronounced, with the amount of reduction dependent on rainfall and corn yield. No yield penalty was found on either the no till (NT) or conventionally tilled (CT) fields. Improved N availability was found under CT (not NT), indicating that the rye cover crop in conjunction with a Pre-Sidedress N Test (PSNT) could reduce fertilizer N requirements (Ball-Coelho and Roy 1997). In another study, rye cover crops sequestered substantial amounts of NO_3 in heavily fertilized maize crops and reduced potential leaching. Less mitigation impact was observed in reduced N fertilized trials, indicating that there might not be a need to attempt to sequester soil N at lower fertilization rates.

Modifications to the Cover Crop BMPs to improve GHG emission reduction are as follows:

- Cover crops in rotation or interseeded and left live over winter can mitigate N_20 fluxes in the spring, when much of the N_20 loss from Ontario soils occurs
- N credits from cover crops can be used along in conjunction with fertilizer requirements and soil tests to reduce fertilizer application

- Cover crops can reduce leaching of N, particularly in dry years on coarse soils
- Crops with low N fertilizer rates might not require cover crops to trap excess N
- Fall kill / ploughing of cover crops should be avoided
- High N–scavenging cover crops will remove more N than N-fixing covers
- No till herbicide kill of cover crops increases soil organic matter, and emits less CO_2 than incorporated residues

Tillage

Results of tillage studies with respect to GHG mitigation are varied and often contradictory. Higher N_2O emissions have been observed during the growing season with no-till (NT) compared to conventional tillage (CT), with higher denitrification rates related to the higher soil moisture and nitrate contents (Fan et al. 1997; Mackenzie et al. 1997). Aeration has been mentioned as a potential means of mitigating GHGs, but any disturbance of the soil through conventional or reduced tillage can also eliminate any of the potential sequestration advantages gained through long-term no till within 6 to 24 months (B. Kay, personal communication).

These results, however, vary from what was observed in studies measuring gas emissions throughout the year. Wagner-Riddle (C. Wagner-Riddle, personal communication) found yearly rates lower under NT, due to the lower spring flux emissions under cover crops that may be due to better spring drainage in NT. If higher rates of CO_2 and N_2O emissions occur during the growing season on NT as compared to CT fields (as a result of NT's decreased soil temperature, increased soil moisture and carbon), then these higher rates more than offset the positive changes due to NT (such as increased SOM, improved soil structure, potential sequestration, erosion control and runoff reduction).

While management changes to reduced and no-till systems have benefited soil conservation efforts, the increased infiltration capacity of lower-till systems can contribute to increased N leachate / groundwater levels. Fertilizer rates should not exceed crop requirements, and all N sources should be accounted for in determining rates.

Modifications to the Tillage BMPs to reduce GHG emissions are as follows:

- Maintain reduced or no till system
- Refine farming systems to complement and enhance no-till practices (crop rotation, varietal selection, residue management, pest and weed control, potentially reduce fertilizer rates)

Residue Management

Additions of crop residues – especially those with a high C: N ratio - can reduce N_2O emissions. Any increases in CO_2 that result from leaving residues on the field are more than compensated for with potential carbon sequestration, improved soil quality, and the reduced risk of soil compaction, erosion, runoff and leaching. C in soil becomes less degraded as N increases to optimal (i.e. non-excess) levels (Kowalenski 1999; Chantigny et al. 1998). Burgess et al. (1999) found in a three year study that fall nitrate levels were greatest where residues were removed in the first year, but the same in years following. Emissions vary with crop choice. For example, Taggart (1999) found that residues from potatoes emit 1.5 times as much as spring barley and 6 times as much as winter wheat.

The potential for residues to release N to the following year's crop can be directly accounted for in the fertilizer recommendations.

The 'efficacies' of adopting BMPs in increasing C in soil storage could be directly associated with the amount of residue returned to the soil. In a 6 year study in Western Canada, no till did not increase SOM but systems *not* fertilized continued to lose SOM (Campbell et al. 1997).

Decomposition of residues, loss of SOM over time, and CO_2 emissions are greatest when the residue is incorporated.

Modifications to the Residue Management BMP to reduce GHG emissions are as follows:

- Residues should be maximized, and left on the surface
- N credits for residues, especially legumes, should be accounted for in the following crop's fertilizer requirements
- If residues must be incorporated, this should be done in spring just prior to planting when ever possible. Residue cover over winter is preferable from a soil conservation as well as GHG mitigation practice over fall incorporation.

3.1.5 Nutrient Management

The potential for Nutrient Management BMPs to mitigate GHG emissions is based on two principles:

- Determining the amount of N to be applied so residual mineral soil N is minimized, particularly during the spring thaw period
- Improving the efficiency of N use so that there is proportionally more available N for the crop and less N_2O production through losses due to volatilization, leaching and denitrification

A review of Canadian research (MacDonald and Thomsen 1999; Kowalenko 1999) showed that the most straightforward farming practice influencing N_2O emission is the addition of nitrogen to the soil as fertilizer or manure. It is also the easiest practice that farmers can control. The key to limiting N_2O emissions from farm systems, then, is to know how much nitrogen is needed for a field. Currently there is no accurate method of determining this value on a field crop basis (P. Von Bertoldi, personal communication). The best available values at present are the OMAFRA Publication 296 N fertilizer recommendations for various crops based on averages for regions within the province. These recommendations are based on supplying a level of N for maximum economic yield production.

Soil and manure testing are currently promoted as Soil and Water BMPs to match crop requirements with N applications to meet provincial guidelines so that contamination of surface and groundwater is minimized. Nutrient management plans (OMAFRA, 1998) and computer programs (NMAN$_2$000, MCLONE4) are available to aid farmers in "budgeting" their available nitrogen sources from soil mineral N, animal manures, legume crop residues and commercial fertilizers. Average values for various N sources have been compiled by OMAFRA to use in these budgeting exercises and are a starting point for "matching" N requirements with N sources. Using soil and manure tests is intended to more accurately reflect N sources on a per farm basis and better reduce the "unused" portion of mineral N in the soil. This unused portion is subject to environmental losses leading to groundwater contamination and N_2O production. The potential to reduce N fertilization to a more environmentally friendly rate using soil and manure testing depends on the sampling and fertilization philosophy, record keeping, and equipment calibration by the producer.

Soil and Manure Testing

The only available soil nitrogen tests at present are the soil nitrate tests (Beauchamp, personal communication) for corn and barley crops. Nitrogen is highly variable in the field year to year, due to variations in the local climate and soil properties for an individual farm, which are not reflected in the provincial averages. Spring sampling of soil nitrate to 30 or 60cm within a 5-day window of planting can indicate the availability of mineralized nitrogen from organic sources or from residual fall N. The research used to calibrate and develop the soil nitrate test for Ontario generally found that N application rates could be reduced by 10-25% of the provincial average recommendations when spring available nitrate was measured (Kachanoski and Beauchamp, unpublished data; K.B. MacDonald, personal communication). The spring soil nitrate test may be less accurate in predicting available N where manure has been applied or where red clover or alfalfa has been ploughed down, as the breakdown of the organic materials has not been fully initiated at this time of year and may not be included in the test. Another reason the spring soil nitrate test has not been widely adopted is because sampling needs to be done at a very busy time of the year for farmers.

A **Pre-Sidedress N Test (PSNT)** is now included in OMAFRA Publication 296 recommendations for corn. In this test, the soil nitrate to 30 or 60cm is sampled when the corn is 6-12 inches high, usually during the first 2 weeks of June. This approach gives producers a wider window of opportunity to conduct the soil test and allows the soil to warm up so that more accurate assessment of available soil nitrogen from inorganic and organic sources can be made (Stewart, 1999). Fertilizer efficiency is also improved using a side-dress application as the crop is in a growth stage when nitrogen is taken up in large quantities (6 leaf stage) and saturated soil conditions which promote denitrification are less likely. Banding of N materials, either surface or subsurface, is typically employed due to the logistics of planting in a row crop and minimizing canopy burning. Banding reduces the surface area of N materials available to microbes, which immobilze it in organic materials, and places N near the crop roots for uptake, which also improve the fertilizer efficiency. The improvement in N determination and fertilizer efficiency lead to a decrease in the amount of fertilizer needed to be applied as side dress applications in SW Ontario to generally 15% that of the provincial recommendations (OMAFRA, 1998).

Manure N content to be field applied can vary greatly depending on the animal species and age, ration fed and manure handling and storage. Manure testing after agitation or complete mixing to obtain representative samples, is recommended to establish the N content in the manure. Once potential seasonal fluctuations for an operation, due to variables such as time in storage, extra rain, and cold temperatures, are established there often is no need to continually test manure unless there is a change in ration or manure handling/storage. Again, manure testing is the only method to arrive at farm specific values that are more accurate than the existing provincial averages that have a high variation. Reduction of GHG emissions due to manure testing will only be realized if the applied manure is fully credited for its fertilizer value, as in a nutrient management plan, so that there is no over-application of manure. Manure is often repeatedly applied to the same field for long periods and this practice should be avoided. N_20 emissions from a soil in western Canada which had received 21 annual applications (60-180 Mg/ha) of solid beef feedlot manure were up to 56 kg N_2O-N/ha (27280 kg CO_2 /ha), reflecting the accumulation of nitrate and organic matter in the soil (Chang et al. 1998).

Improvements in reducing GHG through soil and manure testing can be done through:

- Wider use of manure testing and crediting for fertilizer value
- Wider adoption of spring soil nitrate or PSNT tests
- Minimizing over-application / excess levels of fertilizer and manure N applied

Nutrient Application Type and Timing

Management factors that increase the efficiency of soil and amendment nitrogen could also contribute to minimizing nitrous oxide emission. The effect is not nearly to the same magnitude as adjusting the amount of nitrogen to that which is applied for optimum crop yield (Kowalenko, 1999). Nitrous oxide production from cropland is highly episodic and so management practices may have an effect on N_2O production at only one time of the year or may postpone N_2O production to another time of the year. It has generally been recognized that the form of nitrogen applied may not affect N_2O production to the degree as initially thought (Eichner 1990), but that the application type and timing may be more influential (Mosier and Kroeze 1999).

Current soil and water BMPs recommend timely incorporation (< 1 day) or banding/injection of fertilizers and manures to minimize volatilization losses, reduce odours, and improve fertilizer efficiency. Surface broadcasting of manures and fertilizers leads to high N losses due to NH_3 volatilization (10-90%)(E. Beauchamp, personal communication). It has been estimated that only 1% of this N is emitted as N_2O when it is later deposited on the soil (Mosier et al. 1998). Because less nitrogen remains in the soil, the direct losses of N_2O through leaching are smaller compared to application methods that conserve N in the soil. Incorporation of fertilizers and manures as soon as possible after application can significantly reduce volatilization losses. However, broadcasting and incorporation of fertilizers and manures has been shown to increase N_2O emissions compared to no incorporation because i) the concentration of N in the soil is increased with less NH_3 volatilization, and ii) O_2 availability is decreased below the surface (Petersen 1999).

Banding or injection of fertilizers and manure also tends to produce even higher measured N_2O emissions in the field. The high pH and metabolizable C/moisture contents resulting from subsurface banding of urea or manure, respectively, provide more favourable conditions for release of N_2O during the time immediately following application (Thornton et al.1996; Dosch and Gutser 1996). Conversely, injection of a slurry has also shown less N_2O emission than a broadcast and harrow application because a more complete anaerobic environment for denitrification (N_2 formation) was created (Weslien et al.1998). Thus recommended application techniques to reduce NH_3 volatilization and improve N efficiency tend to increase direct N_2O emissions. Some balance is provided when indirect emissions due to NH_3 volatilization are included which reduces the difference between spreading techniques (Ferm et al.1999). Therefore, application techniques which have been recommended for their soil and water quality and economic benefits will only reduce GHG emissions significantly if the improved fertilizer efficiency is realized and less total fertilizer is applied when banding/injecting in particular.

Manure type or handling may also influence N_2O emissions in the field. Loro et al. (1997) found solid beef manure to have higher total N_2O emissions than liquid dairy manure because the supply of available C was of longer duration from the higher total C application over a 49 day period in the spring. Liquid manures may potentially have higher initial N_2O production because the additional water added and clogging of pores produce conditions conducive to denitrification (Paul 1999). Reductions in emissions from manure which is treated by anaerobic digestion, slurry separation or composting appears to be due to the lower input of metabolizable organic C (Petersen 1999; Paul et al. 1993).

Timing of manure applications is particularly influential on N_2O emissions. Nitrification of the ammonium present in the manures produces nitrate that is highly mobile and susceptible to leaching. Over winter leaching and denitrification losses of N under Ontario conditions are usually about 50% (E. Beauchamp, personal communication). The IPCC estimate of N_2O emissions from leached N is twice that of direct emissions (2.5%), although only a portion (default 30% for IPCC methodology) is considered to leach (Mosier et al. 1998). The potential for leaching and denitrification losses from spring applied manures and fertilizers is much less as the available mineral N can be taken up by growing plants and microbes, and soils with 70-90% water filled pore space do not generally prevail for long periods of time. Weslien et al. (1998) found that N_2O originating from leached N_2O was of the same order of magnitude as the direct emission from manure slurries, while the contribution from NH_4 deposition was small except for surface application. Leaching losses were 6-18% of total applied N in the spring (Apr.-June) and 30-38% in the fall (Sept.-Nov.).

Improvements in reducing GHG emissions through type and timing of manure and fertilizer application include:

- Reducing the amount of fall applied manures; limit amount of mineral N in soil during spring thaw
- Adjusting/lowering amounts of fertilizer/manure applied via banding/injection to account for improved N efficiency

Manure Handling and Storage

Manure Handling

In animal housing and manure handling, CO_2 release comes from:

- Animal respiration (major source)
- Almost immediate breakdown of urea and release of CO_2 and NH_3
- Respiration from aerobic organic matter breakdown
- To a smaller degree, fermentation (anaerobic breakdown of organic matter).

Little data on CO_2 losses from manure handling is available. However, since urea rapidly breaks down to CO_2 and to NH_3, it follows that an assessment of CO_2 losses can be determined by examining NH_3 losses. Loss of NH_3 (and concomitant CO_2) from urea has been shown to occur within the first 24 hours of excretion; N from feces undergoes much slower release. Very large losses of total N from manure have been shown to occur (dairy: 40%-60%, Muck & Richards, 1983; up to 85%, Whitehead & Raistrick 1993; 20-40%, Monteney & Erisman 1998; 23-30%, Paul et al. 1998; beef bedded pack: 29%, Huston et al. 1998; swine: 27%, Burton & Beauchamp 1987; poultry: 75%, Bulley & Lee 1987).

Significant improvements in CO_2 and NH_3 emissions can be made by:

- Reducing the time interval of scraping excreta (22%TN loss to 0% TN loss, scraping time reduced from 3 days to 0.67 hours, Huston et al., 1998)
- Improved floor shape for liquid slurry systems (30% improvement in TN loss with a fully slatted floor over a concrete manure storage compared to a slatted floor over a sloped floor running to temporary storage for swine, Burton & Beauchamp, 1986; 50-60 % improvement in losses with a v-shaped floor or central urine drain, Aarts, 1992)
- Flushing with water (50-65% improvement, Monteney & Erisman, 1998, Bussink & Oenema, 1998) or dilute formaldehyde or acidified slurry (80% improvement, Monteny & Erisman, 1998)
- Forced-air drying of poultry manure (48%, Bulley & Lee, 1987; 60%, Overcash, 1983). This option will almost completely eliminate subsequent storage losses of gases as well.

Solid Storage

In Ontario, solid manure storage tends to be the preferred storage system for beef and poultry, and some dairy operations. In manure piles there will be both aerobic and anaerobic sites, so that CO_2, N_2O, and CH_4 can be produced simultaneously in different areas of the pile.

Carbon dioxide emissions from solid storage results from:

- Aerobic microbial breakdown of the organic matter in the solid manure (respiration).

Nitrous oxide losses from solid storage result from:

- Denitrification processes in the manure pile (anaerobic, primary source)
- Nitrification (aerobic, secondary).

Methane emission from solid manure piles results from:

- Anaerobic decomposition of organic matter by microorganisms (methanogens).

The rates of aerobic respiration, denitrification and nitrification, and anaerobic respiration, and combined gaseous emissions from solid manure storage are functions of:

- Carbon content of the manure (high in solid storage)
- Wind speed crossing the pile
- Temperature
- Oxygen level (Eh)
- Moisture content (which affects the Eh)
- pH

Kachanoski and Berry (1997) reported 57% carbon mineralization in manure stockpiles. Hence, high available carbon will increase the emission of CO_2. However, higher carbon in the form of straw or other amendments also increases the oxygen concentration in the manure resulting in aerobic decomposition of the manure (Mahimairaja et al. 1994). This is to be encouraged, because the alternative anaerobic carbon product is methane, which is potentially much more environmentally damaging. Wind speed increases gaseous emissions from manure piles (Husted 1993), hence covers or roofing should be employed. These measures will also prevent increased moisture levels resulting from precipitation. Manures with high moisture contents have lower redox levels, which encourage N_2O and CH_4 emissions (Brown 1998). Covers, therefore, will result in retained nutrients by eliminating runoff losses and reducing gaseous emissions. All microbial processes are sensitive to temperature, and higher temperatures will increase the rate of CO_2 production. Significant amounts of summer storage should be avoided.

Losses of N_2O from solid storage can be very significant. Petersen et al. (1998) reported losses of 13% and 28% of total nitrogen from dairy and swine manure, respectively (straw bedding was included). Brown (1998) reported smaller losses (5%, dairy manures), but showed that the loss rate increases with increasing straw additions. Straw, or other bedding material, additions result in increased carbon levels which will increase denitrification rates by supplying energy, increased oxygen levels due to improved air movement in the manure pile, and reduced moisture levels. Maximum N_2O production occurs at 55-70% moisture content, 150-200mV and pH 6.0 (Brown, 1998). Loss rates increase with increasing temperature, and manure piles under these conditions can also produce heat. This is especially true for swine manure, and hence N_2O losses from these manures will be greater (Petersen et al.1998).

CH_4 production occurs when the oxygen level drops to Eh = -200 mV or below. Moisture levels will greatly affect the redox level in the pile, with CH_4 production being increasingly more dominant as the moisture level increases. Dried poultry manure will produce very little in the way of greenhouse gas emissions (Caberra et al. 1994). Since temperature affects the rate of microbial activity, eliminating summer storage will be significant in limiting methane emissions. It should be noted that pig manure heaps tend to generate their own heat, and will produce methane year round (Husted 1994).

Significant improvements in total GHG emissions from solid manure storage can be made by:

- Using covers (80% reduction in gaseous losses, Beauchamp, personal communication)
- Eliminating summer storage (Husted 1994)
- Either limiting straw additions to maintain Eh levels below optimum for N_2O emissions, or adding straw to maintain Eh levels above optimum for N_2O and CH_4 emissions.
- Aerobic composting with additions (zeolite, paper waste, Mahimairaja et al. 1994, or zeolite, Kithome et al. 1999)
- Anaerobic composting (Mahimairaja et al. 1994).

Liquid Storage

Liquid storage has become the preferred storage method for most swine and a large proportion of dairy manures. Replacement of earthen manure storages by concrete and other sealed systems prevents leakage of nutrients, particularly nitrates, to the ground water. The liquid storage systems are primarily anaerobic, and methane is the greenhouse gas of primary interest.

Methane emissions result from:

- Anaerobic decomposition (fermentation) of organic matter

In liquid storage the amount of **methane** evolved is related to:

- Redox potential (-150 to -250 mV),
- pH (opt.7-8),
- Available organic matter
- Temperature
- Windspeed.

Shallow earthen or concrete manure storages will exhibit greatest emissions because of their high surface area to volume ratio, and higher temperatures. Typical losses from uncovered earthen or concrete manure storages are in the order of 50 g CH_4/ m^3 /day for swine waste stored in an open manure storage (Husted 1993). Covers can reduce this loss by 60% to over 90%, e.g. complete crust, tarps. polystyrene beads, PVC foil, peat, Leca^R, oil (Hartung & Phillips 1997; Sommer et al. 1993; Beauchamp personal communication). Lids provide the best cover (over 95% reduction). Such closed storage systems will also allow readsorption of any N_2O produced near the surface of the slurry (Béline et al. 1999).

Natural crusting can be efficient, but may develop cracks, resulting in gaseous losses. Crusting may also increase N_2O losses (Paul 1999) because of production of N_2O within the crust. Some covers will require significant additions of C (eg. straw) to maintain their usefulness, and unless the straw is kept separate from the slurry, it can increase total potential methane production. Methane production is a function, also, of the amount of organic matter in the slurry. Additions of bedding, etc. raise the C: N ratio of the slurry and increase the methane emission.

Muck et al. (1984) showed that bottom loading manure storages had less than 10% of the gaseous emissions compared to a top loading manure storage presumably because of the disturbance of the contents of the manure storage, and release of held gasses and reintroduction of organic matter (in the sludge) into the system.

Temperature increases result in significant increases in CH_4 emissions (a 1.8^oC temperature rise resulted in a 13.1% increase in CH_4 emissions (Husted 1993). Sharpe & Harper 1999, showed that increases in emissions were linear with increasing temperature to 22^oC, therefore tanks/concrete manure storages should be built underground or existing aboveground tanks banked to help maintain lower temperatures. Note that anaerobic decomposition is not a heat producing process. This fact has limited the technical and economic success of biogas production in Ontario (cf. Moss, 1994).

The reduction of pH to approximately 4.5 will also almost completely prevent $CH_{4,}$ CO_2, and N_2O losses (Oenema & Velthof, 1993). Care must be exercised to maintain this pH, since allowing it to increase to pH 6 would result in maximum N_2O release.

Aerobic treatment of slurries has been used to decrease the malodorous effect of spreading liquid manure. This treatment will prevent CH_4 and much of the N_2O production (which take place at low Eh values: below –200 mV, and 25 to 250mV, respectively) if properly controlled. Erratic fluctuations of slurry conditions are to be avoided, however, since this will result in N_2O

production. Burton et al. (1993) showed 19% of nitrogen lost as N_2O, therefore proper management must be exercised.

Significant improvements in CH_4 emissions can be made by:

- Use of covers (to 95% reduction; cf. Hartung & Phillips 1997; Sommer et al. 1993)
- Bottom loading systems (Muck et al. 1984)
- Reduced storage time, and eliminate summer storage
- Below ground tanks or banked above ground storage
- Avoid adding organic matter, e.g. bedding
- pH reduction to about pH 4.5 (Oenema & Velthof 1993)

3.1.6 Farm Forestry and Habitat Management

Farm forestry practices include the management of woodlands and other area of natural habitat on farms, and practices that are directly or indirectly incorporated into farming systems. In areas of natural vegetation, the normal range of natural and anthropic disturbances have negligible effects on GHG emissions. However, land use changes and significant changes in drainage and/or the composition or “structure” of vegetation will have significant effects on carbon pools and fluxes. For this project it is assumed that natural vegetation will remain more or less in its existing condition, although the implementation of BMPs may result in significant increases in forested areas in particular situations.

Farm forestry practices that take cropland out of production (e.g. plantation, buffer strips and abandonment) will decrease the use of inorganic N fertilizer resulting in a proportional decrease in N_2O emissions. Ambus and Christensen (1995) measured similar rates of N_2O emissions from a spruce forest, beech forest and a riparian zone; 770, 800 and 660g N_2O-N ha^{-1} yr^{-1}, respectively. These values were considerably lower than values for upland and tile drained agricultural land (3610 and 4670 g N_2O-N ha^{-1} yr^{-1}, respectively) (Ambus and Christensen 1995). While the variability associated with the means reported by the authors is large the means are relatively constant. The forested land appears to emit approximately 80% less N_2O and the riparian zone 85% less, than the cropped land.

Riparian management

Riparian zones under perennial vegetation can reduce N losses in surface water runoff and groundwater leachate, serve as net sinks for methane and offset CO_2 losses through carbon sequestration. These effects can be enhanced by increasing the width of the buffer, by adding trees and shrubs with different root and top growth characteristics, and by incorporating species with high nutrient demands. Planting trees with deep root systems (e.g. silver maple) can extend the biologically active zone further into the soil and shallow ground water by absorbing nutrients, affecting oxygen levels and increasing carbon sequestration.

Riparian zones along permanent or ephemeral watercourses (including grassed waterways) may emit some methane. However, managing for plant species with high water demands may result in shorter periods of time that anoxic conditions will persist. Additionally, permanent cover will enhance conditions for microbial populations by increasing carbon pools as well as improve the structural stability of the soil.

Riparian buffer strips will generally reduce GHG production by intercepting and using nitrogen delivered to or deposited directly in this zone by surface and groundwater flow. This potential to mitigate GHG can be reduced by tile drain systems that bypass this zone by depositing drainage water directly in streams and municipal drains where further denitrification and release of N_2O can occur.

Windbreaks and shelterbelts

Windbreak systems reduce GHG emissions directly by sequestering carbon and indirectly by increasing crop production. However, the greatest benefits may be indirect reductions derived when windbreaks are located around farm buildings, significantly decreasing heating and cooling requirements. This decreases the use of fossil fuels and related GHG emissions.

Windbreaks that are properly designed and managed will increase crop yields and increase carbon sequestration in biomass and soil. Increased crop yields will result in more complete utilization of fertilizers. The additional carbon fixed in the crop may subsequently be released through soil respiration unless additional management practices that conserve soil organic matter are also employed.

Reforestation and Woodland Management

Conversion of cropland to permanent tree cover can sequester carbon and potentially mitigate N losses. In forests and other areas of natural vegetation, net GHG emissions (generally negative) will remain consistent within a wide range of management levels. However, the conversion of fragile (e.g. erodible soils, riparian zones) or marginal land (e.g. wet or eroded areas) to permanent cover types will result in direct emission reductions by the elimination of farm inputs and an increase in carbon sequestration in biomass and soil. The retirement of fragile and marginal lands has been supported by many environmental and soil conservation programs. Adoption of these BMP'' would be linked to support programs since they can be expensive and often do not provide an obvious short-term benefit to farmers.

Intercropping

The use of intercropping systems affects GHG emissions in a similar manner to windbreaks. The difference is that the rows are spaced closer together and affect the entire field uniformly. The benefits are from increased nitrogen utilization from deeper soil horizons by the trees, increased carbon sequestration (above- and below-ground), increased soil organic matter accumulation and reduced N-fertilizer use. Based on estimates of carbon sequestration provided by Thevathasan (personal communication 1999) reductions in net GHG emissions might be in the order of 4 t ha^{-1} yr^{-1}. While this is a substantial amount on an area basis, adoption of this technically demanding system has been limited by ineffective extension and user support systems.

Silvipasture

Silvipastoral systems can help to reduce GHG emissions by increasing sequestration in woody biomass (above- and below-ground) and by capturing nitrogen leached below the rooting zone of forage plants. Forage production can also be increased under silvipastoral systems, increasing the nitrogen consumption (reducing leaching) and sequestration. Indirect, but significant reductions can also be realized by reducing the need for livestock shelter. While these contributions seem substantial on an area basis, adoption of this technically demanding system has been limited by ineffective extension and user support systems.

3.2 Approaches to Promote the Adoption of BMPs

The federal and provincial Agriculture and Environment departments, International Joint Commission, commodity groups, agricultural lobby agencies, farmer organizations and other public environmental agencies and citizen groups have identified environmental problems relating to on-farm practices. Concerns expressed in various farm-related and non-farm sectors (various governmental, public, agribusiness and farm groups), regarding health and safety of food and farmers, and the high dependence on and use of chemicals have added impetus for change. Once a problem has been identified and a need established for remediation, the various stakeholders develop programs and solutions. These solutions reflect a consensus of political, agricultural production, environmental and agri-business goals. For example, some government-initiated programs focus on single or limited-focus solutions, such as conservation tillage adoption, to address some of the environmental problem (soil erosion, water quality) while at the same time allowing for continued crop production and maintenance of production levels (Hall 1998).

There have been a number of incentive programs, supported both at the federal and provincial levels which deal with environmental issues on the farm. Most of the far-reaching projects are aimed at resolution and reconciliation of major conflicts over pesticide and fertilizer pollution, soil depletion and fertility, and productivity and prices. In general, the most effective or successful programs, in terms of achieving environmental goals, maintaining farm sustainability and receiving producer support, are those which: are broad in scope and geographical area; provide solutions which are based on sound research and farmer input; involve farmers and farm groups at all phases; are available to all producers and; provide a comprehensive mix of financial incentives, technical support, risk recognition and long-term commitment from all parties involved.

Support and delivery mechanisms for agri-environmental programs vary. Generally, funding is provided by governmental agencies and transnational agribusiness sources for research, extension, field site trips, demonstration projects, training and farm group activities. Critical to the acceptance and delivery of these programs is the involvement and promotion of solutions through local farmer-driven organizations and groups (e.g. OFEC, Ontario Federation of Agriculture, Agricultural Groups Concerned About Resources and the Environment (AGCARE), Ontario Soil and Crop Improvement Associations and Soil Conservation clubs).

Targeted approaches have been advocated as an appropriate way of applying public policies to encourage improved resource stewardship (Stonehouse 1996). The rationale for targeting is based on knowledge that conservation problems and needs vary between geographical areas, commodity groups and individual farms. Identical application of policies to all farmers is equitable but not efficient in terms of use of public funds or recognition of differing goals for different areas or societal groups (Fox et al. 1995; Stonehouse 1996). As an example, in a theoretical study comparing universal versus targeted approaches to nitrogen contamination of groundwater, a universally applied tax on nitrogen inputs for a Southern Ontario watershed was found to be less efficient than a targeted approach to physically limit nitrogen inputs for corn production (Giraldez and Fox 1995). Other examples of targeted resource strategies include Ontario's Clean Up Rural Beaches program (CURB), and, in the U.S.A., the Conservation Compliance provisions in the 1985 Farm Bill, the Integrated Farm Management Provisions of the 1990 Farm Bill and the Crop Residue Management Action Plan (Stonehouse 1996).

At the planning and policy level, resource targeting for the adoption of soil and water conservation BMPs makes a great deal of sense. In practice and implementation, however, a more equitable, universal approach to availability of programs and funding is generally more preferable to the farming community (OSCIA, personal communication). Broad reaching, larger-budget programs available to all might be perceived as being more comprehensive in nature and having a greater commitment of resources from all government levels, as opposed to short-term lower budget targeted programs. In some instances, targeted approaches might have a lower acceptance rate if the underlying intent or goals of the program are perceived to be suspicious.

On a geographical basis, funding of conservation projects on a universally available basis for all farmers does in fact result in the funds being targeted to areas of greatest need. A review of various conservation programs by the OSCIA indicates that, generally, programs or demonstration projects can be targeted to broad physiological areas with potential for BMP increased BMP adoption (e.g. no-till assistance on heavy soils) but targeting at individual commodity groups or farmers can have negative repercussions for BMP implementation. For the most part, farmers tend to be aware of major conservation issues affecting their farms, and will use existing programs to address these concerns – thus channelling funds to appropriate areas without the implication of a ‘targeted’ group. A relatively adequate level of awareness and management could be assumed for the general farming population. To this effect, a substantial degree of competence or willingness to improve operations could be extrapolated to other aspects of farming. For example, Swanton et al. (1996) suggest that policies and incentives that affect farm management and, generally, ecosystems, should not be based on the misconception that production systems are not energy efficient.

Incentives for adopting BMPs to reduce GHG emissions would be most effective if aimed at increasing the knowledge or implementation of BMPs with large potential growth (e.g. buffer strips, retirement of fragile lands, demonstration sites for innovative technology, nitrogen management, no-till implementation on heavy soils). If any groups are to be ‘targeted’ for funds, then the focus should be placed on those with a proven track record for successful innovations and implementation of conservation technology (e.g. innovative farmers) and not on the laggard adopters. Projects with high capital outlays for the farmer (e.g. reforestation, riparian development, manure storage) should have comprehensive programs with generous funds available. Piecemeal, low budget programs will have little impact on solving environmental problems. BMPs that are well established (e.g. residue management) should not receive large funding incentives unless substantial innovative research indicates drastic methods of improvement. In an environment of limited fiscal resources for programs, targeting of financial incentives at laggard farmers as incentive to adopt well-established programs would be insulting to those who have already adopted the BMP at their own expense and risk (H. Rudy, personal communication).

Adoption of conservation practices by farmers is influenced by the extent to which they perceived environmental degradation to be a problem, their education level, expected crop loss (from pests, weeds), perceived health effects of chemicals, and the availability of information on BMPs (Traore et al. 1998). Weersink et al. (1998) refer to voluntary approaches that aim to build awareness about agri-environmental problems in the producer groups, then present appropriate solutions or practices for remediation as ‘moral suasion’. Often, this approach is supplemented with technical and financial assistance. An alternative method of achieving environmental objectives is through the use of economic instruments such as charges or subsidies, tradable permits and decentralized policies.

3.2.1 Incentives Categories for BMP adoption

The following are categories of incentives that have been used to encourage farmers to adopt various BMP practices. Ontario is perceived to be a leader in innovative incentive programs aimed at BMP adoption, therefore most of the examples of studies or programs given in each category focus on this province. A compilation of some of the more successful / widespread programs used in Ontario and applicable to BMPs are listed in the Appendix in a section entitled: Examples of Programs for Environmental Enhancement and Agricultural Sustainability.

Recognition and awards

Governmental agencies, farm organizations and conservation groups all have programs in place whereby conservation efforts in the farming community are recognized and awarded. For example, in Ontario Conservation Awards are presented to producers who demonstrate consistent and/or innovative soil and water conservation practices on their farms. Commodity groups - such as the B.C. Cattlemen’s Association - present annual Environmental Excellence Awards. Special interest groups (e.g. Soil Conservation Society) give both recognition and financial awards to exemplary farmers, and through these practices and additional extension activities, public workshops and forums and publications provide a means of informing the general public about farming activities.

Education

A range of governmental, public, farm organization and non-farm groups contribute to BMP education. For example, commodity groups such as the Manitoba Pork Producers produce a series of information booklets for both producers and the general public on a number of BMP topics that relate to both environmentally sustainable and responsible farming methods and on public awareness and education. The OMAFRA / OFA BMP publication series has been used as a reference source for programs; however, the books themselves have been the impetus for on farm changes to enhance conservation.
Internet sites, shared by government, commodity groups and agribusinesses are an increasingly accessed information resource. A U.S. example, an Eco-Logic database is part of a Rivercare 2000, sponsored by the Georgia State Government, the Department of Natural Resources and Department of Agricultural and Applied Economics. This database contains information on recommended best management practices, incentives, economic data and laws for controlling pollution in the streams and rivers.

Financial incentives / Cost sharing strategies / Subsidies

Not all BMPs are truly profitable – taxpayers should pay their share – either with public funds or with increased farm revenues (higher farm-gate food prices). A fair rate of return should allow farmers to have more general economic options for abatement, while subsidies can be used to target specific crops or management practices for mitigatory measures.

Crop prices

Crop prices can determine the compliance costs of regulations and even the need for regulations (Weersink et al. 1998). Independent of support programs that might favour one crop over another, market prices will affect crop choice. Even if certain crops were shown to be beneficial from a BMP / GHG BMP perspective to include in rotations, low prices would effectively limit their use in the farming system. Changes in prices can affect optimal crop mixes, leachate potential and on-farm abatement efforts (Weersink et al. 1998).

Support Programs

Support programs can influence crop choice, and since crop selection can have a significant impact on fertilizer requirements and application, and hence direct and indirect GHG emissions, programs could be major compliance tools (Weersink et al. 1998).

Ontario farmers can ensure target revenue per hectare for each of their crops grown under the Gross Revenue Insurance Program (GRIP). Payouts are based on 80% of the difference between current market price and a fifteen-year market average for the crop, lagged by 3 years. The program provides one means of subsidizing the farmer in the event of a poor year. A disadvantage of the program is that highest rates of return are paid for high N-fertilizer using crops, such as corn, encouraging production of these crops over others. Due to the high leachate potential for corn, this in turn has increased the abatement costs for abatement efforts (Weersink et al. 1998).

Taxes

Tax incentives (reductions, rebates) can be used to encourage farmers to adopt BMPs and undertake remedial measures. The incentive rewards the implementation and continuation of a general practice, but may not necessarily reflect the overall success of the practice with respect to environmental benefits. The Managed Forest Tax Incentive and Wetland programs are examples of this approach.

An alternative to straight tax rebate / reductions has been proposed in the form of an **ambient tax/subsidy** scheme (Segerson 1988; Lintner and Weersink 1999). Under this approach aimed at non-point source pollution, farmers would be rewarded for contributing to environmental quality over a given standard and penalized for substandard levels. The standards would pertain to a resource – in this case, a water-body - receiving the pollutant(s). This system might only be applicable for small watersheds with an agricultural base that is relatively homogeneous in type of operation and management levels.

Funding and Subsidies

Programs in Ontario such as OSCEPAP, LSP, CURB, RWQP have made funding available, in the form of grants or cost-sharing incentives for the adoption of conservation measures and BMPs (reduced tillage, installation of buffer strips, manure storage, residue management). Similar methods have been employed by other provinces (e.g. Permanent Cover Program in the Prairies) and in the Great Lake states.

Many of the subsidy programs in Ontario and the other provinces have provisions whereby the farmer must pay back some or all of the grant or subsidy if the BMP is discontinued within a certain time frame. The importance of this clause should not be underestimated in providing long-tem incentives for continuation of BMPs. In the U.S., the success of the Permanent Cover Conservation Reserve Program, which helped retire fragile lands, was undermined through an ‘opt out’ provision – resulting in substantial return of fragile lands to production when corn prices rose (OSCIA, personal communication).

Participation in environmental BMP programs that are not strictly limited to farming activities can enhance farm income and provide incentives for the adoption of additional BMPs. For example, the North American Waterfowl Management Plan costs are shared by federal, Manitoba, U.S.A. and non-governmental groups and used to enhance habitat within a sustainable agricultural system (MacMillian 1998).

An innovative approach to subsidies and rewards is being introduced in the U.S., and if approved could provide a new and comprehensive model for agri-environmental policy and planning. The Conservation Security Program is part of a bill to be introduced in April 2000, which covers a broad range of environmental goals including GHG reduction and carbon sequestration. Under the program, any farmer can develop a farm conservation plan and enter into a contract to implement the plan in return for 5 to 10 years of payments, integrating profitability and environmental protection (Kemp 2000).

This program has several unique features. First, all farms are eligible (including vegetables, orchards, ranches) – traditionally, only commodity crops were targeted – thus changing the regional distribution of government subsidies. Secondly, innovative farmers and those who have always followed environmentally conscientious practices will be rewarded for use of BMPs. In most previous programs both in the U.S. and Canada, incentives were only offered to farmers to adopt BMPs, not for those with BMPs in place, effectively excluding early-adopters from receiving benefits for BMP implementation. To qualify for this program, farms must not exceed a maximum size, based on animal units or gross farm receipts. Farmers may opt to plan at one of three levels, with larger payments earned for more challenging BMPs, and only those with whole farm plans eligible for the greatest incentives in Class III. This program would complement or replace existing programs – although not double-credit payments for any one BMP – and encourage on-farm research, demonstration sites and development of innovative technologies. A pilot project of $6000 million is proposed (Kemp 2000).

Cross compliance

In Ontario and other provinces that have adopted Environmental Farm Plan (EFP) programs, funding for some conservation projects can only be obtained once an EFP is completed and approved. In regards to BMPs for nutrient management planning, approval for building permits for new or expanded livestock barn construction can only be obtained if a Nutrient Management Plan (NMP) is completed and approved.

Legislation

Both federal and provincial government regulatory bodies (Environment Canada, MOE) have acts that include provisions for addressing pollution sources from agricultural activities. Under the current regulations, once an infraction has been identified, the offending producer must obtain a Certificate of Approval to continue operations through remediation of the problem. If no corrective action is taken, charges can be laid.

A slightly different approach was recently attempted in Prince Edward Island, where the Department of Agriculture's (DOA) Round Table on Resource Land Use and Stewardship (released to the public on September 3, 1997) made a recommendation to include BMPs in legislation. The Round Table advocated "that the industry adopt a mandatory crop rotation standard for potatoes based on the following principle: that potatoes are to be grown no more frequently than one year in three, unless the producer has an alternative plan that will maintain soil quality. Such a plan must be approved by a qualified Government soil engineer". Geographic Information Systems were to be used to monitor compliance with such a standard. As of a DOA Progress Report from March 1998, this recommendation had not been implemented.

3.2.2 Implications for GHG Mitigation

There are two major considerations for the mitigation of GHGs and incentives for GHG BMP implementation. These are:

- Any mitigatory practices that will potentially reduce GHG emissions should be included within the context of a comprehensive, whole-farm planning approach. Acceptance and adoption of GHG BMPs will be greater if these practices are tied to remedial measures dealing with other economic and environmental issues, perceived to be of a greater magnitude and urgency by the farming community.

- Society as a whole has much to gain from the reduction of GHG emissions, perhaps more so than the farming community. Society should be prepared to provide the farming community with fair and adequate compensation for GHG reductions, either through increased food prices or through generous financial compensation and subsidies that allow the farmer to include adequate remedial measures in their operations.

GHG emission control in the agricultural industry must take place within the larger context of agricultural planning at all levels – federal, provincial, municipal, farm organization and farm. The following are suggestions for a general approach to comprehensive resource planning that would allow for the incorporation of GHG practices and policies.

- Create a vision and legislative framework for environmental policies and changes, all levels of government (federal, provincial, municipal), farm organizations, environment groups
- Define clear roles for each group (e.g. federal research and funding; provincial – education and funding; farm organizations - farm implementation; regulatory agencies – enforcement)
- Develop clear mandates for legislative enforcement (federal, provincial, municipal)
- Evaluate BMPs through institution-oriented research, on-farm research and development, expert opinion, farm organization input
- Education and extension – change, update and modify EFP, BMP, NMP guidelines and programs to include all resources thoroughly (land, soil, atmosphere, groundwater, surface water, habitat)

- Implementation – Farmers complete plans (EFP, NMP) peer review, large financial incentives, peer monitoring
- Provide a range of fair and generous financial incentives:
  e.g. Tax breaks for innovators and farm leaders and those already applying comprehensive BMPs, through all levels of government. An open option to apply for additional incentives in future would ensure continued reassessment and improvements;
  Large amounts of money should be made available, through combined federal and provincial sources, with negotiations between farmer and funder as to how incentive has addressed problem;
  Sliding scale financial commitments could be used by government agencies over a long time-frame (15-20 years), with most of the funding allocated to the initial phases of the program to cover start-up / practice modification costs, followed by a decrease in financial commitment with a shift to more farm-organization driven education, on-farm research and extension over time
- Additional incentives – EFP workshops, plus additional BMP (systems approach, cropping, habitat etc)
- Provide substantial incentives to local farm organizations for achieving graduated levels of participation
- Coordination of programs
- Target enforcement by county – several per year – with a set term (e.g. 15 years to enforce infractions in every county (random audits, cold calls, environmental monitoring, resource evaluation)
- Offenders identified within the first 5 years – given chance to change through Certificate of Approval and still eligible for financial incentives to correct problem
- After 5 years and no implementation – large fines, possibly more serious penalties
- Peer review and environmental monitoring as follow up, random audits

4 Study Methods

4.1 Development of Best Management Practices for Analysis

To conduct a quantitative analysis it was necessary to define farming practices that were quantifiable using available database information and for which reliable emission coefficients could be devised. The BMPs also needed to be mutually exclusive so that adoption rates could be assigned to specific practices between time periods. To this end, the BMPs were categorized as either a pre-BMP, Soil and Water BMP or Greenhouse Gas BMP practice.

The pre-BMP condition represented a baseline condition to which the adoption of BMPs could be compared. The pre-BMP condition was generally considered "conventional" agricultural practices prior to concern for soil and water conservation (i.e. likely represent some deterioration of the environment if continued indefinitely). The Soil and Water BMPs are those practices promoted by OMAFRA for soil and water conservation and described in the agricultural best management practices booklets. Which BMPs may be currently being used was also considered in this designation. The GHG BMPs were generated by:

1) Consideration of GHG production processes and controlling factors and modifying current BMPs to better address GHG emissions
2) Consideration of which existing OMAFRA BMPs may mitigate GHG emissions but are not widely adopted at present.

The assignment of specific BMPs for which emission coefficients were to be investigated is listed in Table 1. This table also describes the pre BMP, Soil and Water BMP and GHG BMP conditions that were assumed in developing the GHG emission coefficients. This table also described the pre BMP, S&W BMP and GHG BMP conditions that were assumed in developing the GHG emission coefficients.

Table 1. Best Management Practices for Soil and Water and GHG Mitigation

Identified BMP Farming Practice	**Pre BMP Condition**	**Soil and Water BMP**	**Greenhouse Gas BMP**	**GHG Principle**
Soil Management BMPs				
Buffer Strips	No buffers	Buffer strips, 10 m wide	Wider strips, convert to riparian plantings	Reduce indirect N losses; C sequestration
Cover crops (Planted into preceding crop or after harvest, left live over winter)	None	Rye cover crop	1) Use after high N residual crops 2) Use of innovative seeding practices (e.g. Interseeding in previous crop)	Minimize residual N
Crop rotations	Based on regional fertilizer and crop residue	Corn, soybean, winter wheat, spring cereals, forages	Rotations (+ cover crops where applicable) Legume N credit	Minimize residual N
Tillage	Conventional tillage	Reduced	No-till	Reduce indirect N losses; C sequestration
Residue management	Fall tillage; Removal or incorporation of residue	Reduce tillage (partial or no incorporation); Leave residue	Spring or no tillage; Leave residue	Reduce spring denitrification
Nutrient Management				
Nutrient testing				
Soil Testing	None	Spring soil nitrate test	Pre-sidedress nitrate test	Minimize residual N
Manure testing	None, Disposal of manure on land, no N credits given for nutrients	Manure N credits - use published averages to account for nutrients OMAFRA Pub. 296	Manure N testing and adjustment of fertilizer rates	Minimize residual N
Inorganic application	Preplant, delayed incorporation	Banding	Preplant, incorporation < 1 day	Reduce direct and indirect N losses
Organic application	Fall application, no incorporation	Spring application, incorporation < 1 day	Increase spring application	Reduce direct and indirect losses

Identified BMP Farming Practice	**Pre BMP Condition**	**Soil and Water BMP**	**Greenhouse Gas BMP**	**GHG Principle**
Livestock and Poultry Waste Management				
Handling				
Solid	Infrequent clean out, 3-7 days	Frequent clean out, 1-3 days	More efficient clean out, <1day	Minimize decomposition and NH_3 losses
	Dry lot	Storage under cages	Manure belt removal, drying	
Liquid	Infrequent transfer to storage	Frequent / daily transfer to storage	Flushing system	Minimize decomposition and NH_3 losses
	Slats over sloped floor to temporary storage	Wide of partial slatting	Fully slatted over concrete manure storage	
Storage				
Solid	Bedded pack, Pasture	Runoff catchment, uncovered	Covered storage	Minimize anaerobic conditions and leaching / runoff
			Storage of dried manure	
Liquid	Earthen manure storage, large surface area	Concrete manure storage or tank, uncovered	Covered (lid)	Minimize NH_3 losses, reduce exposed surface area
			No summer storage	
Farm Forestry and Habitat Management				
Riparian buffer strip	Absent	Present	Enhanced or increased	C sequestration; land not fertilized; reduce indirect N losses
Shelterbelts / Windbreaks	Absent	Present	Enhanced or increased	C sequestration, land not fertilized

4.2 BMP Emission Coefficient Determination

A three-stage approach was used to arrive at emission coefficient values for the selected BMPs. Firstly, the 1996 Revised International Panel on Climate (IPCC 1997; Mosier et al.1998) and Canadian Economic and Emissions Model for Agriculture (CEEMA) (Kulshreshtha et al.1999) methodologies were studied to arrive at default emission coefficients for the production of carbon dioxide, methane and nitrous oxide gases. These models are intended for the estimation of the Canadian contribution to global GHG emissions and very little consideration has been given to specific agronomic practices in north-central North America.

Secondly, an extensive literature review was undertaken to find published emission coefficients applicable to the selected best management practices for Ontario. There is a wide variation in published emission coefficients, in the order of 100-300%, due to the nature of the production of GHGs and the methods in which they are measured. The published coefficients represent a variety of biophysical environments and management systems that contribute to this variation. Many of the published coefficients were from controlled laboratory studies, which do not always reflect field conditions. Additionally, many field studies use different methods (e.g. closed chambers vs. micro-meteorological techniques), which measure GHG production at different spatial and temporal scales (Wagner-Riddle and Burton 1999), although some studies have shown good agreement between flux gradient and chamber data (Christensen et al. 1996).

The length of time over which gas emission is measured also determines how representative the study is of annual rates. Greenhouse gases are not emitted at a constant rate throughout the year. Research has shown that gases are given off during critical flux periods, predominantly in the spring freeze/thaw periods, and to a lesser extent after nutrient applications and harvest. While emissions are seasonal in nature, emission rates are reported on an annual basis. These annual rates do not represent a steady state of emissions, but constitute a summary of the emissions from all fluxes throughout the year.

Measured coefficients from long-term field data were used whenever possible if the experiment was deemed to be representative of Ontario management and environmental conditions. Other short term and/or controlled experiments provided a basis for comparing coefficients, particularly for relative differences between BMPs, but often were not viewed as ‘representative’ enough to reflect the conditions in Ontario agriculture.

Thirdly, expert consultation was sought with Ontario researchers who provided additional information and validation of the calculated and published coefficients to be used in calculations. The final emission coefficients used in calculations, therefore, represent a combination of i) calculated values from the IPCC and CEEMA methodology, and ii) refined coefficients where there was sufficient evidence based on the quality/applicability of research and expert consultation to alter these default values. Thus the selected coefficients are not a mean or median of the reported range but represent the most likely annual emission rate, due to direct and indirect sources, under Ontario conditions.

The emission coefficients reported for each BMP represent the sum of all three GHG emitted for both direct and indirect losses. Rates are reported on a carbon dioxide equivalent kg per hectare or head basis using a 100-year timeline and conversion factors of 21 CO_2 equivalents for every molecule of CH_4, and 310 CO_2 equivalents for every molecule of NO_2 emitted (AFFC, 1999). Where information was lacking for a particular GHG (e.g. no carbon dioxide emission values available for all manure application types) or no logical estimate could be made, it was not included in any of the corresponding coefficients, so as not to bias any particular BMP. Each BMP tended to have a dominant GHG of concern and the emission coefficients presented reflect the impact of the BMP on the relative emission of at least this gas.

Reporting of emission coefficients was done in consultation with the database managers to ensure the GHG emissions could be calculated using the available data format. Hence some emissions are reported on an aerial basis, % reduction in emission or on a per head basis depending on the type of practice investigated and the production numbers available from the database.

The final EC values used in analysis of BMPs are included in Appendix 8.2 and summary tables are provided in Section 5.2 Table 4. Below the assigned value is a range of values indicating the variability of emission rates found in the literature. The coefficient values are referenced as EC-1, EC-2 and EC-3 corresponding to the specific Pre-BMP, Soil and Water BMP or GHG BMP selected for analysis, respectively. Details necessary for understanding the derivation of Ontario specific GHG emission coefficients are reported below for the 4 BMP categories.

4.2.1 Soil Management ECs

Crop N_20 emission coefficient calculations (IPCC 96 / Mosier 1998) were completed for both direct and indirect losses associated with the selected BMPs. Direct losses refer to the emissions given off from commercial fertilizer amendments, enhanced N_2O production due to biological N-fixation, N from crop residue mineralization and, where applicable for horticultural crops, soil N mineralization due to cultivation of organic soils (Mosier et al.1998). N losses from animal waste applied to the crop were not accounted for in the basic crop emission calculations, but these losses are addressed in the Nutrient Management section. Indirect emissions that were accounted for include losses from volatilization and atmospheric deposition of nitrogen compounds (NO_x and NH_3) and nitrogen leaching and runoff.

Individual crop and **crop rotation** GHG coefficients were based on N_2O calculations using the following information. Yields estimates were based on 5-year average yields, as determined from the Census of Canada (Agricorp 1999). Mosier (1998) suggested that total biomass of a crop can be determined by assuming a default coefficient of 2 (2 kg total biomass/ kg dry yield). Adjusted biomass coefficients were available for various crops (CEEMA 1999), and these were used in place of the default values for total biomass and residue calculations. Average N fertilizer application rates were obtained from the OMAFRA Field Crop and Vegetable Production Recommendation Guides (OMAFRA 1998, 1999) for crops. Wherever possible, different emission coefficients were determined for different areas of the province, and for high, medium and low production classes within each crop. Calculated emission rates were found to be comparable to field observations (C. Wagner-Riddle, personal communication; Beauchamp, 1997).

Carbon dioxide emissions are relatively low for mineral soils, as indicated in the literature, unless a land use change or shift occurs from less to more intensive usage. Since none of the BMPs under consideration recommended a change of this nature, no emission rates for CO_2 were calculated.

Carbon dioxide and nitrous oxide emissions were calculated or estimated for **tillage practices**, based on default values provided in the IPCC guidelines and in the literature (ESG 1999).

For **nitrogen credits** following a plough down legume, a GHG reduction was calculated using an average nitrogen fertilizer credit of 55 kg N/ha from OMAFRA Publication 296. This credit was multiplied by the IPCC coefficient for mineral fertilizer (9.26 kg CO_2 equivalent ha/year) as the fertilizer application could be reduced by this amount the following year.

A **winter cover crop** GHG reduction coefficient was assigned based on research that showed a 10% reduction in leached nitrate over winter that was scavenged by a fall rye crop (Ball-Coelho and Roy, 1996). This was assumed to represent a 10% decrease in the N_2O emissions by indirect leaching losses (C. Wagner-Riddle, personal communication)

4.2.2 Nutrient Management ECs

Inorganic and organic N fertilizer emissions were calculated using the methodology of Mosier et al. (1998) for direct and indirect N_2O losses. These average values were typically higher than those reported in the literature, which may be due to the site specific and short-term nature of most studies, or that no consideration was given to indirect losses in some studies. Given that no consideration was given to N source or application type for the first two analyses, these average values were considered adequate.

In the soil testing analysis, reduction of N fertilizer rates is only considered for the corn crop as it has an existing soil nitrate test and considerably more acreage compared to barley. The data collected by Kachanoski and Beauchamp (undated) during the development of the soil nitrate test was analyzed. The rate of fertilizer recommended using the soil nitrate test was compared to the general recommendation based on a yield of 8 t/ha and a price ratio of 5. The average N rate reduction in >2800 CHU areas was 49 kg N/ha and in <2800 CHU areas was 12 kg N/ha (K.B. MacDonald, personal communication).

An improved BMP to reduce nitrous oxide production would be to recommend **side-dressing** on corn acreage in the >2800 CHU areas. Since most of the nitrogen (whatever is not applied as starter fertilizer) is applied when the crop is most able to use it, fertilizer efficiency is improved and the amount of total fertilizer applied can be reduced by 15% (OMAFRA, 1998).

For inorganic fertilizer application practices, it was found that different coefficients for broadcast versus incorporating and banding of fertilizers were warranted. The values reflect differences in direct emissions, banding>incorporation>broadcasting (Maggiotto et al. 2000; Tenuta and Beauchamp 2000; Thornton 1996; Eichner 1990) and indirect emissions from volatilization losses, broadcasting> incorporation>banding (Keller and Mengel 1986) for the three types. These values encompass the average given by the IPCC methodology.

The variety of manure application practices that occur on Ontario farms have been defined as either liquid or solid, incorporated or not incorporated, and spring or fall/winter applied to simplify the analysis. This results in a total of 8 emission coefficients for manure spreading practices. Coefficients extracted from the literature were compared to the IPCC value for manure and compared to the values used in the Thomsen Corp. model for N_2O production from manure management and field application (E. Beauchamp, personal communication).

Several researchers have found the IPCC estimates to overestimate GHG emission from manure application. The direct N_2O emission rates measured in the field for slurry applications have been lower (Petersen 1999; Ferm et al. 1999) than the IPCC coefficient of 1.25% and the 1.9% average from more recent studies reported by Mosier and Kroeze (1999). This may be because the manure measurements have generally been reported for < 80 days while the fertilizer estimates have been from > 80 day experiments and probably more accurately reflect the total annual emissions. Support for using these lower field measurements is that 67% from the N_2O emitted during a 270 d growing season of a solid manure-fertilized corn crop tends to be lost within the first 7 weeks (Lessard et al. 1996). Experiments in laboratory and field have also tended to use high rates of N application. Some experimental emissions may be higher, therefore, than actual field emissions as N_2O emission increases non-linearly with application rate due to increases in the intensity of the nitrogen cycling processes and increases in the “unused” N in the soil (Paul et al. 1993; Chantigny et al. 1998).

The emission coefficients are calculated based on a total N basis, not distinguishing between organic, nitrate, and ammonium forms. Many manure studies present N_2O emissions based on the amount of NH_4-N applied, since this is the most readily available form of N in fresh manures and is the substrate for the nitrification process. N_2O emissions often exhibit 2 peaks after manure is applied; it is thought the first peak is due to the process of nitrification and the second peak is due to the denitrification process. The organic N forms are slowly mineralized and become available over time. Liquid manures contain more NH_4 - N and so have high initial values of N_2O emissions, but solid manure N_2O emissions may just be delayed until over winter losses (Loro et al. 1997). Coefficients are reported for total N at this point because of a lack of available data for all manure types and application methods. The reported coefficients attempt to reflect the relative difference in manure composition and application on an annual basis. Indirect emission from NH_3 volatilization and NO_3 leaching are included in the coefficients for N_2O production as the differences between specific best management practices are often due to these factors.

4.2.3 Livestock and Poultry Waste Management ECs

In all cases IPCC figures have been used as guideline figures, and in cases where no other numbers were available, were used for pre S&W BMPs.

Emission factors were generated primarily from published literature. The literature was surveyed for emissions of CO_2, CH_4, N_2O and NH_4 from various areas related to manure handling and storage. The processes were divided into housing/handling practices and storage practices, for the four main production types (beef, dairy, swine and poultry).

Many of the studies were laboratory studies, and where these were deemed to represent conditions similar to field conditions, they were used along with on-site farm data, in the compilation of emission figures.

Emission data from the literature was presented in a wide range of units. Data on nitrogen gases was most commonly presented as % total nitrogen lost. Methane and carbon dioxide data was presented in a much more varied form. Sometimes these data were not directly convertible to the basic units of gas production/head/annum because of missing information, e.g. storage volumes or animal numbers. However, if percentage improvements due to management practices were given, these figures were applied to baseline figures from other studies.

Emission data was converted to gas lost (in kg) per head per annum using the average manure outputs per annum given in an OMAF Factsheet, Manure Characteristics, Dec.1991 (Agdex 538).

Very little data was found for CO_2 emissions, NH_3, CH_4 and N_20 being the main gases studied. Primary losses of CO_2 from the barn floor were considered to occur very rapidly due to urea hydrolysis (urea $\rightarrow$ $2(NH_3) + CO_2$). There is a large volume of literature on NH_3 production from urea during the early, manure handling stage. It was considered that the NH_3 data could be used to determine CO_2 emissions from the barn floor. This assumption was only used for short manure residence times (<72 hours). $CH_{4\,:}\,CO_2$ ratios of ca 80:20 are given for anaerobic biogas production. These ratios were considered relevant to anaerobic earthen or concrete manure storage, and some CO_2 emissions were derived from this ratio.

An estimate of 1% of NH_3 emissions resulting as secondary production of N_2O elsewhere in the agricultural system has been given by Mosier et al. (1998), and this figure has been included in the N_2O emissions given.

4.2.4 Farm Forestry and Habitat Management ECs

Woodlot Management

Harvest management was considered to be the BMP; however, greenhouse gas net emissions values were considered negligible with or without the BMP. Woodlot removal did not appear to be an issue at focus group meetings across the province.

Shelterbelts / Windbreaks

The planting of trees in shelterbelts and windbreaks was assumed to provide a significant local impact on GHG emission reduction. The baseline area was taken from the 1991 Census of Agriculture data that reported the distance of shelterbelts / windbreaks by county. The required area determination was calculated by reported length of trees (km) at 2.4m spacing per tree and double-spaced and at planting density that equalled 2500 trees per ha. From the Conservation Authority questionnaires, two rates were suggested for past and present plantings into cash crop and pastureland. These were used to i) determine adoption levels for the period 1990-2000, and ii) the expected change from 2000-2012 under current conditions. The net emission coefficient was assumed to be the average of shelterbelt and windbreak emission rates. An objective 2 GHG BMP adjustment of 20% increased plantings from 2000 to 2012 was calculated.

Riparian Buffers

The riparian buffer area for the baseline year 1990 was assumed to be a factor of the buffer strip area (80%) and shelterbelt / windbreak adoption rate reported in the Permanent Cover 2 program information. The Conservation Authority questionnaire provided planting rate information used to determine rates if increase for the period 1990 to 2000 and the expected rates from 2000 to 2012. The net emission coefficient for an established riparian zone acknowledged; I) a stabilized C: N soil ratio with no N addition, and ii) potential carbon sequestration with these plantings. An increase of riparian buffer areas of 10% above the 2000 levels for the year 2012 was determined as an objective 2 GHG BMP.

4.3 The Use and Adoption Rate for BMPs

A combination of Census of Agriculture, published survey reports, BMP program surveys, questionnaires, and expert opinion were used to determine the extent of implementation and adoption rate of agricultural BMPs. The principle source of data for the county use of BMPs was the Census of Agriculture Reports of 1991and 1996, and regional estimates of 1998. Supplemental information was obtained from the Permanent Cover 2 Program. A questionnaire was sent to all Ontario Conservation Authorities to obtain information on windbreaks, shelterbelts, and riparian buffers that were not available from the Census data. Time trend census data were used to project BMP use back to 1990 and forward to 2000. The same time trend data were used to compute annual rates of adoption for each of the BMPs studied. The initial compilation of BMP use and rates of adoption from 1990-2000 represented a preliminary database. Expert opinion was used to further the database, fill in missing data, and provide future projections of adoption rates for each BMP.

The primary source of expert opinion was obtained from a series of focus group discussions across Ontario. Eight focus group sessions were held across the agricultural regions of the province to augment the BMP database regarding current and potential implementation rates with and without policy instruments. The Ontario Soil and Crop Improvement Association (OSCIA) organized these sessions, inviting 10 to 15 members of their organization and other participants at random to represent the agricultural diversity of each region. The sessions were held at

Midhurst, Woodstock, Simcoe, Clinton, Ridgetown, Verner (between Sudbury and North Bay), Melbourne (near London) and Kenmore (near Ottawa) on February 4th, 7th, 8th, 10th, 11th, 14th, 15th and 18th, respectively. Background information on the GHG issue and the current study were sent to participants and the organizer prior to the meeting (Appendix 9.1.6).

Each focus group began with the organizing representative of the OSCIA welcoming the attendees and having them introduce themselves and asking them to note their kind of agricultural operation. A member of the Soil Resource Group presented brief background material on the Greenhouse Gas issue and this specific project relating to Best Management Practices. The bulk of the focus group session was spent addressing the list of Best Management Practices, one at a time, by having the participants respond to questions such as:

- Has this practice been adopted in this region? If so, how widely i.e. by what percentage of the farmers and/or over what percentage of the area?
- Has the practice been adapted or modified for use in this region? How?
- Is the adoption rate of the practice increasing or decreasing, or has it stabilized? Is there potential for greater adoption of this practice? If the practice has not been adopted in this region, why not?
- What incentives would it take to achieve greater adoption of this practice should that be deemed desirable?

Data considerations for each of the BMPs studied are included in the following text with appropriate linkages to the development of GHG emission coefficients.

Soil Management

Buffer Strips

Buffer strip areas were considered to include all grassed regions alongside field crops and waterways. The past and present rates of adoption of buffer strips, between 1990 and 2000, were derived from focus group expert opinion and the Conservation Authority questionnaire. From these sources, the future adoption rate (beyond year 2000) of this BMP was assumed to be minimal. The distribution and area of buffer strip by county for the baseline year of 1990 was determined from three factors: i) the area of buffer strip being related to the relative adoption of buffer strip and shelterbelts/windbreak area reported in the Permanent Cover 2 program (OSCIA 1995), ii) the area determined from shelterbelts/windbreaks distance reported in the 1991 Census of Agriculture (Statistics Canada 1991) would be the same areal fraction of buffer strip as the rate of adoption reported in (i), and iii) an assumed 1 percent of cropland area.

The emission reduction was reported for the increase in buffer strip area from cropland area over the study period 1990 to 2012. The emission coefficient of buffer strips of –1320 kg CO_2/ha/yr, a net sequestration of GHG) was multiplied by the area of adoption and combined with the emission savings from the cropland taken out of production. The cropland emission coefficient varied by county and represented the average of the predominant cash crop distribution of 2yrs corn-2yrs soybeans-1yr winter wheat. Adjustments under objective 2 provided an improved GHG-BMP to further reduce emissions between 2000 and 2012. The GHG BMP adopted was the conversion of buffer strip area to riparian vegetation. The revised emission reduction was determined by using an emission coefficient of –2625 kg CO_2/ha/yr for riparian vegetation.

Cover Crops

In evaluating a provincial, regional and county level Best Management Practice for cover crops, it was required to adapt available regional and county crop data. This practice considered an overwintering live crop that was actively growing in the fall, remained through the spring period, and was used primarily as a soil erosion protection practice in the province. Therefore, fall rye acreage reported in Census 1991 and 1996 years was used to determine the potential emission reduction using cover crops.

The rate of rye crop increase between 1991 and 1996 was used to back calculate an area value for the 1990 baseline year. Based on OMAFRA crop projections, the rate of change was assumed to increase to 2000. Under Objective 1, the area was assumed not to change between 2000 and 2012. The emission coefficient used was –250 kg CO_2/ha/yr that recognized the savings of indirect N losses from cover crop fall N fixation and reduced winter and spring leaching losses following a high nitrogen-using crop. The Objective 2 GHG-BMP adoption was assumed to have an increase above 2000 levels of 10% between 2000 and 2012 to reflect continued adoption on cropland.

Crop Rotations

Adoption of crop rotation as a Best Management Practice implies reducing continuous row crop production and the increased introduction of legume or cereal crops in a crop sequence. Sufficient information was not available for evaluating specific crop rotations at a county or regional level. The approach to determine crop rotation adoption therefore looked at the overall trend in production area of the five dominant production crops; grain corn, soybeans, winter wheat, forages and spring cereals. Crop area changes between 1991 and 1996 Census information was used to continue the trend backwards to estimate 1990 levels. Based on crop area projections from OMAFRA in years 1997 to 1999, the crop areas in the year 2000 were assumed to be unchanged from 1996. Under Objective 1, crop area changes between 2000 and 2012 were altered at one half the rate as determined between 1991 and 2000.

Corn, soybean and winter wheat emissions were determined based on individual crop emission coefficients from three productivity levels across the province. Emission coefficients for corn growing areas in Eastern and Northern Ontario, Western and Central Ontario, and Southwestern Ontario, 2499, 2314, and 2845kgCO_2/ha/yr, respectively, were applied to the appropriate counties within each region. Western Ontario ‘A’ subregion counties were assumed to be within Southwestern region values. Soybean and winter wheat emission coefficients were based on the yield productivity levels reported in crop insurance data (Agricorp 2000) for each county. Regional calculations were a weighted average of the county values based on crop area. The soybean coefficients were 1400, 1700 and 2173kgCO_2/ha/yr for low yield (<30bu/ac), medium yield (30 to 42bu/ac), and high yield (>42bu/ac) averages. Winter wheat coefficients were 1012, 1301 and 1591kgCO_2/ha/yr for low yield (<65bu/ac), medium yield (65 to 80bu/ac), and high yield (>80bu/ac) averages.

The GHG emission from forage (alfalfa) was determined from the area determined in each year and multiplied by an emission coefficient average of 3 years growth, a coefficient of 1267 kg CO_2/ha/yr. The area under spring cereals (oats, barley and mixed grain crops) was multiplied by the coefficient of 947 kg CO_2/ha/yr in Southwestern Ontario and 712 kg CO_2/ha/yr for the rest of Ontario based on a difference in expected productivity. The objective 2 GHG-BMP considered the potential for annual crediting of N within the existing forage area in the year 2000. An OMAFRA N credit for a crop following legumes of 55 kg N/ha was used. A reduction in emission of 9.3 kg CO_2/ha/yr for each kg of N was derived. The level was then reduced by one third to represent one out of three years of typical forage crop and reduced further by an assumed 50% adoption of the credit. The revised coefficient was lowered from 1266 to 1181 kg CO_2/ha/yr and extrapolated to all forage areas to determine the potential emission reduction realized.

Tillage

Adoption of conservation tillage in Ontario considered the increase of reduced tillage and no-till and the accompanying decrease in conventional tillage as reported for all cropland in the Census of Agriculture data. The predominant adoption of conservation tillage by area was, however, assumed to be on winter wheat, soybeans and grain corn acreage. The fraction of total cropland attributed to the three crops in each county and region was determined and this revised tillage area was carried forward in the calculations.

The determination of tillage distribution by the three crops was taken from Thomsen Corporation estimates by 10 provincial sub regions reflecting 1996 proportional levels of adoption, e.g. Western Ontario ‘A’ grain corn: CT–0.65, RT–0.30, NT–0.05. Weighted coefficients for each tillage type were determined from corn, soybean and winter wheat emission coefficients to reflect the proportion of each crop in that tillage type, and the area of each crop in the region. The tillage type area, as determined for each study year, was then multiplied by the weighted coefficient.

The extent and rate of adoption over the study period was modified from Census data in 1991 and 1996. The rate of change of each tillage type between 1991 and 1996 was used to back calculate a value for the 1990 baseline year. Expert opinion was used in reducing the rate of change to one half the 1991-1996 rate from 1996 up to the year 2000. Under Objective 1, the adoption of conservation tillage from 2000 to 2012 was assumed to level off with no net increase. Under Objective 2, the GHG-BMP applied was an increase in no-till corn area by 10% above 2000 levels with an accompanying equal reduction in reduced till area.

Modifications to the conservation tillage coefficients used Ontario regional emission measurements for the calculations. Reductions in the emission coefficient from conventional tillage levels for reduced and no-till emission levels were attributed to some extent for the savings in indirect N losses. These rates of reduction were 310 kg CO_2/ha/yr (1kgN/ha/yr saved) for reduced tillage and 620kg CO_2/ha/yr (2kgN/ha/yr saved) for no-till crops.

Residue Management

Management of crop residue as a BMP implies leaving as much residue on the soil surface as possible to reduce soil erosion processes. Crop residue left on the surface over the fall, winter and spring period provides an additional benefit in reducing greenhouse gas emission by reducing the denitrification losses from fall residue incorporation and increasing the release of crop residue N to the crop in the following year. To determine the trend in fall or spring cultivation, the tillage calculations were utilized to reflect a reduction in tillage due to no-till adoption. A further assumption of the percent spring primary tillage by county was developed from expert opinion based on dominant soil texture by county and regional differences. The southern region was assumed to have 50% spring tillage except the counties of Lambton and Essex and the regional municipality of Niagara, which had 10%. Western Ontario assumed 40% in western ‘A’ sub region counties and 25% in western ‘B’ sub region counties. Central ‘A’ and Central ‘B’ sub regions had 25% and 10% assumed spring tillage, respectively. Eastern Ontario was assumed to have 10% spring tillage.

The emission determination for the residue management BMP under Objective 1 used a coefficient to represent conventional and reduced tillage based on the individual weighted county coefficients determined from the tillage calculation above. The coefficient was multiplied by the proportional area under fall tillage for both the conventional and reduced tillage area to determine potential emissions in the fall. The spring tillage emission estimates were determined by using a 10% lower modified tillage coefficient. The savings reflected the potential reduction in emission from reduced indirect N losses, as noted above.

Nutrient Management

Nutrient Testing

The use and adoption of two methods of nutrient testing were evaluated for the soil N tests for corn and manure testing. Both testing methods considered the adoption rates reported at the regional focus group meetings. The soil test BMP considered the average county corn yields from crop insurance data (AgriCorp 2000) and the corresponding fertilizer requirements reported in OMAFRA Publication 296. This level of fertilizer N was then reduced by the same percent as the reported adoption rate using two average levels of fertilizer reduction, 49kgN/ha for Southern and Western 'A' and 12kgN/ha for the rest of Ontario (Thomsen Corporation). The reduction in emission was related to the kg of N that was not applied to the corn area for each county.

The soil test was unavailable in 1990 and it was assumed that approximately 5% of farmers performed a spring soil nitrate test in the year 2000. The expected future adoption of the spring test was considered low with an adoption level of 7% for the year 2012. Further improvement to N use efficiency was considered with the pre side-dress soil nitrate test that reduces corn N requirements on average by 15% below spring test results. It was assumed 5% of farmers had a side-dress soil nitrate test taken and therefore 5% of the corn area had an additional 15% reduction in fertilizer N inputs. This level was increased to 7% in 2012 also under calculations for objective 1. The GHG-BMP improvement from 2000 to 2012 used an increased use of both the spring and side-dress soil nitrate test to 10% for both tests.

Use of the manure test to determine N content and adjust the amount of commercial fertilizer was reportedly low (approximately 10%) and changing little with time. Focus group meetings suggested that in 1990, 5% of southern region farmers, 15% of western region farmers, 10% of central region farmers, 15% of eastern region farmers, and 10% of northern region farmers were performing manure tests. In determining a potential emission reduction by using the manure test, this portion of manure nitrogen was credited and reduced from the corn crop fertilizer requirement. The total level of emissions, resulting from application of manure, was reduced by the percent that used the manure test. The objective 2 adoption rate increased the use of the test by 10% above the levels forecast over the period 2000 and 2012 assumed in objective 1.

Application Methods

Inorganic fertilizer and manure fertilizer application methods were included under this BMP with the overall goal of improving nitrogen use efficiency in supplying corn crop nutrient requirements. The use of broadcast or banded inorganic fertilizers reported by region was evaluated as well as the timing of broadcast incorporation, immediate or delayed (banded was assumed to be immediate incorporation). A ratio of broadcast to banded reported by region (typically 50/50) was assumed for the corn area in each county or region as reported in the Focus Group meetings.

To determine emissions from banded N fertilizer for corn, the corn area was multiplied by the percent of area banded, then multiplied by the amount of corn fertilizer requirement based on OMAFRA Publication 296 recommendations in each of the three regions, and then multiplied by the banded coefficient. The remaining broadcast fertilizer corn area for each regional calculation was adjusted with time to reflect the trend of decreasing time interval between application and incorporation. It was assumed 80% of broadcast fertilizer was incorporated immediately or within 1 day in 1990, 90% in 2000 and 95% by 2012. Therefore, to determine emission rates in 1990, the 80% portion incorporated immediately was multiplied by one coefficient and the remaining 20% portion had another emission coefficient. The combined number was then multiplied by the broadcast fertilizer corn area of approximately 50% to determine the broadcast fertilizer portion of total emission for the practice.

In determining the effect of adopting improved GHG-BMPs for objective 2, the ratio of banded to broadcast fertilizer N application was adjusted downward recognizing the higher potential emission from the banding method. The proportion of banded from 2000 to 2012 was reduced by 10% across all regions.

Organic fertilizer or manure application methods considered the timing of application and the time interval before manure was incorporated, for solid and liquid manure. Assumptions made for solid manure changed regionally (see Appendix 9.1.5). For Ontario, it was assumed that 35% of the solid manure was applied in the spring and 65% was applied during the 'rest of the year' when the crop utilization of N would be reduced. It was assumed 50% of spring-applied manure was incorporated immediately, within 1 day, and 20% of the manure applied in the remainder of the year was incorporated immediately. The amount of solid manure nitrogen applied during the rest of the year (65%) was a combined emission level of the coefficient, multiplied by the 20% incorporated and another coefficient multiplied by the 80% non- incorporated. The spring portion of solid manure was a coefficient multiplied by the 50% incorporated and another coefficient multiplied by the 50% non-incorporated manure. The contribution of emission from solid manure application was the sum of spring and rest of year calculations.

The land application of liquid manure had similar assumptions of timing and incorporation but differed slightly by the coefficients selected. It was assumed that the amount of liquid manure applied was split between approximately 40% spring application and a 60% application during the 'rest of the year' for Ontario. It was also assumed that all liquid manure applied in spring was incorporated right away. The amount applied during the rest of the year was assumed to be incorporated immediately 50% of the time. The coefficients used for the rest of the year period of 9.61 and 8.68 kg CO_2/kg N applied were each multiplied by the 50% incorporation and 50% non-incorporation portions. The entire remaining 40% spring application amount was multiplied by the 8.68 kg CO_2/kg N applied coefficient. The combined spring and rest of year emission rates were combined to determine the total liquid manure emissions for each of the study period years. Note that under this scenario, all manure "produced" is applied to the land and manure application by pasturing is assumed to be included in rest of year, non-incorporated portions.

Manure Storage and Handling

Manure Handling

Best Management Practices for manure handling are not well defined but recognize the improved efficiencies of the transfer of livestock waste to permanent storage in improving animal welfare. The consideration for reducing GHG emission 'in the barn' emphasizes the importance of quickly and efficiently removing livestock waste from the time it leaves the animal and transferring it to permanent storage where it will not be disturbed until land application. There is increased potential for CH_4, N_2O and CO_2 losses and therefore reduced availability for crop fertilization with a delay in manure transfer as well as repeated disturbance and movement of manure. The potential for changes to more GHG friendly practices are largely a capital expense. The minimal adoptions, in the province, of more efficient clean-out facilities have likely been realized only from the new larger barn construction designs. The number of animals in each category was then multiplied by the applicable emission coefficient (see coefficient Table 4). For example, the amount of solid beef cattle in a given county would be multiplied by 95% for greater than 3-day storage and then multiplied by the emission coefficient of CO_2 equivalent/head/yr. This would then be added to the remaining 5% of solid beef cattle multiplied by the emission coefficient for 1-3 day clean out.

Manure Storage

Storage practices of manure have been improved from the baseline year to present with available government programs, with the emphasis being on liquid storage facilities. The minimal relative change proposed beyond the present is expected without similar financial incentive programs. The increase in adoption of GHG-BMP for objective 2 assumes the trend to larger operations with increased liquid handling systems and under barn storage may continue. The procedure for determining emissions from manure storage was similar to that for manure handling and used the adoption rates listed in Appendix 9.1.5.

Farm Forestry and Habitat Management

Woodlot management

Harvest management was considered the BMP however greenhouse gas net emission values were considered negligible with or without the BMP. Woodlot removal did not appear to be an issue at focus group meetings across the province.

Shelterbelts/Windbreaks

The planting of trees in shelterbelts and windbreaks was assumed to provide a significant local impact on GHG emission reduction. The baseline area was taken from the 1991 Census of Agriculture data that reported the distance of shelterbelts/windbreaks by county. The required area determination was calculated by reported length of trees (km) at 2.4m spacing per tree and double-spaced and at a planting density that equalled 2500 trees per ha. From the Conservation Authority questionnaires, two rates were suggested for past and present plantings into cash crop and pastureland. These were used to i) determine adoption levels for the period 1990-2000, and ii) the expected change from 2000-2012 under current conditions. The net emission coefficient was assumed to be the average of shelterbelt and windbreak emission rates. An objective 2 GHG-BMP adjustments of 20% increased plantings from 2000 to 2012 was calculated.

Riparian Buffers

The riparian buffer area for the baseline year 1990 was assumed to be a factor of the buffer strip area (80%) and shelterbelt/windbreak adoption rate reported in the Permanent Cover 2 program information. The Conservation Authority questionnaire provided planting rate information used to determine rates of increase for the period 1990 to 2000 and the expected rates from 2000 to 2012. The net emission coefficient for an established riparian zone acknowledged; i.) a stabilized C:N soil ratio with no N addition, and ii) potential carbon sequestration with these plantings. An increase of riparian buffer areas of 10% above 2000 levels for the year 2012 was determined as an objective 2 GHG-BMP.

4.3.1 Assumptions made in Calculations

To avoid duplication with concurrent studies, the BMPs have been analyzed individually to determine their impact on GHG emission. The analysis, therefore, is targeted at specific components of a farming operation, i.e. corn and alfalfa acreage rather than complete rotation. Ideally, a farming systems approach would be best to account for interactions between livestock, cropping and forestry components, but this is beyond the scope of the present project and is being addressed in a concurrent project.

GHG emissions were calculated by individual BMP; however, the determination of total emission rates and any reductions were a sum of a subset of BMPs to avoid duplication in management emissions. BMPs that represented Soil Management contributions were Buffer strips, Cover crops, and the five dominant Crops made up of forage, spring cereals areas and the total Tillage BMP contribution which incorporates corn, soybean and winter wheat crop areas and management. Nutrient Management emission contributions were from organic solid and liquid fertilizer application management as inorganic fertilizer would be incorporated within the above crop management. Livestock and Poultry Waste Management contribution was from solid and liquid Manure Handling and Storage for all livestock types. Farm Forestry and Habitat Management emission from Windbreak/Shelterbelt and Riparian Buffer areas s was also included in the total GHG emission determination.

5 Study Results

5.1 Implementation of Best Management Practices

5.1.1 Implementation of Soil and Water BMPs (1990-2012): Objective 1

The use of BMPs (soil and water) is reported in Table 2. Regional level data on the areas and quantities of the BMPs are reported in Appendix 9.1.1.

- Many of the soil and water BMPs have not been widely adopted in all agricultural regions of Ontario. These include soil management practices such as buffer strips and cover crops, nutrient management practices such as soil and manure testing and the use of covers on manure storage, and any of the farm forestry and habitat management practices.

- A number of the soil and water BMPs have seen significant adoption and/or adaptation across the province including: widespread use of reduced tillage practices, reduction of continuous corn and increased use of rotations including overwintering cereals, a reduction in the winter spreading of manure, and the use of improved facilities for the storage of manure e.g. concrete pads, concrete tanks and earthen manure storages.

Regional data on the use of soil and water BMPs shows the regional variation in implementation of these practices (Appendix 9.1.1). Greatest implementation is in the Southern and Western regions where the greatest concentration in crop and livestock production occurs. Measured rates of adoption and expert opinion were used to develop the provincial rates of adoption for the soil and water and greenhouse gas BMPs reported in Table 2 and 3. BMP incentive programs that were available from 1900 to 2000 contributed significantly to the higher rates of adoption observed during the period. Expert opinion obtained from the focus group discussions indicated the adoption of BMPs beyond year 2000 would be at a much-reduced level than observed when incentives were in place.

Appendix 9.1 provides background information that was used to document the use of soil and water BMPs in the province.

5.1.2 Projected Implementation of Greenhouse Gas BMPs (2000-2012): Objective 2

Projected implementation of greenhouse gas BMPs (2000-2012) for the province is shown in Table 3. Implementation of GHG BMPs for soil management and livestock waste management beyond 2000 were similar to the soil and water BMPs while the nutrient efficiency and farm forestry and habitat management GHG BMPs were implemented at slightly higher rates than the soil and water BMPs over the same time period. In each case, conservative adoption of GHG BMPs (described in section 4.3) was applied across all regions. Increases of GHG BMPs were in the order of 5-10% from 2000-2012. BMPs requiring capital expenditures for improvements, such as covered manure storage, were given lower adoption rates than the adoption of less costly practices such as nutrient testing options, for example. Greater increases in GHG BMP adoption in the future were deemed unlikely without sufficient financial incentives as provided in the past. Producers spoke highly of past incentive programs and discouraged the use of enforcement or controls to gain implementation. Examples of such programs for promoting environmental enhancement and agricultural sustainability that have been used in Ontario are included in Appendix 9.1.8. Information regarding the focus group meetings such as a list of participants, background information provided to the participants, and a discussion template of information collected are reported in Appendix 9.1.6.

Table 2: Adoption Level of Soil and Water Best Management Practices in Ontario 1990-2012

Management category	Soil & Water Best Management Practices	Adoption Level (%)			
		1990	2000	2008	2012
Soil Management					
Buffer strips	>3m grassed (% change from 1990)		<1	<1	<1
Cover crops	fall rye (% of cropland area)	<1	<1	<1	<1
Crop rotation	grain corn (% of cropland area)	26.6	24.3	22.8	22.2
	Soybean	16.2	21.3	23.3	24.3
	wheat	4.4	8.0	10.1	11.1
	alfalfa	30.7	27.9	26.1	25.3
	spring cereal	13.3	7.9	6.3	5.6
Tillage	Minimum till (% of cropland area)	17	24	24	24
	no-till	1	24	24	24
Residue management	spring tillage (% of tilled cropland area)	33	33	33	33
Nutrient Management					
Soil testing	N reduction using spring soil N test for corn	0	10	12	14
Manure testing	% N saved with manure N test and credit	10	10	10	10
Method of application	spring broadcast fertilizer	58	58	58	58
Timing of application	spring liquid manure	42	42	42	42
	spring solid manure	34	34	34	34
Livestock & Poultry Waste Management					
Manure storage	solid beef uncovered pad & contained runoff	15	15	15	15
	solid beef covered	5	10	10	10
	solid dairy uncovered pad & contained runoff	35	35	35	35
	solid dairy covered	5	10	10	10
	solid poultry uncovered pad & contained runoff	15	20	20	20
	solid poultry storage of dried manure	5	5	5	5
	liquid dairy uncovered concrete pit	50	45	45	45
	liquid dairy covered concrete pit	35	40	40	40
	liquid swine uncovered concrete pit	45	40	40	40
	liquid swine covered	45	50	50	50
	liquid poultry uncovered concrete pit	70	65	65	65
	liquid poultry covered	0	5	5	5
Manure handling	solid beef 1-3 day clean out	5	5	5	5
	solid beef < 1 day clean out	0	0	0	0
	solid dairy 1-3 day clean out	95	90	90	90
	solid dairy < 1 day clean out	5	10	10	10
	solid poultry high rise barn	50	48	46	45
	solid poultry shallow gutter barn	45	47	49	50
	liquid dairy 1 day clean out	95	90	90	90
	liquid dairy flushing	5	10	10	10
	liquid swine partial slats	45	40	40	40
	liquid swine slats	25	30	30	30
	liquid poultry high rise barn	75	70	70	70
	liquid poultry shallow gutter barn	20	25	25	25
note:	Dairy	56	56	56	56
liquid manure portion	Beef	5	5	5	5
	Swine	90	90	90	90
	Poultry	10	10	10	10
Farm Forestry & Habitat Management					
Shelterbelts/Fencerows	plantings into cropland (% change from 1990 levels)		3	4	4
Riparian Buffers	riparian plantings (% change from 1990 levels)		<1	<1	<1

Table 3. Projected Use of GHG BMPs in the Province 2000-2012Table 3: Adoption Level of Greenhouse Gas Best Management Practices in Ontario 2000-2012

Management category	Greenhouse Gas Best Management Practices	Adoption level (%)		
		2000	2008	2012
Soil Management				
Buffer strips	riparian planting into grass buffer strips (100% of area)	<1	<1	<1
Cover crops	increased fall rye by 10% (% of cropland)	<1	<1	<1
Crop rotation	grain corn (% of cropland area)	24.3	22.8	22.2
	Soybean	21.3	23.3	24.3
	Wheat	8.0	10.1	11.1
	Alfalfa	27.9	26.1	25.3
	spring cereal	7.9	6.3	5.6
Tillage	Minimum till (% of cropland area)	24	24	24
	increase no-till by 10% in corn (% of cropland area)	24	24	24
Residue management	increased spring tillage by 10% (% of tilled cropland area)	33	40	43
Nutrient Efficiency				
Soil testing	further 15% N reduction using PSNT for corn (by 10%)	10	16	20
Manure testing	increased manure N test use and credit by 10%	10	20	20
Method of application	increased spring broadcast fertilizer (by 10%)	58	68	68
Timing of application	increased spring liquid manure	42	47	50
	increased spring solid manure	34	38	41
Livestock & Poultry Waste Management				
Manure Storage	solid beef uncovered pad & contained runoff	15	10	10
	solid beef covered (5% increase)	10	15	15
	solid dairy uncovered pad & contained runoff	35	35	35
	solid dairy covered (5% increase)	10	15	15
	solid poultry uncovered pad & contained runoff	20	15	15
	solid poultry storage of dried manure (5% increase)	5	10	10
	liquid dairy uncovered concrete pit	45	40	40
	liquid dairy covered concrete pit (5% increase)	40	45	45
	liquid swine uncovered concrete pit	40	35	35
	liquid swine covered (5% increase)	50	55	55
	liquid poultry uncovered concrete pit	65	60	60
	liquid poultry covered (5% increase)	5	8	10
Manure Handling	solid beef 1-3 day clean out (5% increase)	5	8	10
	solid beef < 1 day clean out	0	0	0
	solid dairy 1-3 day clean out	90	85	85
	solid dairy < 1 day clean out (5% increase)	10	15	15
	solid poultry high rise barn	48	45	40
	solid poultry shallow gutter barn (5% increase)	47	50	55
	liquid dairy 1 day clean out	90	85	85
	liquid dairy flushing (5% increase)	10	15	15
	liquid swine partial slats	40	35	35
	liquid swine slats (10% increase)	30	40	40
	liquid poultry high rise barn	70	65	65
	liquid poultry shallow gutter barn (5% increase)	25	30	30
note: liquid manure portion	Dairy	56	56	56
	Beef	5	5	5
	Swine	90	90	90
	Poultry	10	10	10
Farm Forestry & Habitat Management				
Windbreaks/Shelterbelts	increased plantings by 20% above yr2000 (% change)	3	10	14
Riparian buffers	increased woody species plantings by 10% above 1990	<1	7	10

5.2 GHG Emission Coefficients

A summary of the emission coefficients used is given in Table 5. The assigned value and the range of values found in the literature for the management practice are reported in Table 5. The final emission coefficient values used in the analysis of BMPs are reported in Appendix 9.2.

5.2.1 Discussion of GHG Emission Rates

In general, highest emission rates for N_20 were found for: crops that required relatively large inputs of nitrogen fertilizer (corn); crops or practices that did not use or immobilize all available nitrogen during critical N_20 flux periods (spring) or which made extra N_20 available during peak emission conditions (fall plough down of legumes), and where manure was left uncovered for extended periods of time. CH_4 emission coefficients were highest for practices that increased anaerobic conditions, such as uncovered storage facilities. CO_2 production tended to be low to negligible on agricultural land when a gains in carbon sequestration was considered and for most crops an equilibrium situation for carbon losses / carbon gains was assumed; however, changes in permanently vegetated areas, destruction or reduction in woodland, buffer and riparian areas, and changes in tillage practices from no-till to conventional would cause increases in CO_2 production.

Highest emission coefficients reflected conditions where: excessive fertilizer was used; fertilizer or manure incorporation was not immediate or non-existent; manure handling was less frequent and transfer of manure to storage was not done on a daily basis; and storage of manure was in an earthen, uncovered enclosure. Lower coefficients reflected the potential reduction in gas losses through management practices such as limiting the excess application of fertilizers through use of soil and manure tests, use of nitrogen ‘scavenger’ crops and other practices to reduce leachate losses, and efficient transfer of manures to covered, contained storage units.

Table 4. Greenhouse Gas Emission Coefficients

Identified BMP Farming Practice	**Pre BMP Condition EC-1**	**Soil and Water BMP EC-2**	**Greenhouse Gas BMP EC-3**	**Total CO$_2$ Equivalents (Kg/ha/year) Includes Direct and Indirect Losses**		
				EC-1	**EC-2**	**EC-3**
Soil Management						
Buffer Strips	None	Grass, ryegrass strips	Wider strips, convert to riparian plantings	-	-1320	-2625
Cover crops* (planted into preceding crop or after harvest, left live over winter)	None	WW, RC, R (See* at end of table for definitions)	- Use on high N residual crops - Use of innovative seeding practices (e.g. Interseeding in previous crop)		-250	-250
-Legumes	None	Legume cover	Legume cover, no fall kill or plough	-	1949	
-Non legumes	None	Cover crop	No fall kill or plough	-	974	974
Crops	Continuous	Rotations	Rotations (+ cover crops where applicable)	-	Use rotational average	Use rotational average
Grass	Permanent	Permanent	Permanent	146	146	146
Alfalfa	Continuous legume	3 year rotational annual average	Spring kill or incorporate	Average 1267	1266	1181
Canola				1834	1834	1834
Cereals (spring wheat, oats, barley, mixed grain)	SW Ont. Rest of Ont.	In rotation	In rotation, underseeded	1656	947 712	-
- nurse crop, or grain after hay		Underseeded	Underseeded	-	487	487
Winter wheat			Underseeded	1304	1304	-
- High yield, >5 t/ha, 110 kg N fertilizer applied				1591	1591	-
- Medium yield, 4 to 5 t/ha, 90 kg N fertilizer applied				1301	1301	-
- Low yield, <4 t/ha, 70 kg N fertilizer applied				1012	1012	-
Corn - continuous					-	-
Eastern Ontario	Ave. Kg / ha N applied – 142.5 Assumed yield 8.5 t/ha			2499	-	-
West &	Ave. Kg / ha N – 123			2314	-	-

Identified BMP Farming Practice	**Pre BMP Condition EC-1**	**Soil and Water BMP EC-2**	**Greenhouse Gas BMP EC-3**	**Total CO_2 Equivalents (Kg/ha/year) Includes Direct and Indirect Losses**		
				EC-1	**EC-2**	**EC-3**
Central						
South-western Beauchamp values	Ave. Kg / ha N – 188			2845	-	-
				1510 (direct emissions only)	-	-
Average	Ave. Kg / ha N applied – 142.5 Assumed yield 8.5 t/ha			2534	-	-
- after soybeans	No soybean credits	Use N credits from soybeans up to 24% reduction from continuous)	Underseeded	2499	2389	2389
Eastern Ontario (30 kg reduction for soybean N credit)	Ave. Kg / ha N applied – 112.5 Assumed yield 8.5 t/ha			2314	2153	-
West & Central (30 kg reduction for soybean N credit)	Ave. Kg / ha N – 93			2845	1978	-
Southwestern (15 kg reduction for soybean N credit)	Ave. Kg / ha N – 173			1510	2708	
Average	Ave. Kg / ha N applied – 135 Assumed yield 8.5 t/ha			2534	2389	
- after grain, silage corn		Up to 7% reduction from continuous	Underseeded	-	2357	2357
- after hay		Up to 18% reduction	Underseeded	-	2070	2070
Potatoes - on mineral soils	Continuous	Cover crop	In rotation with rye	3410	2750	2357
- on organic soils				5115	5552	5044
Soybeans	Continuous	In rotation	In rotation	2338	2338	2338
- High yield, > 2.5 T/ha, no fertilizer added				2173	2173	
- Medium yield, 2 to 2.5 T/ha, no fertilizer				1700	1700	

Identified BMP Farming Practice	**Pre BMP Condition** **EC-1**	**Soil and Water BMP EC-2**	**Greenhouse Gas BMP** **EC-3**	**Total CO_2 Equivalents (Kg/ha/year) Includes Direct and Indirect Losses**		
				EC-1	**EC-2**	**EC-3**
added						
- Low yield, <2 T/ha, no fertilizer added				1400	1400	
Fallow				1997		
Tillage	Conventional	Reduced	No-till	No reduction	0.5-1 kg N_2O reduction	CT to NT: 1-2 kg N_2O reduction
Reduced-till					-310	
No-till					-620	
Soil type						
Residue manage-ment Incorporation vs. Surface cover	Incorporation	Partial incorporation	Residue left on surface	No reduction	5% reduction	Spring tillage: 10%
Removal vs. Left on field	Removed	Left	Left		Up to 25% in CO_2 emissions increase	Up to 50% in CO_2 emission increase if residue left,

Identified BMP Farming Practice	Pre-BMP Condition	Soil & Water BMP	Greenhouse Gas BMP	Total CO_2 Equivalents (kg/kg N applied/year) Includes Direct and Indirect Emissions		
	EC-1	**EC-2**	**EC-3**	**EC-1**	**EC-2**	**EC-3**
Nutrient Management						
Nutrient testing **Soil testing**	OMAFRA Pub. 296 fertilizer N recommendations	Soil N testing (corn in spring)	Pre side-dress N test (PSNT)	9	Subtract 454 kg CO_2/ha in south and 115 kg CO_2/ha in rest of province for affected corn acreage	Lower corn fertilizer requirement another 15% for side-dressing application (fertilizer applied X EC-1) 9.26
Manure testing	Disposal of manure on land, no N credits given for nutrients	Use manure N to replace commercial fertilizer application	Manure N testing and adjustment of fertilizer rates	9	Subtract (manure N used as fertilizer X EC-1) from total manure emissions	No net change in emissions expecte
Application Method **Inorganic fertilizers**	Preplant, delayed incorporation	Preplant, banding or incorporation (< 1day)	Preplant banding Side-dress Split Applications	11.59	6.57	6.2
Organic fertilizers	Fall application, no incorporation	Spring application and incorporation < 1day	Increase spring application	Manure Types		
	Time and Method of Application			Liquid	Solid	
	Fall, No Incorporation			8.68	8.68	
	Fall, Incorporation			9.61	10.73	
	Spring, No Incorporation			7	6.32	
	Spring, Incorporation			8.68	8.28	

Identified BMP Farming Practice	**Pre-BMP Condition EC-1**	**Soil & Water BMP EC-2**	**Green-house Gas BMP EC-3**	**Animal**	**Total CO$_2$ Equivalents (Kg/head/year)**		
					EC-1	**EC-2**	**EC-3**
Livestock and Poultry Waste Management							
Handling **Solid**	Infrequent clean out, 3-7 days	Frequent clean out, 1-3 days	More efficient clean out, <1day	Beef	96	86	23
	“	“	“	Dairy	122	111	33
	“	Storage under cages	Manure belt removal, drying	Poultry	6	0.3	0.2
Liquid	Infrequent transfer to storage	Frequent / daily transfer to storage	Flushing system	Dairy	84	33	16
	Slats over sloped floor to temporary storage	Wide of partial slatting	Fully slatted over manure storage	Swine	15	12	10
Storage **Solid**	Bedded pack, Pasture	Runoff catchment, uncovered	Covered storage	Beef	722	686	137
	“	“	“	Dairy	1318	1135	228
			Storage of dried manure	Poultry	8	8	0.1
Liquid	Earthen manure storage, large surface area	Concrete manure storage or tank, uncovered	Covered (lid)	Dairy	582	198	23
371% spatial variation	“	“	“ No summer storage	Swine	262	127	15
Farm Forestry and Habitat Management							
Buffer strip	None	Buffer strip	Conversion to riparian planting			-1320	-2625
Riparian buffer strip	None	Riparian buffer	Widen, improve species			-3825	No change
Windbreak/ Shelterbelt	None	Establish windbreak	Widen, improve species			-2625	No change

Table 5 contains a comparison of the emission coefficients compiled for this report and those coefficients reported in other publications. All coefficients are compared relative to the values reported by the IPCC, or calculated according to the standard IPCC methods. A value of 100 indicates that the value from the CEEMA, GEEMA, S&W BMP or GHG BMPs is equivalent to the coefficient reported by IPCC. A lower value indicates a reduction in emission coefficients, and therefore indicates a potential emission reduction, relative to IPCC standards. Values higher than 100 indicate that the coefficients reported by the respective group are higher than those reported by the IPCC.

For many of the management variables, the S&W BMP and GHG BMP coefficients are similar to IPCC values – which should be the case, considering that many of the IPCC equations were used to calculate coefficients, or default IPCC values were used. Slight variations indicate the effect of conditions unique to Ontario conditions. S&W and GHG BMP coefficients differ most markedly from the CEEMA values. Much of this differentiation is caused by use of different methods and assumptions.

Table 5. Emission Coefficients Relative to Baseline IPCC Estimates (IPCC = 100%)

BMP	**IPCC**	**CEEMA**	**GEEMA**	**SW-BMP**	**GHG-BMP**
Residue Management	100	100+	100++	100+	90
Tillage	100	90	100-	-	-
Fertilizer Use	100	6	100	100	100
Soil Testing Based on 188 kg N/ha	-	-	74	74	63
Fertilizer Application Type	-	-	85	67-125	106
Manure Use in Field	100	14	100	100	-
Manure storage Dairy – liquid	100	132	-	112	-
Beef – solid	100	294	-	116	-

5.3 GHG Emissions with Adoption of Soil and Water BMPs 1990-2012 (Objective 1)

Application of current BMP practices and predicted adoption rates for the period from 1990 to 2000 period, followed by an increase in adoption rates for the 2000 to 2012 period. If current adoption rates of BMP practices are maintained, and the mitigational effect of existing Soil and Water Conservation BMPs is maintained, the reduction potential for GHG emissions for all of Ontario is predicted to be approximately 360 Kt by the year 2012 (Table 6). Regional reductions in emissions are repeated in Appendix 9.3.1.

Reductions / Increases in GHG emissions for individual regions of Ontario are as follows:

Central :	- 115 Kt	(Reduction)
Eastern:	- 135 Kt	(Reduction)
Southern:	- 350 Kt	(Reduction)
Northern:	+ 27 Kt	(Increase)
Western:	+ 123 Kt	(Increase)

The greatest impact of GHG mitigation measures was observed in the Southern region of Ontario, and the least in the North, as might be expected given the intensity of farming operations and areal extent of crop cover. More moderate gains were predicted for the Central and Eastern regions of the province. Increases in emissions were forecast for Western Ontario, and to a lesser extent, for Northern Ontario. Predicted increases in emissions could be a reflection of the trend towards the continued intensification of livestock and crop production in the western region, and to a lesser extent, the dependence on livestock production and associated emissions in the north.

Savings in GHG emissions were most evident in the area of tillage conversion – including both method and seasonality of application. Residue management, identified as a separate BMP but in practice is an integral part of the tillage system, also showed potential for mitigation, as might be expected. It should be noted that the term ‘residue management’ in this data set reflects mainly the ‘timing’ of residue treatment (i.e. shifts from fall to spring tillage) as opposed to amount or distribution of residues left on the surface (type of residue, percent cover after harvest).

Changes in crop rotation and an increase in the use of cereal and forage crops, was a major contributor to GHG emission reductions.

Potential for provincial GHG reductions was indicated in the manure application category, although only the Southern, Central and Eastern regions which showed improvements in this category and influenced the overall assessment. Greater potential for GHG reduction was observed in solid manure application changes as compared to liquid application. Only Eastern Ontario was found to have potential improvements in both the solid and liquid manure handling systems.

The overall change in potential emissions from 1990 to 2012 is mainly influenced by projected positive trends in no-till, residue management, and improvements in solid organic fertilizer application. Although projected corn emissions were down, this was more than offset by increased losses in other crops such as soybeans – a crop in which the benefits of lower fertilizer requirements, relative to corn, could not compensate for increases in acreage.

Table 6. Projected Use of GHG BMPs in the Province 2000-2012

	Ontario			
	1990 ktonnes CO$_2$/yr	2000 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012
Soil Management				
Buffer Strips	<1	<-1	<-1	<-1
Cover Crops	-6	-6	-6	-1
Crop Rotations				
- corn	2434	2401	2382	-52
- soybeans	1000	1418	1759	760
- wheat	171	332	503	331
- forage	1314	1289	1275	-39
- spring cereal	388	248	192	-196
Total	5307	5688	6110	803
Tillage				
conventional	2450	1902	1902	-548
reduced	404	706	706	302
No-till	16	388	388	372
total tillage	2870	2996	2996	126
Residue Management				
- spring vs fall tillage	5178	3954	3954	-1224
Nutrient Management				
Nutrient Testing				
- soil testing	1208	1182	1169	-38
- manure testing	1064	961	961	-103
Application Method				
- inorganic fertilizers	1165	1147	1136	-29
- organic fertilizers				
solid	933	739	739	-194
liquid	187	256	256	69
Livestock and Poultry Waste Management				
Handling				
- solid				
beef	121	117	117	-4
dairy	51	40	40	-11
poultry	18	21	20	2
- liquid				
dairy	21	15	15	-6
swine	33	37	37	4
poultry	2	2	2	<1
Storage				
- solid				
beef	873	809	809	-63
dairy	501	442	461	-40
poultry	272	304	304	32
- liquid				
dairy	103	91	91	-12
swine	239	254	254	15
poultry	<1	<1	<1	<1
Farm Forestry & Habitat Management				
Shelterbelts/Windbreaks	-19	-19	-20	<-1
Riparian Buffers	-173	-173	-174	<-1
Sum	**7730**	**7437**	**7372**	**-358**

5.4 GHG Emissions 1990-2012 with Adoption of GHG BMPs 2000-2012 (Objective 2)

Soil and water BMPs were modified, to increase their effectiveness for GHG mitigation. These GHG BMPs were then used to estimate potential reductions / increases in GHGs. To obtain GHG emissions GHG BMP coefficients were substituted for the SW BMPs and combined with predicted adoption rates for the period from 2000 to 2012. If current adoption rates of BMP practices are maintained, and the mitigational effect of GHG BMPs is maintained, the reduction potential for GHG emissions for all of Ontario is predicted to be approximately 665 Kt by the year 2012 (Table 7). Projected regional GH emissions (2000-2012) with the implementation of GHG BMPs are reported in Appendix 9.3.2.

Reductions / Increases in GHG emissions for individual regions of Ontario are as follows:

Central :	- 145 Kt	(Reduction)
Eastern:	- 174 Kt	(Reduction)
Southern:	- 387 Kt	(Reduction)
Western:	- 38 Kt	(Reduction)
Northern:	+ 20 Kt	(Increase)

The results were similar to the implementation of the soil and water BMPs, with the exceptions that:

- Reductions were greater provincially and for all regions except the Northern region
- The Western region showed significant improvement in GHG emissions, moving from a state of increased emissions to a decrease in emissions under the GHG BMP situation
- The Northern still showed an increase in GHG emissions, but this amount was less than that predicted for Objective 1.

The greatest impact of GHG mitigation measures was observed in the Southern region of Ontario, and the least in the North, probably due to the intensity of farming operations and areal extent of crop cover as compared to other land uses. As shown in the results reported for Objective One, the GHG BMP situation showed more moderate gains for the Central and Eastern regions of the province.

Increases in emissions were forecast Northern Ontario, but these were relatively minor compared to the net decrease in emissions for the other areas, and did not effect the overall provincial emission rate to any great extent.

Potential for GHG emission reductions were most evident in the area of tillage conversion and residue management (change from fall incorporation to spring incorporation) , use of crop rotations, improvements in manure handling and storage and increased fertilizer efficiency through soil and manure testing and a reduction in inorganic fertilizers. Reductions from the manure application category were observed on a provincial basis. However, the only regions where improvements were indicated, for this category, were in the Southern and Central regions, where reductions were significant enough to influence the overall assessment. Greater potential for GHG reduction was observed in solid manure application changes as compared to liquid application. Only Eastern Ontario was found to have potential improvements in both the solid and liquid manure handling systems.

The overall positive change in potential emissions from 2000 to 2012 is mainly influenced by projected positive trends in residue management, and to a lesser extent, increases in the use of no-till. Increases in soybean acreage are the most prominent cause of increased emissions.

Table 7. Projected Provincial Greenhouse Gas Emissions 1990-2012 with Greenhouse Gas MPs (2000-2012)

	Ontario			
	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Soil Management				
Buffer Strips	<1	<-1	<-1	<-1
Cover Crops	-6	-6	-7	-1
Crop Rotations				
- corn	2434	2401	2382	-52
- soybeans	1000	1418	1759	760
- wheat	171	332	503	331
- forage	1314	1289	1189	-125
- spring cereal	388	248	192	-196
Total	5307	5688	6025	718
Tillage				
conventional	2450	1902	1810	-641
reduced	404	706	726	322
no-till	16	388	404	388
total tillage	2870	2996	2940	69
Residue Management				
- spring vs fall tillage	5178	3954	3970	-1207
Nutrient Management				
Nutrient Testing				
- soil testing	1208	1182	1164	-44
- manure testing	1064	961	801	-263
Application Method				
- inorganic fertilizers	1165	1147	1136	-29
- organic fertilizers				
solid	933	739	728	-205
liquid	187	256	242	55
Livestock and Poultry Waste Management				
Handling				
- solid				
beef	121	117	117	-4
dairy	51	40	38	-13
poultry	18	21	20	2
- liquid				
dairy	21	15	15	-6
swine	33	37	36	3
poultry	2	2	2	<1
Storage				
- solid				
beef	873	809	776	-97
dairy	501	442	421	-80
poultry	272	304	290	18
- liquid				
dairy	103	91	87	-16
Swine	239	254	237	-2
poultry	<1	<1	<1	<1
Farm Forestry and Habitat Management				
Shelterbelts/Windbreaks	-19	-19	-23	-5
Riparian Buffers	-173	-173	-191	-18
Sum	**7730**	**7437**	**7065**	**-665**

5.5 Potential of BMPs over 2008-2012 to reduce GHG Emissions (6 % of 1990 levels) Over the period 2008-2012 (Objective 3)

Estimates of 1990 GHG emissions from the agricultural production sector range from about 10,000 (CEEMA) to 12,000 kt (Greenhouse Gas Emission and Economic Model for Ontario, GEEMO). Therefore in order to achieve annual GHG reduction scenarios of 2, 4, and 6% of 1990 emission levels, then GHG load reductions of 200-300 kt, 400-500 kt, and 600-700 kt as required respectively.

Several scenarios were evaluated for the 5 years 2008-2012. Scenario 1 used an increase in adoption rates to actual 1990 to 2000 levels for the 2008 to 2012 period. The resultant GHG reductions as calculated from the use of this scenario were 676 Kt (Table 8). Regional GHG emissions for this scenario are reported in Appendix 9.3.3.

The greatest savings in emissions under this scenario are achieved through: conversion of conventionally tilled cropland to no-till systems; a change from fall to spring tillage and subsequent gains in residue management; and manure application methods.

Greatest positive influences on emission reduction are the result of changes from spring to fall residue management.

Table 8: Projected Provincial Greenhouse Gas Emissions 1990-2012 with Increased Adoption of Soil and Water Best Management Practices in 2008-2012 (Scenario 1)

	Ontario			
	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Soil Management				
Buffer Strips	<-1	<-1	<-1	<-1
Cover Crops	-6	-6	-7	-1
Crop Rotations				
- corn	2434	2388	2375	-59
- soybeans	1000	1646	1813	813
- wheat	171	446	510	339
- forage	1314	1280	1270	-44
- spring cereal	388	210	154	-234
Total	5307	5970	6122	815
Tillage				
conventional	2450	1902	1453	-997
Reduced	404	706	789	385
No-till	16	388	536	520
total tillage	2870	2996	2778	-92
Residue Management				
- spring vs fall tillage	5178	3954	3464	-1713
Nutrient Management				
Nutrient Testing				
- soil testing	1208	1174	1166	-42
- manure testing	1064	961	920	-144
Application Method				
- inorganic fertilizers	1165	1139	1133	-32
- organic fertilizers				
Solid	933	739	662	-271
Liquid	187	256	283	96
Livestock and Poultry Waste Management				
Handling				
- solid				
Beef	121	117	116	-5
Dairy	51	40	39	-12
Poultry	18	21	21	3
- liquid				
Dairy	21	15	15	-6
Swine	33	37	39	6
Poultry	2	2	3	<1
Storage				
- solid				
Beef	873	835	799	-74
Dairy	501	461	447	-54
Poultry	272	304	317	46
- liquid				
Dairy	103	91	88	-15
Swine	239	254	265	26
Poultry	<1	<1	<1	<1
Farm Forestry and Habitat Management				
Shelterbelts/Windbreaks	-19	-20	-20	<-1
Riparian Buffers	-173	-174	-174	-1
Sum	**7730**	**7426**	**7054**	**-676**

Scenario 2 used an application of GHG BMP practices and increased the current adoption projections by 5% for the 2008 to 2012 period. The GHG reduction under this scenario was estimated to be 1093 Kt from 1990 levels (Table 9). Regional GHG emissions for this scenario are shown in Appendix 9.3.4.

The greatest savings in emissions under this scenario are achieved through: conversion of conventionally tilled cropland to no-till systems and the changes in associated residue management; increases in the inclusion of spring cereal and forages in rotation, use of manure testing and N credits for manure and legumes, fertilizer application, and improved manure handling and storage.

As in Scenario 1, savings in GHG emissions were most evident in the area of tillage conversion and residue management. – including both method and seasonality of application. After tillage and residue management, manure testing appeared to be the next best area for reduced GHG emissions. Improvements in application methods for solid manures and inorganic fertilizers show potential for GHG reductions. Handling and storage of solid manure can add to the overall mitigation of GHGs through increased adoption and changes to these BMPs.

Table 9. Projected Provincial Greenhouse Gas Emissions 1990-2012: Increased (5%) Adoption of Greenhouse Gas Best Management Practices 2008-2012 Scenario 2)

	Ontario			
	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Soil Management				
Buffer Strips	<-1	<-1	-20	-20
Cover Crops	-6	-7	-7	-1
Crop Rotations				
- corn	2434	2388	2375	-59
- soybeans	1000	1646	1813	813
- wheat	171	446	510	339
- forage	1314	1194	1185	-129
- spring cereal	388	210	154	-234
Total	5307	5884	6037	730
Tillage				
Conventional	2450	1810	1383	-1067
Reduced	404	726	812	408
no-till	16	404	557	541
total tillage	2870	2940	2751	-119
Residue Management				
- spring vs fall tillage	5178	3970	3461	-1717
Nutrient Management				
Nutrient Testing				
- soil testing	1208	1171	1152	-56
- manure testing	1064	801	715	-349
Application Method				
- inorganic fertilizers	1165	1071	1031	-134
- organic fertilizers				
Solid	933	731	645	-288
Liquid	187	247	258	72
Livestock and Poultry Waste Management				
Handling				
- solid				
Beef	121	117	115	-7
Dairy	51	38	36	-15
Poultry	18	20	21	2
- liquid				
Dairy	21	15	14	-7
Swine	33	36	37	4
Poultry	2	2	2	<1
Storage				
- solid				
Beef	873	776	732	-141
Dairy	501	421	390	-111
Poultry	272	290	287	15
- liquid				
Dairy	103	87	80	-23
Swine	239	237	230	-9
Poultry	<1	<1	<1	<1
Farm Forestry and Habitat Management				
Shelterbelts/Windbreaks	-19	-22	-24	-5
Riparian Buffers	-173	-186	-195	-22
Sum	**7730**	**7110**	**6637**	**-1093**

Scenario 3 assumed an accelerated rate of adoption (up to 20%) of GHG BMP practices for the 2008 to 2012 period. Reduction efforts are concentrated on specific BMP practices: Manure storage, manure application and residue management. The GHG reduction was 683 ktonnes under this scenario (Table 10). Regional GHG emissions 2008-2012 for this scenario are reported in Appendix 9.3.5.

The greatest savings in emissions under this scenario are achieved through: conversion of conventionally tilled cropland to no-till systems and the changes in associated residue management; change from fall to spring tillage; inclusion of cereal crops in rotations; better handling and storage of manures, in particular solids; and improved nutrient management through manure nutrient testing. Soil testing and improvements in inorganic fertilizer use can contribute to overall emissions. Savings in GHG emissions were most evident in the area of tillage conversion, although not to the same extent as in Scenario 2.

Potential for provincial GHG reductions was indicated in the manure application category, although only the Southern, Central and Eastern regions showed improvements in this category and influenced the overall assessment. Greater potential for GHG reduction was observed in solid manure application changes as compared to liquid application. Improvements due to changes in the liquid manure storage were estimated for swine for the province, although reductions in liquid dairy storage emissions were obtained for Central and Western regions.
The study databases were used to predict the effect of changing several management practices on GHG emission reduction. The following management practices were assessed for potential emission reductions:

Table 10. Selected Best Management Practices and their Effect on Greenhouse Gas Mitigation

MANAGEMENT PRACTICE		**GHG REDUCTION (CO_2 equivalent kt/yr)**
Reduce Recommended N Use On Corn		
	By 5%	46
	By 15%	140
Grow No-Till Corn On Clay Soils		
	50% Adoption	47
Use N Soil Test		
	100% Adoption	288
Use PSNT Soil Test		
	100% Adoption	468
Use All Available Manure N for Crop Production		650

The proceeding examples show the effect of potential adoption rates and selected management practices on annual GHG emissions. Reducing recommended N application rates on corn by 5 to 15% affects all corn producers and reduces annual emissions by 46 to 140 kt. The use of no-tillage practices on corn crops grown on clay-textured soils affect fewer producers yet reduces GHG emissions by 47 kt. Assuming a 100% adoption of the N or PSNT soil test by regulatory methods results in annual reductions of emission by 288 to 468 kt respectively. Crediting of available manure N produced in the Province for crop production gives an annual emission reduction of 650 kt.

The study results show that the implementation of BMPs can lead to the reduction of greenhouse gas emissions from the agricultural sector. While some reduction in emissions of carbon dioxide and methane were associated with BMP implementation, the most significant reduction in GHG emissions in the Ontario agricultural sector was attributed to the reduction of N_2O emissions associated with crop production and livestock waste management practices. The study concludes that the accelerated adoption of agricultural BMP in Ontario could lead to annual reductions of GHG emissions in the order of 600 to 700 kt.

Table 11: Projected Provincial Greenhouse Gas Emissions 1990-2012 with Targeted Adoption of Best Management Practices in 2008-2012 (Scenario 3)

	Ontario			
	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Soil Management				
Buffer Strips	<-1	<-1	<-1	<-1
Cover Crops	-6	-6	-6	<-1
Crop Rotations				
- corn	2434	2388	2382	-52
- soybeans	1000	1646	1759	760
- wheat	171	446	503	331
- forage	1314	1280	1275	-39
- spring cereal	388	210	192	-196
Total	5307	5970	6110	803
Tillage				
conventional	2450	1902	1902	-548
reduced	404	706	706	302
no-till	16	388	388	372
total tillage	2870	2996	2996	126
Residue Management				
- spring vs fall tillage	5178	3954	5098	-79
Nutrient Management				
Nutrient Testing				
- soil testing	1208	1174	1169	-38
- manure testing	1064	961	961	-103
Application Method				
- inorganic fertilizers	1165	1139	1136	-29
- organic fertilizers				
solid	933	739	708	-225
liquid	187	256	221	34
Livestock and Poultry Waste Management				
Handling				
- solid				
Beef	121	117	117	-4
Dairy	51	40	40	-11
Poultry	18	21	20	2
- liquid				
Dairy	21	15	15	-6
Swine	33	37	37	4
Poultry	2	2	2	<1
Storage				
- solid				
Beef	873	835	665	-207
Dairy	501	461	416	-85
Poultry	272	304	239	-32
- liquid				
Dairy	103	91	194	90
Swine	239	254	146	-93
Poultry	1	1	1	<-1
Farm Forestry and Habitat Management				
Shelterbelts/Windbreaks	-19	-20	-20	<-1
Riparian Buffers	-173	-174	-174	<-1
Sum	**7730**	**7426**	**7047**	**-683**

5.6 Research Needs and Potential BMPs

Early on in the study it was identified that there would be very few field measurements of GHG emissions under Ontario conditions. There is a substantial need for research if we hope to better estimate or mitigate GHG emissions. Also, in the scientific literature there are several theories and practices being tested that may lead to reductions in GHG emissions. Presently these methods have not been proven under Ontario conditions to an extent that they could be considered feasible to include for derivation of emission coefficients in this study. Several of these BMPs were listed in Table 1 but no EC or calculations were done for them subsequently. Following is a list of research needs and potential BMPs that may lead to better understanding of GHG emissions or mitigation.

5.6.1 Soil Management

Buffer strips

The primary functions of buffer strips for GHG mitigation are: to scavenge excess N from surface and groundwater systems moving through the strip, and to sequester carbon. Inclusion of fast-growing tree species in conversions from grass to riparian buffers can result in the following GHG benefits: greater biomass therefore higher sequestration potential (which compensates for the increase in CO_2 emissions from trees); erosion/runoff reductions; and removal of N in leachate from adjacent cropland. Estimates of leachate reduction range from 50% to 70% of NO_3, trapped by 5 to 10m width riparian buffers, respectively (Thevathasan, personal communication) compensated for by benefits. In permanently water-covered riparian fens, denitrification serves as a sink for both dissolved N_2O in groundwater recharging the fen and N_2O produced in the system (Bilcher-Mathieson and Hoffman 1999)

Modifications to the buffer BMP to improve GHG emission reduction are as follows:

- Conversion to riparian (treed) system from grasses, using: greater biomass growth; inclusion of high N-use species (e.g. fast-growing poplars).

Crop rotations

N use efficiency and C sequestration gained through the use of crop rotations can mitigate GHG emissions. Crop type, selective sequencing of these crops, timing of operations, consideration of the major GHG flux periods within the year, addition of cover crops, and use of N legume credits can reduce the excess amount of N in the soil, and decrease the requirements for inorganic fertilizers. Future advances in the development of N-fixing varieties could further reduce the fertilizer dependency, with these varieties along with N-fixing rotational systems having the most potential impact in areas of environmental stress (acidity, water stress and nutrient deficiencies).

Modifications to the Crop Rotation BMP to reduce GHG emissions are as follows:

- Follow high N-production crops with high N-use crops, use biologically-fixed N sources as part of the fertilizer requirements for the following crop, use N credits
- interseed with cover crops

Cover crops

Emissions of N_20 can be reduced during spring thaw period if live vegetation is present during this time (Wagner-Riddle 1998).

Modifications to the Cover Crop BMPs to improve GHG emission reduction are as follows:

- Cover crops in rotation or interseeded and left live over winter can mitigate N_20 fluxes in the spring, when much of the N_20 loss from Ontario soils occurs
- N credits from cover crops can be used along in conjunction with fertilizer requirements and soil tests to reduce fertilizer application

Tillage

Results of tillage studies with respect to GHG mitigation are varied, however the modifications to the SW BMPs assume that a slight reduction of GHGs can be obtained through the use of a no-till system.

While changes to reduced and no-till systems have benefited soil conservation efforts, the increased infiltration capacity of lower-till systems can contribute to increased N leachate / groundwater levels. Fertilizer rates should not exceed crop requirements, and all N sources should be accounted for in determining rates.

Modifications to the Tillage BMPs to reduce GHG emissions are as follows:

- Conversion to no-till system
- Adoption of a systematic approach to no-till, incorporating consideration of fertilizer requirements and residues management

Residue Management

Retaining residue in the field, and maximizing biomass can return carbon to the soil. Higher carbon / nitrogen residues can ‘trap’ residual N, thus reducing or delaying the amount of N lost to denitrification. Depending on the crops grown and the climatic and soil conditions, residues can provide varying amounts of N for the following crop’s fertilizer requirements. Generally, GHG emissions are increased by residue incorporatation.

Modifications to the Residue Management BMP to reduce GHG emissions are as follows:

- If residues must be incorporated, this should be done in spring just prior to planting when ever possible. Residue cover over winter is preferable from a soil conservation as well as GHG mitigation practice over fall incorporation.

5.6.2 Nutrient Management

Soil Testing

Unfortunately, the current soil nitrate tests for corn and barley are not widely utilized because of the difficulty of taking soil samples in the busy spring season and the lack of acceptance of the reliability of the test. Part of this unacceptance is due to inconsistencies in the test results that may be due to inadequate (too few samples) or inappropriate (mixed samples/not reflecting field variability) sampling or non-uniform application of N containing materials (Blackmer, 1997). Large rainfall events, between sampling periods or between sampling and crop uptake, leach soil nitrate, increasing the uncertainty of the test values. There is a need for a method for recommending the rate of nitrogen amendment that is soil specific (considers climate and soil properties), is able to predict mineralization of N from the soil/manure organic pool and is easily implemented in the course of farming activities (Kowalenko, 1999).

Nitrification/Urease Inhibitors

These chemical compounds, used individually or combined attempt to slow the nitrogen transformations in the soil so that nitrogen becomes available when the plant is most able to use it to improve N recovery. In theory and controlled laboratory experiments these inhibitors work relatively well.

1. Nitrification Inhibitors - These substances (dicyandiamide (DCD), N-Serve 24 E, ATC, encapsulated calcium carbide) are toxic to the soil microorganisms responsible for nitrification, temporarily inhibiting the conversion of ammonium to nitrate so that losses due to leaching or denitrification are minimized. They have been found to prevent much of the loss of fall applied N in Ontario and on the prairies when large granules or bands/nesting of urea were used (Singh et al., 1988; Malhi and Nyborg, 1988).

2. Urease Inhibitors -The urease enzyme is impaired so that conversion of urea to NH_4^+ is slowed. Hydroquinone and NBPT (n-(n-butyl) thiophosphoric triamide) delay the time of maximum rate of hydrolysis, increasing the chance of rain moving the urea into the soil, where it would be protected from volatilization (Grant and Bailey, 1997).

There is some field evidence that DCD and encapsulated calcium carbide can reduce N_2O emissions by 45-71% (Mosier et al., 1994). In Ontario field experiments, there has been no trend for greater yield using nitrification inhibitors that is large or consistent enough to meet registration criteria (Ball-Coelho and Roy, 1999). It must be understood that benefits from inhibitors will not occur every year, due to variation in environmental conditions and crop response, and coincidence of conditions suitable for unwanted N transformations with the effective period of the particular chemical (Murphy and Ferguson, 1997; Grant and Bailey, 1997). There was evidence that inhibitors sufficiently reduce nitrate leaching such that inhibitors are relevant to and may be considered for mitigating environmental impacts (Ball-Coelho and Roy 1999).

Other methods of delaying nitrification, such as using slow-release urea (SRU) have only been found to reduce N_2O rates in the short term. The delayed release of N was coincident with subsequent fertilizer applications and with conditions conducive to N_2O emissions and so N_2O production was higher in subsequent years with SRU (Maggiotto et al. 2000)

Site Specific Farming

There is no conclusive evidence from Ontario that site specific farming can i) reduce overall N application rates or ii) apply rates of N in the field such that losses due to denitrification or leaching are minimized (P. Von Bertoldi, personal communication). There is on-going research to determine the way to use variable rate technology to meet crop production and environmental targets. Preliminary experiments conducted in Minnesota have found that the total N required to optimize production could have been reduced by 25-50% of the conventional recommendations if spatial differences were adequately considered (Malzer et al. 1994). N_2O production could potentially be included as part of these research program although it has not been specifically addressed as yet.

Combinations of technologies may also prove to be beneficial. Research at the University of Nebraska has shown the potential for the site-specific application of a nitrification inhibitor to protect yield potential and against leaching loss of nitrate, compared to uniform application of nitrapyrin (Ferguson and Hergert 2000).

Split Application/Side-dressing

Theoretically, splitting nitrogen applications into smaller amounts that are applied while the crop is growing could reduce N_2O emissions because the recovery of soil mineral N by crops may be increased when the application of N is postponed until after crop emergence. Research in the Netherlands using mineral fertilizer or slurry, gave insufficient evidence to recommend farmers to split application routinely (Schröder, 1999). Sufficient N concentrations are needed in due time, be it at the expense of leaching risks. A soil nitrate test was recommended to determine if supplemental/side-dressed N was needed after exceptional weather conditions (heavy leaching). A side-dress application of 40 kg N/ha was uneconomical when more than 175 kg N/ha was present in the upper 60 cm at the 4-6 leaf stage (Schröder, 1999). It was also recognized that if have lower manure rates benefits of split applications may increase because of lower mineralization potential (Schröder, 1999).

Stalk Test

An "end of season" test for nitrogen has been developed to assess the sufficiency of nitrogen supplied to a corn crop (Blackmer and Mallarino, 1995; Reschke, 2000). The lower stalk is sampled at the black layer stage in fall and the sap is analysed with a chlorophyll meter. The test does not allow you to alter this year's nitrogen program but it can give an indication of how well your program is doing overall. There may be potential to use the stalk test to indicate if and where there is significant residual N content in the soil in the fall. A critical threshold may be developed where recommendations to establish cover crops to scavenge the mineral N over winter could be made. Although there is no specific GHG emission reduction that can be associated with this practice, any method to minimize NO_3 in the soil over winter should reduce N_2O emissions.

5.6.3 Manure Handling and Storage

Comments on further treatment of slurries and solids

The following is a summary of a number treatment options for swine manure put forth in the Agro-Environmental Plan for the Hog Industry of Quebec (http://res.agr.ca/em/hems/agenv_plan_qc.html).

The treatments put forth come under the following main categories.

A. Liquid/Solid separation (sedimentation, filtration, mechanical) followed by:

1. Liquid treatment:
   a. filtration (either biological or chemical to remove nutrients)
   b. flocculation
   c. reuse of liquid to flush barn

2. Solid treatment
   a. drying or pressing, with or without pelleting
   b. composting (N_2O losses may be high if not properly managed).

3. Only one system ("Hog-mop") dealt with a treatment, by scrubbing, of the gases from animal housing.

B. Constructed wetlands and filtering marshes (harvesting is required to avoid nutrient buildups).

C. Biogas production usually followed by an aerobic treatment. Low winter temperatures are a problem unless psychrophilic organisms (cold-adapted) are used or the process is carried out in a heated environment, eg. within the animal housing unit, or manure is stored in the winter when there is very little greenhouse gas release and processed to produce methane in the summer.

D. Oligiolysis: electrical treatment to destroy bacteria, and eliminate odours and maintain nutrients.

E. Closely monitored land application using GPS (global positioning system); the company removes the waste as a service to the farmer, and supplies to the same or other farmers a complete fertilizer package with soil testing, GPS and timed applications.

In principle, all the treatments should reduce greenhouse gas emissions if properly managed, but the information given is insufficient to estimate what level of reductions would be accomplished. Composting options, especially, need to be assessed with respect to the amount of N_2O given off, rather than total nitrogen losses, which can be misleading given the possible concurrence of nitrogen fixation and denitrification within the compost material.

The report's conclusion was essentially that none of the proposals had been developed to a stage that could be used in current hog operations. The recommendations were that farmers use water-saving drinking devices, windbreaks, covers, separators, and bedding.

Mitigation of Greenhouse Gas Emissions by Feeding Strategies

A comprehensive study on feeding strategies for mitigating greenhouse gas emissions for domestic animals was carried out by Ball et al. (1999).

For swine, the most promising strategy to reduce nitrogen excretion by pigs is the reduction of dietary protein contents with the addition of free amino acids. Currently animals tend to be significantly "overfed", largely because the amino acid complement of current diets is not ideal. The second strategy recommended was the addition of phytase in swine diets. This enzyme improves phosphorus efficiency in the animals, but also improves the utilization of other nutrients, eg nitrogen. Combined strategies would result in a 35% decrease in nitrogen output (based on 1990 values). Dourmand et al. (1999) determined that it is possible to reduce the nitrogen output into manures by 20-30% with better feeding management. The effect on methane emissions by the animals as a result of these measures is poorly studied.

For poultry, minor reductions (10-15%) in dietary protein content, combined with improved nutrient efficiency of 5%, phytase and NSP-digesting enzymes additions could be immediately adopted, and would result in a 34% decrease in nitrogen output. Methane reductions by the animals would decrease by 19%.
(Ball et al. 1999)

For cattle (dairy and beef), Ball et al. (1999) determined that the two most effective mitigation strategies for reducing methane production by the animals were a reduction in carcass fatness (in fact a return to 1990 values) and an improvement in forage quality. Most methane emissions come from beef cattle that are fed high forage diets. Harper et al. (1999) showed that cattle on high forage diets produced about 3times more methane per day that those given highly digestible/high grain diets. With respect to nitrogen excretions for cattle, Ball et al. (1999) estimated that reduction of dietary protein by 10% would only decrease nitrogen excretions by 2%; the main reason for this being that most beef diets are not supplemented with protein. Therefore the dairy industry could institute changes that would be effective in reducing nitrogen excretions, while adoption of similar strategies for the beef industry would be very expensive. Bussink & Oenoma (1998) however, suggested a reduction in nitrogen content of pasture could be achieved by lowering the nitrogen fertilizer input.

5.6.4 Farm Forestry and Habitat

Riparian management

In general, riparian zones are net sinks for methane and possibly a source of reduced N_2O emissions. The recommended practices of creating permanent cover in these zones will enhance the potential for reducing GHG emissions. Several additional factors may be considered in making recommendations for riparian management. Denitrification potential may be limited by an energy source. Increasing carbon inputs to the soil through the use of deep-rooted species may mitigate this limitation. Employing very deep-rooted species, such as some tree species, will result in carbon being sequestered deep in the soil profile. This can extend the biologically active zone in the soil further enhancing denitrification potential. Employing species with a high nutrient demand (i.e. poplar) will directly remove additional N, primarily as nitrate.

Making these improvements is unlikely to have any significant effect on the water table and, as such, are not likely to favour increased CH_4 emissions. The potential for methane consumption may be somewhat enhanced, especially if converting from cultivated land.

Riparian buffer strips are capable of mitigating GHG production derived from nutrients deposited directly in this zone. Tile drain systems typically bypass this zone by depositing drainage water directly in streams, municipal drains and ditches. Denitrification potential in open waterways is limited by residence time and the presence of adequate carbon substrate required for microbial activity. Increasing the potential for adequate carbon inputs to open waterways can be achieved by utilizing plants that are more likely to deposit detritus directly to the stream, primarily tall shrubs and trees with foliage that extends over the open water. However, this does not address the issue of residence time.

A superior option is to create wetlands, or holding ponds, to collect water from tile drains. High rates of water and nutrient consumption can be achieved by planting species with a high moisture demand. Such species include reeds, bullrushes, sedges, soft maple, elm and many others. In addition to direct nutrient removal increased rates of denitrification will occur according to the process previously described. These constructed wetlands may become a source of methane production under prolonged periods of saturation. The potential for methane emissions needs to be balanced against the potential N_2O emission reductions. Numerous barriers to adoption exist for these management strategies, including: removal of land from active cropping; high establishment and management costs; interference with existing tile drains; and improved habitat for pest species.

Intercropping

The potential for a tree-based intercrop system to mitigate against GHG emissions is relatively small. Mitigation potential may be increased through the use of precision application of N based fertilizers. Current management practices typically include broadcast application of fertilizer. Crop requirements for N fertilizer may be reduced through organically sourced inputs from the trees (litterfall, root exudates, fine root turnover). A reduction in the use of inorganic N may result in lower direct leaching losses of nitrate and a reduction in the potential for denitrification. Further, deep-rooted tree species may intercept some proportion of the nitrate leached from the crop-rooting zone. Barriers to adoption include: interference of trees with operation of equipment; increased competition for resources, primarily light and water; high establishment and management costs; and interference with existing tile drains.

Silvipasture

In terms of animal welfare, there is a strong argument to be made for adopting silvipasture as a management system. Providing a source of cover allows the animals to seek shelter from extreme climatic conditions. However, there are numerous arguments against introducing trees to a pasture. Shade will reduce the productivity. Animals will tend to herd under the trees thus localizing inputs of animal waste and exceeding the biotic potential of the land to support the nutrient inputs. However, there are numerous arguments against introducing trees to a pasture, although there exists little specific research to support these arguments. Shade may reduce forage production. Excessive nutrient inputs and heavy localized grazing will reduce the ability of the plants to regenerate. Combined, this results in the animals foraging for limited and low quality feed. Consequently, animal health becomes an issue. Damage to the trees is inevitable unless exclosures are constructed (high cost). As such, these systems are more acceptable to land owners with small herds (very low stocking density) or for animals that do not tend to herd (i.e. horses). Despite these concerns, silvipastoral systems have been adopted throughout the temperate zone (Gordon and Newman 1997). Factors which could limit adoption include: establishment/maintenance costs; tree damage; excessive nutrient inputs; preferential grazing under the trees; and animal health.

Reforestation

Establishing a plantation is a relatively expensive proposition. Revenues from a plantation are realized many years after planting and may not fully compensate the landowner for lost potential revenue from other land uses. Potential tree growth is directly related to site quality. As such, the most productive agricultural land is also best suited for trees. However, plantations are generally established on marginal or fragile lands where productivity of economic crops might be limited. The high cost of establishment, lost potential revenue from agriculture and long time frame to realize a return on investment could be barriers to adoption.

Woodland Management

Following prescribed management practices is unlikely to result in any change in GHG emissions. There are no real barriers to adoption. A tax rebate program exists to promote active management but requires a management plan to be developed. The cost of creating and implementing a management plan is relatively small and can typically be recovered within the first 5 years.

Natural fencerows

The trend towards large machinery has resulted in the removal of many fencerows. Where fencerows still exist, landowners are unlikely to promote naturalization. The potential for these areas to harbour economic pests (weeds, insects, animals and disease) may outweigh any environmental/ecological benefits.

Windbreaks and shelterbelts

Windbreaks and shelterbelts systems produce a relatively minor contribution to GHG emission reduction. Planting windbreaks/shelterbelts around farm buildings can significantly decrease heating and cooling requirements, thus decreasing the use of fuel, both fossil and biomass. Proper establishment and management of these systems have been shown to increase yields. Thus, a direct correlation can be made between properly managed windbreaks/shelterbelts and annual carbon fixation. The additional carbon fixed in the crop may subsequently be released through soil respiration unless additional management practices that conserve soil organic matter are also employed. Barriers to adoption include: interference of trees with operation of equipment;

increased competition for resources, primarily light and water; high establishment and management costs; and interference with existing tile drains

In general, the adoption of agronomic systems employing trees is limited by 3 main factors:

1. The potential for trees to interfere with the highly mechanized nature of farming
2. The cost of establishment and maintenance combined with a lack of information on the potential revenue that may be realized
3. Cultural momentum. Since European settlement (colonization) began, large tracts of arable land have been cleared of native forest cover to facilitate food and forage production. It runs counter to conventional thought to plant trees in areas where successive generations toiled to remove them.

Factors that may positively influence rates of adoption:

- Economic models that accurately reflect potential costs/revenues for each recommended system under varying soil/climatic conditions
- Financial incentives, including tax relief, loans, grants, etc., to offset the costs and lost potential revenue of removing land from production
- Establishment of regional demonstration sites for the various practices.

Knowledge gaps

Many of the estimates provided here are a best guess determined by combining values from different regions and management systems. There are very few studies that present comparative data. Despite this, measured values of GHG emissions for a general cover type (i.e. forest, grass or crop land) are typically of the same order of magnitude. However, many of the numbers reported in the literature have very high associated error terms. Because of this, the great variation in the biophysical environments and the near infinite range in specific management practices, our estimates must be considered a first approximation.

At a regional level our estimates are likely to provide a good estimate of GHG emissions. However, as scale decreases to the farm or field level the uncertainty associated with the estimate increases.

6 Conclusions

County and regional data were collected from a number of census and conservation programs to document the extent of implementation of GHG practices in Ontario. The implementation of agricultural BMPs increased through the 1990's in response to a number of incentive programs and the promotion of BMPs by OMAFRA extension staff. The release of a number of high quality BMP booklets by OMAFRA during this period assisted in keeping the profile for these practices high. By the turn of the century, the implementation of the BMPs declined significantly with the completion of the incentive programs. Expert opinion obtained from the farm population in focus group meetings suggest no further increased adoption of these BMPs will occur until new incentives become available.

A review of literature on GHG processes and controlling factors revealed that the implementation of soil and water (S&W) BMPs can reduce GHG emissions. A further modification of some of these practices (GHG BMPs) can improve the reduction in GHG that can be realized. Emission coefficients were developed for S&W BMPs and GHG BMPs from IPCC standard coefficients that were modified to reflect Ontario agricultural management and climate. Modification of the IPCC emission coefficients were based on published research results from geographically similar regions and on-going GHG research in the Province. The resulting GHG emission coefficients are more appropriate for use in Ontario than the national and international coefficients that appear in the literature.

The Ontario BMP database was used with the BMP emission coefficient data to compute GHG emissions from the agricultural sector over the period 1990 to 2012. In a business as usual consideration with observed BMP implementation to 2000 and reduced projected implementation to 2012, a 360 k tonne reduction in GHG emission was computed. The use of GHG BMPs from 2000 to 2012 at the same rates of adoption as used previously example resulted in a 676 k tonne reduction in GHG emissions.

Several BMP implementation scenarios were evaluated for the period 2008 to 2012. In these cases, the 'business as usual' calculations were used to obtain emission levels up to 2008. Increasing adoption rates of BMPs from 2008 to 2012 levels observed in the mid 90's resulted in a 676 k tonne reduction of GHG emissions over the period 1990-2012. A 5 % increase in adoption of GHG BMPs in the 2008 to 2012 period reduced GHG emissions by 1093 k tonne from 1990 levels. Residue management, manure management and application BMPs were found to make significant reductions in the emission of GHG. Targeting the implementation of these BMPs with programs that would lead to adoption rates of 20 % resulted in GHG reductions of 683 k tonne.

The potential GHG emission reductions identified in this report consider only the impact of BMPs and associated activities. Factors that were not considered in the calculations include the following:

- Fuel use and transportation
- Other crops of minor areas
- Other livestock of lesser numbers
- Carbon sequestration from some BMP activities (excluding forestry)
- Legume fixation
- Fertilizer use vs. recommendations
- Atmospheric deposition

Under the terms of the Kyoto protocol, the Canadian agricultural sector is committed to a reduction of 6 % from the 1990 emissions levels. Using most recent estimates of 1990 emissions by CEEMA, a 6 % reduction represents about 600 k tonne. It is concluded that the projected reductions in GHG emissions associated with the implementation of GHG BMPs in the Ontario agricultural sector could result in these target loads being achieved.

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9 Appendix

9.1 Study Database

9.1.1 Provincial and Regional BMPs Areas and Quantitiies (1990-2012)

	Ontario			Southern			Western		
Management Category	1990	2000	2012	1990	2000	2012	1990	2000	2012
Soil Management (ha)									
Buffer Strips	82,308	82,395	82,402	44,440	44,470	44,470	21,903	21,960	21,967
Cover Crops	22,702	25,478	25,478	20,289	22,464	22,464	1,419	2,183	2,183
Crop Rotations - corn	899,462	887,319	880,123	443,537	399,049	374,790	262,714	280,296	291,476
soybeans	547,574	776,540	963,546	420,663	495,195	546,921	90,608	193,634	312,250
wheat	150,282	291,295	441,223	75,951	164,907	268,644	53,284	100,718	150,117
forage	1,037,986	1,018,561	1,007,103	91,091	79,615	73,520	248,580	240,620	235,982
spring cereal	451,109	287,830	222,974	54,259	20,281	12,152	234,528	154,053	121,210
Tillage - conventional	2,057,414	1,294,181	1,294,181	923,236	529,425	529,425	670,037	483,958	483,958
reduced	424,088	600,754	600,754	224,061	309,753	309,753	117,777	181,106	181,106
no till	30,429	596,856	596,856	25,259	377,476	377,476	21,969	149,365	149,365
Residue Management – tilled	2,481,502	1,894,935	1,894,935	1,147,297	839,178	839,178	787,814	665,064	665,064
Nutrient Management (kg N/yr)									
Nutrient Testing									
soil testing	130,421,995	128,661,318	127,617,764	82,054,357	73,824,063	69,336,185	30,212,145	32,234,034	33,519,750
manure testing	136,213,100	123,021,243	123,021,243	33,720,808	31,065,710	31,065,710	55,021,412	55,915,952	55,915,952
Application Method									
inorganic fertilizers	130,421,995	128,661,318	127,617,764	82,054,357	73,824,063	69,336,185	30,212,145	32,234,034	33,519,750
organic fertilizers - solid	110,000,066	87,147,851	87,147,851	22,771,595	19,313,189	19,313,189	38,677,004	39,477,208	39,477,208
liquid	26,213,033	35,873,392	35,873,392	10,949,215	11,752,521	11,752,521	16,344,408	16,438,745	16,438,745
Livestock and Poultry Waste Management (animal no.)									
Handling and Storage									
solid - beef	1,269,734	1,229,770	1,229,770	207,812	182,451	182,451	613,176	601,087	601,087
dairy	417,729	386,102	386,102	46,629	70,670	70,670	153,854	142,559	142,559
poultry	34,768,741	39,099,867	39,099,867	15,096,641	15,944,639	15,944,639	12,618,003	13,648,954	13,648,954
liquid - dairy	531,655	491,403	491,403	139,888	106,006	106,006	153,854	142,559	142,559
swine	2,649,336	2,997,900	2,997,900	1,020,752	1,165,732	1,165,732	1,395,746	1,660,680	1,660,680
poultry	3,863,193	4,344,430	4,344,430	1,677,405	1,771,627	1,771,627	1,402,000	1,516,550	1,516,550
Farm Forestry and Habitat Management (ha)									
Shelterbelts/Windbreaks	4,938	5,096	5,127	2,666	2,757	2,778	1,314	1,372	1,383
Riparian Buffers	65,846	66,078	66,172	35,552	35,592	35,616	17,522	17,592	17,639

	Central			Eastern			Northern		
Management Category	1990	2000	2012	1990	2000	2012	1990	2000	2012
Soil Management (ha)									
Buffer Strips	7,598	7,598	7,598	7,085	7,085	7,085	1,282	1,282	1,282
Cover Crops	451	482	482	17	279	279	0	70	70
Crop Rotations - corn	74,980	75,820	76,330	104,425	114,781	121,545	1,019	915	859
soybeans	24,540	15,939	12,466	9,797	37,098	85,609	123	38	21
wheat	18,587	22,808	25,847	2,120	2,644	3,027	341	218	169
Forage	150,356	132,730	123,283	234,368	203,013	186,496	31,633	27,088	24,719
spring cereal	52,898	35,060	27,719	66,108	38,485	28,415	27,134	25,849	25,112
Tillage - conventional	186,531	100,766	100,766	196,520	155,870	155,870	33,388	26,622	26,622
reduced	50,585	60,529	60,529	36,736	44,677	44,677	5,970	5,031	5,031
no till	8,693	49,879	49,879	7,078	18,581	18,581	2,832	1,896	1,896
Residue Management - tilled	237,116	161,294	161,294	233,256	200,547	200,547	39,359	31,653	31,653
Nutrient Management (kg N/yr)									
Nutrient Testing									
soil testing	8,247,793	8,340,227	8,396,246	11,486,712	12,625,951	13,369,910	91,737	82,385	77,293
manure testing	15,792,801	14,864,474	14,864,474	20,857,722	16,880,202	16,880,202	4,778,401	9,124,363	9,124,363
Application Method									
inorganic fertilizers	8,247,793	8,340,227	8,396,246	11,486,712	12,625,951	13,369,910	91,737	82,385	77,293
organic fertilizers – solid	12,633,786	12,290,192	12,290,192	16,057,957	12,875,248	12,875,248	3,934,227	5,684,417	5,684,417
liquid	3,159,015	2,574,281	2,574,281	4,799,765	4,004,954	4,004,954	844,174	3,439,947	3,439,947
Livestock and Poultry Waste Management (animal no.)									
Handling and Storage									
solid - beef	192,303	203,435	203,435	181,671	159,437	159,437	74,195	82,295	82,295
dairy	65,533	60,454	60,454	140,300	127,641	127,641	13,230	12,193	12,193
poultry	4,106,869	3,499,492	3,499,492	2,609,904	2,410,171	2,410,171	240,066	272,144	272,144
liquid – dairy	65,533	60,454	60,454	140,300	127,641	127,641	30,870	28,451	28,451
swine	112,984	85,005	85,005	111,347	99,540	99,540	8,509	12,285	12,285
poultry	456,319	388,832	388,832	289,989	267,797	267,797	26,674	30,238	30,238
Farm Forestry and Habitat Management (ha)									
Shelterbelts/Windbreaks	456	465	465	425	425	425	77	77	77
Riparian Buffers	6,078	6,200	6,224	5,668	5,668	5,668	1,026	1,026	1,026

9.1.2 Missing Data from Census Information

A relatively small number of missing values in the Census of Agriculture databases were modified using the following approach:

Turkey information missing for Haliburton and Parry Sound in 1991 was determined by:

- From 1996 data, the ratio between the number of turkey farms in Haliburton and Parry Sound was used for 1991 (in 1996, Haliburton had 11 turkey farms and Parry Sound had 326), therefore assumed Haliburton has 3.3 % and Parry Sound has 96.7% of turkey farms in 1991

- Taking the total turkeys in Central Ontario, then subtracting this number from the total number of turkeys in all of the other counties determined the number of turkeys in the two counties. To get the number of turkeys in Haliburton multiply this number by 0.033 and multiply by 0.967 for Parry Sound

Missing numbers in the 1996 spreadsheets were determined this way except for the number of beef and dairy cows in 1991. These numbers were determined by multiplying the total number of cows in 1991 by the dairy percent or beef percent from 1996.

In the 1996 livestock type database, several cells had x's for crop area alongside livestock farms numbering 1 or 2. These unknown values were assumed to be 0 ha in area for the required calculations.

9.1.3 Manure quantity calculations

The manure quantity was determined in two steps; by using animal manure characteristics (OMAFRA Agdex538) of daily manure volume produced and assigning these animal categories into Census of Agriculture livestock categories, which were then multiplied by the Census livestock numbers using the following method:

Livestock category assumptions:

- beef category contains beef cows, beef heifers, heifers for slaughter/feeder, steers and calves
- beef heifers include beef heifers, slaughter and feeder heifers
- there are an equal number of heifers between the ages of 6 to 15 months and 15 to 24 months – average of two manure values used
- there are an equal number of calves between the ages of 0 to 3 months and 3 to 6 months – average of two manure values used
- steers produce same amount of manure as a 545 kg beef cow
- dairy category contains dairy cows, dairy heifers, bulls, and calves
- bulls produce same amount of manure as a 545 kg beef cow
- hog category contains all pigs
- boars produce the same amount of manure as a sow
- there are an equal number of pigs between 5 to 10 kg, 11 to 20 kg, 21 to 35 kg, 36 to 55 kg, 56 to 80 kg and 81 to 90 kg – average of six values to determine one manure value for “other pigs” category used
- poultry category contains chickens, turkeys, laying hens in hatchery supply flock and other poultry
- broilers, roasters and cornish all produce the same amount of manure as a broiler (0 to 1.8 kg)
- pullets and pullet chicks produce same amount of manure as a broiler (0 to 1.8 kg)
- there are an equal number of broiler, growing hen and growing tom turkeys – average of three values to determine one manure value for turkeys used

Manure volume calculations:

1991 Ontario livestock number

Total Number of Beef Cattle (excluding calves)
= (beef % of total cows x total cows) + (beef % of total heifers x total heifers) + # steers
= (.47 x 832 655) + (.56 x 514 082) + 333 397
= 1 012 631

Total Number of Dairy Cattle (excluding calves)
= # bulls + (dairy % of total cows x total cows) + (dairy % of total heifers x total heifers)
= 27 691 + (.53 x 832 655) + (.44 x 514 082)
= 695 194

1991 Ontario manure volume

Amount of Chicken Manure (L/d)
= (pullet & pullet chicks % of total x total hens and chickens x 0.08 L/d) + (hens & pullets % of total x total hens and chickens x 0.14 L/d) + (all other chickens % of total x total hens and chickens x 0.11 L/d)
= (.11 x 34 059 285 x .08) + (.24 x 34 059 285 x .14) + (.65 x 34 059 285 x .11)
= 3 879 353 L/d

Amount of Turkey Manure (L/d)
= # of turkeys x 0.20 L/d
= 3 288 508 x 0.20
= 657 702 L/d

Amount of Other Poultry Manure (L/d)
= (# birds in hatchery supply flock + # other poultry) x 0.11 L/d
= (985 507 + 779 871) x 0.11
= 194 192 L/d

Amount of Total Poultry Manure (L/d)
= 3 879 353 + 657 702 + 194 192
= 4 731 247 L/d

Amount of Dairy Cattle Manure (L/d)
= (# bulls x 28.3 L/d) + (dairy % of total cows x total cows x 45.3 L/d) + (dairy % of total heifers x total heifers x 17.7 L/d) + ((# dairy cattle (excluding calves) / # total cattle (excluding calves)) x # calves x 6. 25 L/d
= (27 691 x 28.3) + (.53 x 832 655 x 45.3) + (.44 x 514 082 x 17.7) + ((699 268/(699 268 + 1 008 557)) x 578 129 x 6.25)
= 26 258 006 L/d

Amount of Beef Cattle Manure (L/d)
= (beef % of total cows x total cows x 28.3 L/d) + (beef & slaughter % of total heifers x total heifers x 17.7 L/d) + (# steers x 28.3 L/d) + ((# beef cattle (excluding calves) / # total cattle (excluding calves)) x # calves x 6.25 L/d
= (.47 x 832 655 x 28.3) + (.56 x 514 082 x 17.7) + (333 397 x 28.3) + (1 008 557/(1 008 557 + 699 268)) x 578 129 x 6.25)
= 27 817 970 L/d

Amount of Hog Manure (L/d)
= (boar % of total pigs x total pigs x 11.3 L/d) + (sow % of total pigs x total pigs x 11.3 L/d) + (<20kg % of total pigs x total pigs x 1.7 L/d) + (20-60 kg % of total pigs x total pigs x 4.25 L/d) + (>60kg % of total pigs x total pigs x 8.25 L/d)
= (.01 x 2 924 936 x 11.3) + (.10 x 2 924 936 x 11.3) + (.31 x 2 924 936 x 1.7) +(.31 x 2 924 936 x 4.25) + (.27 x 2 924 936 x 8.25)
= 15 546 035 L/d

1996 Ontario livestock number:

Total # of beef cattle (excluding calves)
= # beef cows + (1991 beef & slaughter % of total heifers x 1996 # of total heifers) + # steers
= 1 042 309

Total # of dairy cattle (excluding calves)
= # bulls + # dairy cows + (1991 dairy % of total heifers x 1996 # of total heifers)
= 635 816

1996 Ontario manure volume

Amount of Chicken Manure (L/d)
= (# broilers, roasters & cornish x 0.08 L/d) + (# pullets & pullet chicks x 0.08 L/d) + (# laying hens x 0.14 L/d)
= (22 775 158 x .08) + (4 152 491 x .08) + (8 669 297 x .014)
= 3 367 914 L/d

Amount of Turkey Manure (L/d)
= # turkeys x 0.20 L/d
= 3 447 259 x .20
= 689 452 L/d

Amount of Other Poultry Manure (L/d)
= (# laying hens in hatchery supply flock + # other poultry) x 0.11 L/d
= (1 413 890 + 1 061 257) x 0.11
= 272 266 L/d

Amount of Total Poultry Manure (L/d)
= 3 367 914 + 689 452 + 272 266
= 4 329 626 L/d

Amount of Beef Cattle Manure (L/d)
= (# beef cows x 28. 3 L/d) + (1991 beef & slaughter % of total heifers x 1996 # of total heifers x 17.7 L/d) + (# steers x 28.3 L/d) + ((# beef cattle (excluding calves) / (total # cattle (excluding calves)) x # calves x 6.25 L/d
= (441 211 x 28.3) + (.56 x 450 777 x 17.7) + (348 663 x 28.3) + ((1 040 218/(1 040 218 + 637 907)) x 607 871 x 6.25)
= 29 176 539 L/d

Amount of Dairy Cattle Manure (L/d)
= (# bulls x 28.3 L/d) + (# dairy cows x 45.3 L/d) + (1991 dairy % of total heifers x total heifers x 17.7 L/d) + ((# dairy cattle (excluding calves) / (total # cattle (excluding calves)) x # calves x 6. 25 L/d
= (32 677 x 28.3) + (404 797 x 45.3) + (.44 x 450 777 x 17.7) + ((637 907/(637 907 + 1 040218)) x 607 871 x 6.25)
= 24 216 905 L/d

Amount of Hog Manure (L/d)
= (# boars x 11.3 L/d) + (# sows x 11.3 L/d) + (# all other pigs x 4.7 L/d)
= (15 777 x 11.3) + (296 306 x 11.3) + (2 518 999 x 4.7)
= 15 365 833 L/d

iii) Ontario manure type distribution
Weighted average values for Ontario solid/liquid ratio based on regional estimates

Dairy	44/56
Beef	95/5
Poultry	90/10
Hog	10/90

Amount of Solid Dairy Manure (L/d)
= 60% x Amount of Dairy Manure
= 0.60 x 24 216 905
= 14 530 143 L/d

Amount of Liquid Dairy Manure (L/d)
= 40% x Amount of Dairy Manure
= 0.40 x 24 216 905
= 9 686 752 L/d

Amount of Solid Beef Manure (L/d)
= 80% x Amount of Beef Manure
= 0.80 x 29 176 539
= 23 341 231 L/d

Amount of Liquid Beef Manure (L/d)
= 20% x Amount of Beef Manure
= 0.20 x 29 176 539
= 5 835 308 L/d

Amount of Solid Poultry Manure (L/d)
= 90% x Amount of Poultry Manure
= 0.9 * 4 329 626
= 3 896 663 L/d

Amount of Liquid Poultry Manure (L/d)
= 10% x Amount of Poultry Manure
= 0.10 x 4 329 626
= 432 963 L/d

Amount of Solid Hog Manure (L/d)
= 5% x Amount of Hog Manure
= 0.05 x 15 365 833
= 768 292 L/d

Amount of Liquid Hog Manure (L/d)
= 95% x Amount of Hog Manure
= 0.95 x 15 365 833
= 14 597 541 L/d

iv) Nitrogen and density assumptions of manure types (NMAN 2000)

The following data base values were used for manure nitrogen concentration and manure density:

Manure Type	% N		% Dry Matter		Average Density (kg/L)	
	Solid	Liquid	Solid	Liquid	Solid	Liquid
Hog	1.0865	0.3675	27.3	3.5	0.82	0.99
Dairy	0.5385	0.2940	20.0	6.7	0.88	0.98
Beef	0.6736	0.2544	27.3	5.5	0.82	0.99
Poultry	2.3967	0.7786	52.5	8.3	0.52	0.98

Example:
Dairy manure type amounts and associated nitrogen
Total Amount of Solid Dairy Manure (kg/yr)
= 0.88 kg/L x Amount of Solid Dairy Manure L/d x 365 d/yr
= 0.88 x 14 530 143 x 365
= 4 667 081 932 kg/yr

Total Amount of Liquid Dairy Manure (kg/yr)
= 0.96 kg/L x Amount of Liquid Dairy L/d x 365 d/yr
= 0.96 x 9 686 752 x 365
= 3 394 237 901 kg/yr

Amount of N in Solid Dairy Manure (kg/yr)
= Amount of Solid Dairy Manure kg/yr x 0.5385% / 100
= 4 557 081 932 x 0.5385 / 100
= 24 539 886 kg/yr

Amount of N in Liquid Dairy Manure (kg/yr)
= Amount of Liquid Dairy Manure kg/yr x 0.2940 % / 100
= 3 394 237 901 x 0.2940 / 100
= 9 979 059 kg/yr

9.1.4 Manure Storage and Handling Adoption Rates for Ontario 1990-2012

Handling – Solid

Beef	**Pre BMP > 3 days**	**S&W BMP 1 -3 days**	**GHG BMP < 1 day**
Objective 1			
1990	95	5	0
2000	95	5	0
2008	95	5	0
2012	95	5	0
Objective 2			
GHG 2008	92	8	0
GHG 2012	90	10	0
Dairy	**> 3 days**	**1 - 3 days**	**< 1 day**
1990	0	95	5
2000	0	90	10
2008	0	90	10
2012	0	90	10
GHG 2008	0	85	15
GHG 2012	0	85	15
Poultry	**pasture**	**high rise**	**shallow gutter barn**
1990	5	50	45
2000	5	48	47
2008	5	46	49
2012	5	45	50
GHG 2008	5	45	50
GHG 2012	5	40	55

Storage – Solid

Beef	**Pre BMP Pasture & Uncovered no containment**	**S&W BMP Uncovered with containment**	**GHG BMP Covered**
Objective 1			
1990	80	15	5
2000	75	15	10
2008	75	15	10
2012	75	15	10
Objective 2			
GHG 2008	75	10	15
GHG 2012	75	10	15
Dairy	**Uncovered**	**Uncovered with Containment**	**Covered**
1990	60	35	5
2000	55	35	10
2008	55	35	10
2012	55	35	10
GHG 2008	50	35	15
GHG 2012	50	35	15
Poultry	**on ground**	**on concrete**	**storage of dried manure**
1990	80	15	5
2000	75	20	5
2008	75	20	5
2012	75	20	5
GHG 2008	75	15	10
GHG 2012	75	15	10

Handling - Liquid

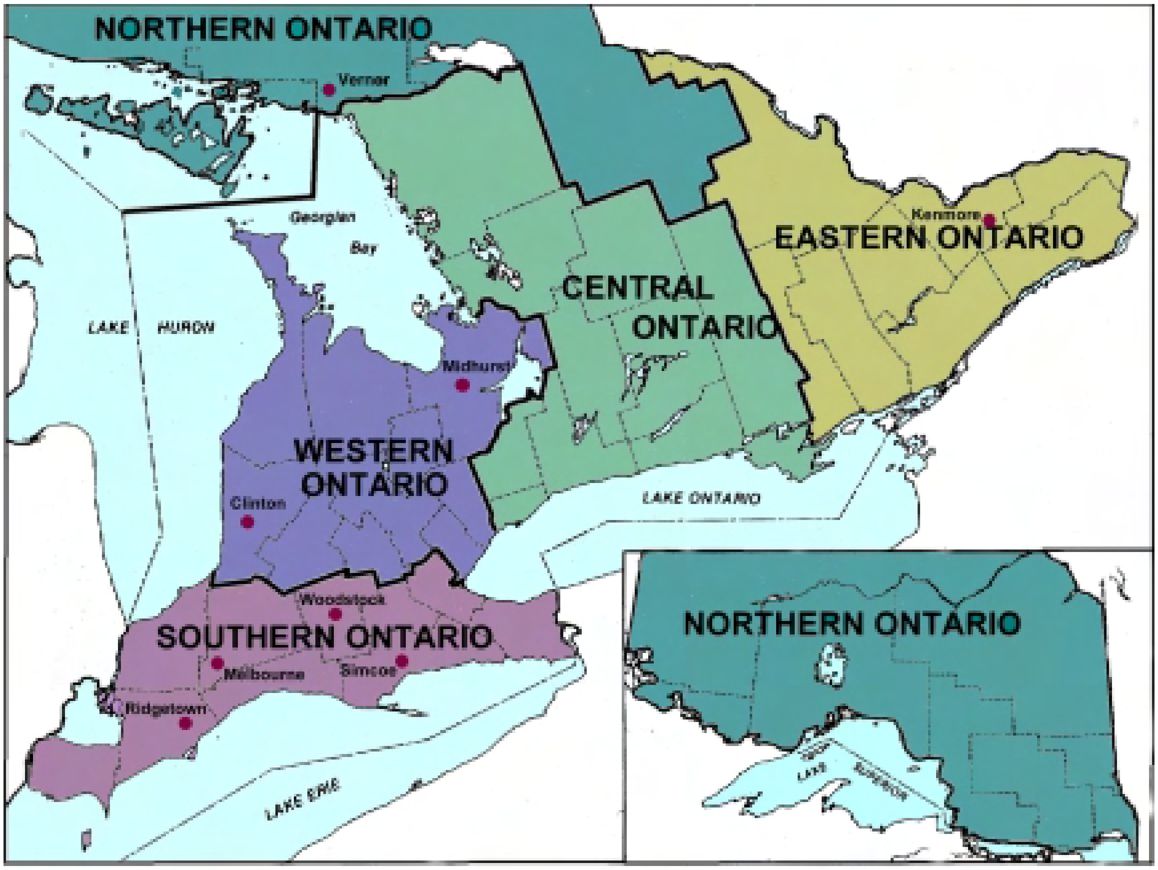
Dairy	**3 day**	**1 day**	**flushing**
1990	0	95	5
2000	0	90	10
2008	0	90	10
2012	0	90	10
GHG 2008	0	85	15
GHG 2012	0	85	15
Swine	**Scraped**	**Partial Slats**	**Slats**
1990	30	45	25
2000	30	40	30
2008	30	40	30
2012	30	40	30
GHG 2008	25	35	40
GHG 2012	25	35	40
Poultry	**pasture**	**high rise**	**shallow gutter barn**
1990	5	75	20
2000	5	70	25
2008	5	70	25
2012	5	70	25
GHG 2008	5	65	30
GHG 2012	5	65	30

Storage – Liquid

Dairy	**Earthen Manure storage**	**Concrete Manure storage**	**Covered**
1990	15	50	35
2000	15	45	40
2008	15	45	40
2012	15	45	40
GHG 2008	15	40	45
GHG 2012	15	40	45
Swine	**Earthen Manure storage**	**Concrete Manure storage**	**Covered**
1990	10	45	45
2000	10	40	50
2008	10	40	50
2012	10	40	50
GHG 2008	10	35	55
GHG 2012	10	35	55
Poultry	**Earthen Manure storage**	**Concrete Manure storage**	**Covered**
1990	30	70	0
2000	30	65	5
2008	30	65	5
2012	30	65	5
GHG 2008	30	60	8
GHG 2012	30	60	10

9.1.5 Focus group Information

9.1.5.1 Map of Focus Group Meeting Locations



9.1.5.2 Background Information Provided to Participants through OMAFRA and the Ontario Soil and Crop Improvement Association

In April 1998, Canada ‘signed’ the Kyoto Protocol. By signing the Protocol, Canada agreed to develop plans to reduce greenhouse gas (GHG) emissions to 6% below the 1990 levels by the year 2008 to 2012. This commitment is not binding for Canada until at least 55 countries (including Canada), representing at least 55% of the world emissions “ratify” the Protocol.

In May 1998, the Federal Government established the National Climate Change Secretariat to develop a National Implementation Strategy (NIS) aimed at reducing Canada’s emissions in keeping with the Protocol. The NIS is being developed with guidance from sixteen Issues Tables. These tables are concluding their efforts in identifying, analyzing, and assessing GHG reduction options and/or strategies for the sector each table represents.

To date, the Agriculture and Agri-Food Issues table has provided preliminary estimates as to the types and quantities of GHG emissions being emitted nationally and provincially. By mid-November of this year, the Table is scheduled to release a final report that will identify ‘options’ for reducing GHG emissions in the Agriculture and Agri-Food sectors, revised estimates of national GHG emissions, and project cost curves for each ‘option’. The options being recommended by the sixteen Issues Tables will be considered by the National Climate Change Secretariat who will then prepare draft National Implementation Strategies for public consideration and debate. It is the Ministry’s understanding that these draft strategies may be available in spring 2000.

In response to the national climate change process, the Province of Ontario identified the Ministry of the Environment (MOE) as the ‘lead’ provincial ministry. The MOE is responsible for preparing Ontario’s on whether the Province should support a decision to ‘ratify’ the Kyoto Protocol. The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) is actively participating in a provincial process aimed at defining how the Province should respond to the challenges of the Protocol.

OMAFRA established a Working Group On Climate Change to guide the Ministry’s research and consultation activities. To date, the Committee has retained a consultant to provide the Ministry with the ability to calculate GHG emissions in Ontario’s agriculture and agri-food sectors, to assess the appropriateness of the federal options/strategies; and to determine whether the federal cost curve information is acceptable to OMAFRA.

This RFP will provide the Ministry and its agricultural stakeholders with information on what effect certain industry practices are presently having on GHG emissions and whether improved GHG reduction efficiencies can be achieved by making technical modifications to these practices. This RFP will also serve to provide the Ministry and its stakeholders with a sensitivity analysis that will identify the types of measures the Ministry may need to consider in order to achieve the GHG reduction of the Kyoto Protocol.

9.1.5.3 Project Approach

The Soil Resource Group has developed an approach to address OMAFRA’s request for proposals for ministry management practices and their effect on green house gas (GHG) emissions in Ontario’s agricultural sector. The objectives of the proposal are to:

- Measure and project the effect of the documented Ministry practices on GHG emissions for the period 1990-2012.
- Identify and recommend technical measures to improve the efficiency and effectiveness of the BMP practices to reduce GHG emissions and project these measures over the period 2000-2012.
- Identify the provisions that the Ministry would need to consider in order to achieve GHG reduction scenarios of 2, 4, and 6 % (based on 1990 emission estimates) with the listed BMPs or any other feasible BMP practice for the period 2008-2012.

The study approach incorporated the development of an experienced research team with background in Ontario agricultural BMPs and the measurement of agricultural GHG emissions in order to respond with confidence to the study objectives in the short time frame of the study.

The study team proposes to develop a provincial BMP database from 1991 and 1996 agricultural census information along with any other useful information that can be obtained from information sources provided by the client. Adoption rates of BMPs can be calculated over 1991-96 time of the database.

In order to obtain missing or questionable information from the BMP and adoption rate database, it is proposed to obtain expert opinion in rural Ontario from a number of round table discussions (8) across each of the agricultural regions. The Ontario Soil and Crop Association (OSCIA) has been subcontracted to set up these round table discussions with representatives from their association. Participants will be representatives of the farm community that have knowledge of BMP practices and in many cases have been involved in the delivery of provincial BMP programs in the past. The expert opinions provided will be especially important in projecting the types and rates of BMP adoption.

The Soil Resource Group will provide the facilitator for each of the meetings and will prepare specific questions on BMPs and adoption rate issues that will be addressed at each meeting to fill gaps in the database. The farm community representatives will be asked to provide their opinions on what are the realistic adoption rates for current and future BMP programs. The Soil Resource Group will compile the focus group expert opinions and revise the BMP and adoption rate database to reflect the expert opinion.

A detailed review of published and ongoing research will be conducted to obtain Provincial GHG emission data for analysis and projecting. The senior agricultural meteorologist on the study team will evaluate Ontario data relative to published IPCC (International Panel on Climatic Change) emission standards to select the most appropriate values for detailed analysis.

The study team will evaluate BMP and recommend on the basis of published literature and experience, a range of technical measures that could improve the efficiency of BMPs for the reduction of GHG emissions. An evaluation of these recommendations by the farm public will be made at the focus group meetings.

Projection of GHG emissions to 2012 with the implementation of existing and new BMP practices will be estimated. Further, the effect of current or new BMPs potential in meeting GHG reduction scenarios of 2, 4, and 6 % from the 1990 levels will be calculated. A senior engineer and economist will guide the scenario testing and the potential use of policy instruments to achieve the desired emission objectives.

A list of the best management practices that are the focus of the round table discussion categories and the broad management categories under which they fall are as follows:

Management Category	**Practices**
Soil Management	Buffer crops Cover crops Crop rotation Minimum till No till Residue management
Nutrient Management	Manure storage and handling systems (liquid and solid manure)
Livestock and Poultry Waste Management	Soil testing Methods of application Timing of application
Farm Forestry and Habitat Management	Woodland management Shelter belts and windbreaks Riparian buffers

9.1.5.4 Lists of Participants in Focus Group Meetings

Midhurst

Ian Campbell
RR#1 Churchill Ontario
L0L 1K0
705-456-0946

Bonnie Den Haan
RR#2 Loretto Ontario
L0G 1L0
705-435-5454

Bruce Drybrough
RR#1 Gilford Ontario
L0L IR0
705-456-5188

Larry Kell
RR#1 Gilford Ontario
L0L 1R0
705-456-3528

Larry Klein Gebbinck
RR#1 Elmvale Ontario
L0L 1P0
705-322-2717

Sam Langman
RR#2 Elmvale Ontario
L0L 1P0
705-322-2555

Midhurst (continued)

Ab Leek
RR#2 Alliston Ontario
L9R 1V2
705-435-7403

Barry Newcombe
RR#4 Cookstown Ontario
L0L 1L0
905-729-3254

Ken Parnell
RR#3 Elmvale Ontario
L0L 1P0
705-322-1949

David Pease
RR#6 Shelburne Ontario
L0N 1S9
519-925-6412

Peter Vander Zaag
Sunrise, RR#3 Alliston Ontario
L9R 1V3
705-435-2827

Woodstock

Jeff Dibble
RR#2 Ingersoll Ontario
519-285-5121

Gord Green
RR#1 Embro Ontario
N0J 1J0
519-475-4690

Gord MacKay
RR#1 Embro Ontario
519-475-4424

Duane Paton
RR#1 Mt. Elgin Ontario
N0J 1N0
519-485-5250

Kevin Rivers
RR#5 Ingersoll Ontario
N5C 3J8
519-423-6797

Simcoe

Larry Bauslaugh
RR#1 Windham Centre Ontario
519-426-2315

Tracy Boerkamp
RR#3 Waterford Ontario
519-443-8754

Gary Chips
RR#3 Delhi Ontario
519-842-2843

Erik Dekeyser
RR#1 Langton Ontario
519-875-2295

George Demaiter
RR#1 Vittoria Ontario
519-426-8956

Rick Kichler
RR#6 Simcoe Ontario
519-428-1378

Arpad Pasztor
RR#2 Pt. Burwell Ontario
519-875-2130

Peter Reimer
RR#3 Port Rowan Ontario
519-586-2864

Paul Ryder
RR#2 Delhi Ontario
519-582-2444

Bauke Vogedzang
RR#3 Waterford Ontario
N0E 1Y0

Clinton

Henry Boot
RR#4 Clinton Ontario N0M 1L0
fax - 519-233-5454
Jubilee@tcc.on.ca

Jody Dorand
RR#2 Zurich Ontario N0M 2Z0
519-236-7374
Durand@hay.net

Andrew Dykstra
RR#2 Clinton Ontario
N0M 1L0
519-482-1375

Gary Haak
RR#4 Clinton Ontario
N0M 1L0
519-482-9960

Bob McKinnon
RR#3 Port Elgin Ontario
N0H 2C7
519-832-6601
Cedarbanc@bmts.com

Tony McQuail
RR#1 Lucknow Ontario
N0G 2H0
519-528-2493
mcqufarm@hurontel.on.ca

Peter Postl
RR#1 Brucefield Ontario
N0M 1J0
519-233-9252

Keith Reid - OMAFRA
RR#3 Walkerton Ontario
N0G 2V0
519-881-3301
keith.reid@omafra.gov.on.ca
fax - 519-443-8120

Evert Ryder
RR#2 Clinton Ontario
N0M 1L0
519-482-5033
eridder@odyssey.on.ca

Pete Rowntree
RR#1 Varna Ontario
N0M 2R0
519-233-3218
hillhill@tcc.on.ca

Laurence Taylor
RR31 Londesboro Ontario
N0M 2H0
519-482-7082

George Thompson
RR#2 Clinton Ontario
N0M 1L0
519-482-9327

Ridgetown

Doug Cameron
RR#1 Dresden Ontario
N0P 1M0
519-683-4695

Walter Charbonneau
RR#6 Chatham Ontario
N7M 5J6
519-436-0606

Jerry Coatsworth
RR#3 Merlin Ontario
N0P 1W0
519-825-7531

Earl Elgie
RR#6 Dresden Ontario
N0P 1M0
519-683-4659

John Faubert
RR#1 Pain Court Ontario
N0P 1Z0
519-351-2409

Ron Faubert, OSCIA Rep.
RR#8 Chatham Ontario
N7M 5J8
519-352-1285

Bruce Johnstone
RR#8 Chatham Ontario
N7M 5J8
519-351-1406

John Lugitigheid
RR#2 Kent Bridge Ontario
N0P 1V0
519-436-0677

Dan McCale
RR#1 Inwood Ontario
N0N 1K0
519-844-2482

John Moerman
RR#1 Ridgetown Ontario
N0P 2C0
519-674-2511

Phil Richards
RR#3 Dresden Ontario
N0P 1M0
519-683-4098

Willie Taves
RR#1 Wheatley Ontario
N0P 2P0
519-825-7671

Bill Weaver
RR#6 Dresden Ontario
N0P 1M0
519-351-2592

Verner

Gerald Beaudry
RR#1 Verner Ontario
P0H 2M0
705-594-9149

Maurice Beaudry
1310 Levac Rd. Cache Bay Ontario
P0H 1G0
705-753-0642

Marcel Heon
RR#1 Monetville Ontario
P0M 2K0
705-989-2097

Dan Olivier
694 Chemin Olivier Verner Ontario
P0H 2M0
705-594-9483

Janet Parsons
1450 Gauthier Rd. Cache Bay Ontario
P0H 1G0
705-753-0730

Gilles Renaud
1175 Stewart Road Cache Bay Ontario
P0H 1G0
705-753-1977

Verner (continued)

Murray Jantzi
RR#1 Warren Ontario
P0H 2N0
705-967-5554

Andre Lemay, OMAFRA
Box 521 Verner Ontario
P0H 2M0
705-594-3212

Steve Mailloux
Walford Ontario
P0P 2R0
705-844-2888

Thom Mueller
Box#44
Vernon Ontario
613-821-4978

Bruno Schoenauer
Chiswick Line 1280 Powassan, Ontario
P0H 1Z0
705-724-1445

Jacques Seguin
299 Chemin Viau Ontario
P0M 2N0
705-898-2414

Martin Smits
Verner Ontario
P0H 2M0
705-594-9246

Melbourne

Brent Clutterbuck
RR#2 Port Stanley Ontario
N5L 1J2
519-769-2789

Frank Dietrich
RR#1 Lucan Ontario
519-227-4150

John R. Johnson
RR#1 Rodney Ontario
20901 Kintyre Line N0L 2C0
519-785-2176
fax - 519-785-1434

Rick McCracken
7189 Parkhouse Dr.
RR#3 Melbourne Ontario
519-289-5576

Larry McGill
4119 Century Dr.
RR#4 Glencoe Ontario
519-287-5292

John Miller
RR#3 Rodney Ontario
519-785-2033

Ken Roodzant
RR#3 Rodney Ontario
519-785-2271
farm - 519-785-0186

Stanley Towers
4402 Olde Dr.
RR#4 Glencoe Ontario
519-289-5743

Kenmore

Garry Brugmans
RR#1 Chesterville Ontario
K0C 1H0
613-448-1214

Pat Chambers
RR#3 Chesterville Ontario
K0C 1H0
613-448-3316

John Hendrikx
9116 Marvelville Rd.
Metcalfe Ontario K0A 2P0
613-821-2729

Arlene Ross
3550 Larry Robinson Rd.
RR#2 Russell Ontario
K4R 1E5

Melbourne (continued)

Raymond Como
RR#2 Winchester Ontario
K0C 2K0
613-448-3408

John Lee Devries
RR#1 Williamsburg Ontario
K0C 2H0
613-774-6322

John Velthuis
8742 Marvelville Rd.
Metcalfe Ontario
613-821-3421

9.1.5.5 Discussion Template and Information Collected

OSCIA Roundtable Discussions - conducted by the Soil Resource Group

Incentives
1. Awards
2. Technical Assistance
3. Grants/Subsidies
4. Cross-Compliance
5. Enforcement

Best Management Practice	**Past Trend**	**Current Trend**	**Comment**	**Potential for Increased Adoption**	**Incentives**					**GRCA**	**Comments**
	0-25%, 25-50%, 50-75%, >75%				**1**	**2**	**3**	**4**	**5**		
SOIL MANAGEMENT											
Buffer Strips (*) "grassed barriers" BMP - > 10 ft. width by water course										75% up to $6000 up to 10 acres	
Cover Crops (**) overwintering crops (eg wheat, pasture) overwinter cover crops (eg red clover) BMP - overwintering crop cover										$20/acre/yr up to 50 acres SW priority area only	
Tillage (***) minimum (reduced) no-till spring vs. fall (texture effects) BMP - increased conservation tillage											
Residue Management (*) residue removal - wheat baled - corn baled BMP - maintain crop residue in field										$20/acre/yr	
Crop Rotations (**) Crop Trends - permanent cover (hay/pasture) - high N crops: - corn - vegetable											

OSCIA Roundtable Discussions - conducted by the Soil Resource Group

Incentives
1. Awards
2. Technical Assistance
3. Grants/Subsidies
4. Cross-Compliance
5. Enforcement

	Past Trend	Current Trend			Incentives						
Best Management Practice	**0-25%, 25-50%, 50-75%, >75%**		**Comment**	**Potential for Increased Adoption**	**1**	**2**	**3**	**4**	**5**	**GRCA**	**Comments**
Crop rotations (continued) - canola - high protein wheat BMP - increased hay/pasture - optimum N use efficiency											
Relative Importance for GHG Mitigation * low ** moderate *** high NUTRIENT MANAGEMENT											
Nutrient Testing (***) soil testing: - fertility (P,K) **- nitrate (N)** manure testing (N,P,K) BMP - increased soil N and manure N testing										50% up to $500 for a NMP	
Commercial Fertilizer											
Application Method (**) broadcast - days to incorporation - < 1 day 1 - 2 days > 2 days banding											
Application Timing (**) pre-plant side-dress split											
BMP - broadcast and incorporation < 1 day											

OSCIA Roundtable Discussions - conducted by the Soil Resource Group

Incentives
1. Awards
2. Technical Assistance
3. Grants/Subsidies
4. Cross-Compliance
5. Enforcement

	Past Trend	**Current Trend**			**Incentives**						
Best Management Practice	**0-25%, 25-50%, 50-75%, >75%**		**Comment**	**Potential for Increased Adoption**	**1**	**2**	**3**	**4**	**5**	**GRCA**	**Comments**
- increased side-dress application											
Manure (solid vs liquid handling by livestock type)	dairy	cattle	poultry	hog							
Application Method (***) days to incorporation - < 1 day 1- 2 days > 2 days											
Application Timing (***) fall spring summer BMP - incorporation < 1 day, spring application											
Relative Importance for GHG Mitigation * low ** moderate *** high LIVESTOCK & POULTRY WASTE MANAGEMENT											
Manure Handling (**) barn clean-out frequency - dairy - cattle - poultry - hog - other top vs. bottom loading - dairy - cattle - poultry - hog										50% up to $15000 for handling & storage	
- other											

OSCIA Roundtable Discussions - conducted by the Soil Resource Group

Incentives
1. Awards
2. Technical Assistance
3. Grants/Subsidies
4. Cross-Compliance
5. Enforcement

Best Management Practice	**Past Trend**	**Current Trend**	**Comment**	**Potential for Increased Adoption**	**Incentives**					**GRCA**	**Comments**
	0-25%, 25-50%, 50-75%, >75%				**1**	**2**	**3**	**4**	**5**		
BMP - frequent barn clean-out, bottom loading											
Manure Storage (**) earthen lagoon concrete pit concrete pad days of storage structure cover crusted cover BMP - covered or crusted manure - increased days of storage										50% up to $15000 for handling & storage	
Relative Importance for GHG Mitigation * low ** moderate *** high FARM FORESTRY & HABITAT MANAGEMENT											
Woodlot Management managed woodlot fenced off BMP - managed harvesting											
Shelterbelts and Windbreaks (Fence Rows) Shelterbelts > 5 rows Windbreaks < 5 rows BMP - increase plantings										75% up to $6000	
Riparian Buffers											

OSCIA Roundtable Discussions - conducted by the Soil Resource Group

Incentives
1. Awards
2. Technical Assistance
3. Grants/Subsidies
4. Cross-Compliance
5. Enforcement

Best Management Practice	**Past Trend**	**Current Trend**	**Comment**	**Potential for Increased Adoption**	**Incentives**					**GRCA**	**Comments**
	0-25%, 25-50%, 50-75%, >75%				**1**	**2**	**3**	**4**	**5**		
BMP - increased woody species											
Agroforestry BMP - inter-cropping											
Improved Best Management Practices To Reduce GHG Emission SOIL MANAGEMENT water table management reclamation of degraded soil bio fuel production management of fine textured soil NUTRIENT MANAGEMENT nutrient management planning site specific N management LIVESTOCK & POULTRY WASTE MANAGEMENT reduce bedding material intensive pasture management and rotational grazing storage tank covers to reduce evaporative losses livestock ration N inhibitors or acidifiers pH management for N immobilization FARM FORESTRY & HABITAT MANAGEMENT land removal from crop production riparian buffer plantings											

9.1.5.6 Additional comments on the potential success / acceptance of BMP programs

(OSCIA, personal communication; comments from Farmer focus group meetings)

- Voluntary landowner participation is preferred, combined with financial and technical support, education, recognition of the landowners' time and commitment through fair compensation for land removed from production.
- Programs are most effective when governmental or other agency support is delivered through partnerships with farm groups and organizations (e.g. local chapters of the Soil and Crop Improvement Association, Soil Conservation Clubs, Innovative Farmer groups, Conservation Authorities)
- Long-term commitment between farmers and agencies provides continuity of funds, technical support, education incentives, greater environmental awareness and interest.
- Wide-reaching programs that all farmers are eligible for are preferable, as programs 'targeted' at one commodity group or geographical area can be seen as less 'long-term' and/or comprehensive in nature, or even viewed with suspicion by the 'targeted' group.
- Barriers to adoption cited by landowners: Contradictory interests of various agribusiness supporters (e.g. sustaining chemical inputs, controlling prices; Hall 1998); credibility of technical support staff (if not part of the farming community, or if credibility has not been gained – i.e. recent OMAFRA cuts have removed a number of established service staff); perception that some measures are disproportionately beneficial to society – taxpayers should pay their share.

9.1.6 *Agroforestry Questionnaire sent to Conservation Authorities*

To the Participant:

This questionnaire has been designed to provide a reasonable estimate of land area managed according to 'Best Management Practices' as described in the Farm Forestry and Habitat Management publication. This information will be used to estimate the potential for reduction of greenhouse gas (GHG) emissions from agricultural lands in Ontario.

Please indicate if your information is derived from accurate sources (i.e. planting records, farm surveys) or are a 'best guess' based on your experience. If data is not avaflable and you do not feel confident in estimating an answer, please leave the field blank In general a knowledgeable estimate is of much more value than no answer. Please indicate if the information is based on a county, watershed or sub-watershed basis. Under the heading 'Rate of adoption', provide an indication of the extent of new plan@gs on an annual basis. Please feel free to make additional comments where appropriate.

Name Phone
County Watershed
Information is provided for the county/watershed/sub-watershed/other (please indicate)

Recommended BMP	Description	Area or Length	Rate of adoption
Windbreak	< 6 rows of trees planted in a continuous belt		Cropland Pasture Buildings
Shelterbelt	> 6 rows of trees planted in a continuous belt		Cropland Pasture Buildings
Reforestation	Establishing now forest cover on cropped, pastured or abandoned lands		Cropland Pasture Abandoned
Buffer Strips	Vegetated strips which protect natural features from surrounding land use		Stream Municipal drain Natural areas
Intercropping	Multiple rows of closely spaced trees which allows active crop management		Orchards Row crops Hort. Crops Other
Silvipasture	Trees planted on managed pasture I		
Woodland Management	Active management of existing woodlands		Forest Plantation

What is the general level of knowledge of these specific practices? What is the level of awareness of available information and programs that provide technical or financial assistance?

Recommended BMP	Description	Level of knowledge (please check one)			Level of knowledge (please check one)		
		Low	Moderate	High	Low	Moderate	High
Windbreak	< 6 rows of trees, planted in a continuous belt						
Shelterbelt	> 6 rows of trees planted in a continuous belt						
Reforestation	Establishing new forest cover on cropped, pastured or abandoned lands						
Buffer Strips	Vegetated strips which protect natural features from surrounding land use						
Intercropping	Multiple rows of closely spaced trees which allows active crop management						
Silvipasture	Trees planted on managed pasture lands						
Woodland Management	Active management of existing woodlands						

Please indicate what, if any, barriers exist that may limit the adoption of these management practices. What steps may be taken to increase the rate of implementation of these Best Management Practices? Any other comments?

9.1.7 Examples of Programs for Environmental Enhancement and Agricultural Sustainability (Ontario)

Conservation Authority and OMAF Joint Programs

Examples: Thames River Implementation Committee TRIC, Grand River Implementation Committee GRIC
BMPs: ***In-field soil and water conservation practices and structures, and stream course stabilization structures***

These programs, the precursors to the OSCEPAP and LSP efforts, were well-received and often initiated by the farming community, generated interest in soil and water conservation and raised the profile of environmental issues in the agricultural sector, and helped to develop a strong rapport between governmental and farm organizations.

Incentives:
- Financial subsidization of on-farm soil and water demonstration sites
- Technical support
- Recognition

Community Fisheries/Wildlife Improvement Program (CFIP and CWIP)

Examples: Ministry of Natural Resources, in partnership with Conservation Authorities; 1980s
BMPs: Riparian buffers, permaculture establishment, bio-engineering of stream habitat

This program was established to encourage and facilitate the development and enhancement of fish and wildlife habitat.

Incentives:
- Financial
- Technical support

OSCEPAP I and II

OMAF, Conservation Authorities
BMPs:
I In-field and streambank erosion control structures (e.g. bank stabilization, stream access and crossings, terraces and strip-cropping)
Pollution control structures (manure storage and septic systems, milkhouse waste)
Pesticide storage
II Retirement of fragile land, establishment of permanent cover (windbreaks, shelterbelts, grass and riparian buffers)

This program was highly successful in initiating a range of soil and water quality projects. Delivery of the program was via a network of government and farm groups, with technical expertise provided by both OMAF and CA field staff and engineers.

Incentives:
- Financial grants and subsidies for structures
- Education
- Technical support
- Voluntary participation, offered to all farmers in province

LSP I and II

OMAF, OSCIA, CAs

BMPs:

LSI ***soil and water conservation practices (tillage, residue management, cover crops, system development for reduced tillage, nutrient management; no support for structures as OSCEPAP was ongoing; no support for structures)***

LSII ***Combination of structural establishment/enhancement and practices***

Land Stewardship II was a continuation and combination of the OSCEPAP II and LSP I programs. Emphasis was placed not only on the establishment of structures or the adoption of conservation measures, but on the development of overall soil and water conservation systems. For example, producers were not only provided with incentives to switch to reduced or no-till farming, but were given technical assistance and education. This allowed producers to adjust all or some of their on-farm practices (nutrient management, crop rotations, pest control, residue management, etc) to match changes in tillage practices – and thereby ensure greater success for the reduced tillage system and, theoretically, ensure sustainable adoption of the practice.

Incentives:

- Financial – fixed or sliding scale grants (depending of rigour of the intended change); cost-sharing for capital structures
- Support provided (financial) for joint programs and research, additional technical expertise and finances available for education of farm groups
- Voluntary, non-targeted
- Education – additional extension staff provided to facilitate local educational and program delivery initiatives

Tillage 2000

OMAF, CAs, OSCIA, College and University researchers, farm organizations

BMPs: ***reduced and no-till, crop rotations, nutrient management***

Tillage 2000 was part of the OSCEPAP and LS programs, with a primary purpose to conduct on-farm research and development to improve reduced tillage farming systems.

Incentives:

- No financial compensation
- Technical assistance, education
- Improved reduced/no-till farming efficiency
- Recognition

Environmental Farm Plan - EFP I, II and III

OMAFRA, Agriculture Canada

BMPs: Crop rotations and systems, cover crops, reduced and no-till, residue management, nutrient management, manure handling and storage, agroforestry

EFP has been funded by Agriculture and Agri-Food Canada. Contents of the plan were developed through consensus of numerous regulatory and non-regulatory government agencies, public environmental groups, farm organizations and individuals from the farming community, during the LSP II program. Farmers develop their own EFPs, with technical expertise provided by OMAFRA staff. The plans are peer-reviewed by local committees of the OSCIA. While the program is voluntary in nature, farmer's must have an approved plan to qualify for financial assistance for implementation of EFP components, up to a maximum of $1500.

Incentives:

- Education, awareness
- Financial

Best Management Practices (BMPs) – Publications

Agriculture and Agri-Food Canada, OMAFRA, OFA, farmers and farm organizations, researchers. 1991 -
BMPs: ***all***

The BMP publication series is funded by Agriculture Canada through the Ontario Federation of Agriculture, which contracts the development and publication of the booklets. OMAFRA contributes technical expertise and coordinates the publications. The information on BMPs represents a consensus of a multitude of stakeholders with regards to the 'best' soil and water conservation and pollution control methods currently available to farmers. Emphasis is placed on solutions and practices that are both environmentally effective and agriculturally practical. The BMP publications are intended as resource material, to be used in conjunction with other soil and water conservation programs or efforts, but have proven to be an effective educational tool and impetus for the implementation of conservation measures in their own right.

Incentives:

- Education

Clean Up Rural Beaches (CURB)

CAs, OMAFRA
BMPs: ***Manure and waste management (milkhouse, farm septic included), fencing of streams, surface water runoff control, crop and tillage systems, stream bank enhancement, buffer strip establishment***

The CURB program followed the LSP II program, and many of the soil and water conservation initiatives started under OSCEPAP and LSP were continued under this program.

Incentives:

- Financial – cost sharing of structure construction costs, grants for in-field conservation projects
- Technical support
- Education
- Public awareness

Canada-Ontario Agreement (COA); Lakewide Area Management Plan (LAMP)

International groups, government agencies
BMPs: ***no specific BMPs, but a legitimization and endorsement of BMP principles***

These programs, while not BMP-specific, bring attention to environmental problems which relate to agricultural activities, and provide an umbrella for the funding of a range of agri-environmental projects. Vulnerable areas are identified and targeted for remedial action and to monitor water quality improvements

Incentives:

- Awareness
- Education, information source
- Funding – for research, government and non-government agencies, not farm groups or individual producers

Managed Forest Tax Rebate Program (MFTRP); Managed Wetland Program (MWP)

MNR
BMPs: ***Agroforestry, shelterbelt, windbreaks, riparian development, reforestation and woodlot management***

Landowners must complete and have approved a long-term plan for forested land management

Incentives:
- Tax rebate for managed land
- Education

WIA – Woodlot Improvement Agreement
MNR
BMPs: ***Agroforestry***
Woodlot owners must complete and have approved a long-term plan for woodlot management

Incentives:
- Tax rebate for managed land

Partners in Nitrogen (PIN) and Partners in Nitrogen Use Efficiency (PINUE)

OMAFRA, research institutions
BMPs: ***Nutrient management***

These programs focused on on-farm research and demonstration of nutrient management techniques.
Incentives:
- Technical support
- Research
- Education
- Recognition

Nutrient Management Planning (NMP)

OMAFRA, MOE, Municipal governments
BMPs: ***Nutrient management, manure handling and storage***

At first, the emphasis of NM Planning was on manure - storage, handling, application methods - and record keeping / accounting. The emphasis was soon broadened, to provide a comprehensive approach to manure management, as well as fertilizer use, environmental impact accounting, soil management, soil and water conservation and neighbourly relations.
Incentives:
- Compliance – an approved NMP is required before a building permit is issued for either a new or barn or expansion of a current livestock enterprise.
- Potential improvement in nutrient efficiency
- Legislation – if an infraction is reported or complaint made, the Ministry of the Environment can charge the producer if they do not modify their operation in order to gain a Certificate of Approval

High Crop Residue Program (NSCP)

AAFC – delivered by OSCIA
BMPs: ***Residue management, reduced tillage systems***

This program was intended to encourage farmers to increase the amount of residue cover on their fields, primarily through the adoption/improved use of no-till or ridge tillage systems.

Incentives:
- Financial – mainly to assist producers in the transition from conventional to reduced ono-till systems
- Technical support from Soil and Crop advisors, CA staff

Soil and Water Environmental Enhancement Program (SWEEP)

Agriculture Canada, OMAFRA, research institutions, farm organizations, producers, agribusiness
BMPs: ***Tillage, cover crops***

Incentives:
- Financial
- Demonstration sites and watersheds
- Technical assistance, technology transfer
- Research
- Public awareness, education

Soil Test program
OMAFRA
BMPs: ***Nutrient management, manure management***

This program was free to all Ontario farmers until 1990's.

Incentives:
- Financial (discontinued)
- Improved nutrient efficiency
- Potential cost savings in fertilizer inputs
- Potential for precision farming application

National Soil Conservation, Permanent Cover I and II Programs
Agriculture and Agri-Food Canada
BMPs: ***Grass and riparian buffers, retirement of fragile lands***

Lands immediately adjacent to watercourses were eligible for retirement from production, in the form of buffer strips and permanent retirement of floodplain areas (OSCIA 2000). Buffer strips were implemented as either demonstration or 'bid' projects, allowing farmers to set their own level of compensation for land retirement, up to a maximum of $10,000 dollars. Compensation for a demonstration project had a maximum set at $20,000. In return for financial incentives, farmers were required to sign a fifteen-year agreement and make a personal financial commitment.

The buffer program was not targeted at specific commodity groups or geographical areas, and was equally available to all farmers. However, most of the interest and projects approved were in Southwestern Ontario, where soil and water conservation practices were most needed. Several key principles of the programs were cited by both cooperating agencies and landowners as having contributed to the success of the program (A. Graham, personal communication):

Niagara Wetland and Riparian Restoration Program
BMPs: ***Riparian buffers***

Incentives for riparian buffers are in the form of individually negotiated compensation agreements. The approach is targeted, in that projects are priorized according to the proposed improvements. Compensation is based on current land values and expected agricultural productivity. A 15 year agreement must be signed, after which time grants must be repaid if performance standards are not met. Participation in the program is voluntary and initial incentives are financial, technical and educational, with expectations that in the future riparian and habitat development will be initiated and/or continued through education, environmental awareness, and recognition and landowner stewardship. (A. Graham, personal communication)

Rural Water Quality Programs - Example: Waterloo Region
BMPs: ***cropping systems, surface and groundwater conservation***
Incentives:

- Financial
- Technical support

9.2 Emission Coefficient Values (detailed) Used in Calculations

Greenhouse Gas Emission Coefficients
Soil Management

Identified BMP Farming Practice	Pre BMP Condition EC-1	Soil and Water BMP EC-2	Greenhouse Gas BMP EC-3	Total CO_2 Equivalents (kg/ha/year) Includes Direct and Indirect Losses		
				EC-1	EC-2	EC-3
Buffer Strips	none	Grass, ryegrass strips	Wider strips, convert to riparian plantings	-		N export in surface flow from manured sites decreased by 75-94% by grass
Cover crops* (planted into preceding crop or after harvest, left live over winter)	None	WW, RC, R (See* at end of table for definit-ions)	- Use on high N residual crops - Use of innovative seeding practices (e.g. Interseeding in previous crop)			Reduction in requirements for following crop range from 15 – 50 kg/ha (Average 10 % reduction in crop needs)
-Legumes	None	Legume cover	Legume cover, no fall kill or plough	-	1949 (1325 – 1949)	
-Non legumes	None	Cover crop	No fall kill or plough	-	974	974
Crops	Continuous	Rotations	Rotations (+ cover crops where applicable)	-	Use rotational average	Use rotational average
Grass	Permanent	Permanent	Permanent	146 (97 – 340)	146 (97 – 340)	146 (97 – 340)
Alfalfa	Continuous legume	3 year rotational annual average	Spring kill or incorporate	Average 1267 (438 - years 1,2; 2923 - year 3 + ploughdown)	1267	1267
Canola				1834	1834	1834
Cereals (spring wheat, oats, barley, mixed grain)		In rotation	In rotation, underseeded	1656 (399 – 1656)		-
- nurse crop, or grain after hay		Underseeded	Underseeded	-	487	487
Winter wheat			Underseeded	1304 (1012 – 1593)	1304	-
- High yield, >5 t/ha, 110 kg N fertilizer applied				1591	1591	-
- Medium yield, 4 to 5 t/ha, 90 kg N fertilizer applied				1301	1301	-
- Low yield, <4 t/ha, 70 kg N fertilizer applied				1012	1012	-
Corn - Continuous	Range			(1510 – 3426)	-	-

Greenhouse Gas Emission Coefficients
Soil Management

Identified BMP Farming Practice	Pre BMP Condition EC-1	Soil and Water BMP EC-2	Greenhouse Gas BMP EC-3	Total CO_2 Equivalents (kg/ha/year) Includes Direct and Indirect Losses		
				EC-1	EC-2	EC-3
corn						
Continuous Corn (continued)						
Eastern Ontario	Ave. Kg / ha N applied – 142.5 Assumed yield 8.5 t/ha			2499	-	-
West & Central	Ave. Kg / ha N – 123			2314	-	-
South-western	Ave. Kg / ha N – 188			2845	-	-
Beauchamp values				1510 (direct emissions only)	-	-
Average	Ave. Kg / ha N applied – 142.5 Assumed yield 8.5 t/ha			2534	-	-
Corn after soybeans	No soybean credits	Use N credits from soybeans up to 24% reduction from continuous)	Underseeded	2499	2389 (1364 – 2708)	2389 (1364 – 2708)
Eastern Ontario (30 kg reduction for soybean N credit)	Ave. Kg / ha N applied – 112.5 Assumed yield 8.5 t/ha			2314	2153	-
West & Central (30 kg reduction for soybean N credit)	Ave. Kg / ha N – 93			2845	1978	-
South-western (15 kg reduction for soybean N credit)	Ave. Kg / ha N – 173			1510 (direct emissions only)	2708	
Average	Ave. Kg / ha N applied – 135 Assumed yield 8.5 t/ha			2534	2389	
- after grain, silage corn		Up to 7% reduction from continuous	Underseeded	-	2357 (2263 – 2357)	2357 (2263 – 2357)
- after hay		Up to 18% reduction	Underseeded	-	2070 (1179 – 2964)	2070 (1179 – 2964)
Potatoes - on mineral soils - on organic soils	Continuous	Cover crop	In rotation with rye	3410 (2022 – 4974) 5115 (4233 – 6114)	2750 (rotational average) 5552 (rotational average)	2357(rotational average) 5044 (rotational average)
Soybeans	Continuous	In rotation	In rotation	2338 (399 – 2338)	2338 (399 – 2338)	2338 (399 – 2338)
High yield, > 2.5 T/ha, no fertilizer added				2173	2173	

Greenhouse Gas Emission Coefficients
Soil Management

Identified BMP Farming Practice	Pre BMP Condition EC-1	Soil and Water BMP EC-2	Greenhouse Gas BMP EC-3	Total CO_2 Equivalents (kg/ha/year) Includes Direct and Indirect Losses		
				EC-1	EC-2	EC-3
Soybeans (continued) Medium yield, 2 to 2.5 T/ha, no fertilizer added				1700	1700	
Soybeans - Low yield, <2 T/ha, no fertilizer added				1400	1400	
Fallow				1997		
Tillage Soil type	Conventional	Reduced	No-till	No reduction	0.5-1 kg N_2O reduction	CT to NT: 1-2 kg N_2O reduction Generally, Clay N_20 emissions > loams > sands
Residue management Incorporation vs. Surface cover	Incorporation	Partial incorporation	Residue left on surface	No reduction	5% (0 – 10%) reduction if residue only partially incorporated (interpolated)	10% reduction if residue left on surface
Residue - Removal vs. Left on field	Removed	Left	Left		Up to 25% in CO_2 emissions increase if residue left, offset by S&W benefits	Slight increase in emissions if residue left if no fertilizer, decrease if left and fall fertilizer used; Up to 50% in CO_2 emission increase if residue left, offset by S&W benefits

Greenhouse Gas Emission Coefficients
Nutrient Management

Identified BMP Farming Practice	**Pre-BMP Condition**	**Soil & Water BMP**	**Greenhouse Gas BMP**	**Total CO$_2$ Equivalents (kg/kg N applied/year) Includes Direct and Indirect Emissions**		
	EC-1	**EC-2**	**EC-3**	**EC-1**	**EC-2**	**EC-3**
Nutrient testing **Soil testing**	OMAFRA Pub. 296 fertilizer N recommendations	Soil N testing (corn in spring)	Pre side-dress N test (PSNT)	9.26 (4.25-35.90)	Subtract 471 kg CO$_2$/ha in south and 115 kg CO$_2$/ha in rest of province for affected corn acreage	Lower corn fertilizer requirement another 15% for side-dressing application (fertilizer applied X EC-1)
Manure testing	Disposal of manure on land, no N credits given for nutrients	Use manure N to replace commercial fertilizer application	Manure N testing and adjustment of fertilizer rates	8.68 (5.61-14.42)	Subtract (manure N used as fertilizer X EC-1) from total manure emissions	No net change in emissions expected– Some producers above and some below average N content in manures
Application Method **Inorganic fertilizers**	Preplant, delayed incorporation	Preplant, banding or incorporation (< 1day)	Preplant banding Side-dress Split Applications	6.57 (4.34-7.78)	6.20 (4.09-9.26)	11.59 (9.61-22.01)
Organic fertilizers	Fall application, no incorporation	Spring application and incorporation < 1day	Increase spring application	Manure Types		The appropriate emission coefficients are applied to the various manure types and application methods
	Time and Method of Application			Liquid	Solid	
	Fall, No Incorporation			8.68 (8.12-13.14)	8.68 (0.97-8.68)	
	Fall, Incorporation			9.61 (8.53-11.19)	10.73 (9.61-11.69)	
	Spring, No Incorporation			6.82 (3.26-6.82)	6.32	
	Spring, Incorporation			8.68 (2.14-9.61)	8.28 (7.32-9.61)	

Greenhouse Gas Emission Coefficients
Livestock and Poultry Waste Management

Identified BMP Farming Practice	Pre-BMP Condition EC-1	Soil & Water BMP EC-2	Green-house Gas BMP EC-3	Live-stock	Total CO_2 Equivalents (kg/head/year)		
					EC-1	EC-2	EC-3
Handling							
Solid	Infrequent clean out, 3-7 days	Frequent clean out, 1-3 days	More efficient clean out, <1day	Beef	96	86	23
	“	“	“	Dairy	122.4	111.3	33
	Dry lot	“	“	Swine	189	20.2	4.9
	“	Storage under cages	Manure belt removal, drying	Poultry	5.6	0.34	0.18
Liquid	Infrequent transfer to storage	Frequent/daily transfer to storage	Flushing system	Dairy	84	32.7	16.4
	Slats over sloped floor to temporary storage	Wide of partial slatting	Fully slatted over concrete manure storage	Swine	14.5	12.2	10.2
Storage							
Solid	Bedded pack, Pasture	Runoff catchment, uncovered	Covered storage	Beef	722	686	137
	“	“	“	Dairy	1318	1135	228
			Storage of dried manure	Poultry	8.36	7.5	0.1
Liquid	Earthen manure storage, large surface area	Concrete manure storage or impermeable tank, uncovered	Covered (lid)	Dairy	582	198	23.1
	“	“	“	Swine	262	127	15.2

Greenhouse Gas Emission Coefficients
Farm Forestry and Habitat Management

Identified BMP Farming Practice	Pre BMP Condition EC-1	Soil and Water BMP EC-2	Greenhouse Gas BMP EC-3	Total CO_2 Equivalents (kg/ha/year) Includes Direct and Indirect Losses		
				EC-1	EC-2	EC-3
Buffer strip	None	Buffer strip	Conversion to riparian planting		-1320 (-1056 to -1452)	-2625 (-2100 to –2888)
Riperian buffer strip	None	Riperian buffer	Widen, improve species		-3825 (-3060 to –4208)	No change
Windbreak/ Shelterbelt	None	Establish windbreak	Widen, improve species		-2625 (-2100 to –2888)	No change

9.2.1 Relative Emission Coefficients as Compared to Baseline IPCC Estimates (IPCC = 100%)

BMP	IPCC	CEEMA	GEEMA	SW-BMP	GHG-BMP
Residue Management	100	100+	100++	100+	90
Tillage	100	CO_2 emissions 96, 85 % of conventional	100-	reductions for reduced till / no till	reductions for reduced till / no till
Fertilizer Use	100	6 Calculates as proportion of all fertilizer sales	100	100	100
Soil Testing Based on 188 kg N/ha			74 Reduce by 49 kg N/ha	74	63 Reduce by another 15%
Fertilizer Application Type			85	67-125 Broadcast to banding	106 Reduce banded amt. by 15%
Manure Use in Field	100	14 Multiply by 0.2 factor which is for volatilization losses	100 Adjust for 50% used as fertilizer N and 50% available	100	
Manure storage Dairy – liquid	100	132		112	
Beef - solid	100	294		116	

9.3 Regional GHG Emission Data

9.3.1 *Projected Regional Greenhouse Gas Emissions 1990-2012 with Current Adoption of Soil and Water Best Management Practices*

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Soil Management																				
Buffer Strips	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1
Cover Crops	-5	-6	-6	-1	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
Crop Rotations																				
- corn	1262	1135	1066	-196	712	760	790	78	174	175	177	3	261	287	304	43	3	2	2	0
- soybeans	781	919	1015	234	158	338	544	386	42	27	21	-21	20	74	172	152	0	0	0	0
- wheat	84	183	299	214	65	122	183	118	19	23	26	7	2	3	3	1	0	0	0	0
- forage	115	101	93	-22	315	305	299	-16	190	168	156	-34	297	257	236	-61	40	34	31	-9
- spring cereal	39	14	9	-30	195	128	101	-94	50	33	26	-24	63	36	27	-36	26	24	24	-2
Total	2281	2353	2482	201	1445	1653	1917	472	474	427	406	-68	642	657	741	99	69	61	57	-11
Tillage																				
conventional	1779	1132	1132	-647	632	679	679	47	102	51	51	-51	109	123	123	13	1	0	0	0
reduced	340	522	522	182	89	204	204	115	23	26	26	3	18	31	31	13	0	0	0	0
no-till	20	331	331	311	8	81	81	73	3	17	17	14	3	11	11	8	0	0	0	0
total tillage	2139	1984	1984	-155	730	964	964	234	129	94	94	-34	130	164	164	34	1	1	1	0
Residue Management																				
- spring vs. fall tillage	2437	1783	1783	-654	1653	1396	1396	-258	391	266	266	-125	491	422	422	-69	69	55	55	-13
Nutrient Management																				
Nutrient Testing																				
- soil testing	760	678	635	-125	280	287	294	14	76	77	77	1	106	116	123	16	1	1	1	0
- manure testing	278	256	256	-22	406	388	388	-18	123	116	116	-7	154	117	117	-37	37	71	71	34
Application Method																				
- inorganic fertilizers	733	658	617	-116	254	270	280	27	74	77	79	6	87	96	101	14	1	1	1	0
- organic fertilizers																				
solid	193	164	164	-29	322	329	329	7	108	105	105	-3	139	111	111	-28	36	52	52	16
liquid	76	82	82	6	115	116	116	1	25	20	20	-5	38	32	32	-6	7	26	26	20

Projected Regional Greenhouse Gas Emissions 1990-2012 with Current Adoption of Soil and Water Best Management Practices (continued)

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Livestock and Poultry Waste Management																				
Handling																				
- solid																				
Beef	20	17	17	-2	59	57	57	-1	18	19	19	1	17	15	15	-2	7	8	8	1
Dairy	6	7	7	2	19	15	15	-4	8	6	6	-2	17	13	13	-4	2	1	1	0
Poultry	8	8	8	0	7	7	7	0	2	2	2	0	1	1	1	0	0	0	0	0
- liquid																				
Dairy	5	3	3	-2	6	4	4	-2	3	2	2	-1	6	4	4	-2	1	1	1	0
Swine	13	14	14	2	17	20	20	3	1	1	1	0	1	1	1	0	0	0	0	0
Poultry	1	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Storage																				
- solid																				
Beef	143	120	120	-23	421	396	396	-26	132	134	134	2	125	105	105	-20	51	54	54	3
Dairy	56	81	83	28	185	163	174	-11	79	69	72	-6	168	146	147	-21	16	14	16	<-1
Poultry	118	124	124	6	99	106	106	7	32	27	27	-5	20	19	19	-2	2	2	2	<1
- liquid																				
Dairy	27	20	20	-8	30	26	26	-3	13	11	11	-2	27	24	24	-4	6	5	5	<-1
Swine	92	99	99	7	126	140	140	15	10	7	7	-3	10	8	8	-2	<1	1	1	1
Poultry	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Farm Forestry and Habitat Management																				
Shelterbelts/Windbreaks	-10	-11	-11	<-1	-5	-5	-5	<-1	-2	-2	-2	<-1	-2	-2	-2	<-1	<-1	<-1	<-1	<-1
Riparian Buffers	-93	-93	-93	<-1	-46	-46	-46	<-1	-16	-16	-16	<-1	-15	-15	-15	<-1	<-1	<-1	<-1	<-1
Sum	**2943**	**2650**	**2595**	**-348**	**2594**	**2734**	**2718**	**123**	**783**	**683**	**667**	**-116**	**1044**	**931**	**908**	**-136**	**191**	**221**	**219**	**28**

9.3.2 *Projected Regional Greenhouse Gas Emissions 1990-2012 with Greenhouse Gas Best Management Practices*

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO$_2$/yr	2000 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2000 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2000 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2000 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2000 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012
Soil Management																				
Buffer Strips	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1
Cover Crops	-5	-6	-6	-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1	<1	<-1	<-1	<-1
Crop Rotations																				
- corn	1262	1135	1066	-196	712	760	790	78	174	175	177	3	261	287	304	43	3	2	2	<-1
- soybeans	781	919	1015	234	158	338	544	386	42	27	21	-21	20	74	172	152	<1	<1	<1	<-1
- wheat	84	183	299	214	65	122	183	118	19	23	26	7	2	3	3	<1	<1	<1	0	<-1
- forage	115	101	87	-28	315	305	279	-36	190	168	146	-45	297	257	220	-76	40	34	29	-11
- spring cereal	39	14	9	-30	195	128	101	-94	50	33	26	-24	63	36	27	-36	26	24	24	-2
Total	2281	2353	2476	195	1445	1653	1897	452	474	427	396	-79	642	657	726	83	69	61	55	-13
Tillage																				
Conventional	1779	1132	1104	-675	632	679	495	-138	102	51	49	-53	109	123	119	10	<1	<1	<1	<-1
Reduced	340	522	542	202	89	204	279	190	23	26	27	4	18	31	31	13	<1	<1	<1	<1
no-till	20	331	353	333	8	81	132	124	3	17	18	15	3	11	11	8	<1	<1	<1	<1
total tillage	2139	1984	1999	-140	730	964	905	176	129	94	94	-34	130	164	162	32	<1	<1	<1	<-1
Residue Management																				
- spring vs fall tillage	2437	1783	1806	-631	1653	1396	1270	-383	391	266	267	-124	491	422	420	-71	69	55	61	-8
Nutrient Management																				
Nutrient Testing																				
- soil testing	760	678	632	-127	280	287	281	2	76	77	77	<1	106	116	122	16	<1	<1	2	<1
- manure testing	278	256	229	-49	406	388	340	-66	123	116	103	-20	154	117	103	-51	37	71	63	26
Application Method																				
- inorganic fertilizers	733	658	580	-153	254	270	280	27	74	77	70	-3	87	96	101	14	<1	<1	2	<1
- organic fertilizers																				
Solid	193	164	161	-32	322	329	324	1	108	105	104	-4	139	111	110	-29	36	52	52	16
Liquid	76	82	77	1	115	116	108	-6	25	20	20	-5	38	32	31	-7	7	26	26	19

Projected Regional Greenhouse Gas Emissions 1990-2012 with Greenhouse Gas Best Management Practices (continued)

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2000 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Livestock and Poultry Waste Management																				
Handling																				
- solid																				
Beef	20	17	17	-3	59	57	57	-1	18	19	19	1	17	15	15	-2	7	8	8	1
Dairy	6	7	7	1	19	15	14	-5	8	6	6	-2	17	13	13	-4	2	1	1	0
Poultry	8	8	8	<1	7	7	7	<1	2	2	2	0	1	1	1	<-1	<1	<1	<1	<1
- liquid																				
Dairy	5	3	3	-2	6	4	4	-2	3	2	2	-1	6	4	4	-2	1	<1	<1	<-1
Swine	13	14	14	1	17	20	20	3	1	1	1	0	1	1	1	<-1	<1	<1	<1	<1
Poultry	1	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Storage																				
- solid																				
Beef	143	120	115	-28	421	396	379	-42	132	134	128	-4	125	105	101	-24	51	54	52	1
Dairy	56	81	77	21	185	163	155	-29	79	69	66	-13	168	146	139	-29	16	14	13	-3
Poultry	118	124	118	<1	99	106	101	2	32	27	26	-6	20	19	18	-3	2	2	2	0
- liquid																				
Dairy	27	20	19	-8	30	26	25	-5	13	11	11	-2	27	24	23	-5	6	5	5	-1
Swine	92	99	92	0	126	140	131	5	10	7	7	-3	10	8	8	-2	<1	<1	<1	<1
Poultry	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Farm Forestry and Habitat Management																				
Shelterbelts/Windbreaks	-10	-11	-13	-2	-5	-5	-6	-1	-2	-2	-2	0	-2	-2	-2	<-1	<-1	<-1	<-1	<-1
Riparian Buffers	-93	-93	-103	-9	-46	-46	-51	-5	-16	-16	-18	-2	-15	-15	-16	-1	-3	-3	-3	<-1
Sum	**2943**	**2650**	**2556**	**-387**	**2594**	**2734**	**2556**	**-38**	**783**	**683**	**638**	**-146**	**1044**	**931**	**870**	**-174**	**191**	**221**	**212**	**20**

9.3.3 *Projected Provincial Greenhouse Gas Emissions 1990-2012 with Increased Adoption of Soil and Water Best Management Practices in 2008-2012 (Scenario 1)*

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Soil Management																				
Buffer Strips	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1
Cover Crops	-5	-6	-6	-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1
Crop Rotations																				
- corn	1262	1089	1039	-223	712	780	799	87	174	176	177	4	261	298	308	48	<1	2	2	<-1
- soybeans	781	983	1038	258	158	475	547	389	42	23	17	-24	20	139	161	141	<1	<1	<1	<-1
- wheat	84	260	300	215	65	163	186	121	19	25	27	8	2	3	3	1	<1	<1	<1	<-1
- forage	115	96	90	-25	315	301	297	-18	190	160	151	-39	297	243	227	-70	40	32	30	-10
- spring cereal	39	11	1	-38	195	110	83	-112	50	29	22	-28	63	30	20	-43	26	24	24	-2
Total	2281	2439	2468	187	1445	1829	1912	467	474	413	394	-80	642	713	719	77	69	59	56	-13
Tillage																				
conventional	1779	1132	795	-984	632	679	575	-58	102	51	34	-68	109	123	110	<1	<1	<1	<1	<-1
reduced	340	522	580	239	89	204	232	143	23	26	28	4	18	31	33	15	<1	<1	<1	<1
no-till	20	331	454	434	8	81	109	101	3	17	23	20	3	11	14	11	<1	<1	<1	<1
total tillage	2139	1984	1828	-310	730	964	915	186	129	94	84	-44	130	164	156	27	<1	<1	<1	<-1
Residue Management																				
- spring vs fall tillage	2437	1783	1521	-916	1653	1396	1293	-361	391	266	216	-175	491	422	395	-96	69	55	50	-19
Nutrient Management																				
Nutrient Testing																				
- soil testing	760	650	619	-141	280	293	298	18	76	77	77	1	106	111	124	18	<1	<1	<1	<-1
- manure testing	278	256	247	-31	406	388	391	-15	123	116	113	-10	154	117	106	-48	37	71	85	48
Application Method																				
- inorganic fertilizers	733	631	601	-132	254	277	284	30	74	79	79	6	87	99	103	15	<1	<1	<1	<-1
- organic fertilizers																				
Solid	193	164	152	-41	322	329	332	9	108	105	104	-4	139	111	100	-39	36	52	58	22
liquid	76	82	84	8	115	116	116	1	25	20	19	-7	38	32	29	-9	7	26	34	28

Projected Provincial Greenhouse Gas Emissions 1990-2012 with Increased Adoption of Soil and Water Best Management Practices in 2008-2012 (Scenario 1) (continued)

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Livestock and Poultry Waste Management																				
Handling																				
- solid																				
Beef	20	17	16	-3	59	57	57	-2	18	19	20	1	17	15	14	-3	7	8	8	1
Dairy	6	7	8	3	19	15	14	-5	8	6	6	-2	17	13	13	-4	2	1	1	0
Poultry	8	8	9	1	7	7	7	1	2	2	2	0	1	1	1	0	0	0	0	0
- liquid																				
Dairy	5	3	3	-3	6	4	4	-2	3	2	2	-1	6	4	4	-2	1	1	1	0
Swine	13	14	15	2	17	20	22	4	1	1	1	0	1	1	1	0	0	0	0	0
Poultry	1	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<-1	<1	<1	<1	<-1	<1	<1	<1	<-1
Storage																				
- solid																				
Beef	143	124	113	-29	421	408	392	-29	132	138	137	5	125	108	99	-26	51	56	56	5
Dairy	56	83	94	38	185	174	168	-16	79	72	70	-8	168	147	141	-27	16	16	15	<-1
Poultry	118	124	127	9	99	106	109	11	32	27	25	-7	20	19	18	-2	2	2	2	<1
- liquid																				
Dairy	27	20	17	-10	30	26	26	-4	13	11	11	-2	27	24	23	-5	6	5	5	<-1
Swine	92	99	104	11	126	140	149	24	10	7	6	-4	10	8	8	-2	1	1	1	<1
Poultry	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Farm Forestry and Habitat Management																				
Shelterbelts/Windbreaks	-10	-11	-11	<-1	-5	-5	-5	<-1	-2	-2	-2	<-1	-2	-2	-2	<-1	<-1	<-1	<-1	<-1
Riparian Buffers	-93	-93	-93	<-1	-46	-46	-46	<-1	-16	-16	-16	<-1	-15	-15	-15	<-1	-3	-3	-3	<-1
Sum	**2943**	**2618**	**2412**	**-531**	**2594**	**2740**	**2659**	**65**	**783**	**678**	**642**	**-141**	**1044**	**909**	**857**	**-187**	**191**	**222**	**234**	**42**

9.3.4 *Projected Provincial Greenhouse Gas Emissions 1990-2012 with 5% Increased Adoption of Greenhouse Gas Best Management Practices in 2008-2012 (Scenario 2)*

	Southern				Western					Central			Eastern				Northern			
	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012
Soil Management																				
Buffer Strips	<-1	<-1	-11	-11	<-1	<-1	-5	-5	<-1	<-1	-2	-2	<-1	<-1	-2	-2	<-1	<-1	<-1	<-1
Cover Crops	-5	-6	-6	-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1
Crop Rotations																				
- corn	1262	1089	1039	-223	712	780	799	87	174	175	177	4	261	298	308	48	3	2	2	<-1
- soybeans	781	983	1038	258	158	475	547	389	42	27	17	-24	20	139	161	141	<1	<1	<1	<-1
- wheat	84	260	300	215	65	163	186	121	19	23	27	8	2	3	3	1	<1	<1	<1	<-1
- forage	115	89	84	-32	315	281	277	-38	190	168	141	-49	297	227	212	-85	40	30	28	-12
- spring cereal	39	11	1	-38	195	110	83	-112	50	33	22	-28	63	30	20	-43	26	24	24	-2
Total	2281	2432	2462	181	1445	1809	1892	447	474	427	384	-91	642	697	704	62	69	57	54	-15
Tillage																				
conventional	1779	1104	775	-1003	632	664	495	-138	102	51	32	-70	109	119	107	-2	<1	<1	<1	<-1
reduced	340	542	602	262	89	210	279	190	23	26	29	6	18	31	34	16	<1	<1	<1	<1
no-till	20	353	484	464	8	89	132	124	3	17	24	21	3	11	14	11	<1	<1	<1	<1
total tillage	2139	1999	1862	-277	730	963	905	176	129	94	85	-43	130	162	154	24	<1	<1	<1	<-1
Residue Management																				
- spring vs fall tillage	2437	1806	1533	-904	1653	1406	1277	-376	391	266	215	-176	491	420	391	-100	69	61	55	-14
Nutrient Management																				
Nutrient Testing																				
- soil testing	760	648	611	-148	280	283	276	-3	76	77	76	<-1	106	120	123	17	<1	<1	2	<1
- manure testing	278	229	208	-70	406	340	317	-88	123	116	107	-16	154	103	86	-68	37	63	71	33
Application Method																				
- inorganic fertilizers	733	593	547	-186	254	277	275	21	74	77	68	-6	87	99	99	12	<1	<1	2	<1
- organic fertilizers																				
solid	193	162	135	-58	322	326	323	<1	108	105	102	-7	139	111	98	-41	36	52	78	43
liquid	76	79	76	<-1	115	111	105	-10	25	20	17	-8	38	31	28	-11	7	26	32	26

Projected Provincial Greenhouse Gas Emissions 1990-2012 with 5% Increased Adoption of Greenhouse Gas Best Management Practices in 2008-2012 (Scenario 2) (continued)

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Livestock and Poultry Waste Management																				
Handling																				
- solid																				
beef	20	17	16	-4	59	57	56	-2	18	19	20	1	17	15	14	-3	7	8	8	1
dairy	6	7	8	2	19	14	13	-6	8	6	6	-2	17	13	12	-5	2	1	1	<-1
poultry	8	8	8	<1	7	7	7	0	2	2	2	<-1	1	1	1	<-1	<1	<1	<1	<1
- liquid																				
dairy	5	3	3	-3	6	4	4	-2	3	2	2	-1	6	4	4	-2	1	<1	<1	<-1
Swine	13	14	15	2	17	20	21	4	1	1	1	-1	1	1	1	<-1	<1	<1	<1	<1
Poultry	1	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<-1	<1	<1	<1	<1	<1	<1	<1	<1
Storage																				
- solid																				
Beef	143	115	104	-39	421	379	360	-62	132	134	125	-7	125	101	91	-34	51	52	52	<1
Dairy	56	77	84	28	185	155	144	-40	79	69	61	-18	168	139	128	-40	16	13	12	-4
Poultry	118	118	115	-3	99	101	99	<1	32	27	23	-9	20	18	16	-4	2	2	2	<1
- liquid																				
Dairy	27	19	16	-12	30	25	23	-7	13	11	10	-3	27	23	21	-7	6	5	5	-1
Swine	92	92	90	-2	126	131	130	4	10	7	5	-5	10	8	7	-3	<1	1	1	<-1
Poultry	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Farm Forestry and Habitat Management																				
Shelterbelts/ Windbreaks	-10	-12	-13	-3	-5	-6	-7	-2	-2	-2	-2	<-1	-2	-2	-2	<-1	<-1	<-1	<-1	<-1
Riparian Buffers	-93	-100	-105	-12	-46	-49	-52	-6	-16	-16	-18	-2	-15	-16	-17	-2	<-1	<-1	<-1	<-1
Sum	**2943**	**2582**	**2333**	**-610**	**2594**	**2633**	**2484**	**-111**	**783**	**683**	**599**	**-184**	**1044**	**879**	**803**	**-241**	**191**	**212**	**242**	**50**

9.3.5 *Projected Provincial Greenhouse Gas Emissions 1990-2012 with Targeted Adoption of Best Management Practices in 2008-2012 (Scenario 3)*

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012	1990 ktonnes CO$_2$/yr	2008 ktonnes CO$_2$/yr	2012 ktonnes CO$_2$/yr	Change 1990-2012
Soil Management																				
Buffer Strips	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1
Cover Crops	-5	-6	-6	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1
Crop Rotations																				
- corn	1262	1089	1066	-196	712	780	790	78	174	176	177	3	261	298	304	43	3	2	2	<-1
- soybeans	781	983	1015	234	158	475	544	386	42	23	21	-21	20	139	172	152	<1	<1	<1	<-1
- wheat	84	260	299	214	65	163	183	118	19	25	26	7	2	3	3	<1	<1	<1	<1	<-1
- forage	115	96	93	-22	315	301	299	-16	190	160	156	-34	297	243	236	-61	40	32	31	-9
- spring cereal	39	11	9	-30	195	110	101	-94	50	29	26	-24	63	30	27	-36	26	24	24	-2
Total	2281	2439	2482	201	1445	1829	1917	472	474	413	406	-68	642	713	741	99	69	59	57	-11
Tillage																				
conventional	1779	1132	1132	-647	632	679	679	47	102	51	51	-51	109	123	123	13	<1	<1	<1	<-1
reduced	340	522	522	182	89	204	204	115	23	26	26	3	18	31	31	13	<1	<1	<1	<1
no-till	20	331	331	311	8	81	81	73	3	17	17	14	3	11	11	8	<1	<1	<1	<1
total tillage	2139	1984	1984	-155	730	964	964	234	129	94	94	-34	130	164	164	34	<1	<1	<1	<-1
Residue Management																				
- spring vs fall tillage	2437	1783	1745	-692	1653	1396	1367	-286	391	266	261	-131	491	422	414	-77	69	55	54	-15
Nutrient Management																				
Nutrient Testing																				
- soil testing	760	650	635	-125	280	293	294	14	76	77	77	1	106	111	123	16	<1	<1	<1	<-1
- manure testing	278	256	256	-22	406	388	388	-18	123	116	116	-7	154	117	117	-37	37	71	71	34
Application Method																				
- inorganic fertilizers	733	631	617	-116	254	277	280	27	74	79	79	6	87	99	101	14	<1	<1	<1	<-1
- organic fertilizers																				
solid	193	164	157	-36	322	329	315	-7	108	105	101	-7	139	111	107	-32	36	52	50	14
liquid	76	82	71	-6	115	116	100	-15	25	20	18	-7	38	32	28	-10	7	26	23	17

Projected Provincial Greenhouse Gas Emissions 1990-2012 with Targeted Adoption of Best Management Practices in 2008-2012 (Scenario 3) (continued)

	Southern				Western				Central				Eastern				Northern			
	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012	1990 ktonnes CO_2/yr	2008 ktonnes CO_2/yr	2012 ktonnes CO_2/yr	Change 1990-2012
Soil Management																				
Buffer Strips	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1
Livestock and Poultry Waste Management																				
Handling																				
- solid																				
beef	20	17	17	-2	59	57	57	-1	18	19	19	1	17	15	14	-3	7	8	8	<1
dairy	6	7	7	2	19	15	15	-4	8	6	6	-2	17	13	13	-4	2	1	1	<-1
poultry	8	8	8	0	7	7	7	<1	2	2	2	<-1	1	1	1	0	<1	<1	<1	<1
- liquid																				
dairy	5	3	3	-2	6	4	4	-2	3	2	2	<-1	6	4	4	-2	1	<1	<1	<-1
swine	13	14	14	2	17	20	20	3	1	1	1	<-1	1	1	1	<-1	<1	<1	<1	<1
poultry	1	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Storage																				
- solid																				
beef	143	124	99	-44	421	408	325	-96	132	138	110	-22	125	108	81	-43	51	56	45	-6
dairy	56	83	73	17	185	174	164	-21	79	72	66	-13	168	147	116	-53	16	16	16	<1
poultry	118	124	98	-20	99	106	84	-15	32	27	21	-11	20	19	14	-6	2	2	2	0
- liquid																				
Dairy	27	20	42	15	30	26	56	26	13	11	24	11	27	24	48	21	6	5	11	5
Swine	92	99	57	-35	126	140	81	-45	10	7	4	-6	10	8	5	-5	<1	1	1	<-1
Poultry	<1	<1	<1	<-1	<1	<1	<1	<-1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Farm Forestry and Habitat Management																				
Shelterbelts/Windbreaks	-10	-11	-11	0	-5	-5	-5	<-1	-2	-2	-2	<1	-2	-2	-2	<1	<-1	<-1	<-1	<1
Riparian Buffers	-93	-93	-93	0	-46	-46	-46	<-1	-16	-16	-16	<-1	-15	-15	-15	<1	-3	-3	-3	<1
Sum	**2943**	**2618**	**2499**	**-444**	**2594**	**2740**	**2555**	**-39**	**783**	**678**	**634**	**-149**	**1044**	**909**	**859**	**-184**	**191**	**222**	**210**	**18**

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