# *The potential for agricultural greenhouse gas emission reductions in the temperate region of Canada through nutrient management planning*


Soil Resource Group

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***Executive Summary***

This project was conducted to determine the potential for greenhouse gas (GHG) emission reductions in agriculture in the temperate regions of Canada through the use of known beneficial nutrient management practices, specifically those related to nitrogen management.

In recent years, nutrient management planning has been promoted as pivotal to environmentally sound livestock production practices, either on a voluntary or regulated basis. In Ontario, new or large livestock producers are required, under the Nutrient Management Act (2002; Ontario Regulation 267/03), to submit nutrient management plans which describe in detail the amount and nutrient content of manure produced, storage capacity, timing and method of manure application, soil fertility, and crop nutrient balances. Quebec farmers are also required to have a fertilization plan (PAEF) that documents the nutrients, mineral or manure, to be applied on a field-by-field basis. The primary focus of this planning has been to maintain or improve soil and water quality; however, improved nutrient management planning and practices are expected to have implications on agricultural greenhouse gas production.

On a $CO_2$-equivalents basis, the predominant contributor to agricultural greenhouse gasses in Central and Eastern Canada is $N_2O$. Central Canada has relatively large nitrogen inputs [fertilizer and manure] for crop production, and some of this nitrogen can be lost as nitrous oxide. By determining the potential implementation of nutrient management practices and the effect of these practices on $N_2O$ losses, the potential emission reductions can be determined.

Significant research has been conducted in the past decade to enable us to move from the use of IPCC 1 default coefficients to country or region-specific coefficients, and thus obtain better estimates of Canada's agricultural sector's contribution to the national greenhouse gas outputs. Further research has been directed towards examining the magnitude of GHG reduction by potential mitigation practices.

These research efforts were reviewed in this study and the results used to obtain estimates of greenhouse gas emissions resulting from land application of nutrients in Ontario and Quebec. The data inputs used were derived from the 2001Census data, the survey of agricultural management practices (Farm Environmental Management Survey, FEMS), and OMAFRA and MAPAQ fertilizer recommendations for Ontario and Quebec, respectively. Two Canadian methodologies exist to calculate emissions: the national inventory methodology NCGAVS, and the GHG farm model. Since the methods vary in their treatment of specific data, and scope for differentiation between management practices, both methods were used in this study for comparative purposes.

Management practices thought to have potential for GHG mitigation in the temperate region of Canada were reviewed. The same methodology was then used to estimate the potential of improved nutrient management practices to reduce emissions. Where separate emission coefficients were not available for individual practices, estimations of the magnitude of change resulting from implementation of specific practices, based on a review of the literature, were applied. Such estimations come from either limited data, expert opinion, or data not specific to Canada, and as such would not be acceptable for official accounting, but do however suit the purpose of this report, that is to determine potential emission reductions through the use of improved nutrient management.

The results of this study indicated potential GHG reductions for Ontario and Quebec resulting from changes in nutrient management practices are in the range of 100 to 800 kt $CO_2$-equivalents for any one practice or scenario. This range is less than ten percent of the overall provincial emissions from soils for 2003 (8200kt $CO_2$-e for both provinces combined) or less than 4% of overall agricultural GHG emissions for the two provinces (18,200kt).

A combination of reduction of 20% fertilizer N use on corn based on the OMAFRA calculator and further reduction based on the soil pre-sidedress nitrate test (PSNT) resulted in the greatest overall emission reductions. Manure management practices such as spring versus fall application, incorporation or sidedress also resulted in significant reductions. Changes in manure handling and storage systems had smaller effects, but it should be noted that this study only considered these practices in terms of nutrient management. Changes in methane emissions were not determined.

The two methods of emissions calculations resulted in small differences for fertilizer application scenarios, but much greater differences for manure application scenarios. For example, a 10% reduction in fertilizer-N applied resulted in about 10% lower emission reductions calculated by the farm model. On the other hand, a 10% reduction in manure application rate resulted in approximately 28% greater emission reductions calculated by the farm model. This is largely the result of the difference in assessment of N-losses from manure from the different livestock categories prior to field application.

The calculations showed maximum GHG emission reductions using reduced N application rates of greater than 0.5t$CO_2$-e per hectare per year, which exceed most reductions expected from improved management practices in pasture and forage management. Furthermore, the reductions would occur on an annual basis as long as the practice was utilized, unlike management changes designed to increase C-sequestration, which has a maximum SOC potential. For example, adoption of no-till practices in the Prairies, considered to be one of the best potential practices for the western regions, results in a sink of about 0.5t $CO_2$-e per hectare per year over 20 years, with no increase after the maximum SOC is reached.

Calculations for the provinces were done for the *potential* emission reductions, or 100% adoption rate, which is unlikely to occur given the barriers to adoption. However, the assessment here is only for nitrogen management aspects of production. Other GHG reducing management practices not considered here, such as alterations of feed rations to reduce enteric emissions, can be added to achieve greater overall reductions.

The balance of offset costs and credits alone may not be sufficient to induce practice changes. However, increased adoption through aggregation of producers, with the result of shared management costs for new practices, will result in higher net benefits for individual producers. Reduced nitrogen fertilizer costs for the proposed scenarios will more likely be the primary incentive.

Current Canada specific emission coefficients were used to determine GHG reduction projections. From the investigation of improved nutrient management practices, it has been found that by greater optimization of fertilizer and manure nitrogen, substantial reductions in GHG emissions can be realized. The reduction of nitrogen application on corn crops in Ontario and Quebec was a promising approach for farmers to meet the combined goals of emission reductions and profitability. Recommended manure management practices that optimize nitrogen retention for maximum crop nutrient use are also promising but require additional management considerations for similar GHG reductions. The study concludes that full adoption of these known agricultural practices in eastern Canada could lead to reductions in the order of 35% of the annual agricultural soil and manure GHG emissions. Given the financial and time constraints of Canadian farmers, realistic adoption rates of these GHG beneficial practices would be limited.

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# *1. Introduction*

It is widely recognized that greenhouse gas emissions from agricultural practices in Eastern Canada are largely driven by the interaction between nitrogen application and high moisture conditions. Whereas GHG reduction strategies in Western Canada are centered on carbon sequestration, the east must focus on reduction of nitrous oxide emissions from soils. Nitrous oxide ($N_2O$) is a secondary product of both denitrification and nitrification processes, therefore it follows that emissions are dependent on the available nitrogen in the soil. Therefore, management practices that limit the available nitrogen in excess of plant requirements, will limit $N_2O$ emissions from the soil.

Beneficial nutrient management practices have been established to reduced the impacts of agricultural practices on soil and water quality. Best Management Practices that are focused on reduction of excess nitrogen in soils will also have a positive impact on the reduction of $N_2O$ emissions.

The objectives of the current project are to review management practices affecting levels of nitrogen in agricultural soils, and using the most recent eastern Canada-specific emissions coefficients, determine the potential of these practices to reduce $N_2O$ emissions in Eastern Canada. Further, this potential reduction is compared to the required GHG emissions reductions. Potential adoption rates, and cost factors and other barriers to acceptance of the required changes in management practices are reviewed.

# *2. Synopsis of Canadian GHG Research Initiatives and Developments*

## 2.1 Climate Change Funding Initiative in Agriculture (CCFIA) Initiatives

A great deal of research has been conducted in Canada over the last ten years on greenhouse gas emissions from agricultural lands as influenced by climate, soil characteristics and management practices. In particular, CARC (Canadian Agri-Food Research Council, AAFC), through the CCFIA, funded research programs aimed at filling in the knowledge gaps in the role of agriculture in climate change. These research efforts have begun to clarify the magnitude and controlling factors of emissions coming from our agricultural systems, and have aided in the development of region-specific emission coefficients. The final research report has been published (CARC-CRAC, 2005). The research has been divided into four main areas, and results of research relevant to the aims of this project are briefly summarized below.

### 2.1.1 GHG measurements and verification

One of the major issues facing the scientific community in assessing greenhouse gas emissions has been the lack of consistent and verifiable methodology for field measurements. The issue of scientifically defensible and verifiable measurements of $N_2O$ emissions was addressed by two groups.

Grant et al. (Alberta, Ontario) measured the sensitivity of $N_2O$ emissions to various management practices (fertilizer products, rates, placement and timing) in different climate zones (Alberta, Ontario). They showed lower emission rates under drier climate conditions regardless of the management practices, reduced emissions with reduced fertilizer rates, higher $N_2O$ in manured fields relative to those fertilized with commercial fertilizer, and little difference with slow release fertilizer.

Pennock et al. (Saskatchewan) examined the use of chamber and aircraft-based methods to estimate the $N_2O$ flux from agroecosystems for large areas, in particular during spring melt, which has been shown to produce a very significant component of the annual $N_2O$ flux. Again emissions were lower for the drier western areas relative to Ontario sites, and manure application resulted in higher emission rates than commercial fertilizer application.

### 2.1.2 Animal Nutrient and Manure Management

Animal nutrient and manure handling, storage and application practices have a large influence on the greenhouse gas impact of livestock operations. Only the manure management practices will be discussed here.

Laugë and Marquis (SK and QU) examined swine facilities and manure storage, and found that $N_2O$ emissions from the livestock housing area were insignificant; however, twice as much methane was produced in areas under fully slatted floors compared to partially slatted floors. In liquid manure storage facilities, $N_2O$ emissions were negligible, and methane dominated. Uncovered storages emitted similar amounts of greenhouse gas regardless of the type, but addition of a straw cover resulted in a significant reduction (5 fold). Depth of storage had no impact, whereas temperature changes through the year were very significant (10X more $CH_4$ and 5X more $CO_2$ in summer relative to fall in a manure treatment system).

Wagner-Riddle (ON) estimated year-round emissions ($N_2O$ and $CH_4$) from outdoor manure storage systems from three swine farms (liquid manure systems). Again, N2O emissions were negligible, and methane emissions were directly related to temperature (daily and yearly). They found that the IPCC emission factor for $CH_4$ overestimated $CH_4$ by 5-10X for the two swine facilities and 5X for dairy facility. Nitrous oxide was overestimated by up to 98X depending on livestock type, and can essentially be ignored for these manure storage systems. Overall, they calculated an emission factor of 3.6kg $N_2O$/head/yr (Park et al. 2006)

For solid manure storage, nitrous oxide emissions are more significant. Wittenberg (MN) estimated a 11g $N_2O$-N per steer from bedded manure pack in pens (128 day period), which was 50% of the IPCC emission figure.

Overall, it was generally found that the emission coefficients for manure handling and storage under Canadian coefficients were somewhat lower that IPCC default values. These lower rates need to be confirmed for range of conditions to establish accepted regional and management specific coefficients.

### 2.1.3 Soil Nutrient Management

Burton (MB,NS) examined delayed fall banding in Western Canada and found emissions that were similar to spring application. Unlike other studies, they did not find a negative effect on retaining residues on the surface; nor was there an increased $N_2O$ flux as a result of direct injection (in contrast to some other studies). Greenhouse gas production was stimulated by manure application, but not tillage method.

Burton et al. also compared effect of land application of composted manure to inorganic fertilizer and liquid swine manure. They found that emissions of $N_2O$ were significantly less for composted manure than for raw manure or composted manure + urea, even though the composted manure was applied using the assumption that only 15% of the N in the compost is available (therefore applied at a rate of 733kg total N/ha).

Measurement of greenhouse gas from potato production by Burton indicated that emission levels were significantly less than suggested by IPCC emission coefficients. Split applications reduced emissions somewhat, and it was further suggested that levels of N could be reduced on the subsequent crop (e.g. barley) in view of the elevated $NO_3$ levels in soils following a potato crop. Nitrogen rates on potatoes need to be high to maintain quality, therefore a simple reduction of rates on the potato crop itself is not acceptable to the producers. This study also confirmed that liquid manure application resulted in greater greenhouse gas emissions than solid manure.

Thompson (BC) determined that application of manure to bare soil resulted in up to 40X higher N2O emissions on bare soil compared to perennial grass, though the actual percentage of manure N applied was small.

Kachanoski et al. (AB, ON, QU) examined the effect of slope position and fertilizer rate on the emissions of $CO_2$ and $N_2O$, and developed a stochastic spatial scale model. Slope position affected the flux of $CO_2$, while $N_2O$ was affected by both slope position and fertilizer rate, with the relation between $N_2O$ flux and N applied being strongest at the lower slope positions. Emissions increased with an increase in application rate from 0 to 200kg N/ha at mid-slope and depression locations, but leveled off at 100kg N/ha on knoll positions. The model predictions of spatial correlation between crop response, applied fertilizer and $N_2O$ flux, though were less successful for Ontario and Quebec sites than for Alberta sites. $N_2O$ flux appeared to be as much related to baseline soil fertility as to fertilizer application rate.

Overall, the IPCC emission coefficient of 1.25% fertilizer-N applied is generally significantly higher than measured emissions in the western regions of Canada, whereas emissions in eastern regions may exceed this rate. The emission response to the form of N applied (fertilizer or manure type) is not yet clear. Furthermore, information is needed on emission response from organic and inorganic forms of N in a variety of raw and treated manures.

## 2.2 Primary Canadian research and review papers

Beyond the CCFIA initiatives described above, there have been significant efforts put into deriving broad coefficients from already available Canadian data. To that end, several groups of authors have compiled the results of research from across the country in an effort to determine the effect of a range of nutrient management practices, crop and tillage practices, and climate and soil type on greenhouse gas emissions or sinks (primarily carbon sequestration). This has resulted in a better understanding of the extent and controlling factors of GHG emissions from agricultural sources. The revised coefficients from these compilations and related expert opinion were used in the national (NCGAVS) and farm-scale (GHGfarm) inventory methodologies described in Section 3.1 below, and are the basis for the calculations in this report. The literature has been divided into two sections: nutrient management and manure management.

### 2.2.1 Nutrient Management

Gregorich et al. (2005) compiled the most up-to-date data on the greenhouse gas contribution of agricultural soils in Eastern Canada, and evaluated the mitigation potential of various management practices. From this summary, specific emission factors for the cool moist conditions in eastern Canada were developed. Unlike in western Canadian regions, no-till did not consistently increase soil carbon reserves. Management practices that increased the fertility of the soil such as fertilization, legume- and forage-based rotations increased the carbon sequestration capacity of soils. However, emission of $N_2O$ increased linearly with the rate of N applied (1.9%). Application of solid manure resulted in lower emission rates than either liquid manure or commercial fertilizer (0.99, 2.83 and 2.82 kg $N_2O$-N/ha/yr, respectively). Cropping rotations that included alfalfa or other legume forage produced lower emissions than fertilized annual crops. Fall plowing manure or crop stubble into the soil resulted in higher annual emissions than if residues were left on the surface (2.41 vs 1.19 kg $N_2O$-N/ha/yr, respectively). Spring freeze/thaw events resulted in large pulses of emissions; hence measurements that only bracketed the growing season underestimated the annual flux. Finally, eastern Canadian soils acted as a weak sink for $CH_4$ emissions, but this is likely to be reduced by increased manuring. The need for complete emissions accounting was emphasized.

Grant et al. (2004) used the Denitrification-Decomposition (DNDC) model to examine the impact of change of management practices on $N_2O$ emissions in the seven major soil regions of Canada. The model indicated that conversion of cultivated land to permanent grassland significantly reduced $N_2O$ emissions, particularly in eastern Canada. A change to no-till, however, only reduced emissions in the western regions. Increasing fertilizer N by 50% increased $N_2O$ emissions by 32%, while decreasing the rate by 50% resulted in 16% decrease in emissions. Fall applied N resulted in slightly higher emissions than spring applied. The DNDC model was combined with the Century Model (Smith et al., 2001), which examines $CO_2$ emissions, to quantify the combined change in $N_2O$ emissions and $CO_2$ sequestering. This modeling indicated a trade-off in GHG flux with a change in 50% above or below the optimum resulting in a net increase in GHG emission balance.

In a related study, VandenBygaart et al. (2003) compiled published data (62 studies) from long-term Canadian studies to assess the effect of agricultural practices on soil organic carbon (SOC). The data indicated that no-till increased SOC in the west, but not in eastern regions. Fertilization, legume crops and manure application also increased SOC. There was a clear relationship between nitrogen applied and SOC up to 50kg N/ha/yr (SOC Mg/ha = 0.11kg N/ha/yr; $r^2 = 0.76$). Beyond that rate, however, the relationship is much more scattered ($r^2 = 0.18$).

Helgason et al. (2005) compiled over 400 treatment measurements of $N_2O$ fluxes in response to nutrient application, and derived a linear coefficient of 1.18% N applied ($r^2 = 0.33$). The relationship was even more scattered for manured soils, likely due to differences in the availability of N in the manure for nitrification and/or denitrification. Nitrous oxide emissions were correlated with soil and crop management practices (N applied as fertilizer, manure or legume residues) and precipitation. Again, no-till tended to reduce emissions in western regions, but increase them in the east. The authors concluded that, because of the variability in fluxes, potential mitigation practices could not be reliably distinguished when emission differences were less than 10%.

While there is ample evidence to suggest that changes to individual management practices can reduce one or more greenhouse gas, there are few demonstrations of the effects of practical suites of management changes. In order to determine the in-field effectiveness of changes in management practices in reducing GHG emissions, Wagner-Riddle et al. (in review) compared a combined set of best management cropping systems (no-till, soil-testing and side-dress fertilizer application, and cover crops) with conventional practices (moldboard plow or disking, conventional seeding, and standard fertilizer rates) on a corn-soybean-wheat rotation in Ontario. Over the five-year study, they found that the combined best management practices resulted in a 34% reduction of $N_2O$ emissions. Further GHG reductions resulted from C-sequestration, reduced fuel consumption and reduced fertilizer use. Furthermore, net revenue was increased for the BMP practices, but crop yield was not compromised (Meyer-Aurich, 2004). More demonstrations of this kind for a variety of management combinations are required to increase producer confidence in the overall value of these mitigation practices.

### 2.2.2 Manure Management (Storage, Treatment and Land Application)

To determine the net effect on GHG emissions of changes in manure management, whole life cycle approaches from enteric fermentation and manure treatment and storage and field application of manure need to be examined. Kebreab et al. (2006) have reviewed over 150 scientific papers related to processes that control enteric and manure related emissions, methodologies for measurement, and required analyses. The authors also briefly discuss potential mitigation strategies. Manure treatment options include composting, anaerobic digestion, diet manipulation, covers and solid-liquid separation. Some of these treatments show conflicting results (e.g. composting) and require further research to clarify net GHG benefits. There are few manure application studies that are linked to specific manure treatments, and this also requires further research on entire life cycle of GHG formation.

Manure storage is a significant source of GHG in Canada, and methane is the primary GHG of concern for liquid systems. However, significant ammonia losses occur in both liquid and solid storage, thus affecting the nutrient value of manure. Wagner-Riddle and coworkers (CCFIA, 2005) determined that, overall, the IPCC emission factors overestimated measured $CH_4$ by 2-5x for swine manure, and 5x for dairy; $N_2O$ was also overestimated by up to 98% depending on animal type.

### 2.2.3 Economic analyses of impacts of adoption of improved nutrient management protocols.

An economic analysis of the effect of adoption of improved nutrient management practices was carried out in 1999 (Thompson Corp. 1999). Potential emission reduction practices centered around improved N-fertilizer efficiency, including reduced N on corn in Ontario and Quebec, on potatoes in the Maritimes (split application), on cereal crops following potatoes, and a change in fertilizer application in the west from fall to spring. In that report, the costs of mitigation were expressed as cost per tonne of $CO_2$ reduction, and included the cost of testing and reduced yields through reduction of fertilizer inputs. They concluded that when fertilization was reduced to the point of a slight crop reduction for the sake of environmental reduction, there was generally an overall cost to the farm sector. If, on the other hand, reductions were derived from better management, such as closer matching of crop requirement in Ontario or spring application of fertilizer in the west, there was a net gain for the farm sector. In Quebec, there was a net cost to the agricultural sector for either scenario.

The aim in the present study is to achieve emission reductions without compromising crop yields.

There is the potential of improved agricultural practices to qualify for $CO_2$-equivalent reduction [offsets] credits. The costs associated with the offset program transactions have been estimated by Marbek Resource Consultants Ltd. (2004), and include development, submission, evaluation, and approval of a proposed GHG reducing project from the private sector. The transaction costs also include the operational monitoring and validation of the GHG reductions once the project was in progress, and administration costs associated with operation of an offset system programme authority.

The Marbek report provided most of the information used to estimate the transaction costs of an offset system project for eastern Canada in the present study.

## *3. Methods*

### 3.1 Methodologies for calculation of Greenhouse Gas emissions from agricultural systems

IPCC Tier I methodology allows for estimates of GHG emissions using a set of default emission coefficients applicable to that sector. For example, the calculation of nitrous oxide from manure storage systems in Canada using this method involves multiplying the amount of N excreted based on the number and type of livestock by default emission coefficients based on general manure storage systems for northern climates. It does not allow for regional differences in climate, feeding regimes or manure management practices.

The IPCC Tier II approach has been developed to enable adjustments in emission coefficients based on country-specific inputs (measurements), as outlined in *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000). The Tier II method takes into account differences in climate, feeding regimes, and management.

For Canada, two methods based on Tier II methodology have been developed for GHG accounting: NCGAVS (National Carbon and Greenhouse gas Accounting and Verification System, Rochette and

Worth, 2005), and the GHGModel farm (Helgason, 2005). Both use coefficients derived from experimental field data in an attempt to more closely represent the magnitude of emissions from any particular practice. For nutrient management, the basic principal behind both methods is to apply a best estimate to the fraction of N applied that is emitted as $N_2O$. Nitrous oxide emissions, of primary interest when examining nutrient management GHG reduction practices, are a function of N applied (fertilizer, manure, crop residues), and are affected by moisture (Helgason et al. 2005), landscape position (Izaurralde et al. 2004), tillage (Lemke et al. 1999), soil type and texture e.g. clay content (Lemke et al. 1998) and nitrate and ammonia (Lemke et al. 1998). The methods differ in how the N sources are calculated and combined, the factors and coefficients used, and whether or not adjustments are made for management practices, soil type, climate and topography. Both methods are used in this study for comparative purposes.

NCGAVS is designed to be a tool for calculating the overall GHG emissions for a country, and relies on data compilations from across the country to derive Canada specific emission coefficients for six regions. For $N_2O$ emissions, the calculation considers all N applied as commercial fertilizer, manure, crop residues, as well as the N mineralized or immobilized in the soil to be susceptible to the same processes of denitrification and nitrification. The sum of these N sources is then multiplied by and site-specific emission factor ($EF_{CTI}$), and then modified by a series of ratio factors that take into account climate (precipitation/potential evapotransporation, P/PE), tillage factors ($RF_{TILL}$), topography ($RF_{TOPO}$), and spring thaw emissions ($RF_{THAW}$). There is no differentiation between soil texture or application timing. For Eastern Canada the following numbers are used: $EF_{CTI,}$ = 0.012, P/PE = 1.0, $RF_{TILL}$= 1.0, $RF_{TOPO}$ at P/PE = 1.0, $RF_{THAW}$ = 1.4. The calculations do account for livestock type and manure storage differences when considering manure application.

The GHGfarm model was developed as an assessment tool for estimating net GHG emissions from individual Canadian farms. For the most part, it is based on the same experimental information as used in the NCGAVS, but the information is treated somewhat differently, with the model having more capacity for site and management specific factors to be included. For nutrient management related $N_2O$ emissions, the model considers direct cropping-based $N_2O$ losses to be from applied commercial fertilizer, crop residue N, as well as N mineralization from summerfallow and organic soils where applicable. Each amount of N is multiplied by soil and area specific fertilizer induced emission coefficients modified by soil texture (fine 0.0167, coarse 0.0083), tillage (intensive till 1.0 and no-till 1.3) and application time (spring 1.3 vs fall 1.8). Emissions from improved pasture and indirect emissions from fertilizer application (volatilization and leaching) are added. Emissions from manure handling and land application of manure are considered separately from the cropping losses. Nitrous oxide from land application of manure is calculated by multiplying the manure nitrogen subject to loss (considered to be 80% of N excreted) by the spring and fall application factor.

The elements for the two methods that are relevant to this project are more fully described and compared in Appendix 1. The equations, coefficients, and factors used for this report have been set out in Tables A1-1 (NCGAVS) and A1-2 (Model Farm).

### 3.2 Selection of nutrient management practices

In Canada's GHG inventory, it estimated that domestic animals directly contribute 32% (19Mt $CO_2$ equivalents, $CO_2$-e), manure management 17% (10Mt), and soils 50% (30Mt) of Canadian agricultural emissions (Kebreab et al 2006). (Ontario: 35%, 17%, 51% of 10Mt, respectively; Quebec: 35%, 21%, 43% of 7.2Mt, respectively, http://www.ec.gc.ca/pdb/ghg/inventory_report/2003_report/ann12_e.cfm). Most methane emissions are derived from enteric fermentation, and most $N_2O$ emissions are derived from soils. Manure management results in $CH_4$ and $N_2O$ emissions of similar proportions in $CO_2$-e, but much less than either enteric or soils related emissions. The major focus of this report will be on nutrient management-based $N_2O$ emission reductions.

The nutrient management practices examined were selected on the basis of potential significant GHG reduction; this could include a small change over a large area as well as a large change per unit area. In order to be acceptable to the agricultural community and enhance adoption rate, the practice change would preferably be simple and low cost. Additional to the GHG benefits, the practices are expected to be beneficial from a soil and water quality perspective. Some of the practice changes are expected to increase net revenue for an individual producer through reduced fertilizer costs. A few manure management practices have been included that would be more expensive to implement but have additional side benefits, such as manure storage covers (reduced odours) or manure digestion (methane/energy production).

### 3.2.1 Nitrogen application reduction

Based on the Census data for agriculture in the year 2001, a comparison of all crop fertilizer-N requirements according to current provincial recommendations and accounting for manure and legume N credits, with N fertilizer sales for the same year, indicates an over-application of commercial fertilizer in Ontario and Quebec of about 2 and 10%, respectively (Rochette and Worth 2005). They showed even greater over-application rates in the Maritime provinces (13% - 39%), however, the agricultural sector is relatively small in these provinces.

In Ontario, field studies have shown that, depending on the location and previous management practices, following current N application guidelines in some areas may result in nitrogen fertilizer application beyond field crop requirements (Soil Resource Group, 2003). Considerable economic and environmental benefits can be gained by reducing fertilizer application in entire fields or specific sections of fields (Thrikawala et al. 1998). The GHG emissions research described above has shown that $N_2O$ emissions are directly related to fertilizer application rates (e.g. Gregorich et al. 2005), hence, not only is there scope for significant efficiency gains in fertilizer use for high N using crops but also reduced $N_2O$ emissions.

#### 3.2.1.1 Reduced fertilizer application rates to corn by 20%

In Ontario, extensive research has resulted in recent changes in field crop nitrogen recommendations. Based on field trial database compiled from1961-2004, new N recommendations for corn have been developed that use a computer program to account for factors including soil type, crop heat units, application timing, expected yield and price ratio, and previous crop (OMAFRA nitrogen calculator, www.gocorn.net). It is estimated that the adoption of these rates may result in an overall N fertilizer reduction of approximately 20% from previous provincial recommendations. An overall reduction in nitrogen fertilizer use in corn is significant as corn represents approximately three quarters of the nitrogen use in Ontario. The potential reduction in $N_2O$ emission was estimated in the corn growing regions of Ontario, and in Quebec, an area comprising 93% of the countries corn acreage. Over-application of N on cereal crops does not tend to be an issue, since it can result in reduced yields and quality from lodging, and is therefore somewhat self-regulating.

#### 3.2.1.2 Reduced fertilizer application rates through fertilizer testing (pre-sidedress nitrate test, PSNT)

A preside-dress soil nitrate test (PSNT) has been developed in Ontario for determining crop N requirement. The test measures nitrate in the soil early in the growing season after considerable nitrogen mineralization has taken place in the soil, and at the time when crops are beginning to require significant nutrients (Soil Resource Group 2003, Ball-Coelho et al. 2005). Because of its timing, the recommended N application rate based on this test is approximately 15% less than the spring application rate, resulting in further reductions in N application and potential $N_2O$ savings. Its adoption has been limited with the reduced window of opportunity for applying at this time, and the tests acceptance as an accurate predictor of soil available plant nitrogen. The potential scenario calculated a combined reduction of spring (20%) and side-dress (15%) rate of nitrogen application.

#### 3.2.1.3 Other commercial fertilizer options considered: Enhanced Efficiency Fertilizers

A group of technologies exist for reducing nitrogen loss following land application by either slowing down the release of nitrogen from fertilizer (slow or controlled release fertilizers (usually polymer or resin-coated)) or preventing the loss of nitrogen following application (urease inhibitors, nitrification inhibitors). These products have a number of advantages including reduced nitrogen application rates, reduced inorganic nitrogen concentrations in soil and subsequent environmental losses, and more flexibility in management options, and even reduced management costs for single pass seeding and fertilization.

Environmentally Smart Nitrogen (ESN) refers to a group of polymer-coated urea fertilizers, and some research has indicated that an application rate reduction is possible, while still supplying the crop with sufficient N at the time required (Agrium, 2005). Furthermore, fall application of ESN may achieve the same crop potential as spring applied conventional fertilizers, without large environmental losses of N. This also allows the producer greater flexibility in their management options. Canadian research indicated reduced $N_2O$ emissions from coated urea, but frequently yields were reduced with ESN compared to uncoated fertilizer, even at the same N rate. It was concluded that spring banded ESN may be beneficial under high soil moisture conditions, but spring release rates might be too slow for cool or dry conditions (Grant, 2005). Where the practice is beneficial (some fall applied), a suggested 10% reduction in application rates may be practical (C. Grant, pers. com.). However, the results of further current research under Canadian conditions are needed before this option can be implemented by producers. A potential reduction of the nitrogen application rate of 10% was evaluated from the current corn recommendations in Eastern Canada in considering this scenario.

### 3.2.2 Optimization of manure N application rate

Livestock manure nutrients are often not fully credited as a nutrient source. As stated in Section 3.2.1, provincial records indicate that there is a potential over-application of N by 2% and 10% in Ontario and Quebec, respectively, based on available N from fertilizer, manure, and legumes compared to provincial nitrogen fertilizer sales. If, by manure and soil-N testing, manure nutrient value can be fully utilized, less commercial fertilizer will need to be applied in livestock-crop operations. Application according to the reduced N guideline levels (above) would result in further reductions. Some intensive livestock operations produce manure in excess of the crop requirements associated with that operation. In this case, the ideal would be to utilize the excess manure on nearby cash crops, and thus reduce the overall commercial fertilizer requirement for the cash crop. Again, the manure rates applied should supply a nitrogen amount equivalent to the revised recommended rates described above. The associated reduction in fertilizer in Ontario and Quebec to overcome the over-application of manure was investigated based on a 2% and 10% reduced use of commercial N.

### 3.2.3 Optimization of manure N application

If manure is land-applied at a time and in a manner such that N-losses are minimized, it can be spread at lower rates and still achieve the same level of plant-available N. Consequently, more commercial fertilizer can be replaced by manure.

### 3.2.3.1 Timing

Considerable research has been carried out on losses of nitrogen following manure application in the fall relative to spring application. A reduction in GHG emissions would originate from two sources. Firstly, $N_2O$ losses have been shown to be very high during the spring-thaw period (Wagner-Riddle and Thurtell, 1998); this pulse could be avoided by applying after this period. Secondly, other N losses are incurred between the time of application and the spring planting period, particularly in response to spring runoff. Thus reductions in $N_2O$ emissions can be realized through spring vs fall application because of reduced fertilizer-N rates to supply the required crop N, and reduced emissions from the manure amount applied (1.3 and 1.8 emission factors for spring and fall, respectively; GHG model farm). Potential losses from fall manure application have also been recognized as an environmental risk, and NMAN (Ontario's nutrient management planning software program) restricts fall application rates relative to spring rates because of the additional leaching risk. The optimum time for application of nutrients is in synchrony with the growing crop's requirements, i.e. side-dress time. As discussed above (3.2.1.2), this results in reduced N application rates, and subsequent $N_2O$ emissions. The relative difference between available N from fall applied manure and spring or side-dress time (June) applied manure depends on the manure type, but is much greater for liquid manures than for solid manures. OMAFRA estimates of the proportion of available N from urea and livestock manures based on application timing are presented in Appendix 2, Table A2-1. The estimates account for ammonia losses as well as organic-N mineralization. These differences in N availability were used to estimate the potential for reduction in $N_2O$ emissions with a change in manure application timing. For example, liquid swine manure injected at side-dress time has 70% of its total N available to the crop, whereas if applied the previous summer, only 23% still remains. Therefore to meet crop needs, three times as much manure would have to be applied in late summer as at side-dress time of the cropping year, and significantly more $N_2O$ emissions would result.

### 3.2.2.2 Tillage/incorporation

Surface application of liquid manure has been shown to result in very high ammonia losses. This has two emission related results: high indirect $N_2O$ emissions from volatilized ammonia, and reduced available N from the manure and subsequent higher spreading rates to reach crop requirements. Incorporation has been shown to reduce ammonia losses by, for example 5 times (16.9% totalN vs 3.6% totalN, pig slurry on canola stubble; Rochette et al. 2001). This results in a reduction in indirect $N_{2-}$O emission based on the amount of ammonia volatilized. Further, because less N is lost, a reduced spreading rate can be used, the manure can be spread further, and more commercial fertilizer can be replaced. OMAFRA estimates of reduced N losses with incorporation for various manure types are included in Appendix 2, Table A2-1, and are used for calculations of manure application rates.

Similarly, if side-dressing is done by surface application, significant ammonia will be released thus reducing the fertilizer value of the manure. For example, Ball-Coelho et al. (2005) reported increased corn yields in response to sidedress injection of swine manure relative to topdress applications. This is likely in response to reduced ammonia losses thus retaining fertilizer value with the injection method. The corollary to this is that yields equivalent to those from topdress applications could be obtained with lower manure rates with injection. Estimates of the available N from incorporated and non-incorporated urea and manure application at side-dress time are also presented in Table A2-1. Nitrous oxide measurements were not taken in the above study, but Burton and coworkers did not determine any difference in $N_2O$ production between injection and incorporation with disc or chisel plow (MacLeod et al. 2005). It has been suggested that injection may increase $N_2O$ emission rates under wet conditions, therefore it is recommended that manure should be injected under dry conditions.

Although not specifically considered in this report, manure digestates in particular, which usually have a higher proportion of N in the ammonia form (cattle slurry, OMAFRA; poultry manure, Field et al. 1986), should be incorporated rather than surface applied to reduce ammonia-N losses.

In the absence of specific incorporation factors or coefficients for manure application in either the NCGAVS and GHG farm model approach, the reduced losses of nitrogen with incorporation, particularly closer to the crop season, were evaluated in terms of associated reductions in $N_2O$ loss. The relative nitrogen savings were equated to the N availability from Table A2-1 to determine reduced losses. For example, if liquid swine manure is incorporated at side-dress time, 70% of its total N is available to the crop, whereas if it is not incorporated, there are significant losses from volatilization of ammonia and only 50% remains available for the crop. Therefore, to meet crop needs, 20% more manure would need to be applied if not incorporated, and approximately 20% more $N_2O$ would result.

### 3.2.4 Manure handling

NCGAVS provides coefficients for total losses of N from manure management systems that range from 15% for solid storage and dry lot (sheep, horses, goats and other large livestock) to 55% for some poultry manure (not in standard liquid or solid manure storage systems). The relative losses from manure storage and handling vary according to manure type and management practice.

The effects of changes in manure handling practices have been studied for methane (Sommer et al. 2004, Lauge and Marquis 2005) and ammonia emissions (Monteney & Verboon cited by Bussink & Oenema 1998). A 15-30% reduction in ammonia emissions through rapid removal of manure from the barn to storage has been estimated (Bussink & Oenema 1998)

Improved management practices for liquid manure handling can include partially versus fully slatted floors for swine barns (Lauge and Marquis 2005; 50% methane reduction) and reduction of temperature of in-barn storage by heat exchange in swine barns (Sommer et al. 2004; 31% methane reduction), flushing of slurry channels for liquid dairy systems (Sommer et al. 2004: 49% methane reduction, Monteney & Erisman: 50-65% ammonia reduction), more rapid removal to storage of swine manure with sloped channels (Burton and Beauchamp, 1996; 30% reduction in ammonia).

Rapid removal of solid manure by frequent scraping can also result in reduced ammonia losses. Hutson et al. (1998) showed a reduction in ammonia loss from 22%TN to 0% if the scraping interval was reduced from 3 days to 0.67 hours. However, increased energy requirements for this sort of system are likely to out-weigh the improved nutrient value of the manure.

One further option that reduces ammonia losses from poultry manure is forced air-drying (48% Bulley & Lee 1987; 60% Overcash 1983). The resultant product will be quite stable throughout storage. This practice, however, would carry with it increased energy consumption, and the net GHG benefit has not been calculated.

The manure nitrogen generated from livestock was calculated using 2001 Census of Agriculture population data and the NCGAVS excretion rates. It should be noted that a reduction in losses during manure handling (getting the manure from the barn floor to storage), will result in higher N remaining in the manure, which can subsequently lead to increased losses during storage (Sommer et al. 2004). For the purposes of this study, the losses given in NCGAVS (which combine handling and storage losses) will be split evenly between manure handling and manure storage. Improved handling practices considered a maximum 30% reduction of the handling losses (or 15% of the overall handling and storage losses).

### 3.2.5 Manure storage

Significant manure nutrient value can be lost through volatilization of N from storage systems. Some of this N will be $N_2O$ (0.2% TN, Sommer et al. 2001), which will account for most of the direct GHG emissions from solid systems, but the most significant losses in terms of nutrient value will be as $N_2$ and

$NH_3$. Some further losses will occur through leaching of solid piles, but this has been estimated to be fairly low (Sommer et al. 2001)

Covering manure storage systems is considered to decrease gaseous losses, but there is limited information on Canadian systems (Kebreab et al. 2006). . Straw covers and naturally forming crusts have been used to reduce odour related emissions from liquid storage systems, but their effectiveness for net GHG emissions appears variable (crust: DeBode 1991, 60-70% reduction in GHG and $NH_3$ is maintained; Paul, 1999, increased $N_2O$ from cracks in the crust; straw: Lague & Marquis 2005, 40% reduction; Cicek et al. 2003, 247% increase in $CH_4$). Nitrous oxide is produced at the interface between the cover and the slurry, and depending on climatic conditions, significant losses can occur (Sommer et al. 2000). Use of these types of covers appears to lead to inconsistent results for GHG purposes.

Floating geotextile or polyethylene foam covers for liquid manure have been shown to prevent losses of ammonia by 80% from swine manure under field conditions (Miner et al. 2003). The same level of reduction in N-volatilization, should be achievable with airtight covers such as suggested by Abou-Nohra et al. (2003) for converting manure storages to an anaerobic digester under Canadian conditions.

Covering solid manure piles also results in greatly reduced emissions. For example losses from uncovered stored deep litter from dairy housing accounted for 26% of TN (about two thirds of the NCGAVS estimates which includes in-barn and handling losses), compared to losses of 5% TN for covered piles ($N_2O$ accounted for 0.2% TN) (Sommer 2001). This equates to a reduction in N loss due to covering of 80%. Similarly compaction of the manure pack, reduced losses to 9%, presumably due to reduced airflow, but the $N_2O$ fraction of emissions was higher (0.3% TN) (Sommer 2001).

Manure storage temperatures affect emission rates, and winter methane emissions from liquid storage systems in Ontario have been shown to be very low (Park et al. 2005). This provides some advantage in storage over winter for spring application, provided the producer has adequate storage capacity.

Using the combined losses given in NCGAVS, improved storage loss reductions considered a maximum 80% reduction of storage losses with the use of covers for liquid and solid storage.

### 3.2.6 Manure treatment

A number of other practices are being utilized on-farm or are being developed that may improve GHG emission reductions. Their potential may be limited due to operating and capital expenses. Furthermore, deriving coefficients from limited research information is not possible at this time. Two such practices are described below.

#### 3.2.6.1 Composting

Composting has been explored as a means of reducing GHG emissions from manure. Studies of losses of GHG during the composting process have produced contrasting results. For example, Thompson et al. (2004) found that aerated composting reduced emissions to as low as 30% of storage of raw swine manure, while non-aerated composting increased emissions to about 330% of storage of raw manure. Hao et al. (2001) however, found that active composting (turning) resulted in more total GHG losses than passive composting (401 vs 240kg$CO_2$-C eq./Mg manure). The authors suggest that the passive manure was not likely fully composted. As well, many studies do not account for the GHG effect of ammonia volatilization, which can result in significant $N_2O$ emissions through indirect losses (0.01*N lost in volatilization, NCGAVS methodology, Rochette & Worth, 2005).

Field applications of compost have reduced GHG emissions from field compared with raw manure because most of the easily mineralizable forms of C and N are lost during the composting process (Eghball et al. 2002). For example, Buckley et al. (2005) showed reduced $N_2O$ emissions from compost relative to liquid hog manure, both applied at 110kg available N/ha (based on the $NH_4$-N content of the manure, and assuming only 15% of the N in the compost would be available to the crop in the first year).

Research is needed that combine the total GHG effect of composting and field application which measure GHG emissions from industrial scale composting operations and field application of raw, composted and biodigested swine manure.

For the current study, the data for GHG reduction from composting is too variable to use for predictions.

#### 3.2.6.2 Digestion

Methane production through anaerobic digestion appears very promising as a means of reducing manure related GHG emissions. However, less than 1% of manure in Canada is treated in this manner. Besides the direct savings in methane emissions, the digestate may form a more stable N source. Only one Canadian study was found that directly compares land application of treated and untreated manure (Chantigny et al. 2005), and there appears to be an overall saving in GHG emissions from land application of the treated manure. Based on this data the N2O emission coefficient can be expected to be slightly less for digestate (0.05% smaller coefficient) because of the reduction in available carbon as substrate for microbial activity (nitrification/ denitrification). In a Danish study, Peterson (1999) compared $N_2O$ emissions following application of digestate (55% cattle, 45% swine, co-digested with organic waste from slaughter houses and food processing plants to increase methane production) or raw slurry (swine and cattle slurries mixed in the same proportion as the digestate). The digestate resulted in 20-40% lower $N_2O$ emissions.

This issue is being studied by a number of groups, but there is insufficient field data to justify altered $N_2O$ emission coefficients for this practice (Philippe Rochette, pers. com.).
There is not sufficient data at this point on which to base estimates of the magnitude of changes in N emissions as the result of digestion for the current study.

### 3.2.7 Combinations of Management Practices

Combinations of manure handling, treatment and land application practices should improve overall emission reductions. For example, Sommer et al. (2004) suggested that combinations of cooling (swine manure) or daily flushing of slurry channels (dairy) and digestion would result in overall methane emission reductions of 59% and 76% from pig slurry and cattle slurry, respectively, for Danish farms. This could be combined with a further reduction of 20-40% reduction in $N_2O$ emissions following field application.

## 3.3 Calculation of Potential GHG emission reductions

The practices chosen for examination for GHG impacts and specific GHG reduction rates for individual management practices are listed below. Based on census data for crop production and livestock populations, and assuming 100% adoption rates, the maximum potential $N_2O$ emission reductions were calculated for each scenario. Realistic adoption rates will vary according to a number of factors including cost, ease of adoption, and confidence of the producer that crop yields will not be compromised.

Ontario and Quebec were considered for reductions based on fertilizer application on corn, as these have the major corn production areas in Eastern Canada. For manure management practices, the Maritime Provinces were included in the calculations.

The calculations do not include reduced fertilizer production costs, which have been estimated to be 2.372 kg $CO_2$-e per kg N (mean of all types; Helgason et al. 2005), therefore for every tonne of N saved in fertilizer reduction, and additional 2.372 tonnes of $CO_2$-e can be added to the total GHG savings. For example, a reduction of 20kgN/ha for 100 hectares of cropland would result in a savings of 2 Mg N, and consequently 4.744 Mg $CO_2$-e. This will result in substantial indirect savings in GHG emissions, but have not been included here because they are not reductions in direct emissions resulting from changes in on-farm nutrient management practices. Nor do the calculations include changes in C-sequestration. One of the base assumptions made is that crop yields are not compromised due to changes in nutrient management. If crop yields are unchanged, there should be little difference in accumulation of soil organic matter (SOM). Manure application usually results in increased SOM, the magnitude of which depends on the interaction between manure type, climate, soil and management practices. However, this study addresses more efficient distribution of manure, which should result in a redistribution of SOM changes, but not net increases over the study area.

Both the NCGAVS and GHGfarm model approaches were calculated and compared in each scenario. General assumptions for the scenarios were that C sequestration or crop yield was not affected by a change in N use. Within the GHGfarm model, soil texture distinctions were not made for Quebec where some research has suggested significant emission differences. The link to the corn growing area was not possible so that all calculations using the GHGfarm model assumed a 50/50 distribution of fine and coarse textured soils by each region. The tillage factor was assumed to be conventional and did not include possible no-till acreage. Also in the GHGfarm model, the season factor was assumed to be spring for N fertilizer application. The precipitation and evapotransporation ratio was assumed to be 1 and did not vary across the study area.

The calculations were completed using the 2001 Census of Agriculture, Census Agricultural Regions for Ontario (5) and Quebec (14) and summarized by Province in the Maritimes. No change in transport costs of manure compared to fertilizer have been included in the calculations.

### 3.3.1 Land Application of Nitrogen:

Crops with high nitrogen requirements were considered for overall N reduction: corn, potatoes, cole crops, tomatoes, peppers, and cucurbits. Optimum fertilizer-N use efficiency for corn has been achieved at lower rates than previously recommended (averaging about 20% in Ontario). Over 93% of Canada's corn is grown in Ontario and Quebec, and therefore reduced N use is a viable option for these two provinces. While application rates for potatoes may be achievable with changes in management practices (David Burton, pers. comm.), there is concern for product quality, and insufficient field trial data is available to recommend significant fertilizer reductions. Similarly, while there are significant acreages of other high-N demanding vegetable crops, producers are concerned about maintaining quality, and as yet, there is insufficient data to demonstrate the feasibility of reduced N rates. Therefore, it was decided to focus on corn, both grain and silage, for reduced fertilizer-N use in Ontario and Quebec.

Corn acreage taken from the 2001 Census was designated baseline N application rates by region based on provincial recommendations (OMAFRA – Publication 811, CRAAQ - Guide de Reference en Fertilisation, 1st edition), including general yield goal expectations and corn heat unit differences.

Regional nitrogen application rates (Table 4.1) varied between 120 to 170kg/ha; rates considered conservative that do not capture the GHG reduction potential of some farmers that exceed these application levels.

*3.3.1.1 Reduced N fertilizer use with N recommendation calculator for corn in Ontario and Quebec*. The calculator is based on individual farm practices, but for the purposes of this report emission reductions will be based on emissions from an average 20% less fertilizer-N applied, compared to recommendations prior to 2006. The emission calculations, then, are based on the difference between previous recommendation rates and 80% of the recommended rates, using the relevant direct and indirect equations from NCGAVS and the GHGfarm model methods.

*3.3.1.2 Pre-sidedress nitrate test (PSNT) for reduced corn N use.* It is estimated that use of the PSNT will result in a further 15% reduction in nitrogen requirement for corn in Ontario and Quebec. Emissions are calculated as above.

*3.3.1.3 Fertilizer technologies to reduce N use (ESN, estimated 10%)* Canadian research indicates that it is reasonable to expect a 10% reduction in fertilizer application rate with the use of ESN. Emissions are calculated as above.

*3.3.1.4 Manure N replacing fertilizer N*

Note: For all manure related emission calculations in the following sections, it is assumed that all manure is land applied, and it is the efficiency of manure nutrient use that can be changed through better management practices such as manure testing, spring vs fall application. Cattle, including dairy, poultry and swine animal numbers were used. Sheep and horse manure were not included as they comprise less than 2% of the manure production and may not be as closely associated with fertilizer replacement for crop production.

Calculations of the difference between crop requirements (at provincial recommended rates) and available manure-N, legume residue-N and fertilizer sold indicate that, in 2003, there was an excess fertilizer-N of 2% in Ontario and 10% in Quebec. One can consider that, on average, if manure were used optimally, 2% and 10% less commercial fertilizer-N could be used, thus achieving the corresponding $N_2O$ reductions. These reductions are calculated as percentages of emissions from 3.3.1.1 above.

*3.3.1.5 Application of manure N at reduced fertilizer rate*

If manure is applied according to the reduced fertilizer rate for corn (3.3.1.1) the manure can be spread further and thus replace more fertilizer. The direct $N_2O$ emissions based on N application rate will be the same as for 3.3.1.1 above, but the indirect emissions will vary slightly (10% higher for the model farm, and varying according to manure management for NCGAVS). What does change significantly is the amount of fertilizer replaced. In this case the overall provincial reduction calculations remain the same. On an individual farm operation basis, there could be significant changes. For example, if a corn cash-crop farmer replaces half of his/her commercial fertilizer-N with a neighbour's poultry manure which would otherwise be over-applied, then the $N_2O$ emissions from the cash crop will remain roughly the same, but there will be an overall $N_2O$ emission reduction over the two farms based on the amount of poultry manure applied on the cash-crop. This scenario determined the reduction in emission from a modest increase in efficiency of manure N use by 10% converted to an equivalent reduction of fertilizer N application.

### 3.3.2 Manure Nitrogen Application Method:

Since more manure-N can be retained with improved manure application timing and incorporation, the manure can be spread further, and more commercial fertilizer replaced. It is assumed that manure N2O production is the same regardless of its placement. Note that the NCGAVS methodology does not have emission coefficients that differentiate between the various management practices.

*3.3.2.1 Timing: spring vs. fall*

Because more N is retained with spring application, OMAFRA estimates of available N are used to calculate application rates. This again improves the fertilizer replacement value of the manure. As well, the effect of timing on the $N_2O$ emissions is reflected in the model farm spring and fall emission coefficients of 1.3% and 1.8% of the N applied. FEMS indicates that, on the basis of farms reporting, current practices are such that manure is spring and fall applied in roughly equal amounts at about 33%and 36% respectively, summer application on crops (probably mostly forage) is about 20%, and winter spreading is less than 10%. For the baseline for these calculations in this report, a 50/50 split between spring and fall applications will be assumed.

*3.3.2.2 Incorporation: surface vs. incorporation*

Neither NCGAVS nor the GHG Model Farm, describe coefficients that differentiate between incorporation practices. Therefore, the emissions reduction will be calculated on the basis of reduced N losses from incorporated manure (OMAFRA, Table A2-1) and corresponding improved fertilizer replacement values.

*3.3.2.3 Sidedress: spring vs. side-dress*

This calculation is similar to 3.3.2.2 based on reduced N losses from spring applied manure over a baseline distribution average of early fall, late fall and pre-plant N availability (OMAFRA, Table A2-1). The side-dress scenario was investigated for the difference in availability of N for liquid swine manure between the baseline average and side-dress application. Since incorporation was assumed throughout this scenario, solid manure at side-dress time was considered impractical.

The percent increase in availability represents an equivalent reduction in nitrogen replacement = CO2 e reduction

### 3.3.3 Manure Storage and Handling

Losses of N from Canadian livestock management systems have been estimated in NCGAVS and vary from 15% for horses and sheep to 55% for storage of poultry manure not handled in standard liquid or solid management systems. (NCGAVS Table 6 is presented in the accompanying results spread sheet). Conversely, the GHGfarm model assumes an overall 20% N loss irrespective of the livestock type or management. The loss rates in the handling and storage stages are interdependent, i.e. a reduction in handling losses may allow for higher losses in the storage stage. For the purposes of the calculations, it will be considered that the N-losses from handling and storage will be evenly split.

*3.3.3.1 Manure handling/cleanout*

From the discussion above in Section 3.2.4, the possible reduction rates vary between manure types and management. In this report, we will assume a maximum reduction of 30% in ammonia losses with improved management (e.g. more rapid cleanout time). The reduction in ammonia losses will result in manure with a higher nutrient value and reduced indirect losses. Note that reduced losses at this stage will result in stored manure with higher N content, which will then be subject to loss. FEMS does not survey improved practices such as rapid cleanout but it was assumedthat there is not significant adoption of these practices already in Eastern Canada.

*3.3.3.2 Manure storage*:
Estimates of reduction in ammonia losses with covers were 80% for both solid and liquid storage (Section 3.2.5). For liquid swine manure systems, the FEMS survey indicates that covered systems account for outside manure storage for about 14% of the swine population, and that no liquid dairy manure is held in covered tanks.

## 3.4 Economic Considerations

### 3.4.1 Assessment of impacts of practice changes on management, production costs and revenues.

The practices described above were assigned subjective (high, medium, low) estimates of the magnitude of changes in costs (time and dollars) and revenues for a practice change. Appendix 3 contains a more complete description of the costs and revenues for each practice.

### 3.4.2 Potential for $CO_2$ carbon credits [offsets]: cost analysis

There is very limited experience and information in Canada about the transaction costs associated with trading [offsets] produced from agricultural practices. The government of Canada did contract a study to estimate these costs. Marbek Resource Consultants Ltd. (2004) conducted an administration and transaction costs study of an offset system for Agriculture and Agri-Food Canada. The transaction costs are those associated with development, submission, evaluation, and approval of a proposed GHG reducing project from the private sector. The transaction costs also include the operational monitoring and validation of the GHG reductions once the project was in progress. This report also covered the administration costs that would be associated with operation of an offset system program authority and are not part of the actual transaction costs. The Marbek report provided most of the information for this current BIOCAP study to estimate the transaction costs of an offset system project for eastern Canada.

The Marbek report created three scenarios for limited, medium, and broad number of participants in an offset project. The limited scenario would typically be 1 or more participants in a very large project. The medium scenario would have more participants and large projects but would still have rigorous monitoring and validation. The broad scenario would be well suited for agricultural projects where one or a few management practices would be grouped, or “pooled”, into one large project; the monitoring and verification would be less intensive. All projects could generate permanent offset credits, but the broad, or pooled, projects could also have temporary credits. The Marbek report stated the numerous assumptions for each scenario clearly, but these assumptions are better suited for western Canada agricultural conditions. Therefore, this eastern Canada study had to adapt the Marbek conclusions for local application.

The methodology to estimate offset transaction costs relied in part from data from the Marbek report except for the verification costs. To estimate the offset transaction costs, the following costs were derived from the Marbek report:
- project *evaluation*,
- project *initiation*,
- project *proposal*,
- project <u>*validation*</u>, and
- project *monitoring and quantification*.

These costs, above, mainly represent the legal and professional fees to bring a project into operation and are mainly one-time costs. Once the project is underway, *verification* costs are required to ensure compliance, accountability, and offset quantification assessments. The verification of pooled agricultural projects would likely involve yearly checking of approximately 20% of the sites [i.e. fields]. Given eastern Canada's intensive agricultural systems, the verification costs needed to be estimated and used in place of the Marbek data.

A summary table of transaction costs adapted from Marbek is provided in Appendix 4.

The verification costs were estimated to be approximately $1/ha. An offset credit was estimated to be $10 for an agricultural project.

Two nitrogen related management practices to reduce $N_2O$ emissions are:

1- Reduced N fertilizer use with N recommendation calculator [-20% applied N], and
2- Pre-sidedress nitrate test (PSNT) for reduced corn N use [additional -15% applied N]. An assumed application rate of 150kgN/ha was used.

The $N_2O$ emission reduction can be calculated using the IPCC coefficient of 0.0125 kg $N_2O$ emission for 1 kg fertilizer N. The GHG warming potential of $N_2O$ to $CO_2$ was determined by multiplying the mass of $N_2O$ by 296 to obtain $CO_2$equivalancy.

## *4. Results and Discussion*

The opportunity for reduced GHG emissions from improved nutrient management practices were investigated for the census agricultural regions (CAR) using both NCGAVS and GHGfarm model approaches. The reductions in $N_2O$emissions resulting from each of the proposed management practices are summarized below in a series of tables. The results of the reduced fertilizer use scenarios and assumptions indicated an approximate 11 to 12% greater emission reduction using the NCGAVS approach. This is accounted for in part by a greater fertilizer emission coefficient. The differences between methods under the manure management scenarios were significantly more variable because of the additional management factors considered in the NCGAVS approach.

### 4.1 Reduced N fertilizer use with N recommendation calculator

Nitrogen emission reductions from 20% lower nitrogen application for the corn growing areas in Ontario and Quebec resulted in significant CO2 equivalent reductions (Table 4.1). The relative area of corn cropped in the two provinces is represented by a doubling of emission reduction potential in Ontario than in Quebec. The combined estimate is approximately 440ktCO2 equivalent reduced annually.

*Table 4.1: Reduction in $N_2O$ emissions resulting from reduced N fertilizer use with N recommendation calculator for corn in Ontario and Quebec, 20% reduction assumed*

| Region | | NCGAVS* | | GHGfarm* | |
|---|---|---|---|---|---|
| | N rate kg/ha | t CO2 e per ha | kt CO2 e regional | t CO2 e per ha | kt CO2 e regional |
| Quebec | | 0.32 | 156.6 | 0.29 | 141.4 |
| Bas-Saint-Laurent - (CAR) | 120 | 0.25 | 0.5 | 0.23 | 0.5 |
| Saguenay--Lac-Saint-Jean/Côte-Nord - (CAR) | 120 | 0.25 | 0.6 | 0.23 | 0.5 |
| Québec - (CAR) | 120 | 0.25 | 1.3 | 0.23 | 1.1 |
| Mauricie - (CAR) | 140 | 0.29 | 6.4 | 0.27 | 5.8 |
| Estrie - (CAR) | 120 | 0.25 | 3.3 | 0.23 | 3.0 |
| Montréal/Laval - (CAR) | 120 | 0.25 | 0.3 | 0.23 | 0.3 |

| | | | | | |
|---|---|---|---|---|---|
| Lanaudière - (CAR) | 140 | 0.29 | 12.6 | 0.27 | 11.4 |
| Outaouais - (CAR) | 120 | 0.25 | 1.5 | 0.23 | 1.4 |
| Laurentides - (CAR) | 140 | 0.29 | 4.2 | 0.27 | 3.8 |
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | 120 | | <0.1 | | <0.1 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | 120 | | <0.1 | | <0.1 |
| Chaudière-Appalaches - (CAR) | 140 | 0.29 | 8.0 | 0.27 | 7.3 |
| Montérégie - (CAR) | 160 | 0.34 | 91.6 | 0.30 | 82.8 |
| Centre-du-Québec - (CAR) | 160 | 0.34 | 26.2 | 0.30 | 23.7 |
| | | | | | |
| Ontario | | 0.33 | 308.0 | 0.30 | 278.3 |
| Southern Ontario Region - (CAR) | 170 | 0.36 | 143.3 | 0.32 | 129.5 |
| Western Ontario Region - (CAR) | 160 | 0.34 | 103.9 | 0.30 | 93.9 |
| Central Ontario Region - (CAR) | 140 | 0.29 | 25.9 | 0.27 | 23.4 |
| Eastern Ontario Region - (CAR) | 120 | 0.25 | 34.9 | 0.23 | 31.5 |
| Northern Ontario Region - (CAR) | 120 | 0.25 | 0.4 | 0.23 | 0.4 |

*Notes:
Calculation: N rate * 0.20 reduction * method (NCGAVS or GHGFarm) * $N_2Oe$ * $CO_2$ e * corn ha
NCGAVS (full explanation of equations given in Appendix Table A1-4)
Direct and indirect losses $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH\ +\ RUNOFF}$
GHGFarm (full explanations of equations given in appendix Table A1-5)
Direct and indirect losses $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP\ +\ RUNOFF}$
Assumptions: ½ fine soils, ½ coarse soils; all conventional tillage; all spring application
Corn Acreage based on 2001 Census of Agriculture, Statistics Canada information;

Small differences in coefficients and factors between methods resulted in a greater reduction using the NCGAVS method over the GHGfarm method of around 11%. Further slight differences between regions would be expected with the incorporation of soil textural weightings using the GHGfarm method. For example, an increased weighting of 70/30 fine to coarse texture within the GHGfarm calculation would raise the emission reduction in a region to the same level as determined with the NCGAVS method.

On a unit area basis, the CO2 equivalent reduction was almost a third of a tonne per hectare. Those regions with the highest baseline N application rates (i.e. southern Ontario – 170kgN/ha, Monteregie – 160kgN/ha) had the greatest incremental reduction in rates and therefore were shown to have the highest potential for reductions on a unit area basis as well, eg. Southern Ontario at 0.36t $CO_2$e/ha.

### 4.2 Reduced N fertilizer use with N recommendation calculator and PSNT

Further nitrogen emission reductions from 20% lower corn nitrogen application and an additional 15% reduction from spring rates for side-dress application resulted in significant CO2 equivalent reductions (Table 4.2). The combined estimate is approximately 750-800ktCO2 equivalent reduced annually. On a unit area basis, the CO2 equivalent reduction was determined to be greater than a half of a tonne per hectare. The highest estimate was found using the NCGAVS method in southern Ontario with a potential reduction level of 0.62t $CO_2$ e/ha.

*Table 4.2: Reduction in $N_2O$ emissions resulting from the use of the pre-sidedress nitrate test (PSNT) for reduced corn N use; 35% reduction assumed including new recommendation reduction.*

| Region | NCGAVS* | | GHGfarm* | |
|---|---|---|---|---|
| | t CO2 e per ha | kt CO2 e regional | t CO2 e per ha | kt CO2 e regional |
| Quebec | 0.56 | 274.1 | 0.50 | 247.6 |

| | | | | |
|---|---|---|---|---|
| Bas-Saint-Laurent - (CAR) | 0.44 | 0.9 | 0.51 | 0.8 |
| Saguenay--Lac-Saint-Jean/Côte-Nord - (CAR) | 0.44 | 1.0 | 0.40 | 0.9 |
| Québec - (CAR) | 0.44 | 2.2 | 0.40 | 2.0 |
| Mauricie - (CAR) | 0.51 | 11.2 | 0.40 | 10.1 |
| Estrie - (CAR) | 0.44 | 5.7 | 0.46 | 5.2 |
| Montréal/Laval - (CAR) | 0.44 | 0.6 | 0.40 | 0.6 |
| Lanaudière - (CAR) | 0.51 | 22.1 | 0.40 | 20.0 |
| Outaouais - (CAR) | 0.44 | 2.6 | 0.46 | 2.4 |
| Laurentides - (CAR) | 0.51 | 7.4 | 0.53 | 6.7 |
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | 0.44 | 0.2 | 0.40 | 0.1 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | | <0.1 | | <0.1 |
| Chaudière-Appalaches - (CAR) | 0.51 | 14.1 | 0.46 | 12.7 |
| Montérégie - (CAR) | 0.59 | 160.3 | 0.53 | 144.8 |
| Centre-du-Québec - (CAR) | 0.59 | 45.9 | 0.53 | 41.4 |
| | | | | |
| Ontario | 0.57 | 539.0 | 0.52 | 487.0 |
| Southern Ontario Region - (CAR) | 0.62 | 250.7 | 0.56 | 226.5 |
| Western Ontario Region - (CAR) | 0.59 | 181.9 | 0.53 | 164.3 |
| Central Ontario Region - (CAR) | 0.51 | 45.4 | 0.46 | 41.0 |
| Eastern Ontario Region - (CAR) | 0.44 | 61.0 | 0.40 | 55.1 |
| Northern Ontario Region - (CAR) | 0.44 | 0.7 | 0.40 | 0.7 |

*Notes:
Calculation: N rate * 0.35 reduction * method (NCGAVS or GHGFarm) * $N_2Oe$ * $CO_2e$ * corn ha
NCGAVS (full explanation of equations given in Appendix Table A1-4)
Direct and indirect losses $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH + RUNOFF}$
GHGFarm (full explanations of equations given in appendix Table A1-5)
Direct and indirect losses $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP + RUNOFF}$
Assumptions: ½ fine soils, ½ coarse soils; all conventional; all spring application
Corn Acreage based on 2001 Census of Agriculture, Statistics Canada information;
Initial application rate region specific, 120-170 kgN/ha

## 4.3 Reduced N fertilizer use with fertilizer technologies

Nitrogen emission reductions from the potential use of fertilizer technologies assumed a 10% reduction in fertilizer use across all corn land. This reduction in use resulted in $CO_2$ equivalent reductions (Table 4.3) proportionately lower than the previous scenarios. The combined estimate from both provinces is approximately 220kt$CO_2$ equivalent reduced annually and represents around a 0.16t $CO_2$ e/ha reduction.

*Table 4.3: Reduction in N2O emissions resulting from the use of fertilizer technologies to reduce N use, assumed 10% reduction*

| Region | NCGAVS | | GHGfarm | |
|---|---|---|---|---|
| | t CO2 e per ha | kt CO2 e regional | t CO2 e per ha | kt CO2 e regional |
| Quebec | 0.16 | 78.3 | 0.15 | 70.8 |
| Bas-Saint-Laurent - (CAR) | | 0.3 | | 0.2 |
| Saguenay--Lac-Saint-Jean/Côte-Nord - (CAR) | | 0.3 | | 0.3 |
| Québec - (CAR) | | 0.6 | | 0.6 |

| | | | | |
|---|---|---|---|---|
| Mauricie - (CAR) | | 3.2 | | 2.9 |
| Estrie - (CAR) | | 1.6 | | 1.5 |
| Montréal/Laval - (CAR) | | 0.2 | | 0.2 |
| Lanaudière - (CAR) | | 6.3 | | 5.7 |
| Outaouais - (CAR) | | 0.8 | | 0.7 |
| Laurentides - (CAR) | | 2.1 | | 1.9 |
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | | <0.1 | | <0.1 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | | <0.1 | | <0.1 |
| Chaudière-Appalaches - (CAR) | | 4.0 | | 3.6 |
| Montérégie - (CAR) | | 45.8 | | 41.4 |
| Centre-du-Québec - (CAR) | | 13.1 | | 11.8 |
| | | | | |
| Ontario | 0.16 | 154.0 | 0.15 | 139.1 |
| Southern Ontario Region - (CAR) | | 71.6 | | 64.7 |
| Western Ontario Region - (CAR) | | 52.0 | | 46.9 |
| Central Ontario Region - (CAR) | | 13.0 | | 11.7 |
| Eastern Ontario Region - (CAR) | | 17.4 | | 15.7 |
| Northern Ontario Region - (CAR) | | 0.2 | | 0.2 |

*Notes:
Calculation: N rate * 0.10 reduction * method (NCGAVS or GHGFarm) * $N_2Oe$ * $CO_2e$ * corn ha
NCGAVS (full explanation of equations given in Appendix Table A1-4)
Direct and indirect losses $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH\ +\ RUNOFF}$
GHGFarm (full explanations of equations given in appendix Table A1-5)
Direct and indirect losses $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP\ +\ RUNOFF}$
Assumptions: ½ fine soils, ½ coarse soils; all conventional; all spring application
Corn Acreage based on 2001 Census of Agriculture, Statistics Canada information;
Application rate region specific, 120-170 kgN/ha

### 4.4 Reduced N fertilizer use with manure N replacement

Assigning the reduced fertilizer use with the estimated over-application of manure (10% for Quebec; 2% for Ontario) resulted in significantly greater nitrogen emission reduction potential in Quebec than Ontario (Table 4.4). The combined estimate is approximately 100kt$CO_2$ equivalent reduced annually.

*Table 4.4: Reduction in $N_2O$ emissions resulting from Manure N replacing fertilizer N, assume provincial reduction level*

| Region | NCGAVS | | GHGfarm | |
|---|---|---|---|---|
| | t CO2 e per ha | kt CO2 e regional | t CO2 e per ha | kt CO2 e regional |
| Quebec (10% reduction) | 0.16 | 78.3 | 0.15 | 70.8 |
| Bas-Saint-Laurent - (CAR) | | 0.3 | | 0.2 |
| Saguenay--Lac-Saint-Jean/Côte-Nord - (CAR) | | 0.3 | | 0.3 |
| Québec - (CAR) | | 0.6 | | 0.6 |
| Mauricie - (CAR) | | 3.2 | | 2.9 |
| Estrie - (CAR) | | 1.6 | | 1.5 |
| Montréal/Laval - (CAR) | | 0.2 | | 0.2 |
| Lanaudière - (CAR) | | 6.3 | | 5.7 |
| Outaouais - (CAR) | | 0.8 | | 0.7 |
| Laurentides - (CAR) | | 2.1 | | 1.9 |

| | | | | |
|---|---|---|---|---|
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | | <0.1 | | <0.1 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | | <0.1 | | <0.1 |
| Chaudière-Appalaches - (CAR) | | 4.0 | | 3.6 |
| Montérégie - (CAR) | | 45.8 | | 41.4 |
| Centre-du-Québec - (CAR) | | 13.1 | | 11.8 |
| | | | | |
| Ontario (2% reduction) | 0.03 | 30.8 | 0.03 | 27.8 |
| Southern Ontario Region - (CAR) | | 14.3 | | 12.9 |
| Western Ontario Region - (CAR) | | 10.4 | | 9.4 |
| Central Ontario Region - (CAR) | | 2.6 | | 2.3 |
| Eastern Ontario Region - (CAR) | | 3.5 | | 3.2 |
| Northern Ontario Region - (CAR) | | 0.0 | | 0.0 |

*Notes:
Calculation: N rate * 0.10 or 0.02 reduction * method (NCGAVS or GHGFarm) * $N_2Oe$ * $CO_2e$ * corn ha
NCGAVS emissions from nutrient application (full explanation of equations given in Appendix Table A1-4)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH} + _{RUNOFF}$
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN} + _{RUNOFF}$
GHGFarm (full explanations of equations given in Appendix Table A1-5)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP} + _{RUNOFF}$
Assumptions: ½ fine soils, ½ coarse soils; all conventional; all spring application
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN} + _{RUNOFF}$
Assumptions: ½ fine soils, ½ coarse soils; all conventional ; 1/2 spring and ½ fall application
Corn Acreage based on 2001 Census of Agriculture, Statistics Canada information;
Initial application rate region specific at 120-170 kgN/ha
Manure N based on animal numbers from 2001Statistics Canada information, and NCGAVS manure excretion and average N information. Swine, beef, dairy, and poultry production were considered.

## 4.5 Reduced N fertilizer use with increased manure use efficiency

The similar livestock populations of the predominant farm types of dairy, hog and poultry were reflected in similar generated manure values (Table 4.5). When the 10% increased efficiency in manure nitrogen use for crop production is converted to CO2 equivalent amounts, the potential for reduction is also similar. Although the hog and poultry populations are similar in Ontario and Quebec, the larger beef industry in Ontario accounts for the observed difference between the provinces. The combined estimate is approximately 210 (NCGAVS) to 270 (GHGfarm) kt $CO_2$ equivalent reduced annually. This modest 10% improvement in manure N efficiency resulted in reduced emissions greater in magnitude than scenario 3 where corn fertilizer N was reduced by 10%.

*Table 4.5: Reduction in N2O emissions resulting from application of manure N at reduced fertilizer rate, 10% efficiency increase*

| Region | NCGAVS | | GHGfarm | |
|---|---|---|---|---|
| | 10% available manure N saved, kg | kt CO2 e reduction | 10% available manure N saved, kg | kt CO2 e reduction |
| Newfoundland and Labrador | 51,335 | 0.5 | 70,029 | 0.7 |
| Prince Edward Island | 413,470 | 4.3 | 571,179 | 5.4 |
| Nova Scotia | 606,169 | 6.4 | 851,755 | 8.1 |
| New Brunswick | 520,635 | 5.5 | 735,007 | 7.0 |
| | | | | |
| Quebec | 8,852,456 | 92.9 | 12,643,795 | 119.8 |
| Bas-Saint-Laurent - (CAR) | 581,860 | 6.1 | 796,187 | 7.5 |
| Saguenay--Lac-Saint-Jean/Côte- | 287,235 | 3.0 | 388,634 | 3.7 |

| | | | | |
|---|---|---|---|---|
| Nord - (CAR) | | | | |
| Québec - (CAR) | 255,051 | 2.7 | 361,664 | 3.4 |
| Mauricie - (CAR) | 365,453 | 3.8 | 513,425 | 4.9 |
| Estrie - (CAR) | 745,422 | 7.8 | 1,035,530 | 9.8 |
| Montréal/Laval - (CAR) | 6,894 | 0.1 | 9,192 | 0.1 |
| Lanaudière - (CAR) | 469,718 | 4.9 | 699,132 | 6.6 |
| Outaouais - (CAR) | 276,131 | 2.9 | 369,544 | 3.5 |
| Laurentides - (CAR) | 228,069 | 2.4 | 312,428 | 3.0 |
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | 246,830 | 2.6 | 330,005 | 3.1 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | 43,016 | 0.5 | 57,354 | 0.5 |
| Chaudière-Appalaches - (CAR) | 1,871,268 | 19.6 | 2,722,561 | 25.8 |
| Montérégie - (CAR) | 2,131,686 | 22.4 | 3,119,567 | 29.6 |
| Centre-du-Québec - (CAR) | 1,292,180 | 13.6 | 1,843,314 | 17.5 |
| | | | | |
| Ontario | 11,492,551 | 120.5 | 16,145,088 | 153.0 |
| Southern Ontario Region - (CAR) | 2,766,968 | 29.0 | 4,034,186 | 38.2 |
| Western Ontario Region - (CAR) | 5,267,963 | 55.3 | 7,435,100 | 70.5 |
| Central Ontario Region - (CAR) | 1,226,667 | 12.9 | 1,670,121 | 15.8 |
| Eastern Ontario Region - (CAR) | 1,766,954 | 18.5 | 2,384,342 | 22.6 |
| Northern Ontario Region - (CAR) | 461,834 | 4.8 | 617,872 | 5.9 |

*Notes:
Calculation: head * N excreted *(1-storage loss) * 0.10 reduction* method (NCGAVS or GHGFarm) * $N_2Oe$ * $CO_2e$
NCGAVS emissions from nutrient application (full explanation of equations given in Appendix Table A1-4)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH + RUNOFF}$
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN + RUNOFF}$
GHGFarm (full explanations of equations given in Appendix Table A1-5)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP + RUNOFF}$
Assumptions: ½ fine soils, ½ coarse soils; all conventional; all spring application
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN + RUNOFF}$
Assumptions: ½ fine soils, ½ coarse soils; all conventional; 1/2 spring and ½ fall application
Manure N based on animal numbers from 2001Census of Agriculture, Statistics Canada information, and NCGAVS manure excretion and average N information. Swine, beef, dairy, and poultry production were considered. Animal types included: cattle (dairy cow, beef cow, bulls, heifers, steers, calves <1yr), poultry (broilers, layers, turkeys), swine

## 4.6 Increased manure N use efficiency with application timing

The GHG emission levels attributed to manure using both methods and assumptions was almost twice the amount using the GHG farm model over the NCGAVS method (Table 4.6). From the GHG values, the potential savings in adjusting the timing of manure application was investigated. The GHGfarm model contains the fall and spring coefficient and when compared for all manures, indicated a potential emission reduction of 12% with the full adoption of spring applied manure compared to a 50/50 distribution. The combined provincial reduction of approximately 560kt $CO_2$ e annually was similar in magnitude to fertilizer reduction levels of around 25%.

*Table 4.6: Reduction in N2O emissions resulting from changes in application timing: spring vs. fall (50%/50% assumed to 100% spring)*

| Region | NCGAVS | GHGfarm | GHGfarm Difference |
|---|---|---|---|
| | kt CO2 e | kt CO2 e | kt CO2 e |
| Newfoundland and Labrador | 4.9 | 10.1 | 1.2 |

| | | | |
|---|---|---|---|
| *spring only* | | 8.9 | |
| Prince Edward Island | 47.9 | 93.9 | 11.0 |
| *spring only* | | 82.8 | |
| Nova Scotia | 72.8 | 138.3 | 16.5 |
| *spring only* | | 121.8 | |
| New Brunswick | 63.2 | 119.3 | 14.3 |
| *spring only* | | 105.1 | |
| | | | |
| Quebec | 1,252.7 | 2,024.5 | 245.5 |
| *spring only* | | *1,778.9* | |
| Bas-Saint-Laurent - (CAR) | 79.4 | 129.3 | 15.5 |
| *spring only* | | *113.9* | |
| Saguenay--Lac-Saint-Jean/Côte-Nord - | 38.7 | 63.2 | 7.5 |
| *spring only* | | *55.6* | |
| Québec - (CAR) | 35.9 | 57.8 | 7.0 |
| *spring only* | | *50.7* | |
| Mauricie - (CAR) | 51.1 | 91.2 | 11.1 |
| *spring only* | | *80.1* | |
| Estrie - (CAR) | 102.6 | 168.0 | 20.1 |
| *spring only* | | *147.9* | |
| Montréal/Laval - (CAR) | 0.9 | 1.6 | 0.2 |
| *spring only* | | *1.4* | |
| Lanaudière - (CAR) | 68.4 | 108.6 | 13.6 |
| *spring only* | | *95.0* | |
| Outaouais - (CAR) | 37.3 | 63.2 | 7.2 |
| *spring only* | | *56.0* | |
| Laurentides - (CAR) | 29.5 | 50.9 | 6.1 |
| *spring only* | | *44.8* | |
| Abitibi-Témiscamingue/Nord-du-Québec - | 33.2 | 55.5 | 6.4 |
| *spring only* | | *49.1* | |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | 5.8 | 9.8 | 1.1 |
| *spring only* | | *8.7* | |
| Chaudière-Appalaches - (CAR) | 269.4 | 430.2 | 52.9 |
| *spring only* | | *377.3* | |
| Montérégie - (CAR) | 307.8 | 494.1 | 60.6 |
| *spring only* | | *433.5* | |
| Centre-du-Québec - (CAR) | 182.5 | 297.5 | 35.8 |
| *spring only* | | *261.7* | |
| | | | |
| Ontario | 1,601.6 | 2,643.5 | 313.5 |
| *spring only* | | *2,330.0* | |
| Southern Ontario Region - (CAR) | 396.8 | 644.3 | 78.3 |
| *spring only* | | *566.0* | |
| Western Ontario Region - (CAR) | 737.1 | 1,218.3 | 144.4 |
| *spring only* | | *1,073.9* | |
| Central Ontario Region - (CAR) | 166.9 | 279.4 | 32.4 |
| *spring only* | | *247.0* | |
| Eastern Ontario Region - (CAR) | 238.3 | 395.9 | 46.3 |
| *spring only* | | *349.6* | |
| Northern Ontario Region - (CAR) | 62.2 | 105.1 | 12.0 |
| *spring only* | | *93.1* | |

*Notes:
Calculation: head * N excreted *(1-storage loss) * method (NCGAVS or GHGFarm(50/50 and all spring) * $N_2Oe$ * $CO_2e$
NCGAVS emissions from nutrient application (full explanation of equations given in Appendix Table A1-4)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH} + _{RUNOFF}$
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN} + _{RUNOFF}$

GHGFarm (full explanations of equations given in Appendix Table A1-5)

Direct and indirect losses from fertilizer $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP\ +\ RUNOFF}$

Assumptions: ½ fine soils, ½ coarse soils; all conventional; all spring application

Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN\ +\ RUNOFF}$

Assumptions: ½ fine soils, ½ coarse soils; all conventional; initial1/2 spring and ½ fall application, modified to all spring

## 4.7 Increased manure N use efficiency with application incorporation

The potential GHG emission reduction with incorporation utilized OMAFRA N availability values for the different livestock types and was extrapolated to the Atlantic Provinces. The NCGAVS method calculations resulted in values that were approximately 75% of the GHGfarm model. While the Atlantic Provinces were low, the Quebec values approached the Ontario figures for a combined reduction of around 150 kt $CO_2$ e annually using NCGAVS and approximately 200kt $CO_2$ e from the GHGfarm model method.

*Table 4.7: Reduction in N2O emissions resulting from changes in manure application practices: incorporation vs. surface application (50%/50% assumed to 100% incorporationg)*

| Region | NCGAVS | GHG |
|---|---|---|
| | kt CO2 e | kt CO2 e |
| Newfoundland and Labrador | <1 | <1 |
| Prince Edward Island | 3 | 3 |
| Nova Scotia | 4 | 5 |
| New Brunswick | 3 | 4 |
| | | |
| Quebec | 62 | 82 |
| Bas-Saint-Laurent - (CAR) | 4 | 5 |
| Saguenay--Lac-Saint-Jean/Côte-Nord - (CAR) | 2 | 2 |
| Québec - (CAR) | 2 | 2 |
| Mauricie - (CAR) | 3 | 3 |
| Estrie - (CAR) | 5 | 6 |
| Montréal/Laval - (CAR) | <1 | <1 |
| Lanaudière - (CAR) | 4 | 5 |
| Outaouais - (CAR) | 2 | 2 |
| Laurentides - (CAR) | 1 | 2 |
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | 1 | 2 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | <1 | <1 |
| Chaudière-Appalaches - (CAR) | 14 | 20 |
| Montérégie - (CAR) | 17 | 22 |
| Centre-du-Québec - (CAR) | 9 | 12 |
| | | |
| Ontario | 73 | 95 |
| Southern Ontario Region - (CAR) | 20 | 27 |
| Western Ontario Region - (CAR) | 35 | 45 |
| Central Ontario Region - (CAR) | 7 | 8 |

| | | |
|---|---|---|
| Eastern Ontario Region - (CAR) | 10 | 12 |
| Northern Ontario Region - (CAR) | 3 | 3 |

*Notes:
Calculation: head * N excreted * (1-storage loss) * method (NCGAVS or GHGFarm) * Navailable(baseline – full incorporation) * $N_2Oe$ * $CO_2e$
NCGAVS emissions from nutrient application (full explanation of equations given in Appendix Table A1-4)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH} + _{RUNOFF}$
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN} + _{RUNOFF}$
Assumes reduction in manure application (MG/ha) with incorporation due to reduced N losses according to Appendix Table A2-1
GHGFarm (full explanations of equations given in Appendix Table A1-5)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP} + _{RUNOFF}$
Assumes ½ fine soils, ½ coarse soils; all conventional; all spring application
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN} + _{RUNOFF}$
Assumes ½ fine soils, ½ coarse soils; all conventional; 1/2 spring and ½ fall application
Assumes reduction in manure application (MG/ha) with incorporation due to reduced N losses according to Appendix Table A2-1
Assumptions from Table A2-1: incorporation N availability an average of bare soil or residue
animal type: swine – “liquid swine”; cattle – “solid cattle/sheep”; poultry – “solid broilers”
Navailable: swine – 0.22, cattle – 0.09, poultry – 0.09 (relative value of solid layers/pullets/broilers)
spring application
baseline: half of manure incorporated within 3 days (swine–0.11, cattle–0.05, poultry–0.05 Navailable)

## 4.8 Increased manure N use efficiency with spring and side-dress application

This scenario relied on the OMAFRA values instead of GHGfarm model coefficients to determine the increased reduction of emission by applying manure in the spring or side-dress compared to a baseline of a combination of fall and spring periods. The opportunity to apply liquid manure at side-dress and reduce N fertilizer use was considered for swine manure only. The increase in N availability with all spring application and therefore the decrease in GHG emission with the reduced use of equivalent fertilizer N resulted in Quebec and Ontario having modest savings of around 110 to 150 kt CO2 e annually for the NCGAVS and GHG farm method, respectively. When considering the potential liquid swine manure use as a side-dress application, the emission reduction is greater than the spring application for all manure combined for Quebec and slightly lower in Ontario (Table 4.8).

*Table 4.8: Reduction in N2O emissions resulting from changes in LIQUID SWINE manure application practices spring application vs. side-dress (50%/50% “late” fall/spring (“pre plant”) assumed to 100% spring to 100% side-dress)*

| Region | Spring (All) | | Side-dress (Swine) | |
|---|---|---|---|---|
| | NCGAVS | GHGfarm | NCGAVS | GHGfarm |
| | kt CO2 e | kt CO2 e | kt CO2 e | kt CO2 e |
| Newfoundland and Labrador | <1 | <1 | <1 | <1 |
| Prince Edward Island | 2 | 3 | 2 | 3 |
| Nova Scotia | 3 | 4 | 2 | 3 |
| New Brunswick | 3 | 3 | 2 | 3 |
| | | | | |
| Quebec | 52 | 69 | 62 | 90 |
| Bas-Saint-Laurent - (CAR) | 3 | 4 | 2 | 3 |
| Saguenay--Lac-Saint-Jean/Côte-Nord - (CAR) | 1 | 2 | <1 | <1 |
| Québec - (CAR) | 1 | 2 | 1 | 2 |
| Mauricie - (CAR) | 2 | 3 | 3 | 4 |
| Estrie - (CAR) | 4 | 5 | 4 | 6 |
| Montréal/Laval - (CAR) | <1 | <1 | <1 | <1 |

| | | | | |
|---|---|---|---|---|
| Lanaudière - (CAR) | 3 | 4 | 4 | 6 |
| Outaouais - (CAR) | 1 | 1 | <1 | <1 |
| Laurentides - (CAR) | 1 | 1 | 1 | 1 |
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | 1 | 1 | <1 | <1 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | <1 | <1 | <1 | <1 |
| Chaudière-Appalaches - (CAR) | 12 | 17 | 18 | 26 |
| Montérégie - (CAR) | 14 | 19 | 21 | 31 |
| Centre-du-Québec - (CAR) | 8 | 10 | 9 | 13 |
| | | | | |
| Ontario | 60 | 78 | 51 | 73 |
| Southern Ontario Region - (CAR) | 16 | 22 | 20 | 30 |
| Western Ontario Region - (CAR) | 29 | 37 | 27 | 40 |
| Central Ontario Region - (CAR) | 5 | 7 | 1 | 2 |
| Eastern Ontario Region - (CAR) | 8 | 9 | 1 | 2 |
| Northern Ontario Region - (CAR) | 2 | 2 | <1 | <1 |

*Notes:

Calculation: head * N excreted * (1-storage loss) * method (NCGAVS or GHGFarm) * Navailable(baseline – time) * $N_2Oe$ * $CO_2e$

NCGAVS emissions from nutrient application (full explanation of equations given in Appendix Table A1-4)

Direct and indirect losses from fertilizer $N_2O\text{-}N_{fert}$ + $N_2O\text{-}N_{VOLATfert}$ + $N_2O\text{-}N_{LEACH + RUNOFF}$

Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED}$ + $N_2O_{VOLAT\ MAN}$ + $N_2O_{LEACH\ MAN + RUNOFF}$

Assumes reduction in manure application (Mg/ha) with side-dress according to Appendix Table A2-1

GHGFarm (full explanations of equations given in Appendix Table A1-5)

Direct and indirect losses from fertilizer $N_2O\text{-}N_{FERT}$ + $N_2O\text{-}N_{VOLAT\ CROP}$ + $N_2O\text{-}N_{LEACH\ CROP + RUNOFF}$

Assumes ½ fine soils, ½ coarse soils; conventional tillage; all spring application

Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED}$ + $N_2O_{VOLAT\ MAN}$ + $N_2O_{LEACH\ MAN + RUNOFF}$

Assumes ½ fine soils, ½ coarse soils; conventional tillage; 1/2 spring and ½ fall application

Assumes reduction in manure application (Mg/ha) with spring and side-dress according to Appendix Table A2-1

Assumptions from Table A2-1: incorporation of manure <24 hours

animal type: swine – “liquid swine”; cattle – “solid cattle/sheep”; poultry – “solid broilers”

Navailable: swine – 0.22, cattle – 0.09, poultry – 0.09 (relative value of solid layers/pullets/broilers)

spring application

baseline: manure evenly distributed between early fall, late fall, pre-plant

pre-plant Navailable difference: swine–0.10, cattle–0.04, poultry–0.03;

side-dress Navailable difference: swine-0.24 (solid manure not practical at side-dress)

### 4.9 Increased manure N use efficiency with more frequent barn cleanout

The amount of reduction of GHG emission from improved manure handling and cleanout practices in the barn is a relatively modest reduction when compared to other scenarios. Regionally, as was observed for all manure scenarios, the values are relatively low for almost all regions except for a couple more densely populated regions in both Quebec and Ontario. The combined totals range from around 100kt CO2 e annually using the GHGfarm model to close to 150kt CO2e annually from the NCGAVS calculation (Table 4.9).

*Table 4.9: Reduction in N2O emissions resulting from changes in manure handling/ cleanout practices (one day cleanout)*

| Region | NCGAVS | GHG |
|---|---|---|
| | kt CO2 e | kt CO2 e |
| Newfoundland and Labrador | <1 | <1 |
| Prince Edward Island | 3 | 2 |
| Nova Scotia | 5 | 3 |

| | | |
|---|---|---|
| New Brunswick | 4 | 3 |
| | | |
| Quebec | 69 | 45 |
| Bas-Saint-Laurent - (CAR) | 4 | 3 |
| Saguenay--Lac-Saint-Jean/Côte-Nord - (CAR) | 2 | 1 |
| Québec - (CAR) | 2 | 1 |
| Mauricie - (CAR) | 3 | 2 |
| Estrie - (CAR) | 6 | 4 |
| Montréal/Laval - (CAR) | <1 | <1 |
| Lanaudière - (CAR) | 4 | 3 |
| Outaouais - (CAR) | 2 | 1 |
| Laurentides - (CAR) | 2 | 1 |
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | 2 | 1 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | <1 | <1 |
| Chaudière-Appalaches - (CAR) | 15 | 10 |
| Montérégie - (CAR) | 17 | 11 |
| Centre-du-Québec - (CAR) | 10 | 7 |
| | | |
| Ontario | 87 | 57 |
| Southern Ontario Region - (CAR) | 22 | 14 |
| Western Ontario Region - (CAR) | 40 | 26 |
| Central Ontario Region - (CAR) | 9 | 6 |
| Eastern Ontario Region - (CAR) | 13 | 9 |
| Northern Ontario Region - (CAR) | 3 | 2 |

*Notes:
Calculation: head * N excreted * % loss reduction * method (NCGAVS or GHGFarm) * $N_2Oe$ * $CO_2e$
NCGAVS emissions from nutrient application (full explanation of equations given in Appendix Table A1-4)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH + RUNOFF}$
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN + RUNOFF}$
Assumes reduction in manure application (MG/ha) with incorporation due to reduced N losses during manure handling of 15% of the storage and handling losses from NCGAVS.
GHGFarm (full explanations of equations given in Appendix Table A1-5)
Direct and indirect losses from fertilizer $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP + RUNOFF}$
Assumes ½ fine soils, ½ coarse soils; conventional tillage; all spring application
Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN + RUNOFF}$
Assumes ½ fine soils, ½ coarse soils; conventional tillage; 1/2 spring and ½ fall application
Assumes reduction in manure application (MG/ha) with incorporation due to reduced N losses during manure handling of 15% of the storage and handling losses from GHGFarm.
Loss reduction example:
GHGfarm – 30% of 20%/2 is 3% for all manure excreted;
NCGAVS – cattle 30% of 40%/2 is 6%; poultry 30% of 50%/2 is 7.5%; swine 30% of 50%/2 is 7.5%

### 4.10 Increased manure N use efficiency with storage covers

With the introduction of covering manure storages, the emission reduction was relatively significant when compared to the other manure management scenarios. The NCGAVS method exceeded 400 kt CO2 e annually in values whereas the GHGfarm model method was less than 300kt CO2 e annually. The magnitude of this potential practice is similar to the range determined from incorporation of land-applied manures.

*Table 4.10: Reduction in N2O emissions resulting from changes in manure storage practices: utilization of covers*

| Region | NCGAVS | GHG |
|---|---|---|
| | kt CO2 e | kt CO2 e |
| Newfoundland and Labrador | 1 | 1 |
| Prince Edward Island | 8 | 5 |
| Nova Scotia | 12 | 8 |
| New Brunswick | 11 | 7 |
| | | |
| Quebec | 183 | 120 |
| Bas-Saint-Laurent - (CAR) | 11 | 8 |
| Saguenay--Lac-Saint-Jean/Côte-Nord - (CAR) | 6 | 4 |
| Québec - (CAR) | 5 | 3 |
| Mauricie - (CAR) | 7 | 5 |
| Estrie - (CAR) | 15 | 10 |
| Montréal/Laval - (CAR) | <1 | <1 |
| Lanaudière - (CAR) | 10 | 7 |
| Outaouais - (CAR) | 5 | 4 |
| Laurentides - (CAR) | 5 | 3 |
| Abitibi-Témiscamingue/Nord-du-Québec - (CAR) | 5 | 3 |
| Gaspésie--Îles-de-la-Madeleine - (CAR) | 1 | 1 |
| Chaudière-Appalaches - (CAR) | 40 | 26 |
| Montérégie - (CAR) | 45 | 30 |
| Centre-du-Québec - (CAR) | 27 | 18 |
| | | |
| Ontario | 232 | 153 |
| Southern Ontario Region - (CAR) | 59 | 38 |
| Western Ontario Region - (CAR) | 107 | 71 |
| Central Ontario Region - (CAR) | 24 | 16 |
| Eastern Ontario Region - (CAR) | 34 | 23 |
| Northern Ontario Region - (CAR) | 9 | 6 |

*Notes:

Calculation: head * N excreted * % loss reduction * method (NCGAVS or GHGFarm) * $N_2Oe$ * $CO_2e$

NCGAVS emissions from nutrient application (full explanation of equations given in Appendix Table A1-4)

Direct and indirect losses from fertilizer $N_2O\text{-}N_{fert} + N_2O\text{-}N_{VOLATfert} + N_2O\text{-}N_{LEACH} + _{RUNOFF}$

Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN} + _{RUNOFF}$

Assumes reduction in manure application (MG/ha) with incorporation due to reduced N losses during manure handling of 80%/2=40% of the storage and handling losses from NCGAVS.

GHGFarm (full explanations of equations given in Appendix Table A1-5)

Direct and indirect losses from fertilizer $N_2O\text{-}N_{FERT} + N_2O\text{-}N_{VOLAT\ CROP} + N_2O\text{-}N_{LEACH\ CROP} + _{RUNOFF}$

Assumes ½ fine soils, ½ coarse soils; conventional tillage; all spring application

Direct and indirect losses from manure applied $N_2O_{MAN\ APPLIED} + N_2O_{VOLAT\ MAN} + N_2O_{LEACH\ MAN} + _{RUNOFF}$

Assumes ½ fine soils, ½ coarse soils; conventional tillage; 1/2 spring and ½ fall application

Assumes reduction in manure application (MG/ha) with incorporation due to reduced N losses during manure handling of 80%/2=40% of the storage and handling losses from GHGFarm.

Loss reduction calculation:

GHGfarm – 80% of 20%/2 is 8% for all manure excreted;

NCGAVS – cattle 80% of 40%/2 is 16%; poultry 80% of 50%/2 is 20%; swine 80% of 50%/2 is 20%

## 4.11 Economic Impacts

### 4.11.1 Ranking of impacts of practice changes on management, production costs and benefits.

The practices described above have been assigned subjective (high, medium, low) estimates of the magnitude of changes in costs (management and dollars) and revenues for a practice change, and are listed in Table 4.11.1. Appendix 3 contains a more complete description of the costs and revenues for each practice.

The implementation of nutrient management practices to reduce GHG emissions comes with a range of costs and benefits to producers. Table 4.11.1 provides a qualitative assessment of the producer costs and benefits relative to the range of nutrient management practices proposed.

Reduced nitrogen fertilizer application (Scenarios 1 and 2) lead to high reduction of $N_2O$ emissions with low cost to the producer and high potential benefit resulting from a reduction in fertilizer costs. On the other hand, practices such as manure composting lead to low GHG reductions, but are associated with high costs and low benefits.

Beyond considerations of GHG reductions there are significant barriers to adoption of these practices by producers, and some of these are listed below.

1. Reduction in fertilizer according to a nutrient management calculator
    - Perception of extra fertilizer as 'crop insurance'

2. Reduction in fertilizer according to PSNT testing
    - Perception of extra fertilizer as 'crop insurance'
    - Time to take the soil tests during a heavy schedule season
    - Turnaround time for tests, and missed weather opportunities

3. Reduction in fertilizer with ESN or other fertilizer technologies
    - Lack of unequivocal data
    - Extra cost

4. Replacement of fertilizer with manure
    - Distance to spread
    - Requirement for manure and soil tests
    - Time

5. Spring vs fall application
    - Requirement to spread in a busy season
    - Variable weather

6. Incorporation
    - Requirement of new or modified equipment
    - Extra time and fuel if not done at the same time as spreading

7. Side dress injection
    - Requirement for new or modified equipment

It should be noted that crop prices will be an overriding consideration for all these practices. On one hand, high crop prices will increase resistance to reduced fertilizer applications, while low prices will lead to resistance to any practice that increase costs.

Because of these barriers, adoption levels are not expected to be very high for most of the practices in the absence of incentive measures such as the following:

- Recognition and awards
- Education, linkages with other environmental measures
- Financial incentives/ cost sharing strategies/ subsidies
- Support programs
- Tax incentives (reductions or rebates)
- Legislation

Furthermore, it is clear that incentives may need to vary depending on the size of operation. For example, if a practice change requires new equipment, the relative cost will be lower for a large operator than for a small operator. Financial incentives, therefore, would need to reflect operation size.

*Table 4.11.1: Economic impacts of management practice changes*

| Nutrient Management Practices | $N_2O$ reduction (kt $CO_2$-e for total area) | Producer Costs | | | | Producer Benefits | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Practice admin. time | Practice time | Capital / other costs | Offset admin costs | Reduction in time | Reduction in fert. costs | Increased net revenue | Offset revenue |
| Land Application of Nitrogen | | | | | | | | | |
| 1. reduced N use with N rec. calculator | H (420-460) | L | N | 0 | H | 0 | H | H | M |
| 2. Pre-sidedress nitrate test (PSNT) for corn N use at lower N rate | H (750-800) | L | M | M | H | negative | H | H | M |
| 3. Fertilizer technologies | M (210-240) | L | N | M | H | 0-M | <0-L | L | L |
| 4. Manure N replacing fertilizer N | L-M (100-270) | L | M | 0-M | H | negative | M-H | H | L |
| 5. manure N application method | | | | | | | | | |
| timing spring | M (210-270) | 0 | 0-M | 0 | H | 0 | L-M | L | L |
| incorporation | L (150-200) | 0 | L-M | M-H | H | 0-negative | L-M | L | L |
| spring (OMAFRA) | L (110-150) | 0 | 0-M | 0 | H | 0 | L-M | L | L |
| sidedress | L (110-160) | 0 | L-M | M-H | H | 0-negative | L-M | L | L |
| Manure Storage & Handling | | | | | | | | | |
| 6. manure storage -covers | M (300-400) | L | L | M-H | H | negative | L-M | L | 0 |
| 7. manure handling/ cleanout | L (100-150) | L | M-H | M-H | H | negative | L | L | 0 |
| 7. manure treatment | | | | | | | | | |
| composting | Not determined | H | H | H | H | negative | L | <0-L | 0 |
| digestion | | H | H | H | H | negative | L | <0-H | H? |

### 4.11.2 Offset transaction costs

The $CO_{2eqv}$ emission reductions and gross income of fertilizer reduction by 20% were estimated for different land areas [1 ha to 100,000 ha] (Table 4.11.2.1). The project costs were calculated and reported as total costs [last column], and on a per hectare basis based on the information supplied in the 2004 Marbeck report. The net income per hectare is calculated by multiplying the tonnes of $CO_{2eqv}$ minus the project cost per hectare. The cost to generate the tonne of $CO_{2eqv}$ is calculated by dividing the total project costs by the number of tonnes of offsets generated. These calculations were performed for the 6 different project areas. The calculations were performed in a spreadsheet so that different prices and costs could be easily modified.

*Table 4.11.2.1. Tonnes of CO2eqv, income, and costs of an offset project using reduced N fertilizer use with N recommendation calculator, reported for six different project areas.*

| ha | t CO2e | Gross income | Cost/ha | Net Income/ha | Cost/t CO2 | Trans. Costs |
|---|---|---|---|---|---|---|
| 1 | 0.111 | $1.11 | $44,500.20 | $(44,499.09) | $400,902.70 | $44,500 |
| 50 | 5.55 | $55.50 | $890.20 | $(889.09) | $8,019.82 | $44,510 |
| 500 | 55.5 | $555.00 | $89.20 | $(88.09) | $803.60 | $44,600 |
| 5000 | 555 | $5,550.00 | $9.10 | $(7.99) | $81.98 | $45,500 |
| 50000 | 5550 | $55,500.00 | $1.09 | $0.02 | $9.82 | $54,400 |
| 100000 | 11100 | $111,000.00 | $0.65 | $0.47 | $5.81 | $64,500 |

Table 4.11.2.2 shows the $CO_{2eqv}$, income, and expenses for the PSNT nitrogen management practice that incorporates both the N recommendation calculator and pre-sidedress nitrate testing.

*Table 4.11.2.2. Tonnes of CO2eqv, income, and costs of an offset project using reduced N fertilizer use with N recommendation calculator as well as pre-sidedress N soil testing, reported for six different project areas.*

| ha | t CO2e | Gross income | Cost/ha | Net Income/ha | Cost/t CO2 | Trans. Costs |
|---|---|---|---|---|---|---|
| 1 | 0.1776 | $1.78 | $44,500.20 | $(44,498.42) | $250,564.19 | $44,500 |
| 50 | 8.88 | $88.80 | $890.20 | $(888.42) | $5,012.39 | $44,510 |
| 500 | 88.8 | $888.00 | $89.20 | $(87.42) | $502.25 | $44,600 |
| 5000 | 888 | $8,880.00 | $9.10 | $(7.32) | $51.24 | $45,500 |
| 50000 | 8880 | $88,800.00 | $1.09 | $0.69 | $6.14 | $54,400 |
| 100000 | 17760 | $177,600.00 | $0.65 | $1.13 | $3.63 | $64,500 |

For demonstration purposes, costs for a 1 ha project show the entire project costs, income, and GHG reducing potential on a per hectare basis. By increasing the number of fields in a pooled project, and spreading the fixed project development costs over a larger number of hectares, the net income per hectare breaks even around 50,000 ha. This is heavily dependant on the offset price being fixed at $10 per tonne.

## *5. Conclusions*

The two methods of emissions calculations resulted in small differences for fertilizer application scenarios, but much greater differences for manure application scenarios. For example, a 10% reduction in fertilizer-N applied resulted in about 10% lower emission reductions calculated by the farm model. On the other hand, a 10% reduction in manure application rate resulted in approximately 28%

greater emission reductions calculated by the farm model. This is largely the result of the difference in assessment of N-losses from manure from the different livestock categories prior to field application.

The potential GHG reductions for Ontario and Quebec resulting from changes in nutrient management practices calculated above are in the range of 100 to 750 kt $CO_2$-equivalents, which are all less than ten percent of the overall provincial emissions from soils for 2003 (8200kt $CO_2$-e for both provinces combined) or less than 4% of overall agricultural GHG emissions for the two provinces (18,200kt).

A combination of reduction of 20% fertilizer N use on corn based on the OMAFRA calculator and further reduction based on the soil pre-sidedress nitrate test (PSNT) resulted in the greatest overall emission reductions. Manure management practices such as spring versus fall application, incorporation or sidedress also resulted in significant reductions. Changes in manure handling and storage systems had smaller effects, but it should be noted that this study only considered these practices in terms of nutrient management. Changes in methane emissions were not determined.

Combinations of practices should have an additive effect. Further, the assessment here is only for nitrogen management aspects of production. Other GHG reducing management practices not considered here, such as alterations of feed rations to reduce enteric emissions or excretion, can also be combined to achieve greater overall reductions.

The calculations showed GHG emission reductions of about 0.2t$CO_2$-e per hectare per year, which are similar to reductions expected from improved management practices in pasture and forage management (Martin and Fredeen, 1999). Furthermore, the reductions would occur on an annual basis as long as the practice was utilized, unlike management changes designed to increase C-sequestration, which has a maximum potential increase in SOC. For example, adoption of no-till practices in the Prairies, considered to be one of the best potential practices for the western regions, results in an increase in approximately 2.9 Mg C per hectare to its maximum after about twenty years (VandenBygaart et al. 2003) or an average of about 0.5t $CO_2$-e per hectare per year, with no increase after the maximum SOC is reached.

The calculations of offsets costs and credits indicate that these credits alone will not be sufficient alone to induce practice changes. However, increased adoption through aggregation of producers, with the result of shared management costs for new practices, will result in higher net benefits for individual producers. Reduced fertilizer costs for the proposed scenarios will be a major incentive.

Calculations for the provinces were done for the *potential* emission reductions, or 100% adoption rate, which is unlikely to occur given the barriers to adoption. However, the assessment here is only for nitrogen management aspects of production. Other GHG reducing management practices not considered here, such as alterations of feed rations to reduce enteric emissions, can be added to achieve greater overall reductions.

Current Canada specific emission coefficients were used to determine GHG reduction projections. From the investigation of improved nutrient management practices, it has been found that by greater optimization of fertilizer and manure nitrogen, substantial reductions in GHG emissions can be realized. The reduction of nitrogen application on corn crops in Ontario and Quebec was a promising approach for farmers to meet the combined goals of emission reductions and profitability. Recommended manure management practices that optimize nitrogen retention for maximum crop nutrient use are also promising but require additional management considerations for similar GHG reductions. The study concludes that full adoption of these known agricultural practices in eastern Canada could lead to reductions in the order of 35% of the annual agricultural soil and manure GHG emissions. Given the financial and time constraints of Canadian farmers, realistic adoption rates of these GHG beneficial practices would be limited.

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**Appendix 1: Comparison of methodologies for calculation of Greenhouse Gas emissions from agricultural systems**

A1.1 IPCC Tier I methodology

IPCC Tier I methodology allows for estimates of GHG emissions using a set of default emission coefficients applicable to that sector. For example, the calculation of nitrous oxide from manure storage systems in Canada involves multiplying the amount of N excreted based on the number and type of livestock by default emission coefficients based on general manure storage systems for northern climates. It does not allow for regional differences in climate, feeding regimes or manure management practices.

A1.2 IPCC Tier II methodology

The IPCC Tier II approach has been developed to enable adjustments in emission coefficients based on country-specific inputs (measurements), as outlined in *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000). The Tier II method takes into differences in climate, feeding regimes, and management.

A1.3 Canadian methodologies for GHG accounting

Both NCGAVS (National Carbon and Greenhouse gas Accounting and Verification System), and the GHGModel farm (Helgason, 2005) are based on Tier II methodology.
The body of research and analyses described above has been used to populate the set of country or region (ecodistrict) specific emission coefficients required to calculate greenhouse gas emissions for overall inventories (NCGAVS) or individual production units (GHG model farm), in accordance with an IPCC II type approach. These coefficients have been derived from experimental field data in an attempt to more closely represent the magnitude of emissions from any particular practice.

For nutrient management, the basic principal behind both methods (NCGAVS, GHG model farm) is to apply the derived emission coefficients to the quantity of nutrients applied. Nitrous oxide emissions, of primary interest when examining nutrient management GHG reduction practices, are a function of N applied (fertilizer, manure, crop residues), and are affected by moisture (Helgason et al. 2005), landscape position (Izaurralde et al. 2004), tillage (Lemke et al. 1999), soil type and texture e.g. clay content, Lemke et al. 1998), nitrate and ammonia (Lemke et al 1998). The methods differ in the factors used, and whether or not adjustments are made for management practices, soil type, climate and topography. The basic formulas and emission coefficients used for each methodology are shown in Tables A1.4 and A1.5.

A1.4 NCGAVS (Rochette et al. 2005)

(Inventory of $N_2O$ Emissions from Canadian Agricultural Soils at the EcoDistrict Scale Using an IPCC Tier II Methodology, Rochette & Worth, 2005)

The NCGAVS is designed as a tool for calculating the overall GHG emissions for a country, and relies data compilations from across the country to derive Canada specific emission coefficients for six regions across the country: Prairies (Brown and Dark Brown), Prairies (Black and Grey), Prairies (Other), Ontario and Quebec, Atlantic and BC.

For N2O emissions, the NCGAVS calculation considers all N applied as commercial fertilizer, manure, crop residues, as well as the N mineralized or immobilized in the soil to be susceptible to the same processes of denitrification and nitrification. The sum of these N sources is then multiplied by site-specific emission factor ($EF_{CTI}$), and then modified by a series of ratio factors that take into account climate (P/PE), tillage factors ($RF_{TILL}$), topography ($RF_{TOPO}$), and spring thaw emissions ($RF_{THAW}$).

The animal manure N from confinement operations is calculated based on the nitrogen excretion rate for each animal type less the fraction of manure N lost by volatilization ($NH_3$, $N_2O$ and $N_2$) for particular manure management systems (18-48% of total manure N). The N excretion rates and volatilization losses are compiled from Canadian and USEPA sources, and are provided in the NCGSVD document. Field applied manure N is then multiplied by the same emission factors described above. Nitrous oxide emissions from pastures are considered separately from confinement operations since the emission coefficients are not the same.

Crop residue N is that amount of N in the crop biomass that is returned to the soil annually after harvest, and is based on the yield and N concentrations in the above and below ground fractions, and the renewal interval of each crop.

Changes in available soil N that results from changes in management practices (which alter the soil organic matter stocks) are also considered in the NCGAVS approach. The amount of soil N that are mineralized or immobilized as a result of management practices are a function of the "magnitude of soil C change, of the C:N ratio of soil organic matter, and the area in which the change in land use or management practice occurred" (Rochette & Worth 2005). $N_{min\text{-}imm}$ is calculated as the difference between the initial and final [soil C stocks times the N:C ratio] for the area under consideration.

For eastern Canada, there is only one $EF_{CTI}$ (0.012) based on a compilation of experimental data where $N_2O$ emissions resulting from N application were measured across all soil types in Eastern Canada. The same P/PE (precipitation/ potential evapotransporation) factor (1.0) is applied for all of Eastern Canada. Compiled eastern data regarding the difference in emissions from conventionally tilled and no-till soils, is not sufficient to modify $EF_{CTI}$, hence $RF_{TILL}$ is set at 1.0. Likewise, there is insufficient data to ascribe different P/PE for upper landscape positions for eastern Canada, and all landscape positions are treated the same (P/PE=1.0). Irrigated crops are treated separately in the equations, but with the exception of potatoes and horticultural crops, this is not a major issue in Eastern Canada. However, because a P/PE of 1.0 is also used for irrigated crops, the overall equations are the same. For the Prairies, emissions from summerfallowing are accounted for separately, but this practice is rare in the eastern regions. Cultivated organic soils, or drained, managed histols are also treated separately from other cropping areas; the emission factor for these soils ($EF_{HISTO}$) is 8 kg $N_2O$-N/ha, according to the Tier I default IPCC Good Practice Guidance. Over 70% of these soils are in Ontario and Quebec, with a further 18% in British Columbia. Nitrous oxide from grazing is determined separately from confined production systems by applying an animal type specific coefficient (0.01 or 0.02) to the amount of N deposited.

Indirect $N_2O$ emissions from leaching and runoff, and volatilization are accounted for. $N_2O_{volatilization}$ is based on losses from $NH_4$ or $N_2O$ volatilization from commercial fertilizer, manure management systems, and manure deposited in grazing systems. The fraction of N lost is dependant on the nitrogen source; the same default IPCC Tier I emission coefficient (0.01) is applied for all N volatilized. $N_2O_{leach}$ is calculated from the N applied as fertilizer, residue, pasture management, manure, and mineralized assumed to be lost to leaching and runoff in a given P/PE (0.3 for Eastern Canada) multiplied by the IPCC Tier I default emission factor (0.0125).

**Table A1-4**

| NCGAVS: Generalized $N_2O$ emission calculations for Eastern Canada (kg $N_2O$-N/ha) | | |
|---|---|---|
| $N_2O\text{-}N_{CROP} = (N_{FERT} + N_{MAN\ A} + N_{RES} + N_{MIN\text{-}IMM}) * EF_{CTI}\ (0.012) * RF_{THAW}\ (1.4) * RF_{TILL}\ (1.0)$; P/PE =1<br>+<br>$N_2O\text{-}N_{HIST} = EF_{HIST}\ (8)$ /ha<br>+<br>$N_2O\text{-}N_{PRP} = N_{EXCRETED\ PRP} * EF_{PRP}\ (0.01\text{-}0.02)$<br>+<br>$N_2O\text{-}N_{VOLAT} = [(N_{FERT} * Frac_{GASFSN}) + (N_{MAN\ E} * Frac_{GASMMS}) + (N_{PRP} * Frac_{GASPRP})] * EF_{VOLAT}\ (0.01)$<br>+<br>$N_2O\text{-}N_{LEACH\ +\ RUNOFF} = N_{FERT,\ RES,\ PRP,\ MAN,\ MIN/IMM} * Frac_{LEACH\ +\ RUN}\ (0.3) * EF_{LEACH}\ (0.0125)$; P/PE=1 | | |
| Parameter | Symbol | Eastern Values |
| Fertilizer nitrogen applied (kg/ha) | $N_{FERT}$ | |
| Manure nitrogen available for land application after adjusting for losses in storage and handling (kg/ha) [$=N_{MAN\ E}$ (1-%volatilized in storage)] | $N_{MAN\ A}$ | |
| Available nitrogen derived from plant residues (kg/ha) | $N_{RES}$ | |
| Increase or decrease in available N as a result of practice changes (kg/ha) | $N_{MIN\text{-}IMM}$ | |
| Manure nitrogen excreted that is available for volatilization (kg) | $N_{MAN\ E}$ | |
| Fertilizer induced $N_2O$ emission factor | $EF_{CTI}$ | 0.012 |
| Ratio Factor adjusting for the effect of tillage | $RF_{TILL}$ | 1.0 |
| Ratio Factor adjusting for the effect of spring thaw | $RF_{THAW}$ | 1.4 |
| Climate factor: precipitation/potential evapotransporation (May-October) – used to account for climatic conditions and the topographical effect of higher emissions in lower slope positions. | P/PE | 1.0 |
| Emission coefficient for drained managed histols | $EF_{HIST}$ | 8 |
| Emission coefficient for pasture, range, paddock | $EF_{PRP}$ | 0.01-0.02 |
| Fraction of N applied as synthetic fertilizer volatilized | $Frac_{GASFSN}$ | 0.2 |
| Fraction of N applied from a manure management system | $Frac_{GASMMS}$ | 0.12-0.48 |
| Fraction of N applied as manure from grazing systems | $Frac_{GASPRP}$ | 0.1 |
| Emission coefficient for N lost to volatilization | $EF_{VOLAT}$ | 0.01 |
| Fraction of N applied considered lost to leaching and runoff From fertilizer, residue, manure, grazing, and mineralization/immobilization | $Frac_{LEACH}$ | 0.3 |
| Emission coefficient for N lost to leaching and runoff | $EF_{LEACH}$ | 0.0125 |

Rochette, P., D. Worth, (R. Lemke, B. McConkey, R. Desjardins, E. Huffman, A. Pennock, J. Brierley, J. Yang, and other contributors) 2005. Inventory of N2O emission from Canadian agricultural soils at the ecodistrict scale using an IPCC Tier II methodology. Draft 24/11/2005

### A1.5 **GHGFarm** (Helgason et al. 2005)

The GHGfarm model was developed as an assessment tool for estimating net GHG emissions from individual Canadian farms. For the most part, It is based on the same experimental information as used in the NCGAVS, but the information is treated somewhat differently, with the model having more capacity for site and management specific factors to be included. Emission sources or sinks are direct and indirect $N_2O$ emissions from cropping, enteric methane from livestock, $N_2O$ from manure handling and land application, $CH_4$ from manure storage, direct and indirect energy losses from non-fertilizer energy and fertilizer production, soil C change, and shelter belt C storage. For the most part, it is based on IPCC 1996 guideline "methods, algorithms and coefficients".

Farm location is referenced to specific ecodistricts, and thus linked to information re soil characteristics, crop yields and fertilizer recommendations. The soils are grouped into broad functional categories for soil C and $N_2O$ estimates, with Eastern Canada being grouped into one mineral soil type and organic soils.

For nutrient management related $N_2O$ emissions, the model considers direct cropping losses from applied commercial fertilizer, crop residue N, as well as N mineralization from summerfallow and organic soils where applicable. Each amount of N is multiplied by soil and area specific fertilizer induced emission coefficients modified by soil texture, tillage and application time (spring vs fall). Emissions from improved pasture and indirect emissions from fertilizer application (volatilization and leaching) are added.

Emissions from manure handling and land application of manure are considered separately from the cropping losses. Unlike NCGAVS, which uses manure N concentrations, the farm model determines manure N based on the difference between protein intake (calculated from the feed) and protein retention, giving protein excreted which can then be used to calculate nitrogen. The N stored is considered to be the same as N excreted, and $N_2O$ from manure storage is calculated by multiplying by an emission factor based on IPCC default values for various storage types, which range from 0 for daily spread to 0.02 (2%) for solid manure, compost, or pasture/range/paddock situations.

Nitrous oxide from land application of manure is calculated by multiplying the nitrogen subject to loss (0.8 of N excreted) by a manure application factor which dependent on time of application (spring 1.3; fall 1.8 for Eastern Canada). The difference between N excreted and N subject to loss appears low (20%) and is not livestock type dependant. This is in contrast with NCGAVS, which uses a range of 18-48% loss of N depending on animal type and manure management system. Manure-N deposited directly is multiplied by the IPCC pasture/range/paddock emission factor ($EF_{STORED}$). Indirect losses from volatilization and leaching are treated in the same manner as the indirect cropping losses. It is considered that 20% of the N is volatilized from applied manure ($R_{VOLAT\ MAN}$) compared to 10% for applied fertilizer ($R_{VOLAT\ FERT}$). These volatilization rates also vary from NCGAVS (manure:12-48%, fertilizer:20%, grazing:10%). Indirect losses from leaching consider only fertilizer and manure N with a 25% leach rate compared to 30% for all N inputs (fertilizer, manure, residue, mineralization, and grazing).

**Table A1-5**

**GHGFarm: Generalized $N_2O$ emission calculations for Eastern Canada**

**$N_2O$ emissions from cropping**

$$N_2O\text{-}N_{FERT} = [(N_{FERTfine} * EF_{FERT\ fine}) + (N_{FERTcoarse} * EF_{FERTcoarse})] * EF_{TILL} * EF_{APPLICATION}$$

+

$$N_2O\text{-}N_{RESIDUE} = [(N_{RESTfine} * EF_{RESfine}) + (N_{REScoarse} * EF_{REScoarse})] * EF_{TILL}$$

+

$$N_2O\text{-}N_{IMPROVED\ PASTURE} = N_{FERT} * 0.0125$$

+

$$N_2O\text{-}N_{CULT\ ORG\ SOILS} = EF_{HIST}\ (8)\ /ha$$

+

$$N_2O\text{-}N_{VOLAT\ CROP} = (N_{FERT}) * R_{VOLAT\ FERT}\ (0.1) * EF_{VOLAT}\ (0.01)$$

+

$$N_2O\text{-}N_{LEACH\ CROP\ +\ RUNOFF} = N_{APPLIED} * R_{LEACH}\ (0.25) * EF_{LEACH}\ (0.0125)$$

**$N_2O$ emissions from manure handling and application**

$$N_2O\text{-}N_{MAN\ STORED} = N_{MAN\ STORED} * EF_{MAN\ STORED}\ (0\text{-}0.2)$$

+

$$N_2O\text{-}N_{MAN\ APPLIED} = (N_{MAN\ AP} * EF_{MAN\ SPRING} * EF_{FERT}) + (N_{MAN\ AP} * EF_{MAN\ FALL} * EF_{FERT})$$

+

$$N_2O\text{-}N_{GRAZING} = N_{EXCRETED} * EF_{STORED\ PRP}\ (0.02)$$

+

$$N_2O\text{-}N_{VOLAT\ MAN} = N_{STORED\ APPLIED} * R_{VOLAT\ MAN\ APPLIED}\ (0.2) * EF_{VOLAT}\ (0.01)$$

+

$$N_2O\text{-}N_{LEACH\ MAN\ +\ RUNOFF} = N_{STORED\ APPLIED} * R_{LEACH\ MAN\ APPLIED}\ (0.25) * EF_{LEACH}\ (0.0125)$$

| Emission or Ratio Factor Terms for Eastern Canada | Symbol | Eastern Values |
|---|---|---|
| Fertilizer induced $N_2O$ emission factor: fine soils | $EF_{FERT\ fine}$ | 0.0167 |
| : coarse soils | $EF_{FERT\ coarse}$ | 0.0083 |
| Emission factor adjusting for the effect of tillage IT (intensive till); NT (no-till) | $EF_{TILL}$ | 1.0 IT<br>1.3 NT |
| Emission factor for spring or fall application | $EF_{APPLICATION}$ | 1.3 Spring<br>1.8 Fall |
| Emission coefficient for drained managed histols | $EF_{HIST}$ | 8 |
| Emission factor for volatilization from applied fertilizer | $EF_{VOLAT}$ | 0.01 |
| Regional volatilization factor | $R_{VOLAT}$ | 0.1 |
| Emission factor for leaching and runoff from applied fertilizer | $EF_{LEACH}$ | 0.0125 |
| Regional leaching factor | $R_{LEACH}$ | 0.25 |
| Emission factor for stored manure (storage system dependent, $N_{STORED} = N_{EXCRETED}$, and $N_{EXCRETED}$ is based on the difference between protein intake and protein retention) | $EF_{MAN\ STORED}$ | 0-0.02 |
| Emission factor for spring or fall application | $EF_{MAN\ SPRING}$<br>$EF_{MAN\ FALL}$ | 1.3<br>1.8 |
| Applied manure volatilization factor | $R_{VOLAT\ MAN\ APPL}$ | 0.2 |
| Applied manure leaching factor | $R_{LEACH\ MAN\ APPL}$ | 0.25 |

Helgason, B, H.H. Janzen, D.A. Angers, M. Boehm, M.Bolinder, R.L. Desjardins, J. Dyer, B.H. Ellert, D.J. Gibb, E.G. Gregorich, R. Lemke, D. Massé, S.M. McGinn, T.A. McAllister, N. Newlands, E. Pattey, P. Rochette, W. Smith, A.J. VandenBygaart, and H. Wang. 2005. GHGFarm: an assessment tool for estimating net greenhouse gas emissions from Canadian farms.

**Appendix 2: OMAFRA estimates of available nitrogen as affected by timing and tillage.**

Table A2-1: Available Nitrogen (as proportion of total nitrogen) from OMAFRA nutrient management workbook.
http://www.omafra.gov.on.ca/english/nm/ar/workbook/workbk.htm

Table 4: Available Nitrogen (as a Proportion of Total Nitrogen[2])

| Application Time | Incorporated (<24 hours) | | | | | Not Incorporated[3] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Late Summer | Early Fall | Late Fall | Pre[1] Plant | Side-dress[1] | Late Summer | Early Fall | Late Fall | Pre-plant[1] | | Side-dress[1] |
| | | | | | | | | | Bare Soil | Residue | |
| Urea (commercial N) | .1 | .2 | .5 | .95 | 1 | -- | .1 | .4 | .85 | .75 | .85 |
| Solid Cattle/Sheep | .27 | .26 | .30 | .34 | .34 | .26 | .24 | .24 | .23 | .27 | .26 |
| Solid Swine | .34 | .34 | .34 | .38 | .36 | .34 | .32 | .28 | .27 | .30 | .33 |
| Solid Poultry - Layers | .28 | .35 | .45 | .52 | .65 | .25 | .30 | .35 | .32 | .40 | .48 |
| Solid Poultry - Pullets | .33 | .37 | .39 | .43 | .48 | .31 | .34 | .33 | .31 | .36 | .41 |
| Solid Poultry - Broilers | .36 | .39 | .35 | .38 | .37 | .35 | .37 | .32 | .31 | .33 | .36 |
| Liquid Cattle | .29 | .36 | .41 | .44 | .54 | .27 | .31 | .32 | .26 | .34 | .41 |
| Liquid Swine | .23 | .33 | .48 | .56 | .70 | .20 | .27 | .35 | .29 | .40 | .50 |
| Liquid Poultry | .26 | .33 | .51 | .62 | .78 | .22 | .26 | .39 | .33 | .44 | .55 |
| Liquid Biosolids | .33 | .37 | .42 | .43 | .48 | .32 | .34 | .36 | .31 | .36 | .40 |

Source: Adapted from Barry, Beauchamp et. al., U of Guelph 2000
Available N in manure = Total Manure N applied x Available N from Table 4
[1] assumes a spring planted crop; Side-dress refers to application to a growing crop
[2] accounts for ammonia loss to atmosphere and mineralization of organic N
[3] for manure incorporated within 3 days Use: (incorporated value + non incorporated value) / 2

**Late Summer** = up to Sept 20, **Early Fall** = Sept 21 to Nov 9, **Late Fall** = Nov 10 to Winter

**Appendix 3: Economic Considerations**

***Land Application of Nitrogen***

Reduced N fertilizer use with N recommendation calculator (OMAFRA – 20%)

Cost:

- Record keeping time if not already

Revenue:

- reduced N fertilizer cost
- Offset claim

Pre-sidedress nitrate test (PSNT) for reduced corn N use (OMAFRA – additional 15%)

Cost:

- PSNT analysis ($16/10ha)
- Sample time
- Side-dress applicator (boom, injectors, tires) OR custom application
- Time

Revenue:

- reduced N fertilizer cost
- Offset claim

Fertilizer technologies to reduce N use (industry – 10%)

Cost:

- Fertilizer premium

Revenue:

- reduced N fertilizer cost
- Offset claim

Manure N replacing fertilizer N

Cost:

- Time to apply manure
- Custom applicator (?) for cash cropper
- Extra fuel cost for livestock farmer

Revenue:

- reduced N fertilizer cost
- Offset claim

***Manure Nitrogen Application Method***

Timing: spring vs. fall

Cost:

- Time to apply manure same but competing with other priorities
- ? more fuel

Revenue:

- reduced N fertilizer cost by increased manure N efficiency
- Offset claim

Incorporation: surface vs. incorporation

Cost:

- Time to incorporate
- Fuel cost to incorporate
- Tillage tool depreciation

Revenue:

- reduced N fertilizer cost by increased manure N efficiency
- Offset claim

Sidedress: spring vs. side-dress
Cost:

- Time to apply manure same but competing with other priorities
- Side-dress applicator (boom, injectors, tires)
- OR custom application?

Revenue:

- o reduced N fertilizer cost by increased manure N efficiency
- o Offset claim

***Manure Storage and Handling***

Manure storage
Cost:

- Cover for liquid pit or solid storage
- Time to manage cover

Revenue:

- o reduced N fertilizer cost by increased manure N retention and use efficiency
- o Offset claim

Manure handling/cleanout
Cost:

- Equipment purchase or modification, usage
- Time to cleanout

Revenue:

- o reduced N fertilizer cost by increased manure N retention and use efficiency
- o herd health
- o Offset claim

Manure treatment: composting
Cost:

- Equipment (e.g. turner)
- Time to manage
- Loss of available nitrogen

Revenue:

- o Offset claim??

Manure treatment: digestion
Cost:

- Equipment (e.g. digestor, pump)
- Time to manage, training

Revenue:

- o Heat and/or hydro
- o Offset claim

**Appendix 4: Offset Systems Transaction Costs**

| Scena-rios[1] | Project Size (Kt/year)[2] | Pooling | Options for Non-permanence | Range | Transaction Cost Elements | | | | | | | | | Total Transaction Costs[6] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Project Evaluation Costs[3] | *Project Initiation*[3] | *Project Proposal Costs*[3] | *Project Validation Costs*[3] | *Monitoring and Quantification Costs*[4] | | *Verification Costs*[4] | | *Required Replacement Transaction Costs*[5] | | |
| | | | | | $'000 | | | | | | | | % | $'000 | $/tonne |
| | | | | | | | | | 1 | 2 | 1 | 2 | | | |
| | | | | Low | 2 | 0 | 10 | 7.5 | 10 | 7.5 | 5 | 2.5 | 3% | 51 | 15.23 |
| Limited | 1.4 | No | Replace | Mode | 3 | 1 | 15 | 10 | 15 | 12.5 | 7.5 | 3.8 | 4% | 61 | 18.56 |
| | | | | High | 4 | 4 | 20 | 15 | 30 | 25 | 15 | 12.5 | 5% | 72 | 21.88 |
| | | | | Low | 1.5 | 0 | 2.5 | 2 | 2 | 2.5 | 1 | 0.5 | 3% | 15 | 4.64 |
| Medium | 1.4 | No | Replace | Mode | 2 | 1 | 5 | 4 | 3 | 5 | 2 | 1 | 4% | 19 | 5.84 |
| | | | | High | 3 | 4 | 10 | 6 | 7 | 7.5 | 5 | 2.5 | 5% | 23 | 7.05 |
| | | | | Low | 0.5 | 0 | 1.5 | 1 | 1 | 1 | 0.5 | 0.8 | | 6 | 1.87 |
| Medium | 1.4 | No | Temp. credits | Mode | 1 | 1 | 3 | 3 | 2 | 2.5 | 1.5 | 0.8 | N/A | 9 | 2.63 |
| | | | | High | 2 | 4 | 7 | 5 | 6 | 5 | 4 | 2 | | 11 | 3.34 |
| | | | | Low | 2.5 | 15 | 10 | 5 | 10 | 5 | 5 | 2.5 | 3% | 112 | 0.19 |
| Medium | 246 | Yes | Replace | Mode | 5 | 25 | 15 | 10 | 10 | 10 | 7.5 | 3.8 | 4% | 125 | 0.22 |
| | | | | High | 10 | 50 | 20 | 15 | 15 | 15 | 10 | 5 | 5% | 137 | 0.24 |
| | | | | Low | 2 | 15 | 7.5 | 2.5 | 3 | 5 | 3 | 1.5 | | 37 | 0.06 |
| Medium | 246 | Yes | Temp. credits | Mode | 4 | 25 | 12.5 | 7.5 | 8 | 7.5 | 5.5 | 2.8 | N/A | 48 | 0.08 |
| | | | | High | 8 | 50 | 17.5 | 12.5 | 12 | 10 | 8 | 4 | | 59 | 0.1 |
| | | | | Low | 1.5 | 0 | 4.5 | 3 | 3 | 2.5 | 2 | 1 | | 16 | 2.54 |
| Broad | 1.4 | No | Risk mgt. | Mode | 2 | 1 | 7 | 5 | 5 | 5 | 3 | 1.5 | N/A | 19 | 3.08 |
| | | | | High | 3 | 4 | 12 | 7 | 9 | 7.5 | 6 | 3 | | 22 | 3.63 |
| | | | | Low | 2.5 | 15 | 12.5 | 7.5 | 7 | 7.5 | 5 | 2.5 | | 61 | 0.06 |
| Broad | 246 | Yes | Risk mgt. | Mode | 5 | 30 | 17.5 | 12.5 | 12 | 12.5 | 7.5 | 3.8 | N/A | 78 | 0.07 |
| | | | | High | 10 | 70 | 22.5 | 20 | 18 | 15 | 10 | 5 | | 94 | 0.09 |
| | | | | Low | 2500 | 15000 | 12500 | 7500 | 7000 | 7500 | 5000 | 2500 | | 61 | 0.06 |
| Broad | 246 | Yes | Risk mgt. | Mode | 5000 | 30000 | 17500 | 12500 | 12000 | 12500 | 7500 | 3800 | N/A | 78 | 0.07 |
| | | | | High | 10000 | 70000 | 22500 | 20000 | 18000 | 15000 | 10000 | 5000 | | 94 | 0.09 |

Notes:
[1] Limited is very rigorous but limits participation (higher costs) and broad encourages more participation but is less rigorous.
[2] Two agricultural products size – small independent project (1.4kt/yr) and large projects (246kt/yr)
[3] One time costs
[4] On-going costs
[5] Purchase of replacement credits or insurance involves brokerage fees for the transactions
[6] Represents total costs and costs per tonne in 2002 dollars, with both dollars and tonnes discounted at a rate of 10% per year