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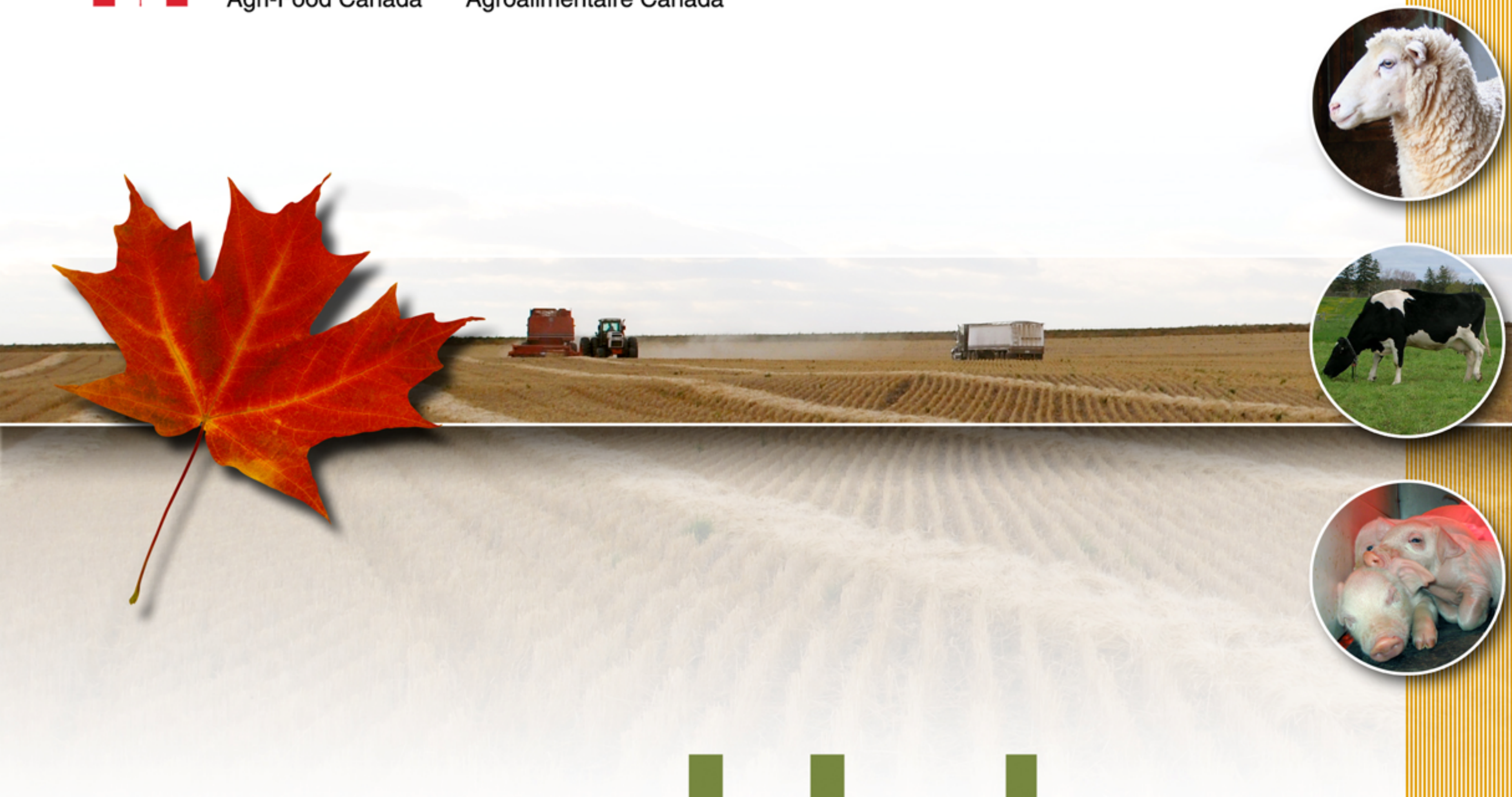

# Holos

## *A tool to estimate and reduce GHGs from farms*

Canada

Cat. No. A52-136/2008E-PDF
ISBN 978-1-100-11424-8
N° AAC 10862E

*Aussi offert en français sous le titre :*
*Holos – un outil pour estimer et réduire les GES émis par les fermes.*

SPCS (S. Hindson)

# Holos

## A tool to estimate and reduce greenhouse gases from farms

## Methodology & algorithms for version 1.1.x

Shannan Little, Julia Lindeman, Ken Maclean, Henry Janzen

# Preface

The following document describes the software program Holos - A tool to estimate and reduce GHGs from farms, Version 1.1.x. To fully comprehend this document, we recommend the reader have the Holos software installed and running, allowing comparisons between the document and the program.

The algorithms and assumptions in Holos are subject to continual revision and refinement as research continues. The equations presented in this document, therefore, may have been superseded in more recent versions of the software.

# Acknowledgements

Holos was preceded by GHGFarm and the work of B.L. Helgason, 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.

Valuable advice, suggestions and expertise were provided by Karen Beauchemin, Marie Boehm, Ray Desjardins, Jim Dyer, Bernie Genswein, Darryl Gibb, Brian Grant, Roger Hohm, Travis Hulstein, Robert Janzen, Sean McGinn, Chris McKinnon, Cedric McLeod, Philippe Rochette, Elwin Smith, Ward Smith, Matthew Wiens, Devon Worth, Fred Van Herk and Xavier Vergé. Ray Desjardins was especially instrumental in providing leadership for this project.

The Ottawa GHG Calculator Workshop group (March 29, 2007) also provided us with practical suggestions to improve on the program, making it more user-friendly and widely applicable.

Numerous testers from within Agriculture and Agri-Food Canada and beyond helped us to improve the usability of Holos, notably the diligent efforts of José Barbieri.

We thank Sheila Torgunrud for guiding us in the design of the logo, and Dave Gresiuk and Alvin Melenchenko for technical support.

# Table of Contents

# Summary

Holos is a whole-farm modelling software program that estimates greenhouse gas (GHG) emissions based on information entered for individual farms. The main purpose of Holos is to envision and test possible ways of reducing GHG emissions from farms. Holos is the culmination of extensive, collaborative study of GHG emissions from Canadian farms. Much of this research was conducted by Agriculture and Agri-Food Canada scientists in the Model Farm research program.

Holos has several unique features. One of these is the use of ‘scenarios’ – common packages of Canadian farm management practices.  The user selects scenarios that best describe his/her farm and then adds detail to the extent desired. This makes Holos easy to use, while still allowing flexibility for more intensive analyses.

Using a gaming approach, Holos allows users to contemplate possible options that might reduce emissions, and to estimate how those options affect whole-farm emissions. Holos is intended to look into the future, to envision hypothetical scenarios, and look for those practices that best reduce emissions at a specific site before they are implemented. Holos, therefore, is designed primarily as an exploratory tool, rather than as an accounting or inventory tool. It is intended to look into the future and ask ‘what if?’, rather than looking at the past and asking ‘what were my emissions?’ Holos also provides a set of possible mitigation options unique to each farm and lets users explore the impact of these options.

Algorithms used in the Holos model are generally based on the Intergovernmental Panel on Climate Change methods, but have been modified for Canadian conditions. The approach has been to emphasize the interaction of various components on the farm, rather than use exceedingly complex sub-routines of individual facets. Holos focuses specifically on those practices and conditions that might conceivably have significant mitigative effect. The level of detail is also dictated by the amount of supportive scientific information available.

Holos estimates carbon dioxide, nitrous oxide and methane emissions from enteric fermentation and manure management, cropping systems and energy use. Carbon storage and loss from lineal tree plantings and changes in land use and management are also estimated resulting in a whole-farm GHG estimate. The estimate is based on a yearly time-step and results are provided as reports or comparative charts.

# Background

## The importance of GHG science

The concentration of greenhouse gases (GHGs) in the atmosphere is increasing (Figure 1). These GHGs slow the escape of heat from the atmosphere, thereby creating a warm layer essential for life on earth. But if the concentrations rise too much, too quickly, the further warming may have undesirable effects on climates.

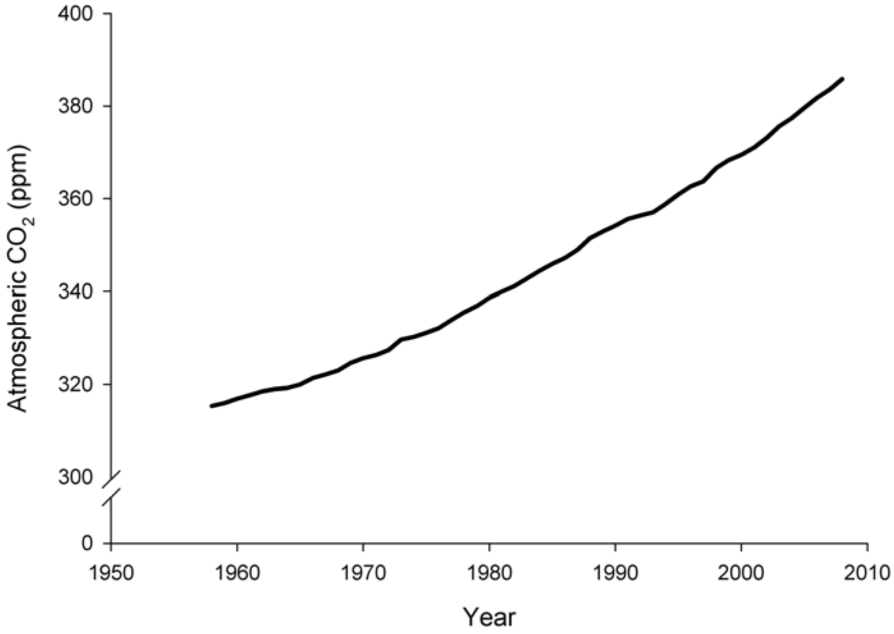

**Figure 1. Increases in atmospheric $CO_2$ concentrations (parts per million) - measured at Mauna Loa, Hawaii (Keeling *et al.* 2001).**

As a result of this warming, scientists predict that the sea levels will rise, rainfall patterns will change and severe weather events will increase. This, in turn, affects biodiversity, food production, and human settlement and health.

The increase of GHGs in the atmosphere is largely due to human activities. Burning fossil fuels and forests increases the concentration of $CO_2$. Other GHG concentrations have also increased due to anthropogenic sources, including agriculture.

## The link to agriculture

Agriculture is closely tied to three GHGs: carbon dioxide ($CO_2$); nitrous oxide ($N_2O$); and methane ($CH_4$). Historically, large amounts of $CO_2$ were released when forests were burned and grasslands ploughed to clear lands for farming. Even today, farming is a significant source of GHGs, accounting for about 10 to 12% of global emissions. (This does not include $CO_2$ emissions from converting grasslands and forests to farmland.) (Janzen *et al.* 2008).

Agriculture is the main source for $CH_4$ and $N_2O$ emissions (Smith *et al.* 2007). $CH_4$ emissions are largely due to ruminant livestock while $N_2O$ emissions are largely a result of high nitrogen concentrations in soil due to fertilizer and manure additions. Annual GHG emissions from agriculture are expected to increase in the future as population increases and the demand for food escalates (Smith *et al.* 2007). However, through management practices, farmlands may also regain lost carbon, thereby removing $CO_2$ from the atmosphere. Therefore, farms may serve not only as a source of GHGs but also as a sink, absorbing GHGs.

## Model Farm Program

The Agriculture and Agri-Food Canada (AAFC) Model Farm Program was an extensive, collaborative study intended to improve the accuracy of GHG emissions from Canadian agriculture and to identify ways to reduce farm emissions.

Three specific objectives of the Model Farm Program were:

- to improve scientific understanding of emissions from Canadian farms,
- to verify the inventory of Canadian emissions for international commitments, and
- to devise a method for holistic analysis of GHG emissions from entire farming systems (Janzen *et al.* 2008).

One goal of the Model Farm program was to develop a model which could estimate overall GHG emissions from farms.

## An early version: GHGFarm

GHGFarm was developed as a simple model and software program which could estimate GHG emissions from Canadian farms. Version 1.0 was released in 2005; Version 2.0 was released in 2007. Based on management practices and farm conditions, GHGFarm estimated whole-farm GHG emissions. Through consultations with users and with new research developments, areas of improvement were identified, justifying a more advanced model and software program.

## An enhanced version: Holos

### *Whole-systems approach*

An ecosystem consists of not only the organisms and the environment they live in but also the interactions within and between. A whole systems approach seeks to describe and understand the entire system as an integrated whole, rather than as individual components – the whole rather than the sum of the parts. This holistic approach can be very complex and describing the processes difficult. One method to conceptualize a *whole system* is with a mathematical model.

Many available models estimate GHG emissions from one component of farming or one agricultural operation. Others model nutrient flows through a farm ecosystem, or calculate emissions of individual GHGs (e.g., $CH_4$ or $N_2O$) from the entire farm. But few models seek to estimate all GHGs - $CO_2$, $CH_4$ and $N_2O$ - from the entire, integrated farm operation and from all potential emissions sources; that is, few models examine the farm as a *whole system*, rather than as single elements or processes.

This whole-systems approach ensures the effects of management changes are transferred throughout the entire system to the resulting net farm emissions. In some cases, reducing one GHG will actually increase the emissions of another. The whole-systems approach avoids potentially ill-advised practices based on preoccupation with one individual GHG.

The approach of Holos has been to emphasize the interaction of various components on the farm, rather than use exceedingly complex sub-routines of individual facets. Holos focuses specifically on those practices and conditions that might have significant mitigative effect. The level of detail is also dictated by the amount of supportive scientific information available. The end result is an estimate of $CO_2$, $CH_4$ and $N_2O$, and net emissions as $CO_2$ equivalents ($CO_2$ eq), from not only the various components of the farm, but from the entire farm system.

### *Purpose of Holos*

The main purpose of Holos is to envision and test possible ways of reducing GHG emissions from farms. Using a gaming approach, Holos allows users to contemplate possible options that might reduce emissions, and to estimate how those options affect whole-farm emissions. Holos is intended to look into the future, to envision hypothetical scenarios, and look for those practices that best reduce emissions at a specific site before they are implemented. Holos, therefore, is designed primarily as an exploratory tool, rather than as an accounting or inventory tool. It is intended to look into the future and ask ‘what if?’, rather than looking at the past and asking ‘what were my emissions?’ Holos also provides a set of possible mitigation options unique to each farm and lets users explore the impact of these options.

Holos has other potential applications including use as a learning and communication tool, allowing users to explore the response of the system to variation of input. The process of building this model has also been enlightening in understanding farms as ecosystems and ensuring all GHG sources are considered when calculating net farm emissions. Such models can pinpoint areas where further research is needed (Janzen *et al.* 2006).

# Greenhouse gases

There are three key greenhouse gases produced from agriculture – carbon dioxide, nitrous oxide and methane. In addition to producing GHGs, farms can also serve as a sink, or reservoir, for storing carbon. This carbon storage essentially removes $CO_2$ from the air.

These gases differ in their ability to trap heat in the atmosphere. The Global Warming Potential (GWP) of a gas is a measure of its warming effect relative to $CO_2$. $CH_4$ is 23 times as effective at trapping heat as $CO_2$, while $N_2O$ is 296 times as powerful (IPCC 2006). Therefore, GHGs are not equal in their contribution to global warming. This must be taken into account when analyzing management practices which affect GHG emissions.

Each of these GHGs does not stand alone. Their cycles are interwoven and what affects one, also affects the other. Therefore, farm management practices which reduce one emission may, in fact, increase another. The whole-systems approach ensures these interactions are taken into account and the effects of management changes are transferred throughout the whole farm and the resulting emissions.

## Carbon dioxide

$CO_2$ is cycled through the atmosphere and the ecosystem by uptake from plant photosynthesis and by release through respiration, decomposition and combustion. Without disturbance, this cycle remains in balance. $CO_2$ is taken up by plants and converted to carbohydrates. Plant carbohydrates are taken in by other organisms and used for energy and converted to $CO_2$. Carbon is also returned to the soil to decompose. $CO_2$ is produced through decomposition and the cycle renews.

In Canadian soils, large amounts of carbon are stored in organic matter. Some of this organic matter carbon is lost from soils when farm lands are first cropped because tillage accelerates decomposition and the removal of harvests results in less carbon returning to the soil. To regain soil carbon lost, more carbon needs to be returned to the system than is removed. By increasing the amount of carbon stored in soils, $CO_2$ can be removed from the atmosphere. Canadian farms have the opportunity to store increasing amounts of carbon in their soils, through various farm management practices, until equilibrium is again reached. Typically, this equilibrium is reached a few decades after introduction of a new practice. Practices that increase organic matter and carbon in soils include reducing tillage, restoring grasslands and peat bogs, planting perennial crops and eliminating fallowing of land (Smith *et al.* 2007, Desjardins *et al.* 2008, Janzen *et al.* 2008).

IPCC inventories do not consider non-managed stands of trees when calculating the net $CO_2$ exchanges between trees and the atmosphere (IPCC 2006). However, carbon can be stored in the tree plantings. Planting new trees in areas where trees were not previously is another method of storing carbon thereby removing $CO_2$ from the atmosphere (Desjardins *et al.* 2008). However, the fate and management of a tree planting will determine its long term value for carbon storage (Kort and Turnock 1999).

$CO_2$ is not only emitted from disturbance of lands, but also from energy use by the burning of fossil fuels. Tilling fields, harvesting crops, irrigating the land, producing fertilizer and herbicide, heating and cooling and cleaning barns, milking cows all require the use of fossil fuels either as diesel or gasoline or through the production of electricity. Certain practices, such as reducing fertilizer use or changing tillage practices to reduce fuel use, may substantially reduce $CO_2$ emissions from energy use.

The amount of $CO_2$ produced by a farm varies according to management practices. The amount of carbon potentially stored also varies across Canadian farms due to regional conditions and past farm management practices.

## Nitrous oxide

$N_2O$ is directly emitted from Canadian farms through the processes of nitrification and denitrification. The amount of $N_2O$ produced is roughly proportional to the amount of nitrogen added to the soil. Thus, as the amount of nitrogen added increases to support higher and higher yields, so do the losses as $N_2O$ to the atmosphere (Bouwman and Boumans 2002).

$N_2O$ is also directly emitted from livestock manure. The amount depends on the nitrogen content of the manure and the duration and type of manure handling and storage. Well-aerated manures generally produce more $N_2O$ emissions. Manure is eventually applied to the soil and further $N_2O$ losses occur (Mosier *et al.* 1998).

Some of the nitrogen on farms is lost to the air by volatilization or to ground or surface water by leaching and run-off. This nitrogen is also subject to nitrification and denitrification after loss from the farm, producing $N_2O$ referred to as ‘indirect’ emissions.

Sources of farm $N_2O$ emissions include crop residue decomposition, fertilizer use, manure deposition and handling, nitrogen mineralization, and drainage of organic (peat or boggy) soils. The amount of $N_2O$ lost depends on local climatic conditions, soil type and texture, and farm management practices. Emissions can be decreased through more efficient use of fertilizer thereby lowering nitrogen inputs, reducing tillage and fallow to lessen the emissions of nitrogen inputs, optimizing protein balance in animal feeds to reduce nitrogen excretion, and changing manure management practices (Kebreab *et al.* 2006, Janzen *et al.* 2008).

## Methane

$CH_4$ is produced by enteric fermentation mainly in ruminant livestock such as cattle and sheep. It is produced as a by-product of digestion in the rumen as carbohydrates are broken down for energy and escape the animal through exhalation, eructation or flatulation. The amount of $CH_4$ produced depends not only on the animal, but on feed quality and additives. For instance, $CH_4$ emissions can be reduced by feeding more digestible feeds, or by adding fats, oils or anti-microbial agents to the livestock rations. Highly digestible feeds may also reduce the amount of manure produced (Kebreab *et al.* 2006, Beauchemin *et al.* 2008, Desjardins *et al.* 2008).

$CH_4$ is also produced in manure handling systems. In anaerobic conditions, microbes produce $CH_4$ instead of $CO_2$ in the breakdown of carbon for energy. The amount of $CH_4$ produced from manure depends on the manure handling system, temperature and duration of storage. $CH_4$ emissions from manure can be reduced by changing manure management practices such as storage systems, season of manure land application (thereby not storing large quantities of manure in warm seasons), and applying manure to land more frequently (Desjardins *et al.* 2008). Further, $CH_4$ and $CO_2$ from manure decomposition can be captured and utilized to produce energy for on-farm use rather than released to the atmosphere (Kebreab et al. 2006).

## How much?

According to the National Inventory Report, Canada, in 2005, produced 747 million tonnes of $CO_2$ equivalents (Mt $CO_2$ eq) from all sources. $CO_2$ from energy use accounted for most of the emissions while agriculture accounted for about 8%. (This value does not include emissions from farm energy use; when this is counted, agriculture accounts for roughly 10% of Canada's emissions.) As mentioned, farm soils *remove* $CO_2$ from the air when soils gain carbon under improved practices and about 10 Mt $CO_2$ eq were removed in 2005. However, because these removals are almost exactly balanced by carbon losses from land recently converted to cropland, the net exchange of $CO_2$ between agricultural land and air is small.

$N_2O$ accounts for about half of Canadian agriculture emissions while $CH_4$ accounts for the other half. Livestock enteric fermentation and manure management produce 66 percent of the total GHG emissions from agriculture. Agricultural soil emissions from crop residue decomposition, fertilizer use, manure deposition and handling, and drainage of organic soils account for about 34 percent of the sector's total emissions (Figure 2).

The annual total of GHG emissions from farms in Canada has stayed reasonably constant from 1990 to 2005, falling by about 5 percent. However, individual sources and emissions have changed. From 1990 to 2005, $CH_4$ emissions have increased by a quarter due to greater numbers of livestock. $N_2O$ from agricultural soil direct sources has increased by 14 percent due to increased synthetic nitrogen fertilizer use and additional manure from larger livestock numbers. These increases in the time period, however, have been offset by decreases in net soil $CO_2$ emissions driven by increased adoption of soil carbon storage management practices (Janzen *et al.* 2008).

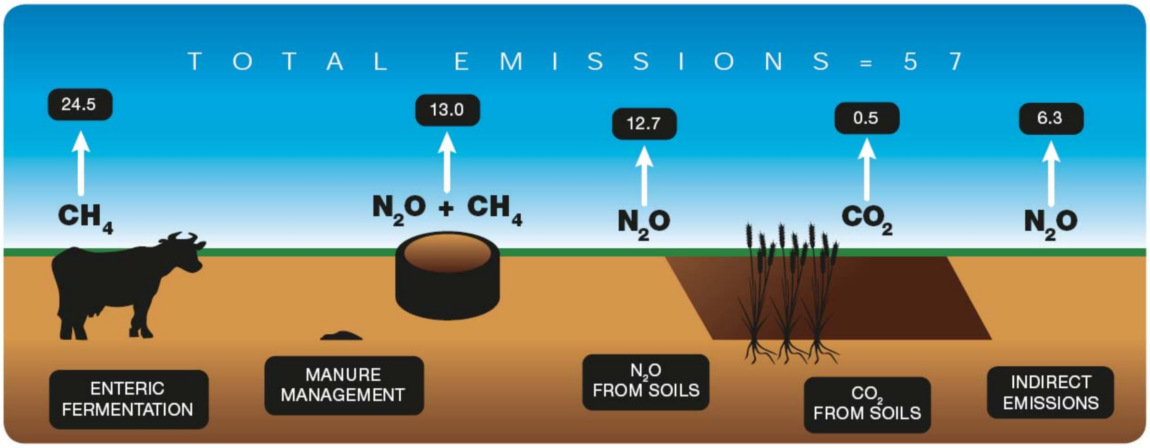

**Figure 2. Sources of GHG emissions from Canadian agriculture in 2005 (excluding $CO_2$ emissions associated with energy use). In Mt $CO_2$ eq. From Janzen *et al*. 2008.**

# Methodology

The primary source for Holos methodology was the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. This provides methodologies for estimating national inventories of anthropogenic emissions by sources and removals by sinks of greenhouse gases. The most common, simple methodological approach is to combine information on the extent to which a human activity takes place (called *activity data*) with coefficients which quantify the emissions or removals per unit activity (called *emission factors*).

The IPCC Guidelines recommend introducing complexity and country-specific methods and factors. Holos includes unique Canadian modifications which occur primarily in the estimation of soil and cropping $N_2O$, manure management $CH_4$, energy $CO_2$ emissions, as well as soil and tree carbon storage and removal.

The IPCC Guidelines were created for calculating country-wide GHG inventories. Holos estimates emissions from a farm-level scale. As such, algorithms were modified to reflect farm-scale specific detail and practices.

Holos calculates emission estimates for:

- Soil/cropping $N_2O$ – direct emissions
- Carbon storage and emissions from soil/land use management
- Enteric $CH_4$
- $CH_4$ from manure management
- $N_2O$ from manure management – direct emissions
- Indirect $N_2O$ emissions due to leaching or runoff and volatilization
- Carbon storage from lineal tree plantings
- $CO_2$ from on-farm energy use
- Net farm emissions ($CO_2$ eq)

Holos calculates emissions estimates from common Canadian farm operations listed in Table 1. Each operation requires farm-specific information and contributes to individual and net farm GHG emissions. The information required for each operation in order to calculate the associated emissions is acquired through individual components, or forms, in the Holos program. The results, itemized in accordance with the preceding list, are presented in chart format. However, operation specific emissions are also available in a detailed report.

The physical area of the farm is organized as in Figure 3. Essentially, the area of the farm is divided into cropland or grassland. The small areas of farmyards, cattle and sheep lots, barns, tree plantings, wetlands and water bodies are not considered as the land involved and resulting contribution to overall emissions is assumed to be negligible.

Holos is an empirical model, calculating emissions based on a yearly time-step. The system described by Holos, in general, includes all emissions on the farm itself, as well as those from manufacture and transport of inputs used directly on the farm. For example, the boundaries of the system described with Holos are at the farm gate. However, Holos estimates $CO_2$ emissions related to the manufacture of fertilizer and herbicide used on-farm. Crop residue and manure are attributed to the farm of origin. Emissions from the production of livestock feed are accounted for by entering in the required crop complex.[1] Emissions from the production of livestock feed are assigned to the farms where the feed is produced.

**Table 1. Overview of Holos.**

| **Farm operation** | **User input required** | **Defaults provided, user may override** | **Emissions calculated** |
|---|---|---|---|
| Crops/grassland/ land use change | Area of annual crops & fallow<br>Area of perennial crops (past and present)<br>Area of grassland (past and present)<br>Tillage system (past and present)<br>Area of irrigation<br>Herbicide usage | Fertilizer inputs<br>Crop yields<br>Soil type and texture | Soil $N_2O$<br>Soil carbon storage or emission<br>Energy $CO_2$ |
| Beef cow-calf | # cows<br>Type of grazing area<br>Pasture and feed quality<br>Feed additives in diet<br>Spring or fall calving<br>Year round grazing or winter feeding<br>Calves sold or kept for backgrounding & # months kept<br>Manure handling system for backgrounders | Calf crop rate<br># bulls | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$<br>Energy $CO_2$ |
| Beef feedlot | Type of feedlot (finishing or backgrounding)<br>Feedlot capacity and/ or #months filled<br>Barn housing usage<br>Ration mix<br>Feed additives in diet<br>% steers in lot<br>Feed:gain ratio (if known)<br>Average daily gain (if known)<br>Manure handling system | Initial and final weights | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$<br>Energy $CO_2$ |
| Beef stocker | # cattle<br># months grazed<br>Pasture quality<br>Feed additives in diet<br>% steers in herd<br>Average daily gain (if known) | Initial and final weights | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$ |
| Dairy | # cows<br># months calves kept<br>Feed additives in diet<br>Pasture usage and length of time used<br>Manure handling system<br>Season of manure application | # replacement heifers<br># bulls<br># calves<br>Length of dry period<br>Total digestible nutrients or net energy for lactation and protein content in diets (dry and lactation) | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$<br>Energy $CO_2$ |

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[1] The crop complex is defined as the land base or area used to grow the crops used to feed livestock (Vergé *et al.* 2007).

| **Farm operation** | **User input required** | **Defaults provided, user may override** | **Emissions calculated** |
|---|---|---|---|
| Swine | Type of operation (farrow to wean, farrow to finish, nursery or finishing barn)<br># pigs (in each category, defaults provided in some cases)<br>Type of diet<br>Manure handling system<br>Season of manure application | Yearly birth rate<br>Pre-weaning death loss | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$<br>Energy $CO_2$ |
| Sheep – market lamb | # ewes<br>Weaned lambs sold or kept on farm<br>Feed quality<br>Pasture usage and length of time used<br>Type of pasture<br>Manure handling system | # rams<br>lambing rate<br># lambs per birth | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$ |
| Sheep feedlot | Feedlot capacity<br># months filled<br>Feed quality<br>Manure handling system | | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$ |
| Poultry | Type of poultry<br>Barn capacity<br>Wet or dry manure system | | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$<br>Energy $CO_2$ |
| Other animals (goats, llamas & alpacas, deer & elk, horses, mules, bison) | # animals | | Enteric $CH_4$<br>Manure $CH_4$<br>Manure $N_2O$ |
| Lineal tree plantings/ shelterbelts | Type of tree<br>Age of planting<br>Length of planting | | Carbon storage |

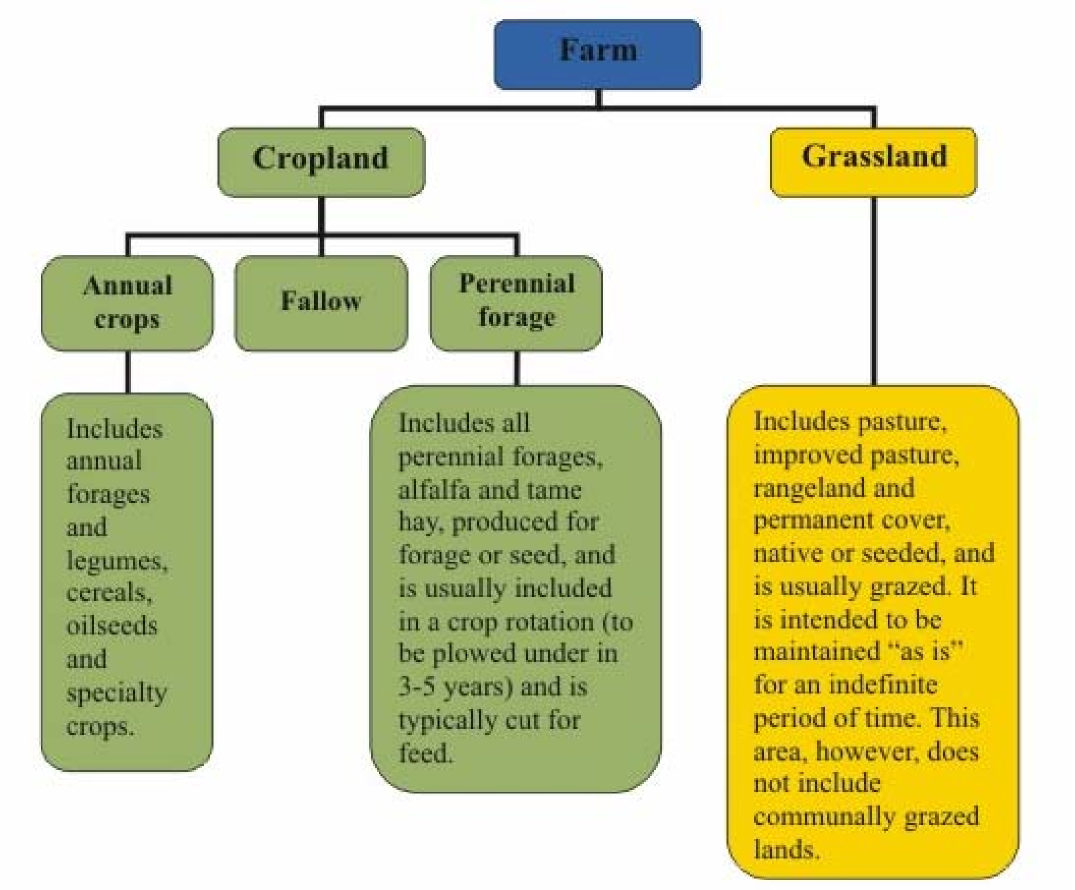

**Figure 3. Organization of the farm area.**

# Spatial location

Due to the differences in climate, land and soil types, and farm management practices across Canada, GHG processes and emission factors vary amongst Canadian farms. To capture the underlying location dependent factors, the farm is located on the Holos ecodistrict map. This location is spatially referenced to an ecodistrict[2], reporting zone[3] and province. Each ecodistrict is linked to default values for soil type and texture. Also associated with each ecodistrict are precipitation, potential evapotranspiration and land topography data. Coefficients in further emission equations are associated with soil type, soil texture and farm location.

Soil ecodistrict shape files, soil data and climate data were obtained from the Canadian Soil Information System (CanSIS), National Ecological Framework (Marshall *et al.* 1999). Topography data were summarized into one descriptive variable (Rochette *et al.* 2008).

Each ecodistrict contains an associated Soil Great Group. These soils were grouped into broad soil type categories (Brown Chernozem, Dark Brown Chernozem, Black Chernozem or Eastern Canada soil) (Helgason *et al.* 2005). The user has the ability to override the soil type default (Table 2).

Each ecodistrict is also associated with one or more soil textures. The default soil texture used by Holos is the dominant texture of the ecodistrict. The user has the ability to override the default soil texture with the most common soil texture of the farm.

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[2] An ecodistrict is a subdivision in the National Ecological Framework of Canada and is defined as geographical area characterized by distinctive assemblages of relief, landforms, geology, soil, vegetation, water bodies and fauna (Marshall *et al.* 1999).

[3] Reporting zones are essentially the same as the National Ecological Framework of Canada ecozones except the Boreal Shield and Taiga Shield are split into east and west components and Prairies is divided into semi-arid and subhumid. The Reporting Zone is defined by CanAg-MARS (McConkey *et al.* 2007).

**Table 2. Soil great group functional categories.**

| | Soil type, by province | |
|---|---:|---:|
| **Soil Great Group** | **BC AB SK MB** | **ON QC NB NS PE NF** |
| Brown Chernozem | Brown Chernozem | n/a |
| Dark Brown Chernozem | Dark Brown Chernozem | n/a |
| Black Chernozem | Black Chernozem | n/a |
| Dark Gray Chernozem | Black Chernozem | n/a |
| Solonetz | Brown Chernozem | Eastern Canada soil |
| Solodized Solonetz | Brown Chernozem | Eastern Canada soil |
| Solod | Brown Chernozem | Eastern Canada soil |
| Vertic Solonetz | Brown Chernozem | Eastern Canada soil |
| Grey Brown Luvisol | n/a | Eastern Canada soil |
| Gray Luvisol | Black Chernozem | Eastern Canada soil |
| Humic Podzol | Brown Chernozem | Eastern Canada soil |
| Ferro-humic Podzol | Brown Chernozem | Eastern Canada soil |
| Humo-ferric Podzol | Brown Chernozem | Eastern Canada soil |
| Melanic Brunisol | Brown Chernozem | Eastern Canada soil |
| Eutric Brunisol | Brown Chernozem | Eastern Canada soil |
| Sombric Brunisol | Brown Chernozem | Eastern Canada soil |
| Dystric Brunisol | Brown Chernozem | Eastern Canada soil |
| Humic Gleysol | Brown Chernozem | Eastern Canada soil |
| Gleysol | Brown Chernozem | Eastern Canada soil |
| Luvic Gleysol | Black Chernozem | Eastern Canada soil |
| Fibrisol* | Black Chernozem | Eastern Canada soil |
| Mesisol* | Black Chernozem | Eastern Canada soil |
| Organic Cryosol* | Black Chernozem | Eastern Canada soil |

* While the final three soil great group categories are actually organic soils (peat or boggy), for the purposes of Holos, these will utilize the coefficients of the soil types listed.

# Scenarios

The framework of Holos exploits the use of ‘scenarios’: common farm management practices and the associated assumptions and equations. Using scenarios greatly reduces and simplifies user inputs. For instance, rather then a user recreating an entire cow-calf cycle and inputting seasonal management changes, Holos gives the user options of typical Canadian cycles and requests a small amount of additional information such as number of cows and feed quality. Holos describes these scenarios and, in some cases, presents the yearly cycle in a diagram. Utilizing the practices and cycle indicated by the various scenario choices, Holos runs through a series of algorithms to calculate the GHG emission estimate for the entire package.

Each farm component or agricultural operation (Table 1) contains at least one scenario. The user selects operations and scenarios that best describe his/her farm and then adds detail to the extent desired. While not every farm is exactly represented nor every detail included, the goal of Holos is to demonstrate how changing practices can change emissions.

Holos utilizes fixed estimates for many variables that are either considered impractical to modify for GHG mitigation (e.g., weight of cows), unlikely to be known (e.g. digestible energy value of grassland forage) or exert little effect on cumulative GHG emission (e.g., length of grazing season). These fixed values are based on Canadian averages and/or expert opinion.

Some coefficients are set as constants by the choice of scenario (e.g., cow-calf scenario) while others vary depending on specific user input (e.g., dairy cattle breed). Holos also provides default values for many inputs. For instance, default nitrogen fertilizer rates for crops are provided based on crop type, province and soil type. The user can override these default values. Descriptions are provided for all inputs.

All of this makes it easy for users, even those without in-depth knowledge of the farm system or without complex farm records, to explore hypothetical farms. However, Holos still maintains flexibility for more intensive analyses.

# Operations/emission sources

Each farm operation or component will result in its own set of GHG emissions. As such, each requires unique user inputs and utilizes applicable algorithms. The user can enter data into one or all of the operations and one or all of the associated scenarios.

The farm operations in Holos are:
- crops/grassland/land use
- beef cow-calf
- beef feedlot
- beef stocker or grasser
- dairy
- sheep-market lamb
- sheep feedlot
- swine
- poultry
- other animals
- lineal tree plantings

Holos also calculates energy $CO_2$ emissions from information derived from the farm operations.

The results are presented in chart format for the following emission categories:
- Soil/cropping $N_2O$ – direct emissions
- Carbon storage and emissions from soil/land use management
- Enteric $CH_4$
- $CH_4$ from manure management
- $N_2O$ from manure management – direct emissions
- Indirect $N_2O$ emissions from manure management and soil/cropping
- Carbon storage from lineal tree plantings
- $CO_2$ from on-farm energy use
- Net farm emissions ($CO_2$ eq)

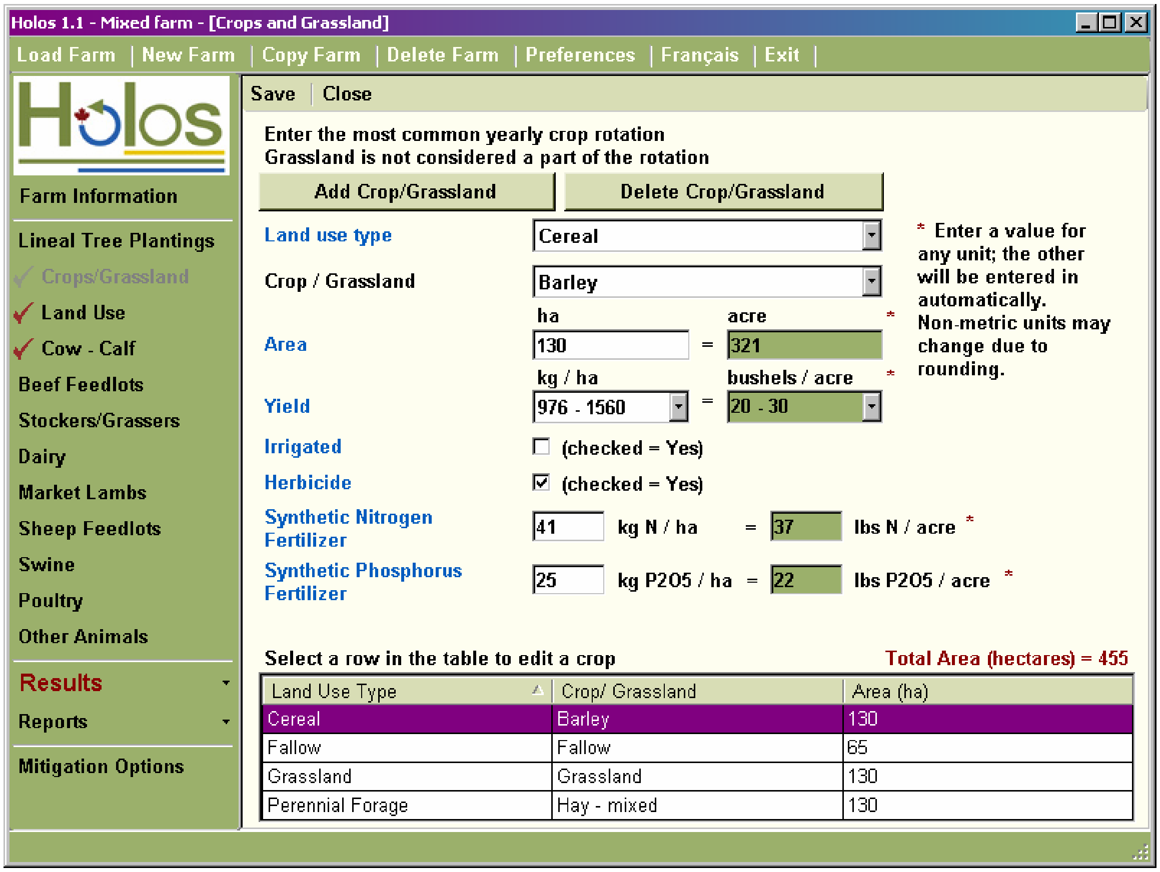
However, operation-specific emissions are available in a detailed report.

In Holos, enteric fermentation and manure management emissions are calculated together in a whole-systems approach. As such, manure management emission algorithms, including pasture manure emissions, are included in the livestock operation scenarios. After the manure is removed from a handling system it is applied to the land. These land-applied manure $N_2O$ emissions are then calculated and reported as soil $N_2O$ emissions.

The farm operations are briefly described. Details of equations can be found in Appendix 4. Each set of algorithms applies to a yearly cycle of the farm operation.

## Cropping/land use – direct and indirect soil $N_2O$ emissions

Holos includes one general crops/grasslands scenario which is used to calculate direct and indirect soil $N_2O$ emissions (Figure 4). Additional information required is obtained from the land use form. This same information is also used to calculate soil carbon storage and emissions and emissions due to energy use.



Enter the most common yearly crop rotation
Grassland is not considered a part of the rotation

|  |  |  |  |
|---|---|---|---|
| Land use type | Cereal |  |  |
| Crop / Grassland | Barley |  |  |
|  | ha |  | acre * |
| Area | 130 | = | 321 |
|  | kg / ha |  | bushels / acre * |
| Yield | 976 - 1560 | = | 20 - 30 |
| Irrigated | ☐ (checked = Yes) |  |  |
| Herbicide | ☑ (checked = Yes) |  |  |
| Synthetic Nitrogen Fertilizer | 41 kg N / ha | = | 37 lbs N / acre * |
| Synthetic Phosphorus Fertilizer | 25 kg P2O5 / ha | = | 22 lbs P2O5 / acre * |

* Enter a value for any unit; the other will be entered in automatically. Non-metric units may change due to rounding.

Select a row in the table to edit a crop — Total Area (hectares) = 455

| Land Use Type | Crop/ Grassland | Area (ha) |
|---|---|---|
| Cereal | Barley | 130 |
| Fallow | Fallow | 65 |
| Grassland | Grassland | 130 |
| Perennial Forage | Hay - mixed | 130 |

**Figure 4. Crops/Grassland scenario form.**

The methodology for calculating soil $N_2O$ emissions in Holos is based on that developed for the National Inventory Report (2007) specifically for Canada (Rochette *et al.* 2008). This method was developed to estimate agricultural soil $N_2O$ emissions on a regional scale so modifications have been made to reflect the farm scale of Holos.

Holos includes additional equations that are used to calculate the nitrogen inputs of the farm. Inputs include nitrogen fertilizer, above and below ground crop residue decomposition, nitrogen mineralization[4] and nitrogen from land-applied manure.

Holos categorizes land-applied manure as a soil nitrogen input and calculates $N_2O$ emissions from land-applied manure as a soil emission. Emissions from the manure of grazed animals, however, is calculated in the livestock operation and reported as manure emissions. In Holos, all manure from handling systems is applied yearly.

---

[4] Emissions from nitrogen mineralization emissions are a function of soil carbon (IPCC 2006).

To obtain emission estimates, the user must enter the farm's typical crop rotation with areas, fertilizer and herbicide inputs, crop yields and irrigation usage. Default values based on location and soil type are provided for fertilizer inputs and crop yields. The user must also choose the current tillage system (intensive, reduced or no-till). The tillage system selected reflects practices on the entire cropped area, rather than on individual fields or crops. This restriction avoids errors arising from intermittent tillage. For example, if a cropland area is assigned to a two-year rotation, in which one of two crops is tilled, then that tillage event may largely negate any benefits from no-tillage in the other year. The area of any cultivated organic (peat or boggy) soil is also entered.

While other land use types in the crops/grassland form are necessary to calculate other emissions, the inputs used to calculate soil $N_2O$ emissions are those related to the annual crops, perennial forages and fallow lands. Holos assumes that grasslands contribute no soil $N_2O$ emissions.

The emission factor used to estimate the emissions depends on location, as influenced by the growing season precipitation and potential evapotranspiration of the applicable ecodistrict. Emissions are modified by tillage, soil texture, topography and irrigation and fallow use. Indirect emissions – those from nitrogen lost to adjacent environments via leaching and run-off or volatilization – are also adjusted for growing season precipitation and potential evapotranspiration (Rochette *et al.* 2008).

In Holos, manure and the associated emissions cannot be imported or exported and are calculated at the farm of origin. Benefits to importing manure can be accounted for by lowering synthetic fertilizer rates. Crop residue emissions are also calculated at the farm of origin – presently in Holos, removal of crop residues from the farm does not reduce estimated emissions.

Emissions due to the cultivation of organic soils are also calculated (IPCC 2006), but emissions from biological nitrogen fixation are assumed to be negligible (Rochette and Janzen 2005).

**Assumptions:**

- All manure is land-applied yearly.
- Land-applied manure emissions are allotted to the farm of manure origin.
- Crop residue emissions are allotted to the farm of residue origin.
- Emissions are calculated based on the most common soil texture on the farm.
- The farm utilizes only one type of tillage (farm must be completely and continuously no-till to be considered as no-till).
- Perennial crops are plowed under every 5 years.
- Emissions from biological nitrogen fixation are negligible. (The $N_2O$ emissions from decay of residues containing biologically-fixed nitrogen, however, are included.)

## Land use - soil carbon storage and emissions

Holos uses the methodology developed for the National Inventory Report, the Canadian Agriculture Monitoring Accounting and Reporting System (CanAG-MARS)[5] to estimate $CO_2$ emissions or removal from soil carbon change. This carbon change is based on changes in tillage practice, use of fallow, percentage of perennial crops and areas of permanent cover or grassland. As previously described, practices that increase organic matter and carbon in soils, such as reducing tillage, restoring grasslands, planting perennial crops and eliminating fallow, can remove $CO_2$ from the atmosphere. Subsequently, the reverse practices actually release $CO_2$ into the atmosphere (McConkey *et al.* 2007).

Soil carbon gains and losses are based on changes in management practices, the area affected by the change in management, and the time since the change. The various carbon factors associated with each situation were derived using the CENTURY model. If no change in management practice has occurred, the net carbon change is zero (McConkey *et al.* 2007). These algorithms are used for mineral soils only (Table 2).

CanAG-MARS was developed to calculate carbon change on a regional scale. While CanAG-MARS utilizes historical and current statistical data to determine changes in management practices, Holos is able to solicit this specific information directly from the user in the cropping/grassland and land use forms of the software.

The user enters the area of grassland in the crops/grassland form and specifies for each entry if it is native grassland[6] or when it was seeded. In the land use form, which is only available if crops are entered, the user chooses the present and past tillage system. The time since the change in practice, if any, is indicated. The user will also specify if grassland has been broken within the last 20 years and when this occurred. As well, based on the crop inputs, the user will indicate if there has been a change in the percentage of perennial crops on the farm or a change in the percentage of fallow land. Time since these changes is also specified. To make user entry more manageable, ranges of years for time since changes are provided with Holos utilizing the midpoint of these ranges for calculations (Figure 5).

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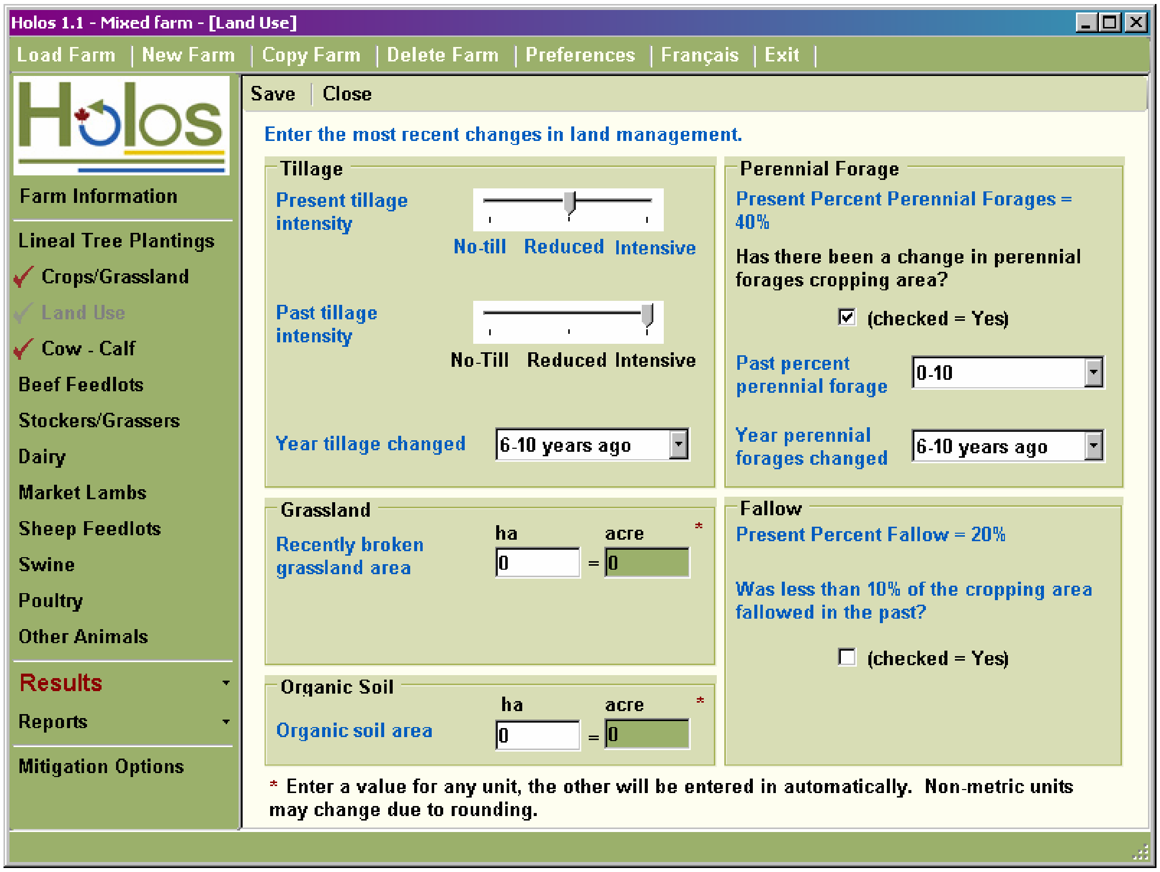
[5] CanAG-MARS was previously titled National Soil Carbon and Greenhouse Gas Accounting and Verification System (NCGAVS).

[6] Holos assumes that native grassland has negligible effect on soil carbon.



Enter the most recent changes in land management.

**Tillage**

Present tillage intensity: No-till | Reduced | Intensive (set to Reduced)

Past tillage intensity: No-Till | Reduced | Intensive (set to Intensive)

Year tillage changed: 6-10 years ago

**Perennial Forage**

Present Percent Perennial Forages = 40%

Has there been a change in perennial forages cropping area?

☑ (checked = Yes)

Past percent perennial forage: 0-10

Year perennial forages changed: 6-10 years ago

**Grassland**

Recently broken grassland area: ha 0 = acre 0 *

**Fallow**

Present Percent Fallow = 20%

Was less than 10% of the cropping area fallowed in the past?

☐ (checked = Yes)

**Organic Soil**

Organic soil area: ha 0 = acre 0 *

* Enter a value for any unit, the other will be entered in automatically. Non-metric units may change due to rounding.

Figure 5. Land Use form.

$CO_2$ emissions from the cultivation of organic soil, as entered by the user, are calculated, based on the method of IPCC (2006). Net $CH_4$ emissions from soils are assumed to be negligible: oxidation in dry, aerobic areas is assumed to be offset by $CH_4$ emissions from wet areas.

**Assumptions:**

- Net $CH_4$ exchange to and from soils is zero.
- The past and present farm area is assumed to be constant. (This avoids artifactual effects on GHG emissions from changes in farm size.)
- All cultivated organic soil is cropped.
- For carbon storage due to reduction in fallow use, all fallow must be eliminated (to less than 10% of cropland area).
- ‘Continuous cropping’ denotes that less than 10% of cropland area in fallow.
- Past fallow will assume 33% of the cropland area was fallow.
- Perennial crop area losses are attributed to conversions to annual crops. Perennial conversions to permanent cover do not occur.
- Each seeded grassland/permanent cover was converted from annual cropland.
- Broken grassland was converted to annual cropland.
- No organic soil is converted to or from grassland.
- Time since management changes refers to the most recent management change.
- No-till is defined as no tillage at any point in the rotation except at seeding.

- Reduced tillage is defined as one or few tillage passes with most residue retained on the surface.
- Intensive tillage is defined as complete burial of residue.
- When a change of management is specified to have occurred more than 20 years ago, Holos assumes the change occurred 23 years ago (i.e., the effect on soil C is small).

## Beef cow-calf – enteric and manure $CH_4$ and manure $N_2O$ emissions

The cow-calf operation is the first stage of the beef production process. Calves are generally sold to feedlots to grow and finish prior to processing as beef. A beef cow-calf operation consists of mature cows, bulls and calves. In some scenarios, weaned calves are also included as grazing livestock or backgrounders[7].

The user chooses between seven different cow-calf scenarios. The seven scenarios differ in their use of spring or fall calving, year-round grazing or winter feeding, and the management of calves after weaning (sold, grazed or backgrounded on farm). Besides a description, Holos also provides a diagram of the cow-calf scenario chosen (Figure 6).

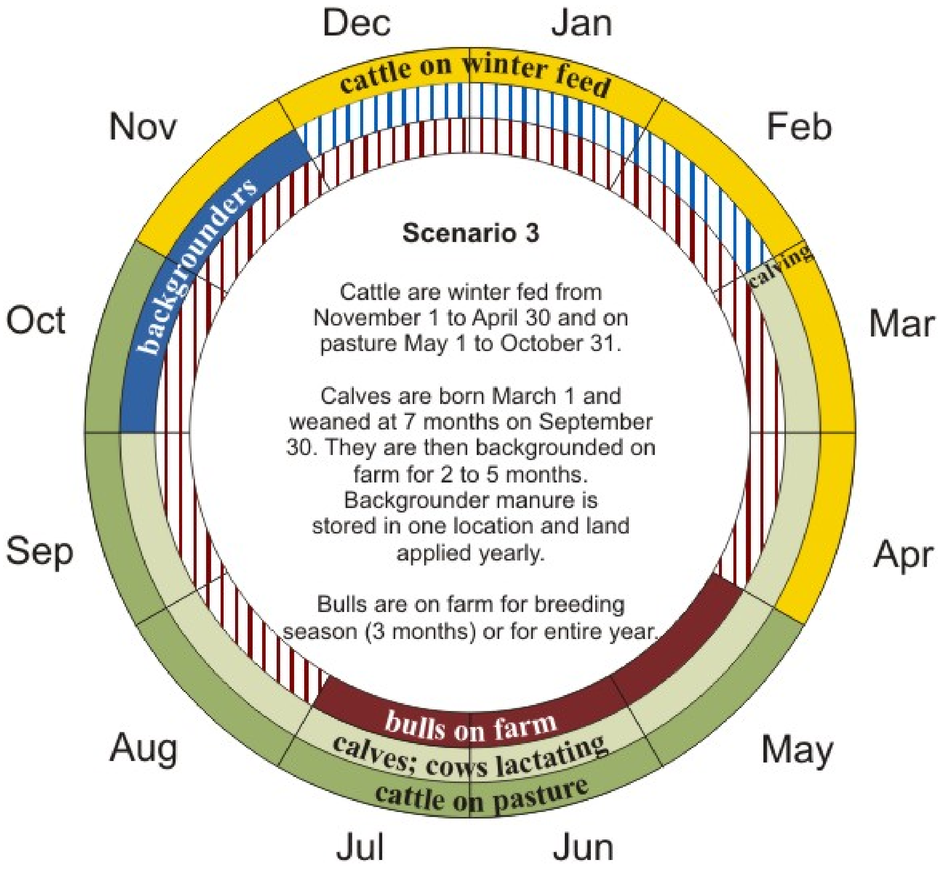


**Figure 6. Example of a scenario diagram. This diagram describes cow-calf scenario 3.**

Users will also enter the number of cows and bulls in the herd and the average calf crop. Users indicate feed quality (both winter feed and pasture) and type of grazing land. If calves are kept for backgrounding, the applicable manure handling system is selected. Users also indicate if feed additives, fats or ionophores, are utilized. The user has

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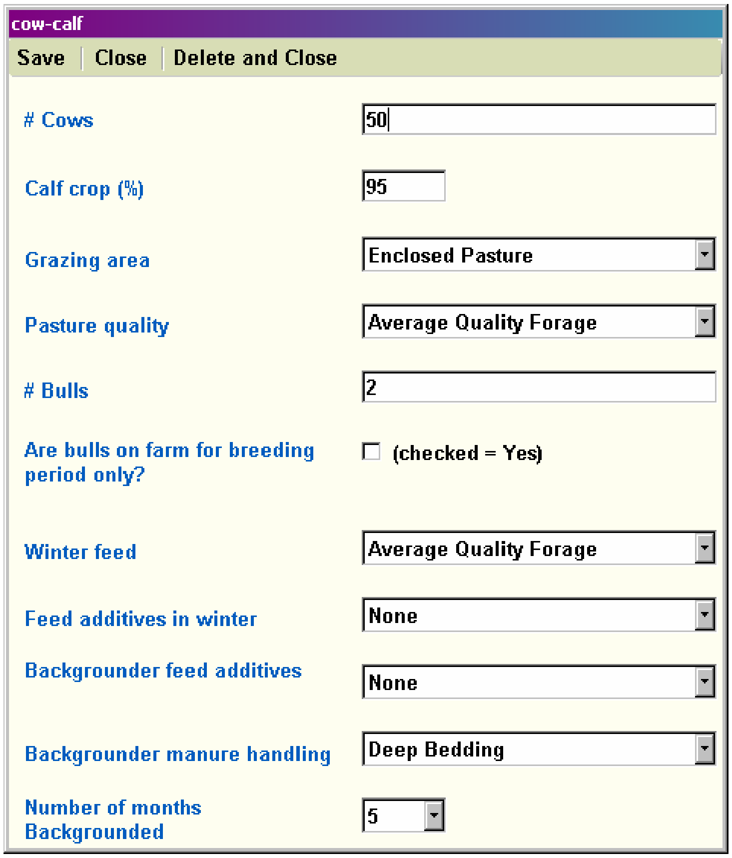
[7] Backgrounders are weaned calves that are fed in a lot prior to moving to a finishing feedlot

opportunity to indicate the number of months both weaned calves and bulls are kept on farm (Figure 7).



| | |
|---|---|
| # Cows | 50 |
| Calf crop (%) | 95 |
| Grazing area | Enclosed Pasture |
| Pasture quality | Average Quality Forage |
| # Bulls | 2 |
| Are bulls on farm for breeding period only? | ☐ (checked = Yes) |
| Winter feed | Average Quality Forage |
| Feed additives in winter | None |
| Backgrounder feed additives | None |
| Backgrounder manure handling | Deep Bedding |
| Number of months Backgrounded | 5 |

**Figure 7. Cow-calf scenario form.**

Emissions are calculated for each cattle class (cows-lactating and dry, bulls, calves and backgrounders) following IPCC 2006 methodology. Complexity has been introduced in order to determine energy in feed, dry matter intake and average daily gain (National Research Council 2000). The algorithms depend on the cattle cycle as selected by the choice of scenario.

To estimate enteric and manure $CH_4$ emissions, Holos first calculates the net energy requirements of the animal.[8] This varies depending on such things as the cattle class, type of grazing area and lactation. Dry matter intake, net energy available in feed and potential average daily gain[9], based on animal size and choice of user entered feed quality, are also determined. For growing cattle (steers and heifers), the net energy available for gain is calculated. This leads to a calculation of gross energy requirements for each cattle class and a subsequent $CH_4$ emission estimate. The enteric $CH_4$ emission is modified by the use of feed additives, as entered by the user.

Volatile solids production is also calculated from gross energy requirements. Manure $CH_4$ emissions are estimated based on volatile solids production and manure management

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[8] This method of calculation and result is known as the metabolic animal.

[9] With IPCC 2006, average daily gain is not calculated and must be assigned.

system. For cow-calf livestock (excluding backgrounders), all manure is assumed to be deposited on pasture.

Protein intake is based on dry matter intake and the protein content of the feed. Protein intake and retention are used to calculate nitrogen excretion rates. This rate, along with the manure handling system, is used to estimate manure $N_2O$ emissions, both direct and indirect. Manure from backgrounder manure handling systems is eventually land-applied. (These emissions are calculated in the soil $N_2O$ component.)

**Assumptions:**

- Cattle feed intake is equal to energy requirements.
- Feed quality remains constant over feeding period (winter or grazing season).
- All feed is utilized. Waste feed emissions are not accounted for.
- All cows are pregnant.
- Cows have average weight of 600 kg, milk yield of 8 kg $day^{-1}$, with milk fat of 4% and milk protein of 3.5%.
- 5 kg of protein is retained for every pregnancy.
- Calves are born at 40 kg and weaned at 40% of the mother cow’s weight (at 7 months). Calves consume 1% of their own body weight as solid food.
- Calves retain 20% of protein intake from dry feed and 40% of protein intake from milk.
- The sex ratio for calves/backgrounders is 1:1.
- Spring calving - Calves are born March 1 and sold September 30.
- Fall calving - Calves are born October 1 are sold April 30.
- Summer grazing/ winter feeding - Cattle are fed November 1 to April 30 and on pasture May 1 to October 31.
- Year-round grazing - Cattle are on pasture or grazing land all year.
- Year-round grazing - Bulls are kept year round.
- Backgrounders are fed rations from October 1 in a confined location.
- If kept past weaning and on pasture, calves are grazed until next fall (in which case one year has passed; if the user carries yearlings, they need to be included in the stocker/grasser operation).
- All cow, bull and calf manure is deposited on pasture.
- All backgrounder manure is stored in one location and land-applied yearly (unless deposited on pasture).
- Manure can not be imported or exported and emissions are calculated at the farm of origin.

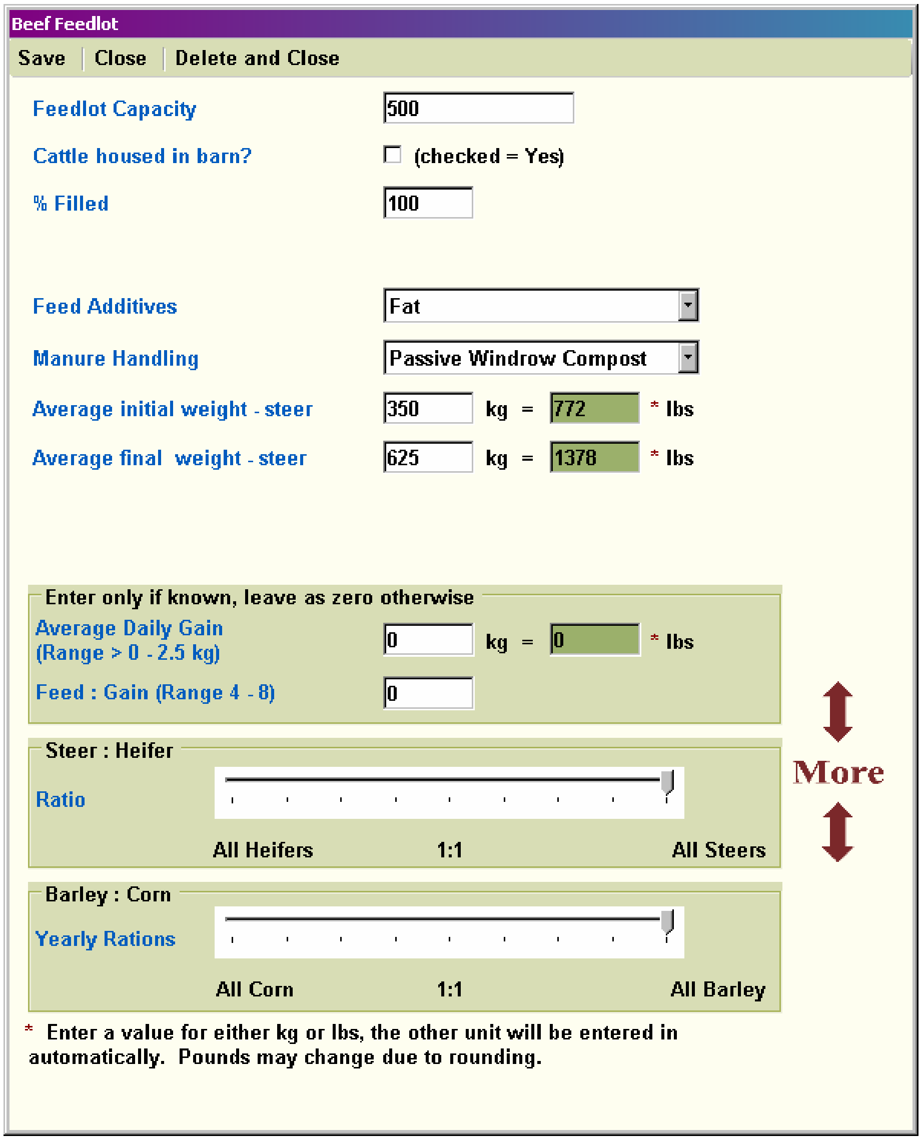
## Beef feedlot– enteric and manure $CH_4$ and manure $N_2O$ emissions

Calves not kept on farms as breeding stock will be sold to feedlots to be fattened to market weight on high energy rations prior to processing as beef. Feedlots typically fall into two categories: finishing feedlots, which fatten cattle prior to processing, and backgrounding lots, which feed cattle prior to moving to a finishing feedlot. The user has a choice between the two feedlot scenarios.

Users enter the capacity of the feedlot and, depending on the scenarios, enter the proportion of the capacity occupied or the number of months it contains livestock. The user also indicates the steer-to-heifer ratio. With a finishing feedlot, the user enters the barley-to-corn ratio of the feed. The user has the option of housing cattle in a barn and feeding additives (fats or ionophores). As well, the user selects the appropriate manure handling system.

Default values are provided for initial and final weights of both steers and heifers, depending on the scenario. However, this can vary with feedlot management so the user can override these values to adjust Holos to the feedlot situation. These values are used to calculate an average animal weight for use in further equations.

With feedlots, the user has the option of entering the feed-to-gain ratio and/or average daily gain. If entered, Holos will override the calculated potential average daily gain. The entered feed-to-gain ratio and average daily gain is used to calculate dry matter intake and gross energy requirements (Figure 8).



Feedlot Capacity: 500

Cattle housed in barn? ☐ (checked = Yes)

% Filled: 100

Feed Additives: Fat

Manure Handling: Passive Windrow Compost

Average initial weight - steer: 350 kg = 772 * lbs

Average final weight - steer: 625 kg = 1378 * lbs

Enter only if known, leave as zero otherwise

Average Daily Gain (Range > 0 - 2.5 kg): 0 kg = 0 * lbs

Feed : Gain (Range 4 - 8): 0

Steer : Heifer

Ratio: All Heifers — 1:1 — All Steers

Barley : Corn

Yearly Rations: All Corn — 1:1 — All Barley

* Enter a value for either kg or lbs, the other unit will be entered in automatically. Pounds may change due to rounding.

**Figure 8. Beef finishing feedlot form.**

Emissions are calculated as with the cow-calf scenarios for both steers and heifers.

## Assumptions:

- The number of animals, as entered, stays constant throughout the year or the number of months entered.
- Cattle feed intake is equal to energy requirements.
- Feed quality remains constant over feeding time period.
- All feed is utilized. Waste feed emissions are not accounted for.
- Finishing - Cattle are fed typical barley and/or corn finishing rations.
- Finishing - Cattle are present all year at the entered percentage capacity filled.
- Backgrounding - Cattle are fed a standard backgrounding diet.
- Backgrounding - The feedlot is at capacity for the number of months backgrounders are in the lot.
- The sex ratio of the feedlot stays constant throughout the year.

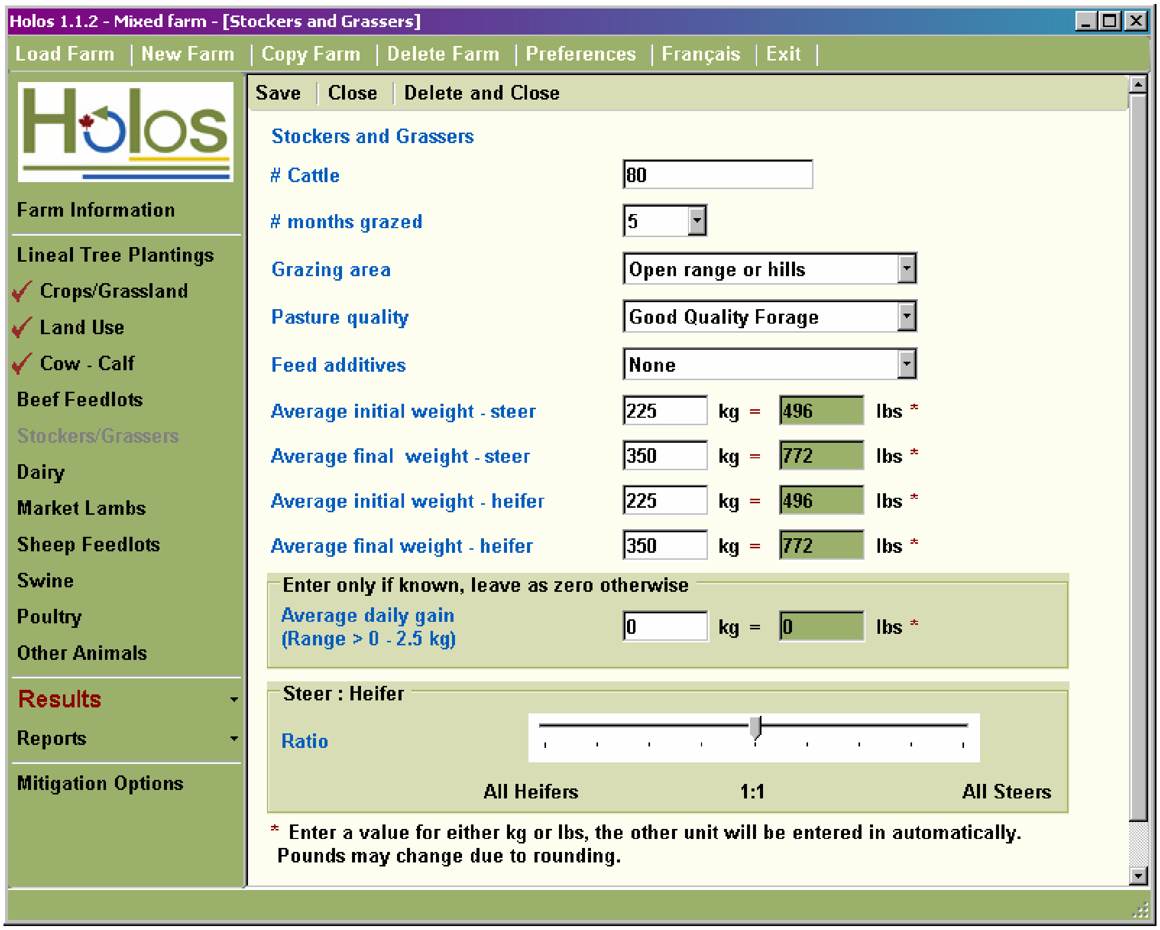
- All feedlot manure is stored in one location and land-applied yearly (unless located on pasture).
- Manure cannot be imported or exported and emissions are assigned to the farm of origin.

## Beef stocker/grasser– enteric and manure $CH_4$ and manure $N_2O$ emissions

In some cases, calves are grazed as yearlings on pasture prior to being moved to a finishing feedlot. In Canada, this is termed a stocker or grasser operation. Holos includes one stocker/grasser scenario. If these cattle are fed rations through the winter prior to grazing, this is considered a separate operation and can be accounted for in the cow-calf or feedlot scenarios (as backgrounding cattle).

The user enters the size of the stocker herd, the number of months grazed, and the steer-to-heifer ratio. The user indicates the type of grazing area and the quality of the forage. The set values for poor quality forage in Holos will not sustain growing, grazing animals and this choice is not presented in the stocker scenario. Users have the option of feeding additives (fats or ionophores).

As for feedlots, the user has the option of overriding default values for initial and final weights. The user also has the option of entering the average daily gain. If entered, this will override the calculated potential average daily gain (Figure 9).



Stockers and Grassers

\# Cattle: 80

\# months grazed: 5

Grazing area: Open range or hills

Pasture quality: Good Quality Forage

Feed additives: None

Average initial weight - steer: 225 kg = 496 lbs *

Average final weight - steer: 350 kg = 772 lbs *

Average initial weight - heifer: 225 kg = 496 lbs *

Average final weight - heifer: 350 kg = 772 lbs *

Enter only if known, leave as zero otherwise

Average daily gain (Range > 0 - 2.5 kg): 0 kg = 0 lbs *

Steer : Heifer

Ratio

* Enter a value for either kg or lbs, the other unit will be entered in automatically. Pounds may change due to rounding.

**Figure 9. Stockers/Grassers scenario form.**

Emissions are calculated as with the cow-calf scenarios for both steers and heifers.

**Assumptions:**

- The number of animals, as entered, stays constant throughout the number of months entered.
- Cattle feed intake is equal to energy requirements.
- Feed quality remains constant over feeding time period.
- The sex ratio of the cattle stays constant throughout the year.
- All stocker/grasser manure is deposited on pasture.
- Manure can not be imported or exported and emissions are assigned to the farm of origin.

## Dairy cattle – enteric and manure $CH_4$ and manure $N_2O$ emissions

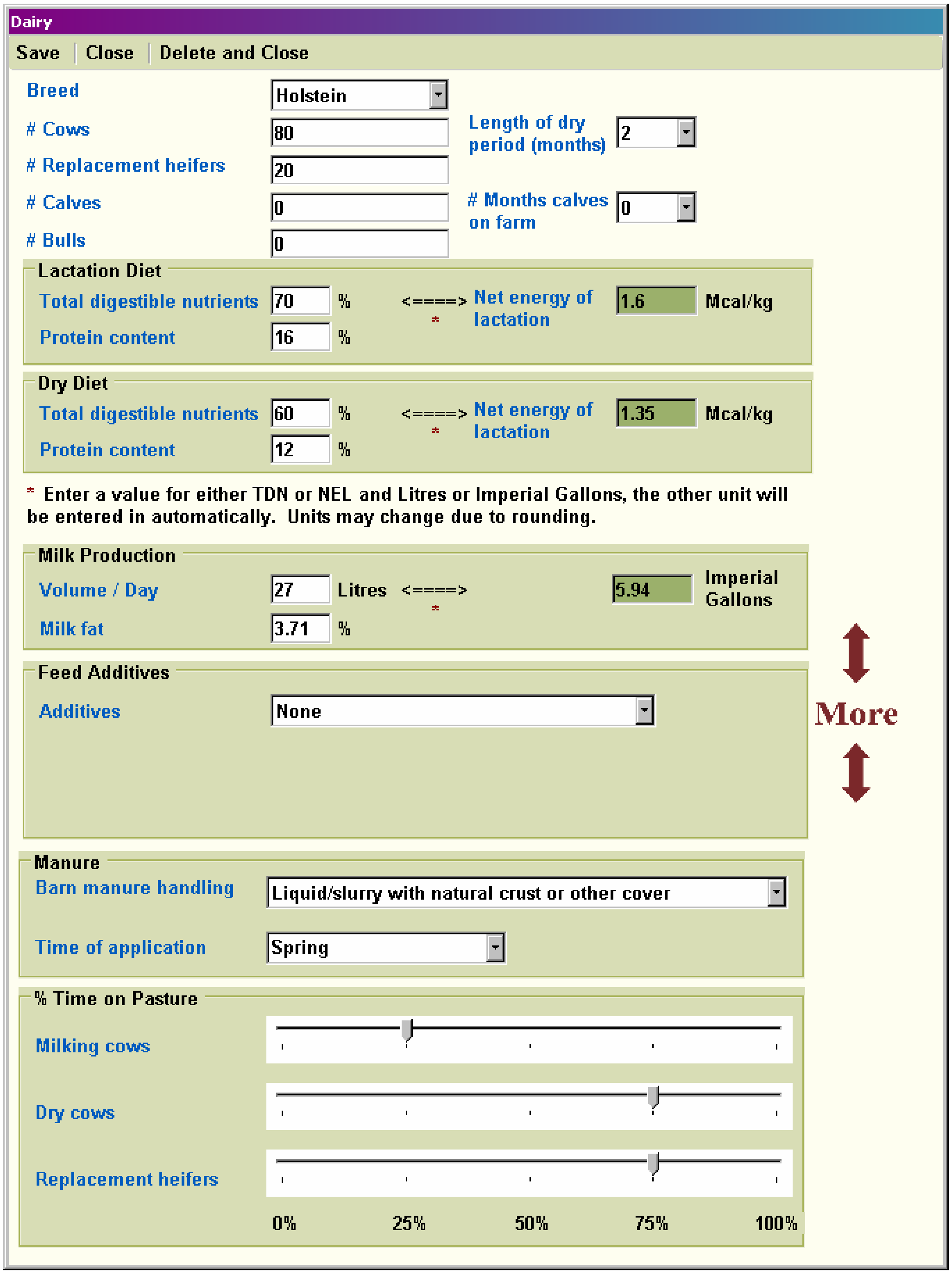
The goal of a dairy operation is to produce milk. A dairy herd consists of mature cows with cycles of lactation and dry periods. The herd may also include replacement heifers and bulls. Calves may be kept on farm. In Holos, calves kept on farm are milk-fed. If calves are kept on farm and fed rations, this is considered in the feedlot operation scenarios.

Holos includes two dairy scenarios. In the first, the herd (other then bulls) is housed in a barn all year. With the second, the user indicates the amount of time that milking cows, dry cows and replacement heifers spend on pasture. Bulls are considered on pasture with both scenarios.

The user enters the number of milk cows in the herd. The number of replacement heifers, bulls and calves is calculated from this input with the ability to override these values. The user also has a choice of cattle breed – Holstein, Jersey or other. This choice is used to set constants such as cattle size and to provide default values for milk production and milk fat. The user can override these values.

With the dairy scenarios, the user also has the option of indicating the length of the dry period. The number of months calves are kept on farm is also entered. Default diet values are provided for the lactation diet and the dry diet. However, many Canadian dairy operators are familiar with this information and, as such, these values can be entered. The diet values include the protein content and the total digestible nutrients or net energy of lactation for the feed. The user also has the option to enter feed additive use - fats or ionophores - and the percentage of fat added.

The manure handling system of the barn is indicated. If the handling system is a liquid system, the season of land application of manure is required (Figure 10). The methane conversion factor for liquid systems is selected by the province of the farm and season of application, taking into account average temperatures and duration of storage (Vergé *et al.* 2006).



Breed: Holstein

# Cows: 80

# Replacement heifers: 20

# Calves: 0

# Bulls: 0

Length of dry period (months): 2

# Months calves on farm: 0

**Lactation Diet**

Total digestible nutrients: 70 % <====> * Net energy of lactation: 1.6 Mcal/kg

Protein content: 16 %

**Dry Diet**

Total digestible nutrients: 60 % <====> * Net energy of lactation: 1.35 Mcal/kg

Protein content: 12 %

* Enter a value for either TDN or NEL and Litres or Imperial Gallons, the other unit will be entered in automatically. Units may change due to rounding.

**Milk Production**

Volume / Day: 27 Litres <====> * 5.94 Imperial Gallons

Milk fat: 3.71 %

**Feed Additives**

Additives: None

**Manure**

Barn manure handling: Liquid/slurry with natural crust or other cover

Time of application: Spring

**% Time on Pasture**

Milking cows

Dry cows

Replacement heifers

**Figure 10. Dairy scenario form.**

Emissions are calculated for each cattle class (cows-milking and dry, replacement heifers, bulls and calves) following IPCC 2006 methodology. As with beef cattle, complexity has been introduced to determine energy in feed, dry matter intake and average daily gain (National Research Council 2001). The algorithms depend on the cattle cycle as selected by the choice of scenario and user inputs and emissions are calculated as with beef cattle operations.

**Assumptions:**

- All cows are pregnant (no cull cows).
- 5 kg of protein is retained for every pregnancy.
- All lactating cows are considered mature.
- Animal average weight, based on breed, is set.
- Replacement heifers are assumed to have an initial weight of 72% of mature weight.
- All feed is utilized. Waste feed emissions are not accounted for.
- Diet is consistent throughout year (with the exception of moving to dry diet). While on pasture (when used), the diet values were assumed to be consistent with feed values.
- Diet additives are added to both lactation and dry diets.
- Replacement heifers and bulls are fed the dry diet.
- Total digestible nutrients value is considered equal to digestible energy used in equations.
- Cattle feed intake is equal to energy requirements.
- Milk production is constant throughout year and there is one milk production cycle per year.
- Emissions from bedding are not calculated.
- Veal calves are milk-fed only. (After this, emissions may be calculated in the feedlot scenarios.)
- Veal calf manure is handled as barn manure.
- All barn manure uses the same handling system.
- The amount of manure in each land application is constant. Manure must be applied at least once per year.
- All bull manure is deposited on pasture.
- Pasture is considered to be enclosed pasture.

## Swine – enteric and manure $CH_4$ and manure $N_2O$ emissions

The production of pork involves various stages of management as pigs are raised from birth to market. Swine operations vary in the stages of production they include and the pig classes involved (Table 3). The production stages include breeding, gestation, farrowing, nursing, growing and finishing for market. Holos provides four typical swine operation scenarios: farrow to finish, farrow to wean, finishing and nursery.

**Table 3. Pig classes used in Holos.**

| Pig class | Description* |
|---|---|
| Starters | 5-20 kg |
| Growers | 20-60 kg |
| Finishers | 60-110 kg |
| Sows-lactating | Mature animals |
| Sows-dry | Mature animals, includes bred gilts |
| Boars | Mature animals, 6 months and older |

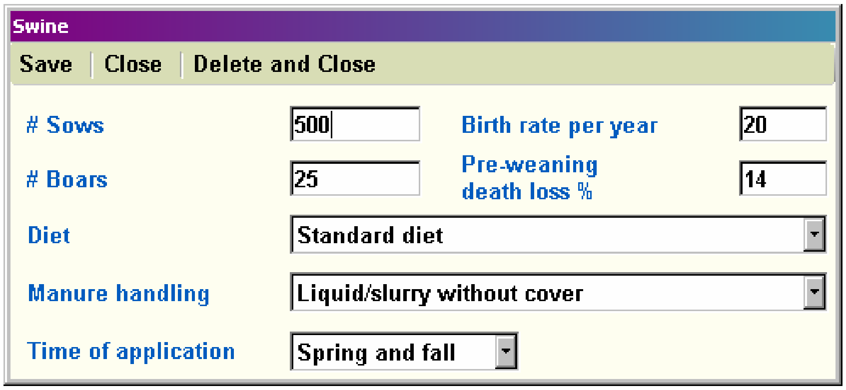
* Descriptions from Statistics Canada.

A farrow to finish operation includes pigs in all classes. The number of sows is entered by the user. The number of boars is provided as a default value which the user can override. The user also enters the yearly birth rate per sow and the pre-weaning death loss rate. These values are used to calculate the number of pigs in subsequent classes (Figure 11).

A farrow to wean operation includes sows and boars. Again, the number of sows is entered and the number of boars provided.

A finishing operation includes growers and finishers. A nursery operation includes starters only. In each scenario, the number of pigs is determined by the user entering a value as barn capacity.

All scenarios require the user to enter the type of diet, the manure management system utilized and the timing of manure land application.



# Sows 500

# Boars 25

Birth rate per year 20

Pre-weaning death loss % 14

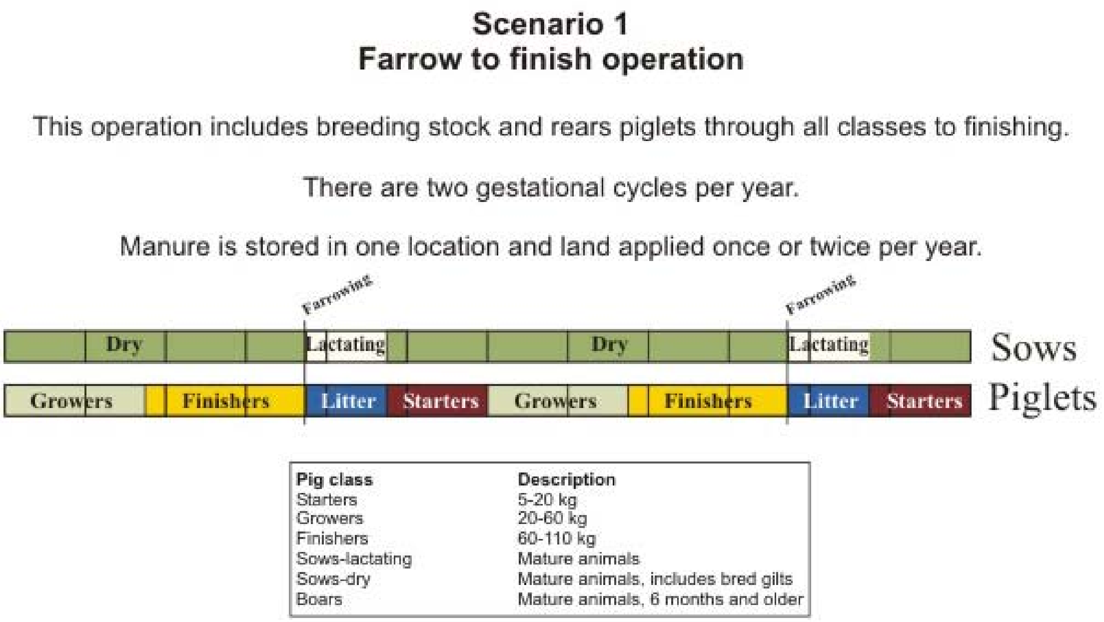
Diet: Standard diet

Manure handling: Liquid/slurry without cover

Time of application: Spring and fall

**Figure 11. Farrow to finish swine operation form.**

The scenarios differ not only in the pig classes included but in the yearly cycle of the barn. Holos provides a description and a diagram of each scenario (Figure 12).



Scenario 1
Farrow to finish operation

This operation includes breeding stock and rears piglets through all classes to finishing.

There are two gestational cycles per year.

Manure is stored in one location and land applied once or twice per year.

| Pig class | Description |
|---|---|
| Starters | 5-20 kg |
| Growers | 20-60 kg |
| Finishers | 60-110 kg |
| Sows-lactating | Mature animals |
| Sows-dry | Mature animals, includes bred gilts |
| Boars | Mature animals, 6 months and older |

**Figure 12. Example of a scenario diagram. This diagram describes swine scenario 1.**

Emissions are calculated following IPCC 2006 methodology. However, Holos uses values provided in the Greenhouse Gas System Pork Protocol (2006) for feed intake, protein content of feed, and volatile solid excretion. The yearly barn cycle and time period for each pig class also comes from the Greenhouse Gas System Pork Protocol (2006).

Holos calculates emissions for each pig class (Table 3). To estimate enteric $CH_4$, Holos uses the IPCC 2006 value of 1.5 kg $CH_4$ head$^{-1}$ year$^{-1}$ and adjusts for number of days.

Holos uses feed intake and volatile solid production values, which vary by province, to calculate manure $CH_4$ emissions. This value can be modified by diet choice with the standard diet based on corn and soy for Ontario and Quebec and barley, wheat, canola and soy for the rest of Canada (Greenhouse Gas System Pork Protocol 2006). Manure $CH_4$ emissions also depend on selection of handling system and season of manure application. As with the dairy operations, the methane conversion factors of liquid systems vary by province and season of application (Vergé *et al.* 2006).

To estimate $N_2O$ emissions from manure management, Holos utilizes the protein content of the feed and the feed intake of each pig class to calculate nitrogen excretion rates. This varies by province and can be modified by diet choice (Greenhouse Gas System Pork Protocol 2006). The nitrogen excretion rate, along with the manure handling system, is used to estimate manure $N_2O$ emissions, both direct and indirect. Manure is eventually land-applied. (These emissions are calculated in the soil $N_2O$ component.)

**Assumptions:**

- All feed is utilized. Waste feed emissions are not accounted for.
- Diet is consistent throughout year (with the exception of sows moving to dry diet).
- Diet choice (standard, low protein or highly digestible feed) selects diet for all pig classes in scenario.
- Boars and dry sows are fed the same diet.
- All barn manure uses the same handling system.
- The amount of manure in each land application is constant. Manure must be applied at least once per year.
- There are no emissions from nursing piglets.
- Farrow to finish - There are two gestational cycles per year.
- Farrow to finish - Piglets nurse for 23 days, are starters for 34 days, growers for 47 days and finishers for 54 days.
- Farrow to finish - 95% of starters move to grower class.
- Farrow to finish - 95% of growers move to finisher class.
- Farrow to wean - There are two gestational cycles per year.
- Farrow to wean - Piglets nurse for 23 days.
- Finishing operation - The barn operates on an approximate 17 week cycle, 3 cycles per year.
- Finishing operation - For 3 weeks of the year the barn is empty for cleaning.
- Finishing operation - 95% of growers move to finisher class.
- Nursery operation - The barn operates at capacity all year.

## Sheep – market lamb – enteric and manure $CH_4$ and manure $N_2O$ emissions

Market lamb operations raise lambs until market weight for meat production or until weaning where they move into a sheep feedlot for finishing prior to slaughter. There are three scenarios for market lamb operations differing in their use of pasture. Farm flocks use a combination of pasture and indoor housing. Other sheep flocks are completely pasture based or are completely contained in barns. The user has the choice of keeping weaned lambs on farm or selling them. Holos provides a description and diagram of each scenario (Figure 13).

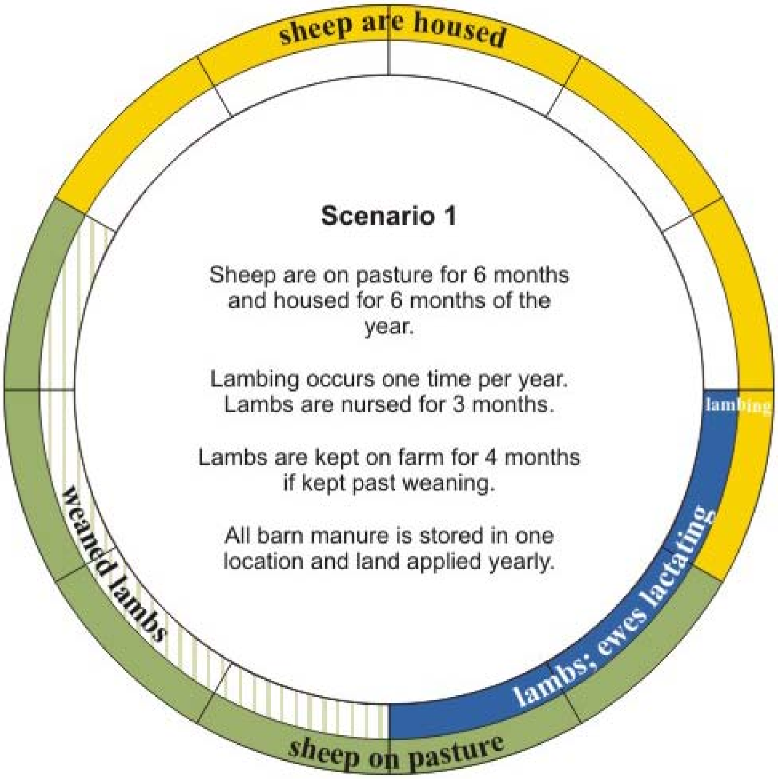
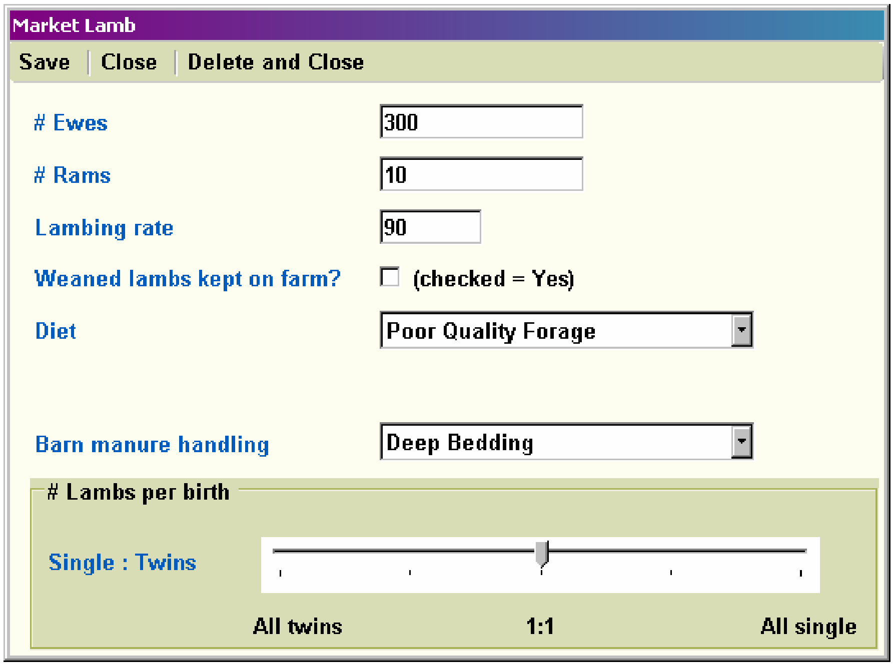


**Figure 13. Example of a scenario diagram. This diagram describes market lamb scenario 1.**

The user enters the number of ewes in the flock. The number of rams is calculated but can be overridden. The user chooses the ratio of single births to twin births in the flock and the lambing success rate. The quality of forage is selected. For scenarios with indoor housing, the user selects the manure handling system used (Figure 14). For the scenario that is entirely pasture based, the user selects the type of grazing area.



# Ewes: 300

# Rams: 10

Lambing rate: 90

Weaned lambs kept on farm? ☐ (checked = Yes)

Diet: Poor Quality Forage

Barn manure handling: Deep Bedding

# Lambs per birth

Single : Twins

**Figure 14. Market lamb scenario form.**

Emissions are calculated following IPCC 2006 methodology and are calculated for each sheep class (ewes, rams and weaned lambs). The algorithms depend on the flock cycle as selected by the choice of scenario and options.

As with cattle, Holos calculates the net energy requirements of the animal which vary depending on such things as animal class, housing and the number of lambs per birth. Net energy for gain is based on initial and final weights (for mature sheep, these are equivalent). Net energy, along with the energy in feed, determines the enteric $CH_4$ emission.

Volatile solids production is also calculated from gross energy requirements. Manure $CH_4$ emissions are estimated based on volatile solids production and manure management system. In the case of the pasture based scenario, all manure is located on pasture.

For sheep, the protein intake is based on gross energy requirements and the protein content of the feed. Protein intake and retention are used to calculate nitrogen excretion rates. This rate, along with the manure handling system, is used to estimate manure $N_2O$ emissions, both direct and indirect. Manure from the indoor confinement manure handling systems is eventually land-applied. (These emissions are calculated in the soil $N_2O$ component.)

**Assumptions:**

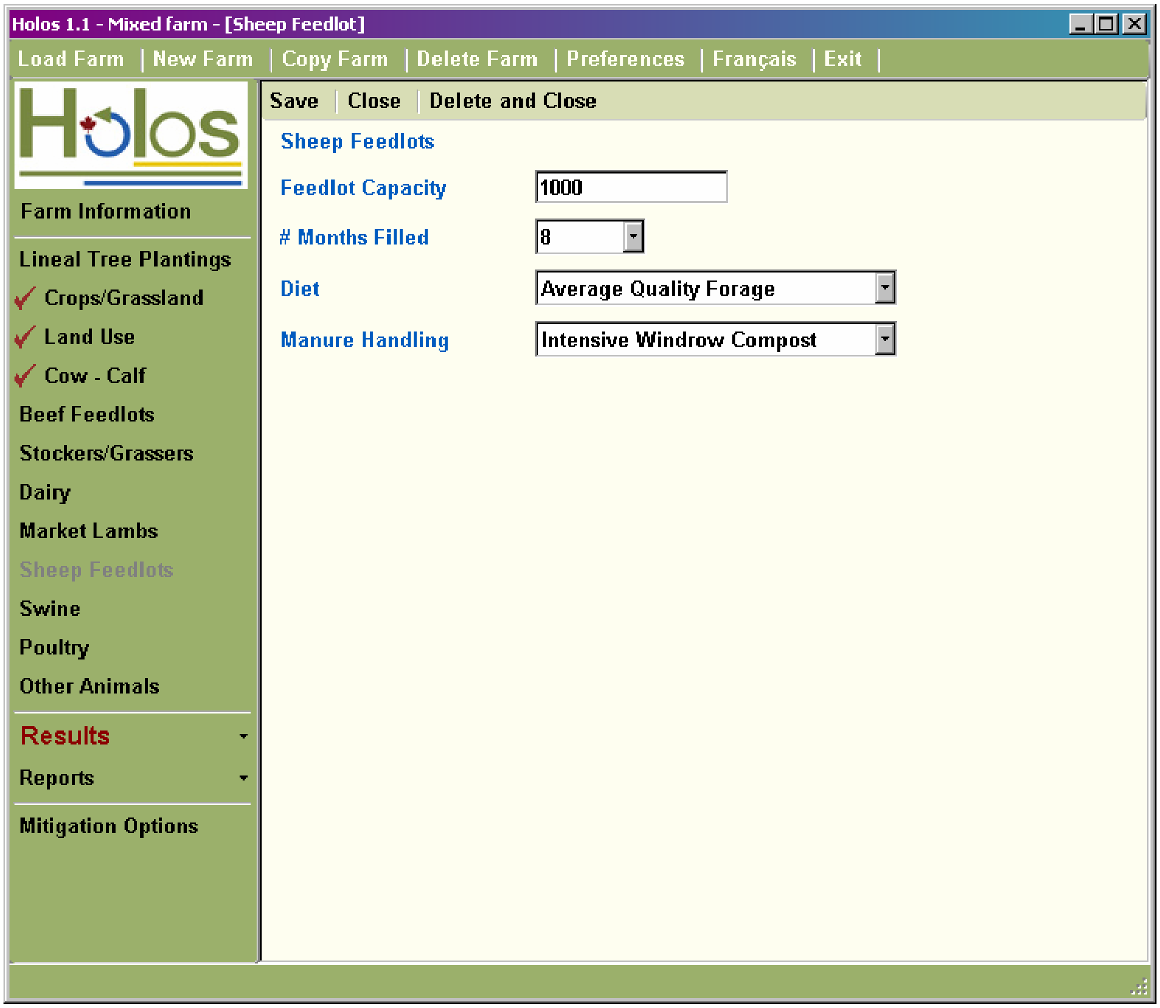
- 100% sheep survival rate.
- Lambing occurs one time per year.
- There are no emissions from nursing lambs.
- Lambs are nursed for 3 months.
- Lambs are on feed for 4 months (if kept on farm post-weaning).

- All sheep are on the same diet year-round.
- Sheep feed intake is equal to energy requirements.
- All feed is utilized. Waste feed emissions are not accounted for.
- All barn manure is handled in one system and land-applied yearly.
- Farm flock/partial confinement – Farm flocks are on pasture for 6 months and confined for 6 months.
- Farm flock/partial confinement – Pasture is assumed to be flat and sheep walk less than 1 km a day.
- Farm flock/partial confinement – Weaned lamb manure is considered on pasture (if lambs are kept past weaning).
- Pasture run – Flocks are grazed year round (marginal shelter may be offered).
- Pasture run – All manure is deposited on pasture.
- Total confinement – Flocks are confined year round.

## Sheep feedlot – enteric and manure $CH_4$ and manure $N_2O$ emissions

A sheep feedlot fattens lambs on high energy diets prior to processing. Holos includes one sheep feedlot scenario.

Users will enter the capacity of the feedlot and the number of months it is filled. Users will also choose between forage qualities for diet and select the manure handling system utilized (Figure 15).



**Sheep Feedlots**

| | |
|---|---|
| Feedlot Capacity | 1000 |
| # Months Filled | 8 |
| Diet | Average Quality Forage |
| Manure Handling | Intensive Windrow Compost |

**Figure 15. Sheep feedlot scenario form.**

Emissions are calculated as with the market lamb scenarios for weaned lambs.

**Assumptions:**

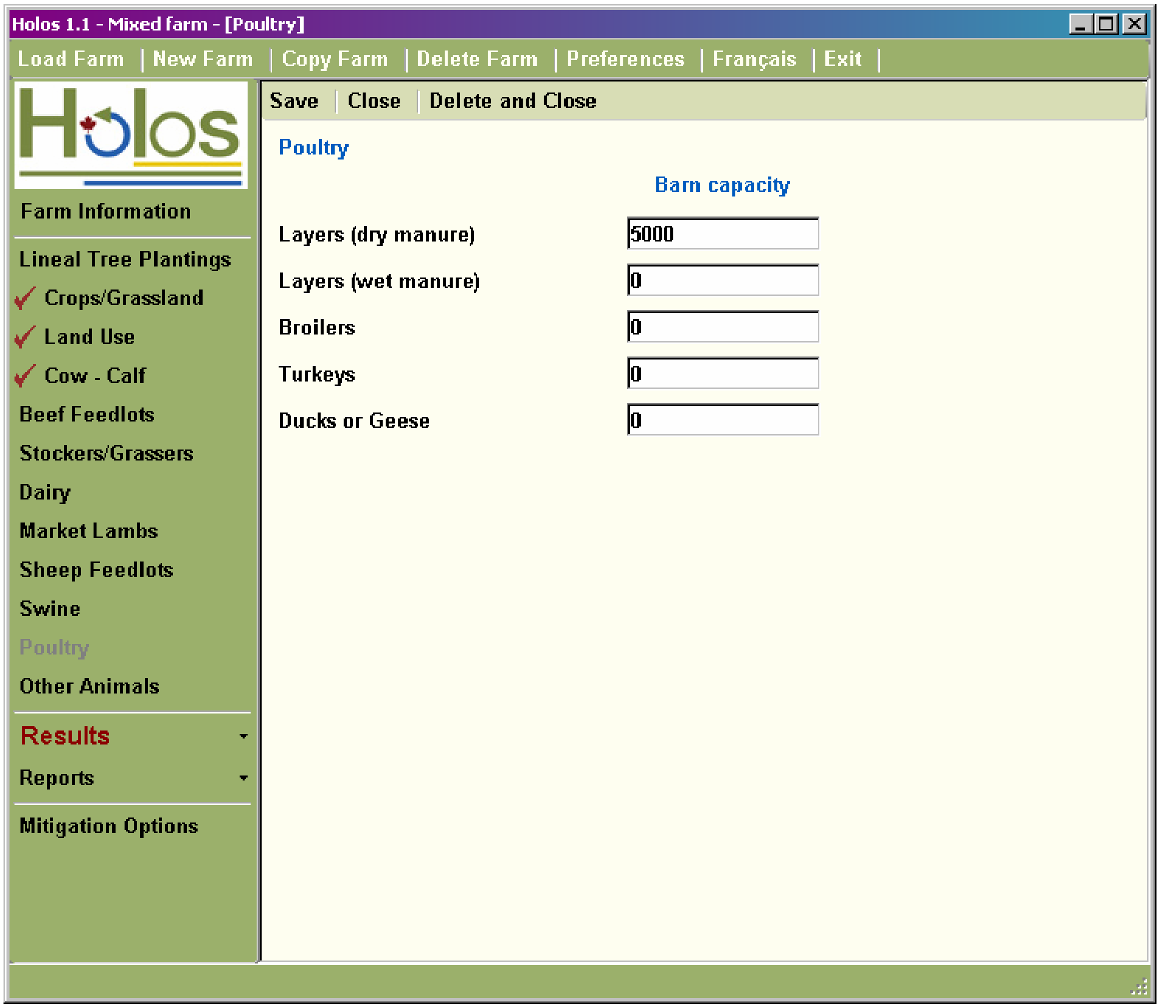
- The sex ratio of the feedlot is 1:1.
- Feedlot is at capacity for the number of months filled.
- 100% sheep survival rate.
- All sheep are on the same diet year-round.

- Sheep feed intake is equal to energy requirements.
- All feed is utilized. Waste feed emissions are not accounted for.
- All barn manure is handled in one system and land-applied yearly.

## Poultry – enteric and manure $CH_4$ and manure $N_2O$ emissions

Poultry operations involve the production of eggs or meat. Poultry life cycles range from 5 to 54 weeks. As such, a producer will have several individuals cycle through the operation over the course of a year. The rates for calculating emissions that are used by Holos are per year, rather than per animal life cycle. As such, emissions are calculated on barn capacity rather than number of animals.

The user has a choice of various poultry types (layers, broilers, turkeys, ducks or geese) and, with layers, the choice of manure handling as wet or dry (Figure 16). Emissions are calculated following IPCC 2006 methodology. There are no enteric $CH_4$ emissions from poultry. Manure $CH_4$ is estimated from a yearly rate and the capacity of the barn. Manure $N_2O$ is estimated from a nitrogen excretion rate, barn capacity and a direct emission factor. Indirect emissions are also calculated and manure is eventually land-applied. (These emissions are calculated in the soil $N_2O$ component.)



Poultry

| | Barn capacity |
|---|---|
| Layers (dry manure) | 5000 |
| Layers (wet manure) | 0 |
| Broilers | 0 |
| Turkeys | 0 |
| Ducks or Geese | 0 |

**Figure 16. Poultry scenario form.**

### Assumptions:

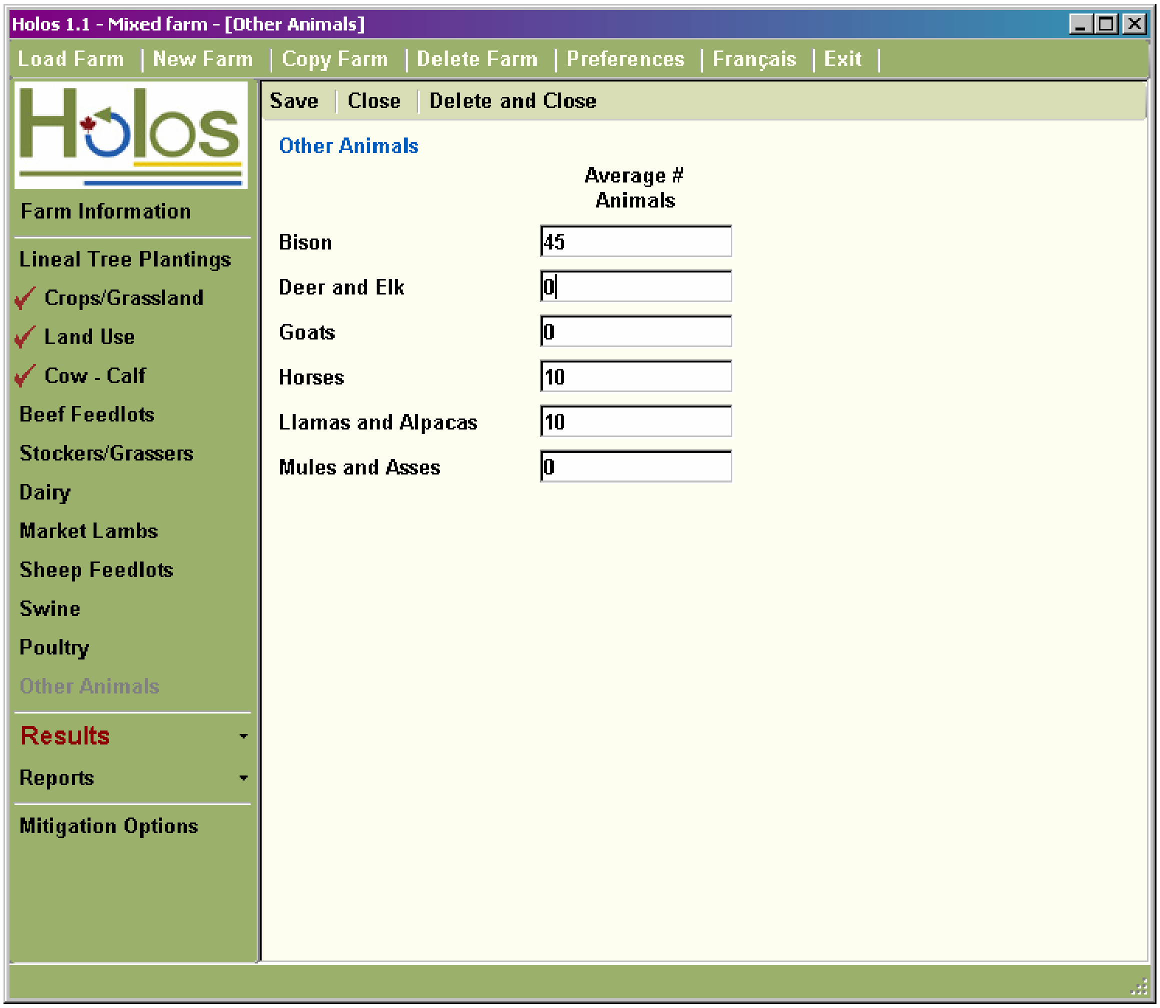
- Barn is assumed at capacity year-round.

- All manure from poultry is handled in a storage system and then land-applied once per year.

## Other animals – enteric and manure $CH_4$ and manure $N_2O$ emissions

Farms may include other animals and, as such, Holos calculates emissions for goats, llamas and alpacas, deer and elk, horses, mules and bison (Figure 17).

Emissions are calculated following IPCC 2006 methodology. Enteric and manure $CH_4$ are calculated from a yearly rate per animal. Manure $N_2O$ is estimated from a yearly nitrogen excretion rate per animal and a direct emission factor. Indirect emissions are also calculated. All manure is assumed to be deposited on pasture and, as such, is not applied to land after storage.



Other Animals

| | Average # Animals |
|---|---|
| Bison | 45 |
| Deer and Elk | 0 |
| Goats | 0 |
| Horses | 10 |
| Llamas and Alpacas | 10 |
| Mules and Asses | 0 |

**Figure 17. Other Animals scenario form.**

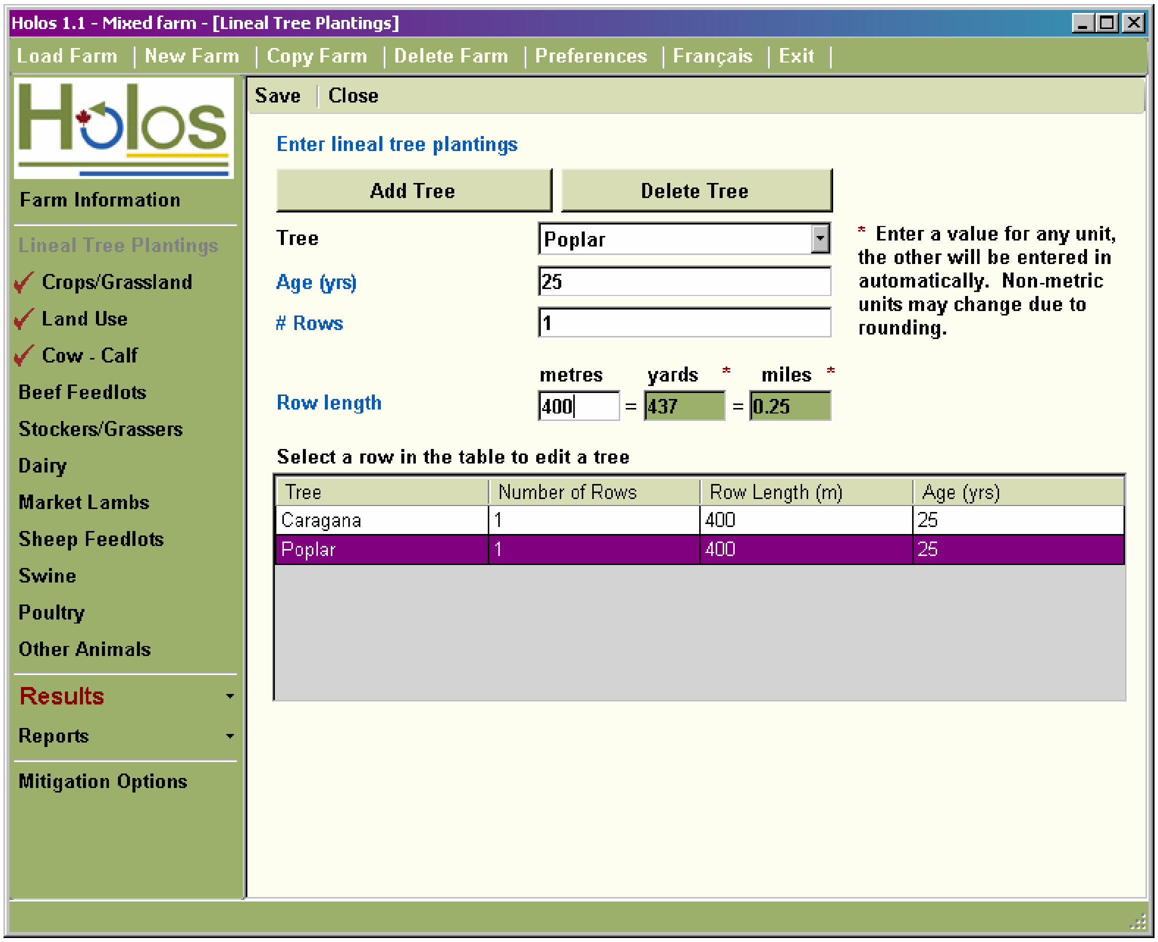
### Assumptions:

- All manure from other animals is deposited on pasture, range or paddock.

## Lineal tree plantings - soil carbon storage

Lineal tree plantings, farm shelterbelts or riparian plantings, are a potential method of storing carbon thereby removing $CO_2$ from the atmosphere. The amount of carbon stored annually is based on the size of the trees, and therefore age, and the size of the planting. Different species of trees have different storage potential (Kort and Turnock 1998).

Holos calculates annual carbon storage per tree based on user-entered planting ages and, using common planting distances and the user-defined size of planting, estimates carbon storage per year for the entire planting (Figure 18). Carbon storage for caragana is based on a 10 metre long planting rather than as per tree.



Enter lineal tree plantings

Tree: Poplar

Age (yrs): 25

# Rows: 1

* Enter a value for any unit, the other will be entered in automatically. Non-metric units may change due to rounding.

Row length: metres 400 = yards* 437 = miles* 0.25

Select a row in the table to edit a tree

| Tree | Number of Rows | Row Length (m) | Age (yrs) |
|---|---|---|---|
| Caragana | 1 | 400 | 25 |
| Poplar | 1 | 400 | 25 |

**Figure 18. Lineal Tree Plantings form.**

Holos does not calculate storage or emissions from managed, long-established or natural woodlots. For Holos version 1.1, it is assumed that carbon storage in biomass growth is balanced by removals through decay and harvest.

### Assumptions:

- 100% survival of trees.
- All trees are healthy and intact.

- Trees (and caragana) 2 years of age or less, will have an annual carbon storage of zero.
- Carbon accumulation for Eastern Canada will be equivalent to accumulation for trees on Black chernozem soils.
- Trees take two years to reach breast height.[10]

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[10] In Holos, the user inputs specifies the age of the shelterbelt, while the methodology developed by Kort and Turnock (1998) uses age at breast height. It is noted that most tree species used in shelterbelts would take on average 2 years to reach breast height and therefore we have considered age at breast height equal to user entered age - 2 years. The exception to this is caragana.

## Energy use – $CO_2$ emissions

Holos calculates energy use $CO_2$ emissions from primary and secondary sources (as defined by Gifford 1984). Primary sources use fuel and power directly on the farm - tillage, seeding, spraying, harvesting, pumping water, spreading manure, feeding animals and heating, cooling, lighting and cleaning barns. Secondary sources of energy use include the manufacture of fertilizers and herbicides. Tertiary sources of energy use emissions (e.g., acquisition of raw materials and machinery manufacture) were not included in Holos. Emissions associated with transport of products to and from the farm are not included.

Holos estimates emission from on-farm energy use from information acquired from the farm operations. As such, user entry specific to energy use emissions is accomplished in the farm operation forms. Holos reports energy use emissions from cropping and from livestock, including manure spreading.

Emissions are estimated by various calculations of energy used based on operation and size or numbers. Energy used is converted to $CO_2$ emissions by various factors, depending on the type of energy (e.g., diesel, natural gas, electricity) (Table 4).

**Table 4. Descriptions of energy use $CO_2$ emission estimates and sources.**

| Source of energy use | Affected by | Source for energy coefficients | Conversion of energy to $CO_2$ emissions | Source for conversion factors |
|---|---|---|---|---|
| Cropping (including fallow land in Western Canada) | Location of farm<br>Soil type<br>Tillage system<br>Area of crop<br>Crop type (Eastern Canada only) | Eastern Canada - Farm Fieldwork and Fossil Fuel Energy and Emissions (F4E2) model (Dyer and Desjardins 2003)<br>Western Canada - Derived from modelling typical machines used in the different regions and the number of field passes. Fuel consumption per area was determined from the work load and the efficiency of the field operation. Fuel energy used is a straight conversion from the volume used for all field operations (Elwin Smith, personal communication). | Energy in diesel fuel to $CO_2$ emissions | National Inventory Report 1990-2005;<br>Bioenergy Feedstock Information Network (BFIN) |

| **Source of energy use** | **Affected by** | **Source for energy coefficients** | **Conversion of energy to $CO_2$ emissions** | **Source for conversion factors** |
|---|---|---|---|---|
| Herbicide manufacturing | Location of farm<br>Soil type<br>Tillage system<br>Area of crop<br>Crop type (Eastern Canada only) | Eastern Canada - Dyer and Desjardins 2004<br>Western Canada - Herbicide energy use coefficients were based on the energy to manufacture specific herbicides and the recommended rate of herbicide application. The herbicide specified for a crop was the most common, typically controlling broadleaf and grassy weeds (Elwin Smith, personal communication). | Energy for herbicide manufacture to $CO_2$ emissions | Dyer and Desjardins 2007 |
| Nitrogen fertilizer production | Area fertilized<br>Rate of application for each crop | Conversion from fertilizer use directly to emissions. | Based on weighted average of 1/3 anhydrous, 2/3 urea | Nagy 2000 |
| Phosphorus fertilizer production | Area fertilized<br>Rate of application for each crop | Conversion from fertilizer use directly to emissions. | | Nagy 2000 |
| Irrigation | Area irrigated | Based on the energy used by a low pressure centre pivot system with a 43 horse power motor applying 15 inches (38 cm) of water (Harms and Helgason 2003) | Electrical and natural gas energy use to $CO_2$ emissions. Emissions from natural gas and electrical systems were averaged to create one factor. | National Inventory Report 1990-2005 |
| Dairy operations | Number of dairy cows | Vergé *et al.* 2007 | Electrical energy use to $CO_2$ emissions | National Inventory Report 1990-2005 (Canadian average coefficient) |
| Swine operations | Scenario 1 and 2 – Number of sows and boars<br>Scenario 3 and 4 – Barn capacity | Dyer and Desjardins 2006 | Electrical energy use to $CO_2$ emissions | National Inventory Report 1990-2005 (Canadian average coefficient) |

| **Source of energy use** | **Affected by** | **Source for energy coefficients** | **Conversion of energy to $CO_2$ emissions** | **Source for conversion factors** |
|---|---|---|---|---|
| Poultry barns | Barn capacity | Dyer and Desjardins 2006 | Electrical energy use to $CO_2$ emissions | National Inventory Report 1990-2005 (Canadian average coefficient) |
| Housed beef cattle | Feedlot capacity, if housed in barn | Dyer and Desjardins 2006 | Electrical energy use to $CO_2$ emissions | National Inventory Report 1990-2005 (Canadian average coefficient) |
| Land application of manure | Amount of manure nitrogen available for land application as previously calculated<br>Typical nitrogen concentration of manure, liquid or solid, by animal type (Agricultural Operation Practices Act (2001) as cited in Ormann 2005, Tri-Provincial Manure Application and Use Guidelines 2004) | Based on hauling distance of 1.81 km, application rate of 81.5 cubic metres per hectare, average of drag hose or slurry wagon (M. Wiens, La Broquerie project, University of Manitoba, personal communication) | Energy in diesel fuel to $CO_2$ emissions | National Inventory Report 1990-2005; Bioenergy Feedstock Information Network (BFIN) |

## Summations and conversions

When storage or emissions are calculated as atomic weights, these are converted to molecular weight (Table 5).

**Table 5. Conversion factors from atomic weight to molecular weight.**

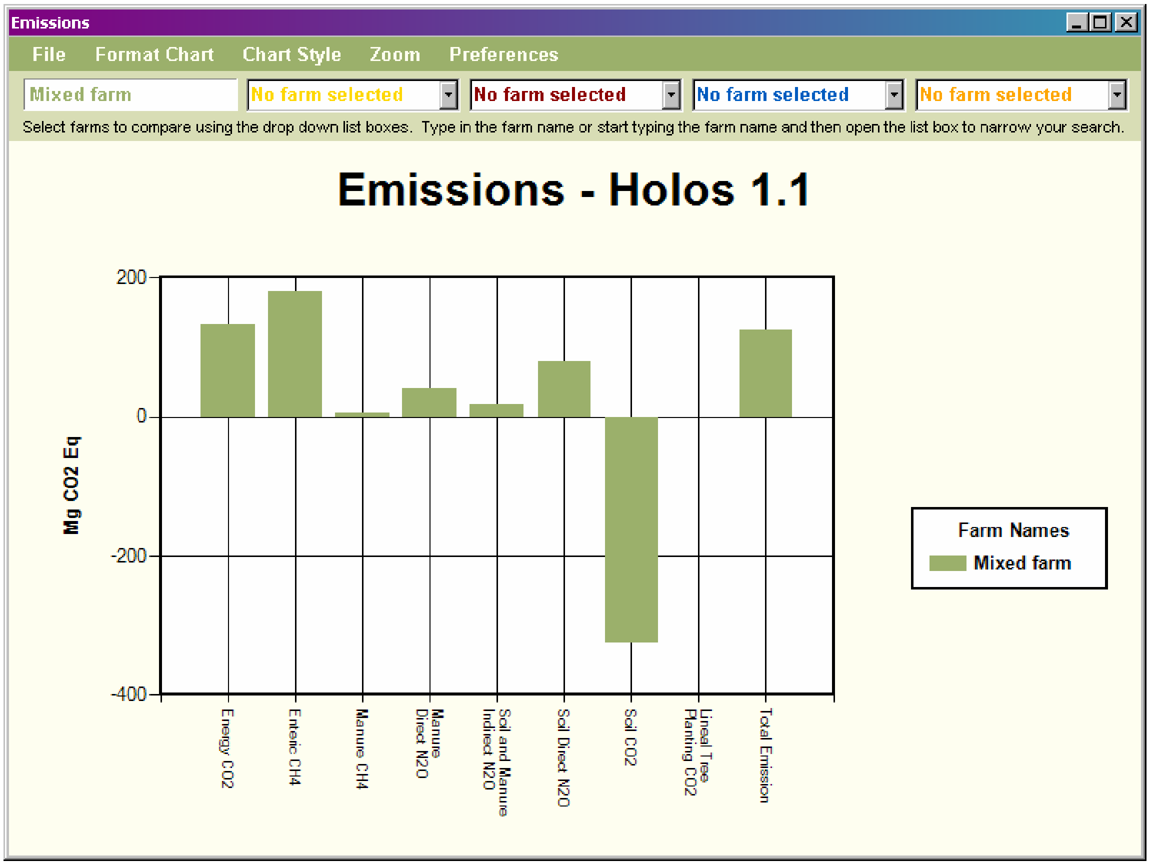
| To convert from: | To: | Multiply by: |
|---|---|---|
| $CO_2$-C | $CO_2$ | 44/12 |
| $CH_4$-C | $CH_4$ | 16/12 |
| $N_2O$-N | $N_2O$ | 44/28 |

By default, Holos uses the IPCC 2006 global warming potential conversion factors to convert emissions to $CO_2$ equivalents ($CO_2$ eq), based on units of mass (tonne/tonne) (Table 6). The user can enter other conversion factors.

**Table 6. Global warming potential conversion factors (IPCC 2006).**

| Greenhouse gas | Conversion factor |
|---|---:|
| $CO_2$ | 1 |
| $CH_4$ | 23 |
| $N_2O$ | 296 |

Holos sums emissions from all components and displays the results as a detailed report or as a comparative chart (Figure 19).



Select farms to compare using the drop down list boxes. Type in the farm name or start typing the farm name and then open the list box to narrow your search.

**Figure 19. Emission reported in a comparative chart.**

# Uncertainty

A rough estimate of uncertainty was developed, based on expert opinion, for each of the categories of emission given in the Holos output (Table 7). A system of color-coding was developed to express the relative level of uncertainty in the graphical output (Figure 20). These estimates are best viewed as crude markers, rather than as definitive assessments, provided merely to alert users especially to the areas of potentially high uncertainty.

**Table 7. Uncertainties for each emission category.**

| Emission category | Relative uncertainty | Percentage |
|---|---:|---:|
| Soil $N_2O$ - direct | high | ± <60% |
| Soil carbon | medium | ± <40% |
| Enteric $CH_4$ | low | ± <20% |
| Manure $N_2O$ - direct | medium | ± <40% |
| Soil & manure $N_2O$ - indirect | very high | ± >60% |
| Manure $CH_4$ | low | ± <20% |
| Lineal tree planting carbon | low | ± <20% |
| Energy use $CO_2$ | medium | ± <40% |

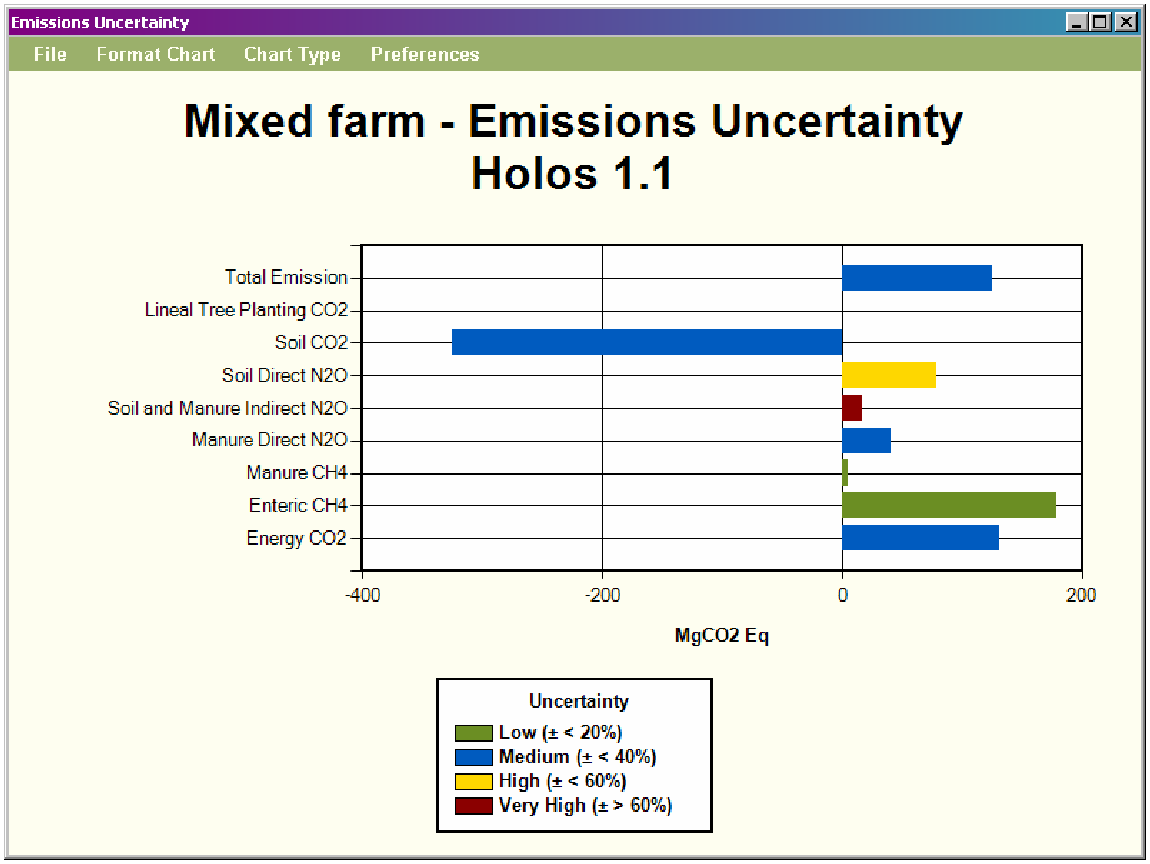


**Figure 20. Emissions Uncertainty chart with colour-coding for relative uncertainty categories.**

A weighted measures approach was used to derive the overall uncertainty for the estimate of net GHG emissions from a specified set of farm conditions.

# Mitigation

Farms in Canada have the ability to directly reduce on-farm emissions through changes in management. They also have the ability to remove $CO_2$ from the atmosphere by increasing carbon storage in soils and trees. Besides the reduction in GHG emissions, many mitigation practices also have co-benefits - social, environmental and cost saving.

Mitigation options may influence more than one GHG or involve trade-offs between gases, with one GHG decreasing while another increases. Different climate, soil types, management history and other farm variables will alter the effectiveness of mitigation options. A highly effective mitigation practice on one farm may have no effect on another (Smith *et al.* 2007).

There is no universally established set of mitigation practices and, as such, the goal of Holos is to encourage users to contemplate possible options that might reduce emissions. Holos is intended to look into the future, to envision hypothetical scenarios, and look for those practices that best reduce emissions at a specific site before they are implemented. To facilitate this, Holos provides a set of possible mitigation options unique to each farm and lets users explore the impact of these options (Table 8).

**Table 8. Mitigation options demonstrated with Holos.**

| **Mitigation practice*** | **Method of action** | **Co-benefitsʜ** |
|---|---|---|
| Add/ increase grassland | Increases carbon storage in soils until equilibrium is reached.<br>Energy $CO_2$ emissions may also be decreased through reduced fossil fuel use. | Prevents soil erosion.<br>Improves wildlife habitat.<br>Fossil fuel and machinery use may be reduced. |
| Add/ increase perennial crops | Increases carbon storage in soils until equilibrium is reached. | Increase soil structural stability and soil organic matter.<br>Soil nitrogen may also be increased. |
| Reduce tillage | Increases carbon storage in soils until equilibrium is reached.<br>Energy $CO_2$ emissions may also be decreased through reduced fossil fuel use.<br>Soil $N_2O$ emissions may decrease (semi-arid Prairies) or increase (humid East). | May also cut costs.<br>Increases soil structural stability.<br>Prevents soil erosion.<br>Increase ground cover and nesting habitat. |
| Eliminate fallow | Increases carbon storage in soils until equilibrium is reached. | Increases organic matter in the soil. |
| Plant trees | Carbon is stored in tree biomass. | Provide livestock and farmyard protection.<br>Provide cover for wildlife.<br>Prevent soil erosion.<br>Control of snow distribution.<br>Filter pollutants from runoff and groundwater.<br>Reduce odor from intensive livestock operations. |

| **Mitigation practice*** | **Method of action** | **Co-benefitsH** |
|---|---|---|
| Reduce synthetic nitrogen fertilizer§ | Decreases soil $N_2O$ and energy $CO_2$ emissions. | Cuts production costs.<br>Lessens nitrogen pollutants entering the environment. |
| Include feed additives in ruminant diets | Decreases enteric $CH_4$ production. | Fats increase the energy density of the diet.<br>Ionophores help to control bloat. |
| Feed livestock a reduced protein dietI | Reduces manure $N_2O$ emissions. | Feed costs may be lowered.<br>Odors may be reduced. |
| Feed livestock higher energy/ highly digestible feed | Decreases enteric $CH_4$ production.<br>Manure $CH_4$ emissions may be reduced. | Animal productivity may increase.<br>The volume of manure produced may be reduced. |
| Feed beef cattle more corn | Reduces enteric $CH_4$ emissions. | |
| Utilize an anaerobic digester | Manure $CH_4$ emissions are greatly reduced. | The collected biogas can be utilized to generate heat or electricity for on-farm use. |
| Spread liquid/ slurry manure more frequently | Decreases manure $CH_4$ emissions. | Increasing nutrient use efficiency may reduce commercial fertilizer costs. |
| Spread liquid/ slurry manure in spring** | Decreases manure $CH_4$ emissions. | Spreading manure in spring allows incorporation with the soil and coincides with crop nutrient uptake.<br>Increasing nutrient use efficiency may reduce commercial fertilizer costs. |

* For more information see Kebreab *et al.* 2006, Smith *et al.* 2007, Beauchemin *et al.* 2008, Desjardins *et al.* 2008 and Janzen *et al.* 2008.

H Co-benefits may or may not occur depending on specific farm situation.

§ Synthetic fertilizer use can be reduced by adjusting rates to coincide with plant needs, by placing fertilizer near the roots, by using slow-release forms, or by replacing synthetic fertilizer nitrogen with organic nitrogen (e.g., manure).

I A reduced protein diet can be achieved by avoiding inefficient protein utilization. Either by optimizing rumen-degradable protein while not over feeding undegradable protein for cattle or by optimizing amino acid balance in swine feed.

** Spreading liquid/slurry manure in the spring ensures that large volumes of manure are not stored in the warmest months of the year.

# Future improvements and dreams

Holos attempts to estimate net emissions from the whole farm and to encourage users explore potential practices to reduce emissions. This, however, is an evolving objective; as new practices are developed and as understanding grows, new opportunities and complexities emerge. In building this model, several means to improve on Holos were identified for further attention (Table 9). This is not a comprehensive list, but gives examples of proposed improvements and illustrates the merits of continued updates to the software.

**Table 9. Possible improvements for future versions of Holos.**

| **Area of improvement** | **Holos version 1.1** | **Improvement** |
|---|---|---|
| Topography | Ecodistrict topography used. | Allow the user to choose topography of farm. |
| Nitrogen input practices | No differentiation between nitrogen fertilizer or manure amendment practices. | Additional coefficients for different amendment practices (e.g., placement, timing, fertilizer forms, etc.). |
| Manure management | One system only.<br>Duration of storage reflected in emission factors. | Allow movement from one handling system to another.<br>Take into account duration of storage directly. |
| Bedding | Emissions from livestock bedding are not calculated.* | Include various bedding materials and emissions. |
| Feed additives | Only used for cattle. | Feed additive options could be used for sheep.<br>Feed additive reduction factors could be refined. |
| $C_f$ values for beef cattle | The $C_f$ value uses an average Canadian winter temperature of -2.5EC. | Ecodistrict data could be used to calculate ecodistrict mean winter temperature and subsequent $C_f$ value. |
| Forage type | Differentiation between forage quality. | Include different forage types (e.g., alfalfa, grass). |
| $Y_m$ values | General $Y_m$ values used. | New research has provided more refined $Y_m$ values. |
| Below-ground biomass from trees | Above-ground biomass only included. | Include below-ground biomass for trees. |
| Electricity emissions | Canada-wide coefficient for emissions due to electricity use. | Province-specific coefficients are available in the National Inventory report. |
| Woodlots/orchards | Woodlots/orchards are not included. | Include woodlots/orchards. |
| Organic soil restoration | Organic soil restoration is not included. | Include organic soil restoration. |
| Cultivated forestlands | Cultivated forestlands are not included. | Include cultivated forestlands. |

* However, emissions from crop residues are calculated at the farm of origin. This residue may be used for bedding.

Besides these basic improvements, Holos developers have dreams about incorporating a modifiable database to allow the user to alter or create new emission factors, coefficients and set values. As research continues, coefficients and algorithms are being continually refined (e.g., methane conversion factors, $Y_m$). Allowing user modification would enable the exploration of hypothetical situations (e.g., larger or smaller emission factors) and their downstream effects.

Another goal would be to include real-time results. Results would be graphically presented immediately as farm conditions were entered or modified.

Holos incorporates direct methods of mitigation. If intensity (emissions per unit of production) were to be built in, indirect methods of mitigation could be included. These include practices that reduce emissions per unit of production (e.g., extend lactation period, increase rate of gain, increase crop yield).

As resources allow, future versions of the software may also include a ‘biofuel’ subroutine, and allow for more direct economic analysis by merging the outputs with those of existing economic models.

Finally, the next generation of software might use mass-balance relationships and balanced nutrient cycles, rather than separate coefficients and algorithms, to undergird the projections of net GHG emissions.

# References

Beauchemin, K. A., D. M. Kreuzer, F. O'Mara and T. A. McAllister. 2008. Nutritional management for enteric methane abatement: a review. Australian Journal of Experimental Agriculture 48: 21-27.

Bioenergy Feedstock Information Network (BFIN). Undated. Energy Conversion Factors. [Online]
Available: http://bioenergy.ornl.gov/papers/misc/energy_conv.html [accessed 5 May 2008].

Bouwman, A.F. and L.J.M. Boumans. 2002. Emissions of $N_2O$ and NO from fertilized fields: Summary of available measurement data. Global Biogeochemical Cycles 16:6-1 to 6-13.

Desjardins, R.L., H.H. Janzen, P. Rochette, B. McConkey, M. Boehm and D. Worth. 2008. Moving Canadian agricultural landscapes from GHG source to sink. Pages 19-35 *in* H. Hengeveld, L. Braithwaite, R. Desjardins, J.Gorjup, and P. Hall, eds. Enhancement of Greenhouse Gas Sinks: A Canadian Science Assessment. Environment Canada: Atmospheric Science Assessment and Integration. Environment Canada, Toronto, Canada.

Dyer, J.A. and R.L. Desjardins. 2003. Simulated farm fieldwork, energy consumption and related greenhouse gas emissions in Canada. Biosystems Engineering 85: 503–513.

Dyer, J.A. and R.L. Desjardins. 2004. The Impact of Energy use in Canadian Agriculture on the Sector's Greenhouse Gas (GHG) Emissions. Research Branch, Agriculture and Agri-Food Canada, Technical Report, 17pp.
Available: http://www.canren.gc.ca/re-farms/documents/elecPub.cfm

Dyer, J.A. and R.L. Desjardins. 2006. An integrated index of electrical energy use in Canadian agriculture with implications for greenhouse gas emissions. Biosystems Engineering 95 (3): 449-460.

Dyer, J.A. and R.L. Desjardins. 2007. Energy based GHG emissions from Canadian agriculture. Journal of the Energy Institute 80 (2): 93-95.

Gifford, R.M. 1984. Energy in different agricultural systems: renewable and nonrenewable sources. Pages 84-112 *in* G. Stanhill, ed. Energy and Agriculture. Springer-Verlag, Berlin, Germany.

Greenhouse Gas System Pork Protocol: The Innovative Feeding of Swine and Storing and Spreading of Swine Manure (Draft) dated July 31, 2006. Prepared by the Pork Technical Working Group (PTWG), a sub-committee of the National Offsets Quantification Team (NOQT).

Harms, T. and W. Helgason. 2003. Irrigation Pumping Costs Calculator. Irrigation Branch, Alberta Agriculture, Food and Rural Development.

Helgason, B.L., 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. Agriculture and Agri-Food Canada.

IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme, H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara and K. Tanabe. (Eds). IGES, Japan.
Available: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm

Janzen, H. H., D. A. Angers, M. Boehm, M. Bolinder, R. L. Desjardins, J. A. Dyer, B. H. Ellert, D. J. Gibb, E. G. Gregorich, B. L. Helgason, R. Lemke, D. Massé, S. M. McGinn, T. A. McAllister, N. Newlands, E. Pattey, P. Rochette, W. Smith, A. J. VandenBygaart, and H. Wang. 2006. A proposed approach to estimate and reduce net greenhouse gas emissions from whole farms. Canadian Journal of Soil Science 86: 401–418.

Janzen, H.H., R.L. Desjardins, P. Rochette, M. Boehm and D. Worth (Eds). 2008. Better Farming Better Air: A scientific analysis of farming practice and greenhouse gases in Canada. Agriculture and Agri-Food Canada: Ottawa, Canada. 146 pp.

Kebreab, E., K. Clark, C. Wagner-Riddle, and J. France. 2006. Methane and nitrous oxide emissions from Canadian animal agriculture: A review. Canadian Journal of Animal Science 86:135-158.

Keeling, C.D., S.C. Piper, R.B. Bacastow, M. Wahlen, T.P. Whorf, M. Heimann and H.A. Major. 2001. Exchanges of atmospheric $CO_2$ and $^{13}CO_2$ with the terrestrial biosphere and oceans from 1978 to 2000. I. Global aspects. SJD Reference Series. No. 01-06, Scripps Institution of Oceanography, San Diego, USA. 88pp.
Available: http://scrippsco2.ucsd.edu/data/data.html

Kort, J. and R. Turnock. 1998. Annual carbon accumulations in agroforestry plantations. Agriculture and Agri-Food Canada, PFRA Shelterbelt Centre, Indian Head, Canada. 7 pp.
Available:
http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1199722936936&lang=e

Kort, J. and R. Turnock. 1999. Carbon reservoir and biomass in Canadian prairie shelterbelts. Agroforestry Systems. 44:175-186.

Marshall, I.B., P Schut and M. Ballard (compilers). 1999. A National Ecological Framework for Canada: Attribute Data. Environmental Quality Branch, Ecosystems Science Directorate, Environment Canada and Research Branch, Agriculture and Agri-Food Canada, Ottawa/Hull, Canada.
Available: http://sis.agr.gc.ca/cansis/nsdb/ecostrat/data_files.html

McConkey, B.G., D.A. Angers, M. Bentham, M. Boehm, T. Brierley, D. Cerkowniak, C. Liang, P. Collas, H. de Gooijer, R. Desjardins, S. Gameda, B. Grant, E. Huffman, J. Hutchinson, L. Hill, P. Krug, T. Martin, G. Patterson, P. Rochette, W. Smith, B. VandenBygaart, X. Vergé, and D. Worth. 2007. Canadian Agricultural Greenhouse Gas Monitoring Accounting and Reporting System: Methodology and greenhouse gas estimates for agricultural land in the LULUCF sector for NIR 2006. Agriculture and Agri-Food Canada, Ottawa, Canada.

Mosier, A.R., J.M. Duxbury, J.R. Freney, O. Heinemeyer, and K. Minami. 1998. Assessing and mitigating $N_2O$ emissions from agricultural soils. Climatic Change 40:7-38.

Nagy, C.N. 2000. Energy and greenhouse gas emissions coefficients for inputs used in agriculture. Report to the Prairie Adaptation Research Collaborative. 11 pp.

National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990-2005. 2007. Prepared by the Greenhouse Gas Division, Environment Canada. Environment Canada, Gatineau, Canada. 611 pp.
Available: http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/tdm-toc_eng.cfm

National Research Council. 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. National Academy Press, Washington, USA.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle: Seventh Revised Edition: 2001. National Academy Press, Washington, USA.

Ormann, T. 2005. Manure Nutrient Value: Wisdom Gained from Experience in Southern Alberta. County of Lethbridge, Canada.
Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw9921

Rochette, P. and H.H. Janzen. 2005. Towards a revised coefficient for estimating $N_2O$ from legumes. Nutrient Cycling in Agroecosystems 73: 171-179.

Rochette, P., D.E. Worth, R.L. Lemke, B.G. McConkey, D.J. Pennock, C. Wagner-Riddle and R.L. Desjardins. 2008. Estimation of $N_2O$ emissions from agricultural soils in Canada. I. Development of a country-specific methodology. Canadian Journal of Soil Science 88: 641-654.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O’Mara, C. Rice, B. Scholes and O. Sirotenko. 2007. Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (Eds.)], Cambridge University Press, Cambridge, UK and New York, USA.
Available: http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter8.pdf

Tri-Provincial Manure Application and Use Guidelines. 2004. Prepared by The Prairie Province's Committee on Livestock Development and Manure Management. Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw8709?opendocument

Vergé, X., D. Worth, J. Hutchinson amd R. Desjardins. 2006. Greenhouse gas emission from Canadian Agro-ecosystems. Cat. no.: AAFC-10181E. Agriculture and Agri-Food Canada, Ottawa, Canada. 38 pp.

Vergé, X.P.C., J.A. Dyer, R.L. Desjardins and D. Worth. 2007. Greenhouse gas emissions from the Canadian dairy industry in 2001. Agricultural Systems 94: 683-693.

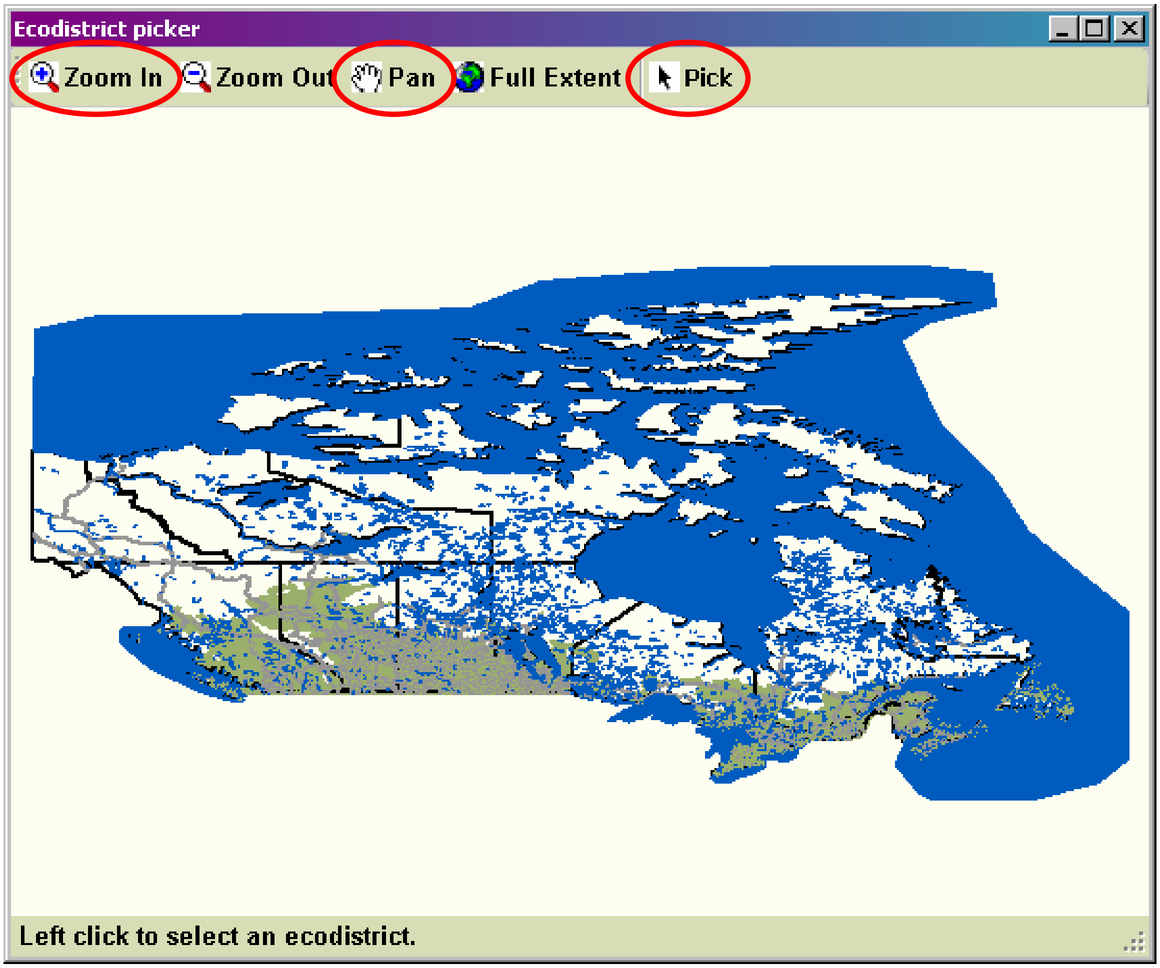
# Appendix 1 – Example farm

The following will guide you through the set up of an example mixed farm (cow-calf, forage, grain) in southern Alberta.

1. Launch Holos.
   a. If your Welcome Screen is enabled, choose your language and then choose Create a new farm.)
   b. If your Welcome Screen is not viewed at start up, click New Farm.

2. The Ecodistrict picker will launch. Click on the Pick arrow and choose the location of the farm in southern Alberta (Lethbridge). Zoom in or Pan the map if necessary (Figure 21).

3. OK the ecodistrict choice.

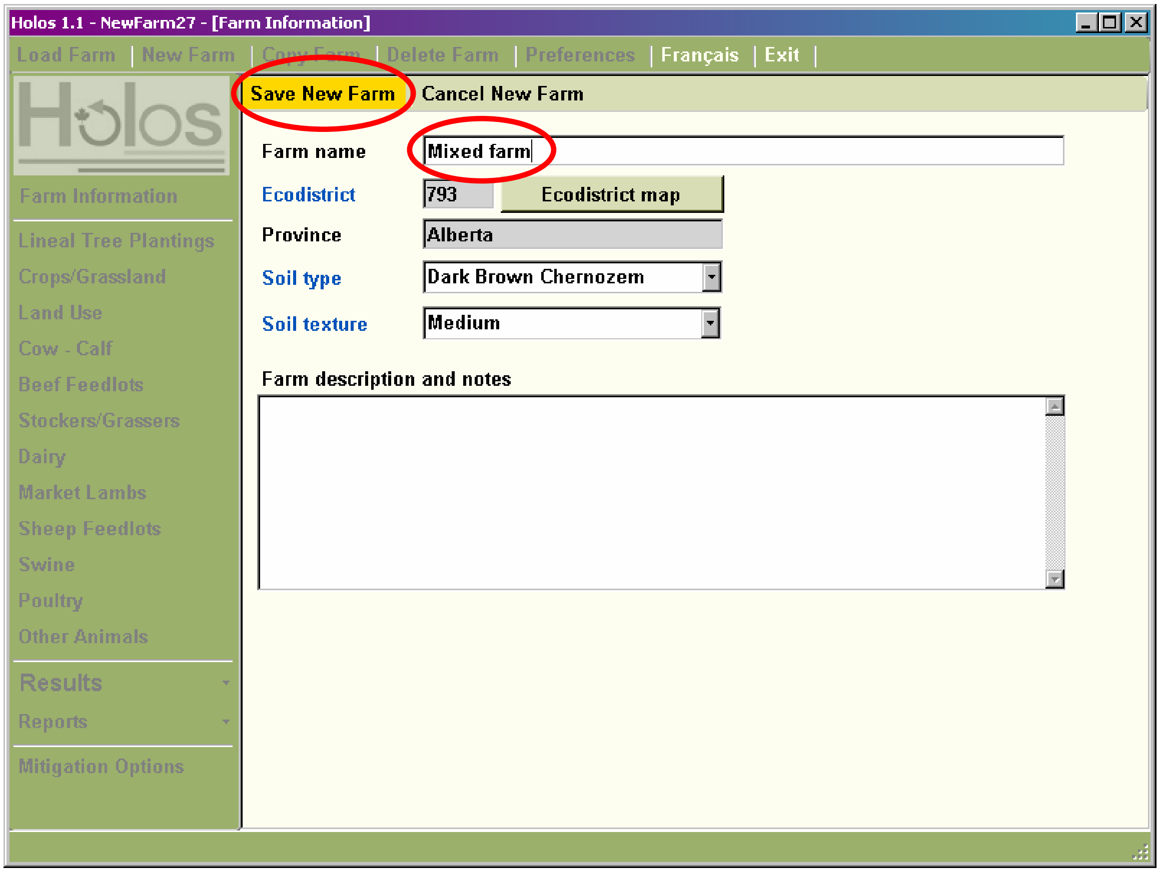


Left click to select an ecodistrict.

**Figure 21. Ecodistrict picker. Zoom In, Pan and Pick buttons circled.**

4. Enter Farm name as Mixed farm.

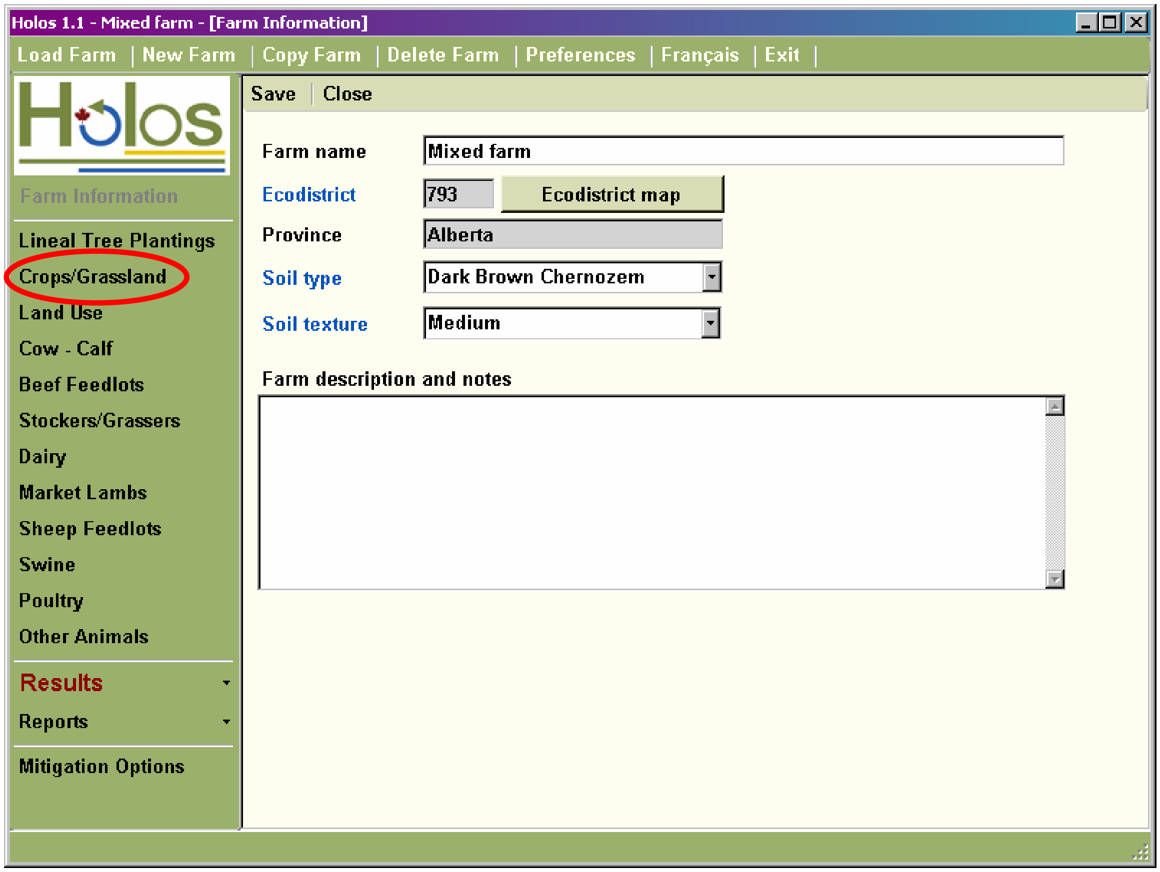
5. Click on Save New Farm (Figure 22).



Farm name: Mixed farm
Ecodistrict: 793
Province: Alberta
Soil type: Dark Brown Chernozem
Soil texture: Medium
Farm description and notes

**Figure 22. Farm information form. Entered Farm name and Save New Farm button circled. Items in blue text may be clicked on for further information or explanation.**

6. Choose Crops/Grassland from the navigation menu (Figure 23).



Farm name: Mixed farm

Ecodistrict: 793

Province: Alberta

Soil type: Dark Brown Chernozem

Soil texture: Medium

Farm description and notes

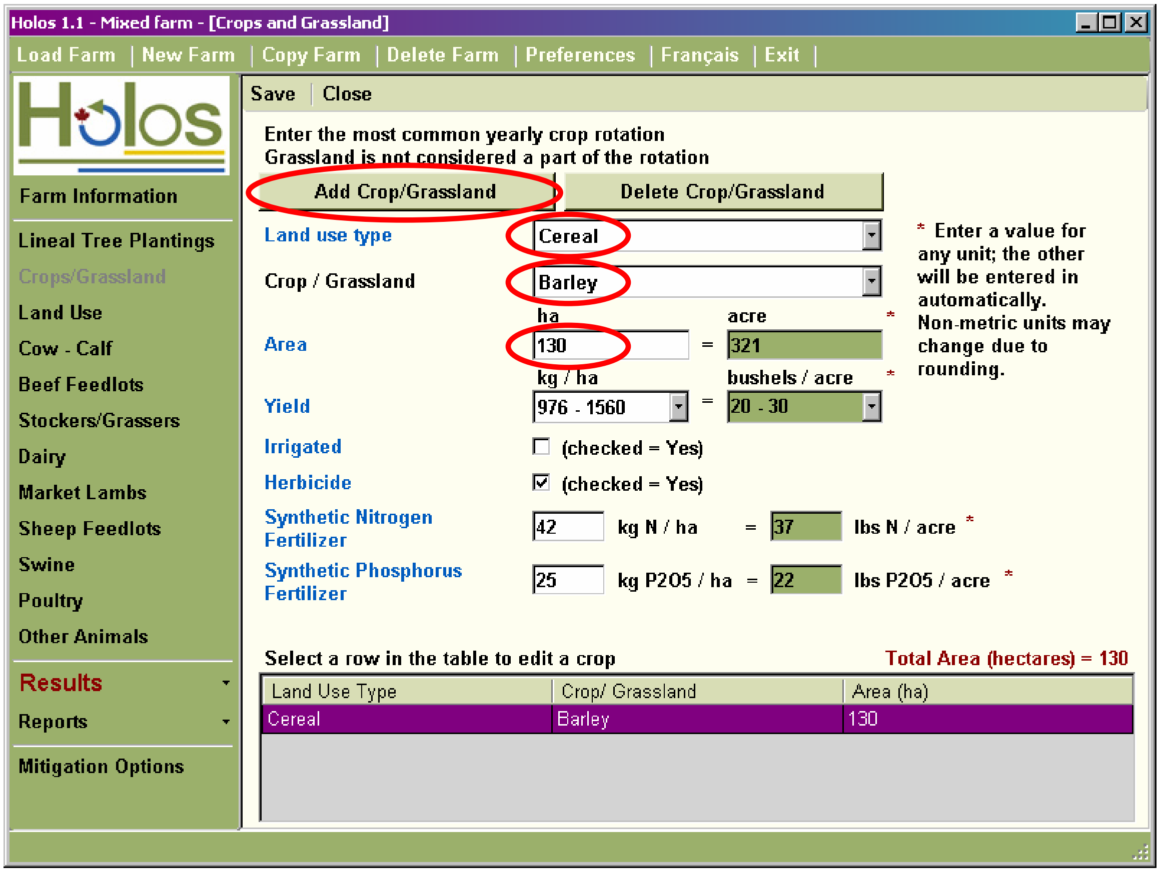
**Figure 23. Navigation menu. Crops/Grassland operation button circled.**

7. Choose **Cereal** from the **Land use type** drop-down menu.

8. Choose **Barley** as the crop.

9. Enter **130 hectares** as the **Area**. Leave default values for other inputs.

10. Click on **Add Crop/Grassland** (Figure 24).



Enter the most common yearly crop rotation
Grassland is not considered a part of the rotation

Land use type: Cereal

Crop / Grassland: Barley

Area: 130 ha = 321 acre *

Yield: 976 - 1560 kg / ha = 20 - 30 bushels / acre *

Irrigated: ☐ (checked = Yes)

Herbicide: ☑ (checked = Yes)

Synthetic Nitrogen Fertilizer: 42 kg N / ha = 37 lbs N / acre *

Synthetic Phosphorus Fertilizer: 25 kg P205 / ha = 22 lbs P205 / acre *

* Enter a value for any unit; the other will be entered in automatically. Non-metric units may change due to rounding.

Select a row in the table to edit a crop

Total Area (hectares) = 130

| Land Use Type | Crop/ Grassland | Area (ha) |
|---|---|---|
| Cereal | Barley | 130 |

**Figure 24. Crops/Grassland form. Land use type and Crop/Grassland drop-down menus, Area input box and Add Crop/Grassland button circled.**

11. Choose **Perennial Forage** from the **Land use type** drop-down menu.

12. Choose **Hay-mixed.**

13. Enter **130 hectares** as the **Area.**

14. Check **Irrigated** check box.

15. Modify default yield by selecting **2561-3520 kg/ha** from the **Yield** drop-down menu.

16. Click on **Add Crop/Grassland.**

17. Choose **Fallow** from the Land use type drop-down menu.

18. Enter **65 hectares** as the **Area**.
19. Click on **Add Crop/Grassland.**
20. Choose **Grassland** from the **Land use type** drop-down menu.
21. Enter **130 hectares** as the **Area**.
22. Select **Native Grassland** from the **Year grassland seeded** drop-down menu.
23. Click on **Save**.

24. Choose Land Use from the navigation menu.

25. Slide Present tillage intensity slider to Reduced and Past tillage intensity to Intensive .

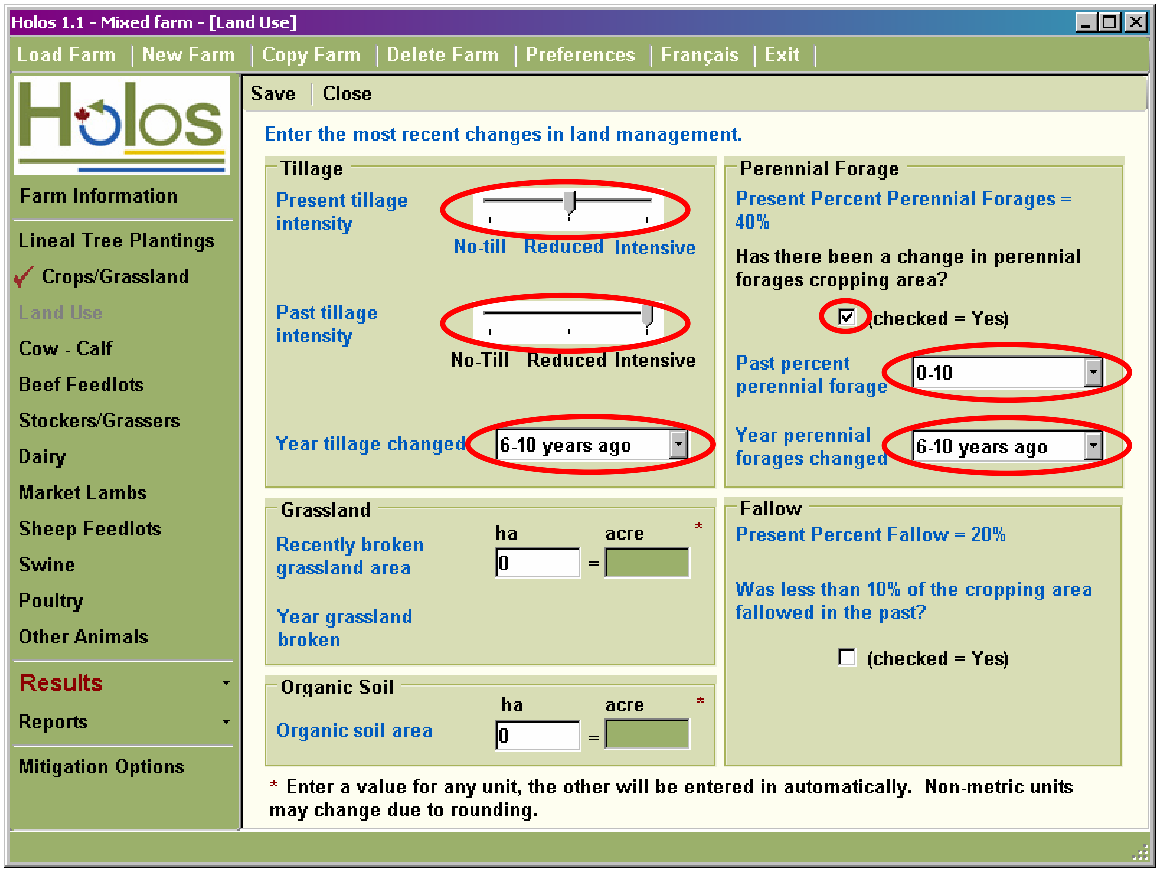
26. Select 6-10 years ago on the Year tillage changed drop-down menu.

27. Check that there has been a change in perennial forages cropping area.

28. Select Past percent perennial forage as 0-10.

29. Select 6-10 years ago on the Year perennial forages changed drop-down menu (Figure 25).

30. Click on Save.



Enter the most recent changes in land management.

Tillage

Present tillage intensity: No-till Reduced Intensive

Past tillage intensity: No-Till Reduced Intensive

Year tillage changed: 6-10 years ago

Perennial Forage

Present Percent Perennial Forages = 40%

Has there been a change in perennial forages cropping area?

☑ (checked = Yes)

Past percent perennial forage: 0-10

Year perennial forages changed: 6-10 years ago

Grassland

Recently broken grassland area: ha 0 = acre *

Year grassland broken

Fallow

Present Percent Fallow = 20%

Was less than 10% of the cropping area fallowed in the past?

☐ (checked = Yes)

Organic Soil

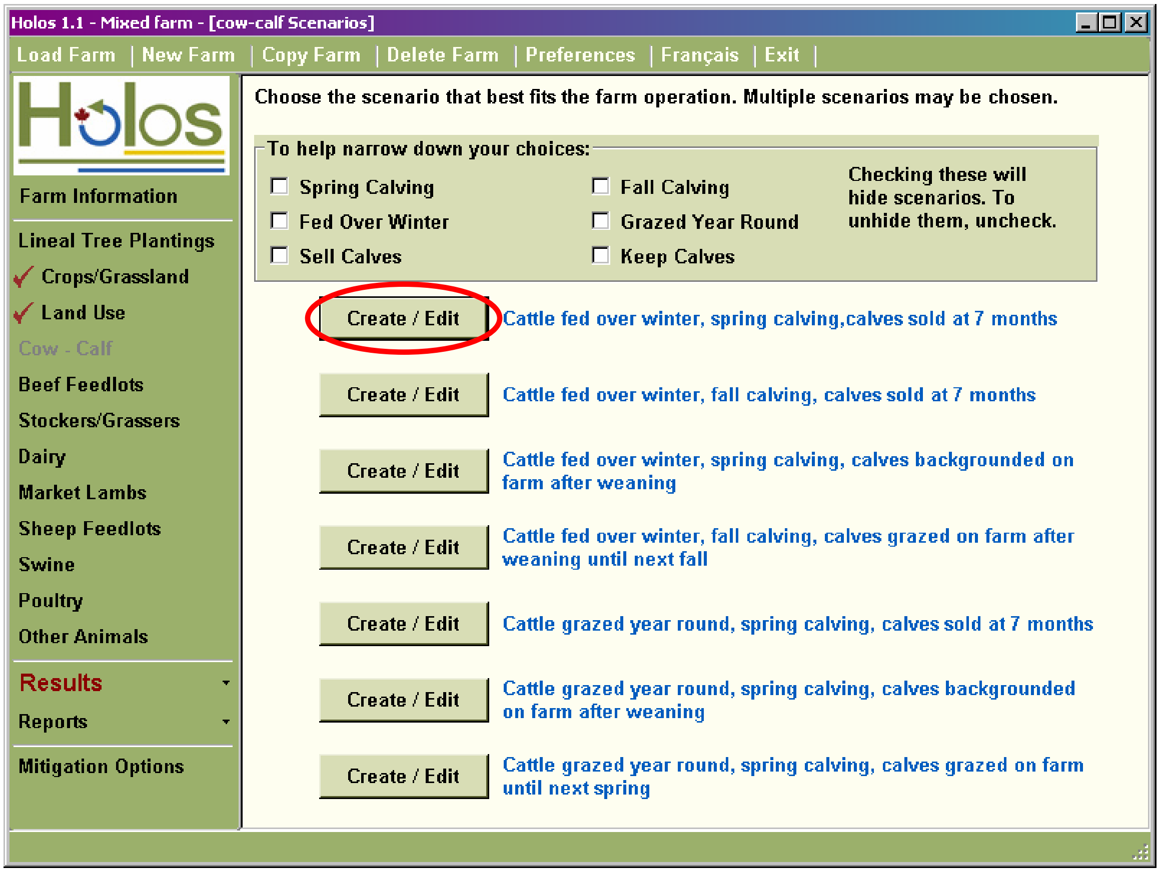
Organic soil area: ha 0 = acre *

* Enter a value for any unit, the other will be entered in automatically. Non-metric units may change due to rounding.

**Figure 25. Land Use form. Present and Past tillage intensity sliders, Year tillage changed and Year perennial forages changed drop-down menus, perennial forages cropping area change check box circled.**

31. Choose **Cow-Calf** from the navigation menu.

32. Choose the first scenario by clicking on the **Create/Edit** button (Figure 26).



Choose the scenario that best fits the farm operation. Multiple scenarios may be chosen.

Checking these will hide scenarios. To unhide them, uncheck.

Create / Edit Cattle fed over winter, spring calving,calves sold at 7 months

Create / Edit Cattle fed over winter, fall calving, calves sold at 7 months

Create / Edit Cattle fed over winter, spring calving, calves backgrounded on farm after weaning

Create / Edit Cattle fed over winter, fall calving, calves grazed on farm after weaning until next fall

Create / Edit Cattle grazed year round, spring calving, calves sold at 7 months

Create / Edit Cattle grazed year round, spring calving, calves backgrounded on farm after weaning

Create / Edit Cattle grazed year round, spring calving, calves grazed on farm until next spring

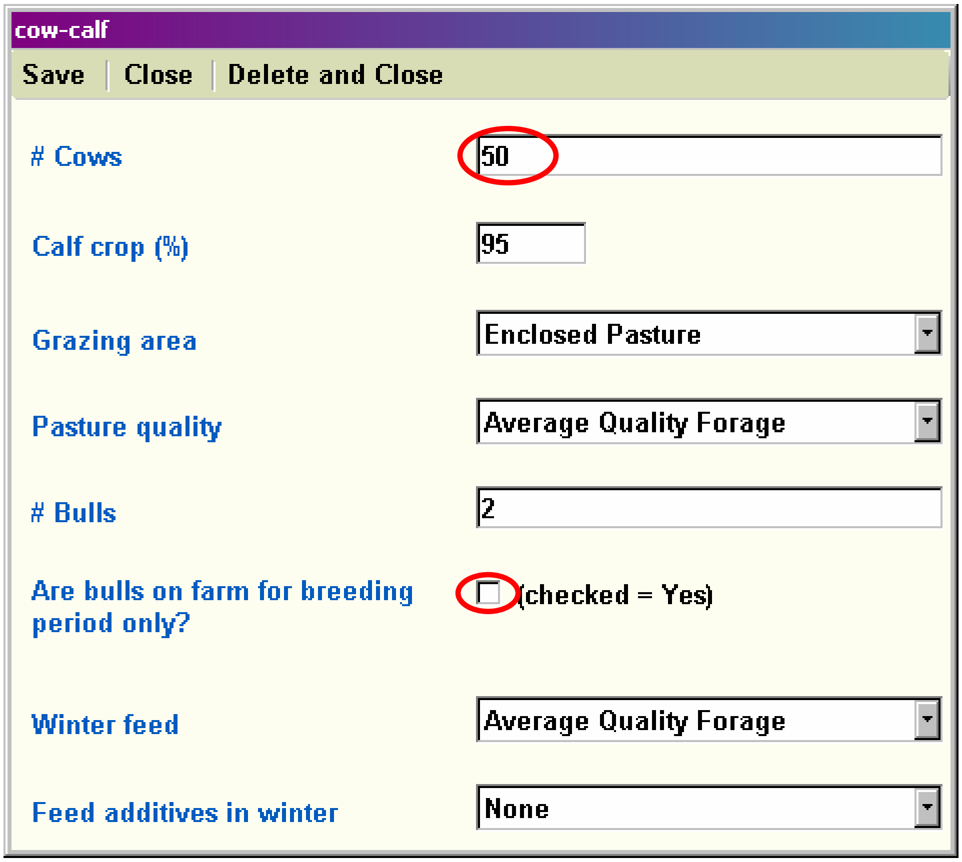
**Figure 26. Cow-calf scenario form. Create/Edit button for Scenario 1 circled. Clicking on the blue text describing the scenario will launch a diagram describing the scenario in detail.**

33. Enter 50 as the # Cows.

34. Leave default values of 2 Bulls, 95% Calf crop, Enclosed Pasture, Average Quality Forage and no Feed additives in winter.

35. Uncheck Are bulls on farm for breeding period only? (Figure 27).

36. Click on Save, then Close.

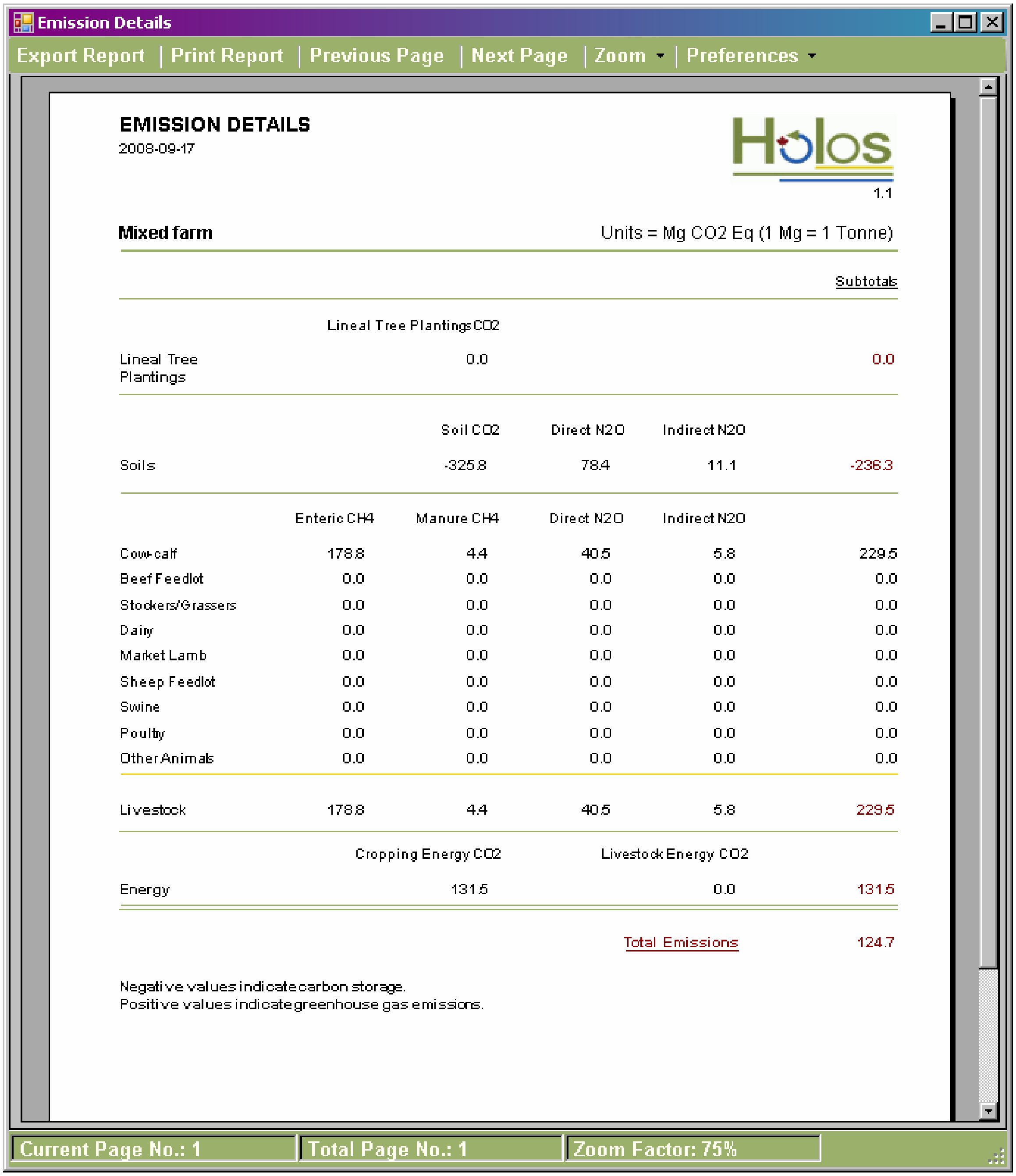


| | |
|---|---|
| # Cows | 50 |
| Calf crop (%) | 95 |
| Grazing area | Enclosed Pasture |
| Pasture quality | Average Quality Forage |
| # Bulls | 2 |
| Are bulls on farm for breeding period only? | ☐ (checked = Yes) |
| Winter feed | Average Quality Forage |
| Feed additives in winter | None |

**Figure 27. Cow-Calf scenario 1 form. Number of cows and bulls on farm for breeding period only check box circled.**

37. To view the details of this farm, select **Reports** from the navigation menu and **Farm Details**.

38. To view the emission estimate of this farm, choose **Results** and **Emission Details Report** for a report (Figure 28) or **Emission Comparison Chart** for a bar chart (multiple farm entries can be compared on this chart).



**EMISSION DETAILS**
2008-09-17

**Mixed farm**
Units = Mg CO2 Eq (1 Mg = 1 Tonne)

|  | Lineal Tree Plantings CO2 | Subtotals |
|---|---|---|
| Lineal Tree Plantings | 0.0 | 0.0 |

|  | Soil CO2 | Direct N2O | Indirect N2O |  |
|---|---|---|---|---|
| Soils | -325.8 | 78.4 | 11.1 | -236.3 |

|  | Enteric CH4 | Manure CH4 | Direct N2O | Indirect N2O |  |
|---|---|---|---|---|---|
| Cow-calf | 178.8 | 4.4 | 40.5 | 5.8 | 229.5 |
| Beef Feedlot | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Stockers/Grassers | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dairy | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Market Lamb | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sheep Feedlot | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Swine | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Poultry | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other Animals | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Livestock | 178.8 | 4.4 | 40.5 | 5.8 | 229.5 |

|  | Cropping Energy CO2 | Livestock Energy CO2 |  |
|---|---|---|---|
| Energy | 131.5 | 0.0 | 131.5 |

Total Emissions 124.7

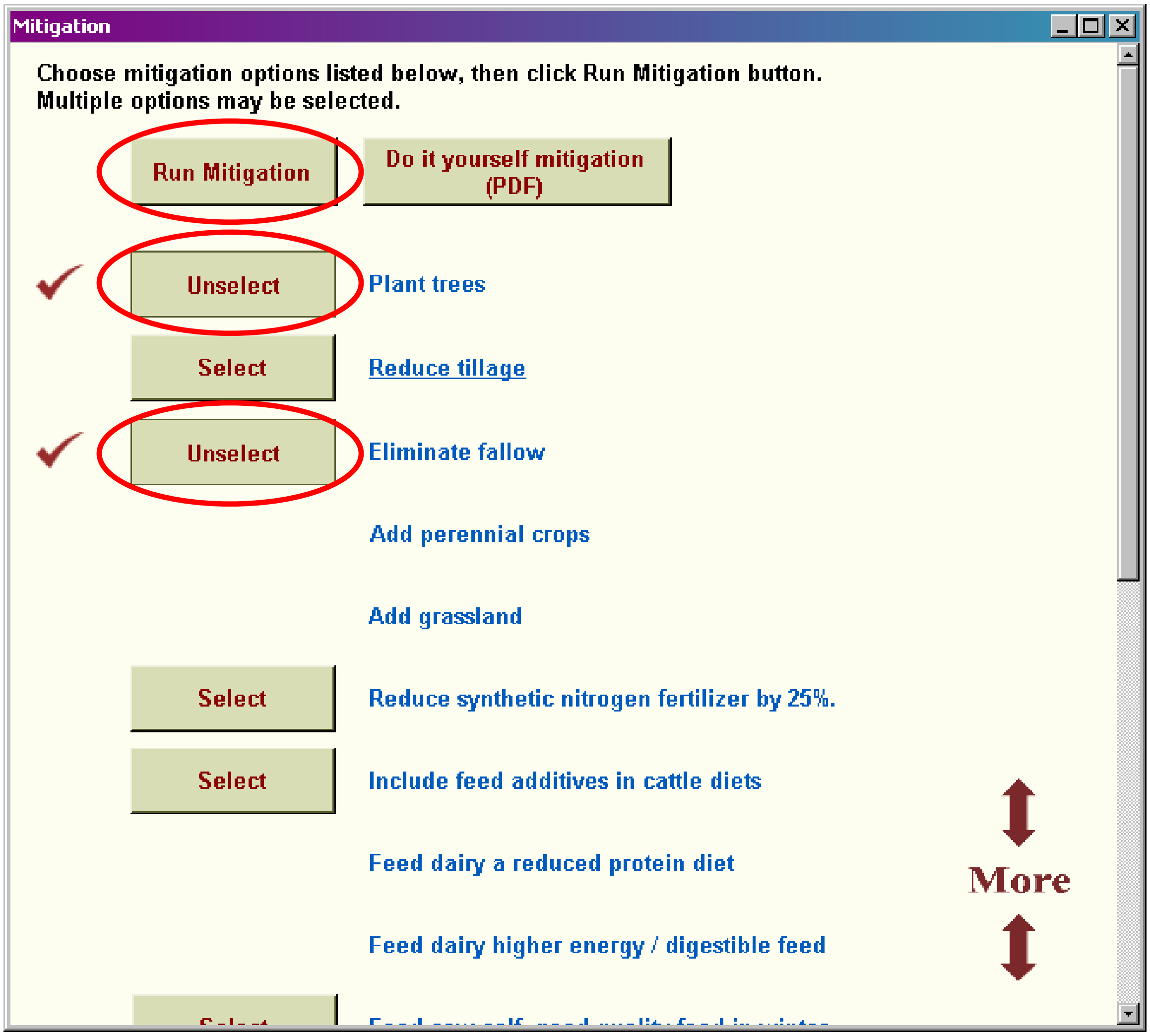
Negative values indicate carbon storage.
Positive values indicate greenhouse gas emissions.

**Figure 28. Emission Details Report. This report can be exported and saved or printed. Preferences such as display unit and language can be changed.**

39. After viewing results, click Mitigation Options from the navigation menu.

40. Various mitigation options will be displayed, choose Plant trees and Eliminate fallow by clicking on the Select button.

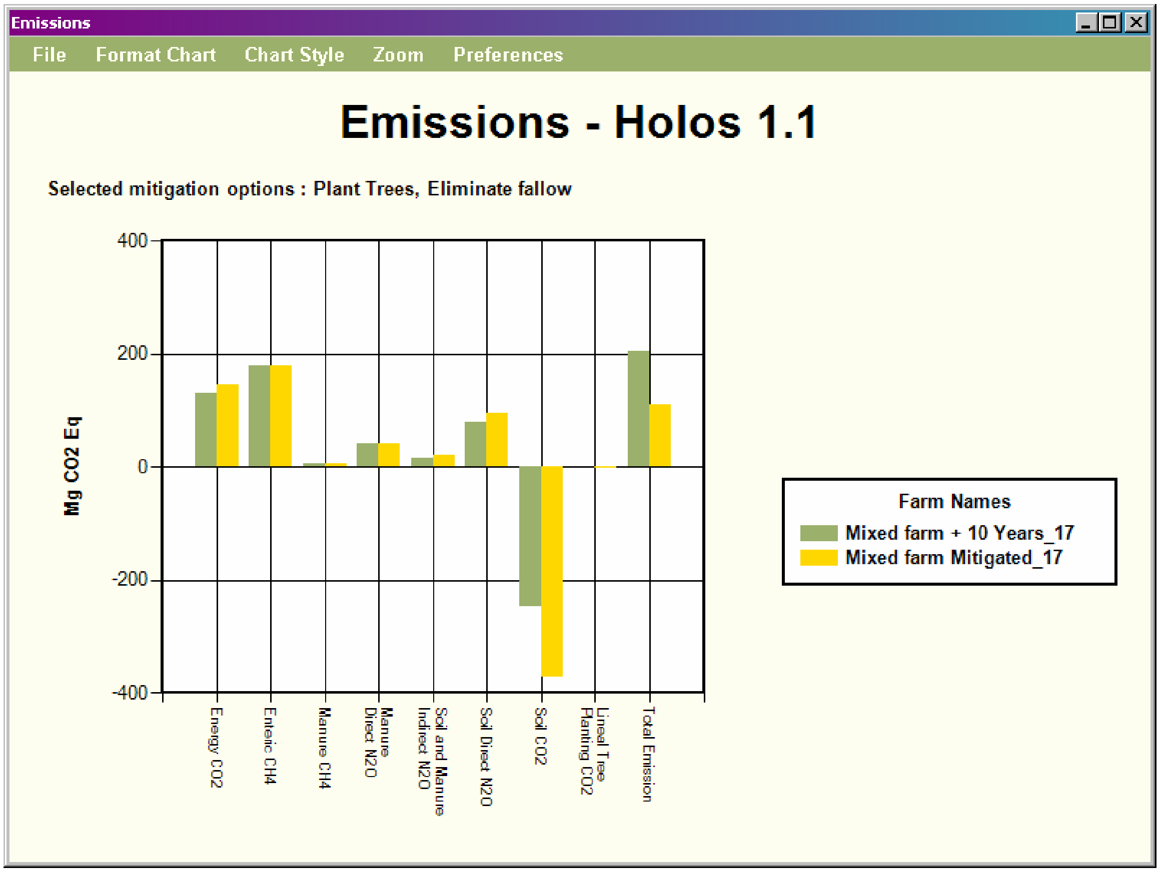
41. Click on Run Mitigation (Figure 29).



Choose mitigation options listed below, then click Run Mitigation button.
Multiple options may be selected.

**Figure 29. Mitigation form. Plant trees and Eliminate fallow selection buttons and Run Mitigation button circled. Clicking on the blue font will launch an explanation of the mitigation practice, with co-benefits described.**

42. The results of this change in management will be displayed (Figure 30).[11]



Selected mitigation options : Plant Trees, Eliminate fallow

**Figure 30. Mitigation options comparison chart comparing the original Mixed farm 10 years from input and the Mixed farm 10 years from input with mitigation practices, as selected, established.**

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[11] The original farm emissions are calculated in the future. This provides comparison between leaving the farm as it is to establishing mitigation practices. The Holos one button mitigation options use 10 years in the future. This is like saying, “If I implement this change now, what will my farm emissions be 10 years from now compared to my farm emissions had I made no change?”

# Appendix 2 – Entering less common farm types

While not every type of Canadian farm is represented in Holos, the user interface has been designed with flexibility. This allows scenario input to be modified in order to accommodate less common farms. Table 10 describes some of these farms and how to enter them into Holos.

**Table 10. Entering less common farms in Holos.**

| Farm type | Modified scenario | Input |
|---|---|---|
| Purebred bull | Cow-calf scenario 1 | Zero cows<br>Number of bulls<br>Uncheck bulls kept on farm for breeding period only<br>Choose feed and pasture type |
| Milk-fed veal | Dairy scenario 1 | Zero cows<br>Zero bulls<br>Number of calves<br>Number of months calves are on farm<br>Choose manure handling system |
| Grain-fed veal | Beef feedlot scenario 1 | Number of cattle<br>Veal weights<br>Choose sex ratio, diet, manure handling system |
| Crops not listed | Crop/grassland scenario | Choose the crop most similar<br>Modify fertilizer rates and yield |
| Multiple tillage systems | Enter as two farms | Enter the rotations as two separate farms and sum emissions.<br>This is to be used only if two rotations use completely separate tillage systems. The no-till farm rotation can only use tillage at seeding. |
| Multiple feedlots | Enter as more than one farm | If feedlot practices are completely different, enter as separate farms and sum emissions. |

# Appendix 3 – Development specifications

Holos was developed for the Microsoft Windows 2000/XP/VISTA operating system using the Microsoft Visual Studio .NET 2005 Professional edition Integrated Development Environment (IDE). The primary programming languages used include Visual Basic .NET and ADO.NET. Holos uses a Microsoft Access backend database to store user data and coefficients. The reporting systems were developed using the Crystal Reports engine from Business Objects America that is included in Microsoft Visual Studio .NET 2005. The charting components for Holos use Dundas Chart for Windows Forms Professional Edition from Dundas Data Visualization, Inc. The GIS component of the program uses the MapWinGIS 4.4 Active X component developed by Idaho State University.

Holos was built from the ground up using iterative programming techniques. Data results were tested and compared to an independent model. Object oriented methodologies were implemented in the design of the software. Client feedback and beta testing was used to improve the software in an ongoing process. Maintenance of the software occurs from direct response of client use. Troubleshooting and client support is available through holos@agr.gc.ca.

### *The minimum recommended system requirements are:*

Microsoft Windows XP/Vista 32 bit operating system
Intel /AMD 1.0 GHZ processor
512 MB RAM
200 MB of hard disk space (400 MB if .Net 2.0 is not preinstalled)
800x600 Screen resolution

### *Software development references*

Business Objects Americas. 2005. Crystal Reports for Visual Studio 2005 AAC60-G0CSA4B-V7000AY. North American Corporate Headquarters
3030 Orchard Parkway, San Jose, California, USA.

Dundas Data Visualization, Inc. 2007. Dundas Chart for Windows Forms Professional Edition v6.0. 500 - 250 Ferrand Drive, Toronto, Ontario, Canada.

Idaho State University. 2007. MapWinGIS 4.6 Active X Component. Idaho State University, Campus Box 8265, Pocatello, Idaho, USA.

Microsoft Corporation. 2001. Microsoft .NET Framework Version 2.0.50727 SP1. One Microsoft Way, Redmond, Washington, USA.

Microsoft Corporation. 2001. Microsoft Windows XP Professional (5.1.2600) Service Pack 2 Build 2600. One Microsoft Way, Redmond, Washington, USA.

Microsoft Corporation. 2002. Microsoft Access 2002 (10.6771.6839) Service Pack 3. One Microsoft Way, Redmond, Washington, USA.

Microsoft Corporation. 2005. Microsoft Visual Studio 2005 Professional Edition Version 8.0.50727.42 (RTM.050727-4200). One Microsoft Way, Redmond, Washington, USA.

Microsoft Corporation. 2005. Microsoft Visual Basic 2005 77626-009-0000007-41154. One Microsoft Way, Redmond, Washington, USA.

# Appendix 4 – Equations

## 1 Soil $N_2O$ emissions from cropping and land use

**Mineral and organic soils**

Equations (1.1) to (1.24) are to be calculated for mineral and organic soils.

### 1.1 *Emission factor*

$$EF_{eco} = 0.022 * \frac{P}{PE} - 0.0048 \tag{1.1}$$

Rochette *et al.* 2008

| | |
|---|---|
| $EF_{eco}$ | Ecodistrict emission factor [kg $N_2O$-N (kg N)$^{-1}$]<br>**Range from 0.0016-0.0170 (Values < 0.0016 are set to 0.0016, values > 0.0170 are set to 0.0170)** |
| $P$ | Growing season precipitation, by ecodistrict (May – October) |
| $PE$ | Growing season potential evapotranspiration, by ecodistrict (May – October) |

*P* and *PE* are obtained from CanSIS using the average of 1971-2000 data (Marshall *et al.* 1999).

### 1.2 *Direct emissions*

#### 1.2.1 Emissions due to inputs

##### *1.2.1.1 Fertilizer N inputs*

Fertilizer input calculations should be completed for all crop types, including annual crops, perennial forages and improved grassland/pasture (improved grassland/pasture is pasture that is fertilized and/or irrigated).

$$N_{fert} = N\_fert\_applied * area \tag{1.2}$$

| | |
|---|---|
| $N_{fert}$ | N inputs from synthetic fertilizer (kg N) |
| $N\_fert\_applied$ | N fertilizer applied (kg ha$^{-1}$) |
| $area$ | Area of crop (ha) |

$$Total\_N_{fert} = \sum_{allcrops} N_{fert} \tag{1.3}$$

| | |
|---|---|
| $Total\_N_{fert}$ | Total N inputs from synthetic fertilizer (kg N) |

### 1.2.1.2 *Residue N inputs*

Residue input calculations should be completed for all crop types, including annual crops and perennial forages.

**Above ground residue**

$$AGresidue\_yield = \left[ Yield - \left( moisture\_content * Yield \right) \right] * \frac{AGresidue\_ratio}{Yield\_ratio} \qquad (1.4)$$

| | |
|---|---|
| *AGresidue_yield* | Above ground residue yield (kg ha$^{-1}$) |
| *Yield* | Crop yield (kg ha$^{-1}$) |
| *moisture_content* | Moisture content of crop yield (w/w) (Table A4-1, by crop) |
| *AGresidue_ratio* | Ratio of above ground residue (Table A4-1, by crop) |
| *Yield_ratio* | Ratio of yield (Table A4-1, by crop) |

$$AGresidue\_N = AGresidue\_yield * AGresidue\_N\_conc \qquad (1.5)$$

| | |
|---|---|
| *AGresidue_N* | Above ground residue N (kg N ha$^{-1}$) |
| *AGresidue_N_conc* | Above ground residue N concentration (kg N kg$^{-1}$) (Table A4-1, by crop) |

**Below ground residue**

Equation (1.6) should be used for all annual crop types while equation (1.7) is used for perennial forage.

**For annual crops:**

$$BGresidue\_yield = \left[ Yield - \left( moisture\_content * Yield \right) \right] * \frac{BGresidue\_ratio}{Yield\_ratio} \qquad (1.6)$$

**For perennial forage (hay):**

$$BGresidue\_yield = 0.2 * \left[ \left[ Yield - \left( moisture\_content * Yield \right) \right] * \frac{BGresidue\_ratio}{Yield\_ratio} \right] \qquad (1.7)$$

| | |
|---|---|
| *BGresidue_yield* | Below ground residue yield (kg ha$^{-1}$) |
| *Yield* | Crop yield (kg ha$^{-1}$) |
| *moisture_content* | Moisture content of crop yield (w/w) (Table A4-1, by crop) |
| *BGresidue_ratio* | Ratio of below ground residue (Table A4-1, by crop) |
| *Yield_ratio* | Ratio of yield (Table A4-1, by crop) |

Multiplication by 0.2 accounts for the perennial nature of these crops and assumes that every 5 years the crop will be plowed under. Therefore, entire below ground residue is prorated over 5 years.

$$BGresidue\_N = BGresidue\_yield * BGresidue\_N\_conc \qquad (1.8)$$

| | |
|---|---|
| *BGresidue_N* | Below ground residue N (kg N ha$^{-1}$) |
| *BGresidue_N_conc* | Below ground residue N concentration (kg N kg$^{-1}$) (Table A4-1, by crop) |

**Total residue**

$$N_{res} = (AGresidue\_N + BGresidue\_N) * area \tag{1.9}$$

| | |
|---|---|
| $N_{res}$ | N inputs from crop residue returned to soil (kg N) |
| *area* | Area of crop (ha) |

$$Total\_N_{res} = \sum_{allcrops} N_{res} \tag{1.10}$$

| | |
|---|---|
| $Total\_N_{res}$ | Total N inputs from crop residue (kg N) |

#### 1.2.1.3 Mineralization N inputs

$$N_{min} = C_{mineral} * \frac{1}{10} \tag{1.11}$$

IPCC 2006

| | |
|---|---|
| $N_{min}$ | N inputs from mineralization of native soil organic matter (kg N)<br>This value can only be positive.<br>**If the result is negative, then $N_{min}$ is equal to zero.** |
| $C_{mineral}$ | C change (kg) (from soil carbon equations – equation (2.13)) |
| 10 | C:N ratio of soil organic matter in Canada (H. Janzen, personal communication) |

Mineralization N emissions are a function of soil carbon.

#### 1.2.1.4 Land applied manure N inputs

$$Total\_N_{landmanure} = \sum_{allscenarios} Scenario\_N_{landmanure} \tag{1.12}$$

| | |
|---|---|
| $Total\_N_{landmanure}$ | Total N inputs from all land applied manure (kg - includes on farm produced manure from all livestock scenarios). |
| $Scenario\_N_{landmanure}$ | Land applied manure (kg) (from livestock equations (3.62), (4.56), (5.26), (6.35) and/or (7.15)) |

#### 1.2.1.5 Emissions from total N inputs

$$N_2O\text{-}N_{inputs} = (Total\_N_{fert} + Total\_N_{res} + N_{min} + Total\_N_{landmanure}) * EF_{eco} \tag{1.13}$$

Rochette *et al.* 2008

| | |
|---|---|
| $N_2O\text{-}N_{inputs}$ | N emissions due to soil inputs (kg $N_2O$-N) |
| $EF_{eco}$ | Ecodistrict emission factor [kg $N_2O$-N (kg N)$^{-1}$] |

### 1.2.2 Emissions due to tillage

$$N_2O\text{-}N_{till} = N_2O\text{-}N_{inputs} * (RF_{till} - 1) \tag{1.14}$$

Rochette *et al.* 2008

| | |
|---|---|
| $N_2O\text{-}N_{till}$ | N emissions due to tillage (kg $N_2O$-N) |
| $RF_{till}$ | Ratio factor (Table A4-2 by province, soil type, tillage) |

### 1.2.3 Emissions due to soil texture

$$N_2O\text{-}N_{text} = N_2O\text{-}N_{inputs} * (RF_{text} - 1) \quad (1.15)$$

Rochette *et al.* 2008

| | |
|---|---|
| $N_2O\text{-}N_{text}$ | N emissions due to soil texture (kg $N_2O$-N) |
| $RF_{text}$ | Ratio factor (Table A4-2 by province, soil texture) |

### 1.2.4 Emissions due to irrigation

**Fraction of land irrigated**

$$F_{irrig} = \frac{area_{irrig}}{total\_area} \quad (1.16)$$

Rochette *et al.* 2008

| | |
|---|---|
| $F_{irrig}$ | Fraction of agricultural land under irrigation |
| $area_{irrig}$ | Area of all irrigated crops (ha) |
| $total\_area$ | Total area of crop land (crops, forages, fallow) and improved grassland/pasture (ha) |

$$N_2O - N_{irrig} = N_2O - N_{inputs} * \frac{(0.017 - EF_{eco})}{EF_{eco}} * F_{irrig} \quad (1.17)$$

Rochette *et al.* 2008

| | |
|---|---|
| $N_2O\text{-}N_{irrig}$ | N emissions due to irrigation (kg $N_2O$-N) |

### 1.2.5 Emissions due to position in landscape/topography

$$N_2O - N_{topo} = N_2O - N_{inputs} * \frac{(0.017 - EF_{eco})}{EF_{eco}} * F_{topo} \quad (1.18)$$

Rochette *et al.* 2008

| | |
|---|---|
| $N_2O\text{-}N_{topo}$ | N emissions due to position in landscape (kg $N_2O$-N) |
| $F_{topo}$ | Fraction of land occupied by lower portions of landscape (from Rochette *et al.* 2008) |

### 1.2.6 Emissions due to fallow

These emissions are calculated for prairie provinces only.

**N potentially mineralized during fallow**

$$N\_mineralized = N_{appl}\_stubble - N_{appl}\_fallow \quad (1.19)$$

| | |
|---|---|
| $N\_mineralized$ | N mineralized (kg $ha^{-1}$) |
| $N_{appl}\_stubble$ | N fertilizer rate for spring wheat on stubble (kg $ha^{-1}$) (Table A4-3, by province, soil type) |
| $N_{appl}\_fallow$ | N fertilizer rate for spring wheat on fallow (kg $ha^{-1}$) (Table A4-3, by province, soil type) |

$$N_2O_{fallow}rate = N\_mineralized * EF_{eco} \tag{1.20}$$

| | |
|---|---|
| $N_2O_{fallow}rate$ | N emission rate from fallow (kg $N_2O$-N $ha^{-1}$) |

$$N_2O\text{-}N_{fallow} = N_2O_{fallow}rate * area\_of\_fallow \tag{1.21}$$

| | |
|---|---|
| $N_2O\text{-}N_{fallow}$ | N emissions due to fallow (kg $N_2O$-N) |
| $area\_of\_fallow$ | Area of fallow (ha) |

## 1.3 Indirect emissions

### 1.3.1 Emissions due to leaching and runoff

**Leaching and runoff fraction**

$$Frac_{leach} = 0.3247 * \frac{P}{PE} - 0.0247 \tag{1.22}$$

Rochette *et al.* 2008

| | |
|---|---|
| $Frac_{leach}$ | Fraction of N lost by leaching and runoff<br>**Range from 0.05 - 0.3. (Values <0.05 are set to 0.05, values > 0.3 are set to 0.3)** |
| $P$ | Growing season precipitation, by ecodistrict (May – October) |
| $PE$ | Growing season potential evapotranspiration, by ecodistrict (May – October) |

*P* and *PE* are obtained from CanSIS using the average of 1971-2000 data (Marshall *et al.* 1999).

$$N_2O\text{-}N_{leach} = (Total\_N_{fert} + Total\_N_{res} + N_{min} + Total\_N_{landmanure}) * Frac_{leach} * EF_{leachcrop} \tag{1.23}$$

Rochette *et al.* 2008

| | |
|---|---|
| $N_2O\text{-}N_{leach}$ | N emissions due to leaching and runoff (kg $N_2O$-N) |
| $Total\_N_{fert}$ | Total N inputs from synthetic fertilizer (kg N) |
| $Total\_N_{res}$ | Total N inputs from crop residue (kg N) |
| $N_{min}$ | N inputs from mineralization of native soil organic matter (kg N) |
| $Total\_N_{landmanure}$ | Total N inputs from all land applied manure (kg) |
| $EF_{leachcrop}$ | Emission factor for leaching and runoff [kg $N_2O$-N (kg N)$^{-1}$] |

Holos uses 0.0075 for $EF_{leachcrop}$ (IPCC 2006).

### 1.3.2 Emissions due to volatilization

$$N_2O\text{-}N_{volatilization} = (Total\_N_{fert} + Total\_N_{landmanure}) * Frac_{volatilizationcrop} * EF_{volatilizationcrop} \tag{1.24}$$

Rochette *et al.* 2008

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}$ | N emissions due to volatilization (kg $N_2O$-N) |
| $Frac_{volatilizationcrop}$ | Fraction of N lost by volatilization |
| $EF_{volatilizationcrop}$ | Emission factor for volatilization [kg $N_2O$-N (kg N)$^{-1}$] |

Holos uses 0.1 for $Frac_{volatilizationcrop}$ and 0.01 for $EF_{volatilizationcrop}$ (IPCC 2006).

## 1.4 Emissions due to organic soil cultivation

These emissions are in addition to those calculate in previous equations and calculated for organic soils only.

$$N_2O\text{-}N_{organic} = 8 * organicsoil\_area \tag{1.25}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{organic}$ | N emissions from organic soil (kg $N_2O$-N) |
| 8 | Emission factor for cultivating organic soils (kg $N_2O$-N ha$^{-1}$) (IPCC 2006) |
| $organicsoil\_area$ | Organic soil area (ha) |

## 1.5 Total emissions

**Direct emissions**

$$N_2O\text{-}N_{directsoil} = N_2O\text{-}N_{inputs} + N_2O\text{-}N_{till} + N_2O\text{-}N_{text} + N_2O\text{-}N_{irrig} + N_2O\text{-}N_{topo} + N_2O\text{-}N_{fallow} + N_2O\text{-}N_{organic} \tag{1.26}$$

Rochette *et al.* 2008

| | |
|---|---|
| $N_2O\text{-}N_{directsoil}$ | Total direct N emissions (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{inputs}$ | N emissions due to soil inputs (kg $N_2O$-N) |
| $N_2O\text{-}N_{till}$ | N emissions due to tillage (kg $N_2O$-N) |
| $N_2O\text{-}N_{text}$ | N emissions due to soil texture (kg $N_2O$-N) |
| $N_2O\text{-}N_{irrig}$ | N emissions due to irrigation (kg $N_2O$-N) |
| $N_2O\text{-}N_{topo}$ | N emissions due to position in landscape (kg $N_2O$-N) |
| $N_2O\text{-}N_{fallow}$ | N emissions due to fallow (kg $N_2O$-N) |
| $N_2O\text{-}N_{organic}$ | N emissions from organic soil (kg $N_2O$-N) |

**Indirect emissions**

$$N_2O\text{-}N_{indirectsoil} = N_2O\text{-}N_{leach} + N_2O\text{-}N_{volatilization} \tag{1.27}$$

| | |
|---|---|
| $N_2O\text{-}N_{indirectsoil}$ | Total indirect N emissions (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{leach}$ | N emissions due to leaching and runoff (kg $N_2O$-N) |
| $N_2O\text{-}N_{volatilization}$ | N emissions due to volatilization (kg $N_2O$-N) |

**Total emissions**

$$N_2O\text{-}N_{soils} = N_2O\text{-}N_{direct} + N_2O\text{-}N_{indirect} \tag{1.28}$$

| | |
|---|---|
| $N_2O\text{-}N_{soils}$ | Total N emissions (kg $N_2O$-N year$^{-1}$) |

## 1.6 Conversion from $N_2O$-N to $N_2O$

**Direct emissions**

$$N_2O_{directsoil} = N_2O\text{-}N_{directsoil} * \frac{44}{28} \tag{1.29}$$

| | |
|---|---|
| $N_2O_{directsoil}$ | Direct $N_2O$ emissions from soils (kg $N_2O$ year$^{-1}$) |
| $N_2O\text{-}N_{directsoil}$ | Total direct N emissions (kg $N_2O$-N year$^{-1}$) |
| 44/28 | Conversion from $N_2O$-N to $N_2O$ |

**Indirect emissions**

$$N_2O_{indirectsoil} = N_2O\text{-}N_{indirectsoil} * \frac{44}{28} \tag{1.30}$$

| | |
|---|---|
| $N_2O_{indirectsoil}$ | Indirect $N_2O$ emissions from soils (kg $N_2O$ year$^{-1}$) |
| $N_2O\text{-}N_{indirectsoil}$ | Total indirect N emissions (kg $N_2O$-N year$^{-1}$) |

**Total emissions**

$$N_2O_{soils} = N_2O\text{-}N_{soils} * \frac{44}{28} \tag{1.31}$$

| | |
|---|---|
| $N_2O_{soils}$ | Total $N_2O$ emissions from soils (kg $N_2O$ year$^{-1}$) |
| $N_2O\text{-}N_{soils}$ | Total N emissions (kg $N_2O$-N year$^{-1}$) |

**Table A4-1. Crop factors.**

| | | | | Relative dry matter allocation | | |
|---|---|---|---|---|---|---|
| Crop | *moisture_content* (w/w) | *AGresidue_N_conc* (kg N kg$^{-1}$) | *BGresidue_N_conc* (kg N kg$^{-1}$) | *Yield_ratio* | *AGresidue_ratio* | *BGresidue_ratio* |
| Barley | 0.12 | 0.007 | 0.01 | 0.38 | 0.47 | 0.15 |
| Buckwheat | 0.12 | 0.006 | 0.01 | 0.24 | 0.56 | 0.20 |
| Canary seed | 0.12 | 0.007 | 0.01 | 0.20 | 0.60 | 0.20 |
| Canola | 0.09 | 0.008 | 0.01 | 0.26 | 0.60 | 0.15 |
| Chickpeas | 0.13 | 0.018 | 0.01 | 0.29 | 0.51 | 0.20 |
| Coloured, white, faba beans | 0.13 | 0.010 | 0.01 | 0.46 | 0.34 | 0.20 |
| Dry peas | 0.13 | 0.018 | 0.01 | 0.29 | 0.51 | 0.20 |
| Flaxseed | 0.08 | 0.007 | 0.01 | 0.26 | 0.60 | 0.15 |
| Fodder corn | 0.70 | 0.013 | 0.007 | 0.72 | 0.08 | 0.20 |
| Grain corn (shelled) | 0.15 | 0.005 | 0.007 | 0.47 | 0.38 | 0.15 |
| Hay and forage seed | 0.13 | 0.015 | 0.013 | 0.12 | 0.48 | 0.40 |
| Hay - grass | 0.13 | 0.016 | 0.01 | 0.18 | 0.12 | 0.70 |
| Hay - legume | 0.13 | 0.015 | 0.015 | 0.40 | 0.10 | 0.50 |
| Hay - mixed | 0.13 | 0.015 | 0.015 | 0.40 | 0.10 | 0.50 |
| Lentils | 0.13 | 0.010 | 0.01 | 0.28 | 0.52 | 0.20 |
| Mixed grains | 0.12 | 0.0063 | 0.01 | 0.33 | 0.47 | 0.20 |
| Mustard seed | 0.09 | 0.008 | 0.01 | 0.26 | 0.60 | 0.15 |
| Oats | 0.12 | 0.006 | 0.01 | 0.33 | 0.47 | 0.20 |
| Potatoes | 0.75 | 0.020 | 0.01 | 0.68 | 0.23 | 0.10 |
| Rye | 0.12 | 0.006 | 0.01 | 0.34 | 0.51 | 0.15 |
| Safflower | 0.02 | 0.010 | 0.01 | 0.27 | 0.53 | 0.20 |
| Soybeans | 0.14 | 0.006 | 0.01 | 0.30 | 0.45 | 0.25 |
| Spring wheat, durum | 0.12 | 0.006 | 0.01 | 0.34 | 0.51 | 0.15 |
| Sunflower seed | 0.02 | 0.010 | 0.01 | 0.27 | 0.53 | 0.20 |
| Triticale | 0.12 | 0.006 | 0.01 | 0.32 | 0.48 | 0.20 |
| Winter wheat | 0.12 | 0.006 | 0.01 | 0.34 | 0.51 | 0.15 |

Janzen *et al.* 2003.

**Table A4-2. Ratio factors for direct soil $N_2O$ emissions.**

| Province | Soil type | Tillage | Texture | $RF_{till}$ | $RF_{text}$ |
|---|---|---|---|---:|---:|
| AB SK MB | Brown & Dark brown | Intensive | All | 1.0 | 1.0 |
| | | Reduced & No-till | All | 0.8 | 1.0 |
| AB SK MB | Black | Intensive | All | 1.0 | 1.0 |
| | | Reduced & No-till | All | 0.8 | 1.0 |
| ON QB | All | Intensive | Fine | 1.0 | 1.2 |
| | | | Medium | 1.0 | 0.8 |
| | | | Coarse | 1.0 | 0.8 |
| | | Reduced & No-till | Fine | 1.1 | 1.2 |
| | | | Medium | 1.1 | 0.8 |
| | | | Coarse | 1.1 | 0.8 |
| NB NS PE NF | All | Intensive | Fine | 1.0 | 1.2 |
| | | | Medium | 1.0 | 0.8 |
| | | | Coarse | 1.0 | 0.8 |
| | | Reduced & No-till | Fine | 1.1 | 1.2 |
| | | | Medium | 1.1 | 0.8 |
| | | | Coarse | 1.1 | 0.8 |
| BC | All | All | All | 1.0 | 1.0 |

Rochette *et al.* 2008.

**Table A4-3. Nitrogen application rates for spring wheat stubble and fallow crops (for Prairie provinces only).**

| Province | Soil type | $N_{appl}$_*stubble* (kg N $ha^{-1}$) | $N_{appl}$_*fallow* (kg N $ha^{-1}$) | *N_mineralized* (stubble-fallow) (kg N $ha^{-1}$) |
|---|---|---:|---:|---:|
| AB | Brown | 51 | 17 | 34 |
| AB | Dark brown | 47 | 14 | 33 |
| AB | Black | 61 | 21 | 40 |
| SK | Brown | 54 | 21 | 33 |
| SK | Dark brown | 45 | 7 | 38 |
| SK | Black | 77 | 41 | 36 |
| MB | All | 90 | 17 | 73 |

These values are from CanAG-MARS (McConkey *et al.* 2007) with averaging and some modification.

# 2 Soil carbon change emissions from land use

## 2.1 *Carbon change in mineral soils*

Equations (2.1) to (2.14) are to be calculated for mineral soils.

### 2.1.1 Carbon change due to change in tillage practice

$$\Delta C = lumC_{max} * \left(e^{\left[-k*(y-1)\right]} - e^{\left[-k*y\right]}\right) \tag{2.1}$$

McConkey *et al.* 2007

| | |
|---|---|
| $\Delta C$ | C change rate for tillage (g m$^{-2}$ year$^{-1}$) |
| $lumC_{max}$ | Maximum C produced by management change (g m$^{-2}$) (Table A4-4, by management change, reporting zone, soil texture) |
| $e$ | Exponential function |
| $k$ | Rate constant (Table A4-4, by management change, reporting zone, soil texture) |
| $y$ | Time since management change (years) |

$$C_{tillage} = \Delta C * 10 * area \tag{2.2}$$

McConkey *et al.* 2007

| | |
|---|---|
| $C_{tillage}$ | C change for tillage (kg C year$^{-1}$) |
| 10 | Conversion from g m$^{-2}$ to kg ha$^{-1}$ |
| *area* | Area of management change (ha) |

$$CO_{2tillage} = -1 * C_{tillage} * \frac{44}{12} \tag{2.3}$$

| | |
|---|---|
| $CO_{2tillage}$ | $CO_2$ change for tillage (kg $CO_2$ year$^{-1}$) |
| 44/12 | Conversion from C to $CO_2$ |

Multiplying by -1 converts the result to an emission. (Positive value is an emission, negative value is sequestration.)

### 2.1.2 Carbon change due to change in fallow area

$$\Delta C = lumC_{max} * \left(e^{\left[-k*(y-1)\right]} - e^{\left[-k*y\right]}\right) \tag{2.4}$$

McConkey *et al.* 2007

| | |
|---|---|
| $\Delta C$ | C change rate for fallow (g m$^{-2}$ year$^{-1}$) |
| $lumC_{max}$ | Maximum C produced by managment change (g m$^{-2}$) (Table A4-5, by management change, reporting zone, soil texture) |
| $e$ | Exponential function |
| $k$ | Rate constant (Table A4-5, by management change, reporting zone, soil texture) |
| $y$ | Time since management change (years) |

$$C_{fallow} = \Delta C * 10 * area \tag{2.5}$$

McConkey *et al.* 2007

| | |
|---|---|
| $C_{fallow}$ | C change for fallow (kg C $year^{-1}$) |
| 10 | Conversion from g $m^{-2}$ to kg $ha^{-1}$ |
| *area* | Area of management change (ha) |

$$CO_{2fallow} = -1 * C_{fallow} * \frac{44}{12} \tag{2.6}$$

| | |
|---|---|
| $CO_{2fallow}$ | $CO_2$ change for fallow (kg $CO_2$ $year^{-1}$) |
| 44/12 | Conversion from C to $CO_2$ |

Multiplying by -1 converts the result to an emission. (Positive value is an emission, negative value is sequestration.)

### 2.1.3 Carbon change due to change in perennial:annual crop areas

$$\Delta C = lumC_{max} * \left( e^{\left[-k*(y-1)\right]} - e^{\left[-k*y\right]} \right) \tag{2.7}$$

McConkey *et al.* 2007

| | |
|---|---|
| $\Delta C$ | C change rate for perennial:annual (g $m^{-2}$ $year^{-1}$) |
| $lumC_{max}$ | Maximum C produced by managment change (g $m^{-2}$) (Table A4-6, by management change, reporting zone, soil texture) |
| $e$ | Exponential function |
| $k$ | Rate constant (Table A4-6, by management change, reporting zone, soil texture) |
| $y$ | Time since management change (years) |

$$C_{perennial} = \Delta C * 10 * area \tag{2.8}$$

McConkey *et al.* 2007

| | |
|---|---|
| $C_{perennial}$ | C change for perennial:annual (kg C $year^{-1}$) |
| 10 | Conversion from g $m^{-2}$ to kg $ha^{-1}$ |
| *area* | Area of management change (ha) |

$$CO_{2perennial} = -1 * C_{perennial} * \frac{44}{12} \tag{2.9}$$

| | |
|---|---|
| $CO_{2perennial}$ | $CO_2$ change for perennial:annual (kg $CO_2$ $year^{-1}$) |
| 44/12 | Conversion from C to $CO_2$ |

Multiplying by -1 converts the result to an emission. (Positive value is an emission, negative value is sequestration.)

### 2.1.4 Carbon change due to change in grassland

$$\Delta C = lumC_{max} * \left( e^{\left[-k*(y-1)\right]} - e^{\left[-k*y\right]} \right) \tag{2.10}$$

McConkey *et al.* 2007

| | |
|---|---|
| $\Delta C$ | C change rate for grassland (g $m^{-2}$ $year^{-1}$) |

| | |
|---|---|
| $lumC_{max}$ | Maximum C produced by managment change (g $m^{-2}$) (Table A4-6, by management change, reporting zone, soil texture) |
| $e$ | Exponential function |
| $k$ | Rate constant (Table A4-6, by management change, reporting zone, soil texture) |
| $y$ | Time since management change (years) |

$$C_{grassland} = \Delta C * 10 * area \tag{2.11}$$

McConkey *et al.* 2007

| | |
|---|---|
| $C_{grassland}$ | C change for grassland (kg C $year^{-1}$) |
| 10 | Conversion from g $m^{-2}$ to kg $ha^{-1}$ |
| $area$ | Area of management change (ha) |

$$CO_{2grassland} = -1 * C_{grassland} * \frac{44}{12} \tag{2.12}$$

| | |
|---|---|
| $CO_{2grassland}$ | $CO_2$ change for grassland (kg $CO_2$ $year^{-1}$) |
| 44/12 | Conversion from C to $CO_2$ |

Multiplying by -1 converts the result to an emission. (Positive value is an emission, negative value is sequestration.)

### 2.1.5 Carbon change in mineral soils

$$C_{mineral} = -1 * (C_{tillage} + C_{fallow} + C_{perennial} + C_{grassland}) \tag{2.13}$$

| | |
|---|---|
| $C_{mineral}$ | C change for mineral soils (kg C $year^{-1}$) |

This value is transferred to Equation (1.11) in the soil $N_2O$ equations. Multiplying by -1 converts the result to an emission. (Positive value is an emission, negative value is sequestration.)

$$CO_{2mineral} = CO_{2tillage} + CO_{2fallow} + CO_{2perennial} + CO_{2grassland} \tag{2.14}$$

| | |
|---|---|
| $CO_{2mineral}$ | $CO_2$ change for mineral soils (kg $CO_2$ $year^{-1}$) |

## 2.2 Carbon change in organic soils

Equations (2.15) and (2.16) are to be calculated for organic soils.

$$C_{organic} = organicsoil\_area * 5 * 1000 \tag{2.15}$$

| | |
|---|---|
| $C_{organic}$ | C change for organic soils (kg C $year^{-1}$) |
| $organicsoil\_area$ | Organic soil area (ha) |
| 5 | Yearly emission factor for cultivated organic soils (Mg $ha^{-1}$) (IPCC 2006) |
| 1000 | Conversion from Mg to kg |

$$CO_{2organic} = C_{organic} * \frac{44}{12} \tag{2.16}$$

| | |
|---|---|
| $CO_{2organic}$ | $CO_2$ change for organic soils (kg $CO_2$ year$^{-1}$) |
| 44/12 | Conversion from C to $CO_2$ |

## 2.3 Total carbon change for farm

$$CO_{2soil} = CO_{2mineral} + CO_{2organic} \tag{2.17}$$

| | |
|---|---|
| $CO_{2soil}$ | $CO_2$ emissions from soils (kg $CO_2$ year$^{-1}$) |
| $CO_{2mineral}$ | $CO_2$ change for mineral soils (kg $CO_2$ year$^{-1}$) |
| $CO_{2organic}$ | $CO_2$ change for organic soils (kg $CO_2$ year$^{-1}$) |

**Table A4-4. $LumC_{max}$ and $k$ values for tillage practice change.**

| | | Tillage practice change | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | From intensive tillage to reduced tillage | | From reduced tillage to no tillage | | From intensive tillage to no tillage | | From reduced tillage to intensive tillage | | From no tillage to reduced tillage | | From no tillage to intensive tillage | |
| Reporting Zone | Soil texture | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ |
| Boreal Shield West | Coarse | 143 | 0.0262 | 441 | 0.0284 | 584 | 0.0306 | -143 | 0.0262 | -441 | 0.0284 | -584 | 0.0306 |
| Boreal Shield West | Medium | 217 | 0.0253 | 478 | 0.0282 | 695 | 0.0311 | -217 | 0.0253 | -478 | 0.0282 | -695 | 0.0311 |
| Boreal Shield West | Fine | 155 | 0.0258 | 398 | 0.0331 | 553 | 0.0403 | -155 | 0.0258 | -398 | 0.0331 | -553 | 0.0403 |
| Atlantic Maritime | Coarse | 232 | 0.0282 | 25 | 0.0252 | 257 | 0.0222 | -232 | 0.0282 | -25 | 0.0252 | -257 | 0.0222 |
| Atlantic Maritime | Medium | 246 | 0.0227 | 241 | 0.0219 | 486 | 0.0211 | -246 | 0.0227 | -241 | 0.0219 | -486 | 0.0211 |
| Atlantic Maritime | Fine | 349 | 0.0285 | 184 | 0.0291 | 533 | 0.0298 | -349 | 0.0285 | -184 | 0.0291 | -533 | 0.0298 |
| Boreal Plains | Coarse | 221 | 0.0270 | 450 | 0.0283 | 671 | 0.0296 | -221 | 0.0270 | -450 | 0.0283 | -671 | 0.0296 |
| Boreal Plains | Medium | 233 | 0.0219 | 464 | 0.0238 | 698 | 0.0258 | -233 | 0.0219 | -464 | 0.0238 | -698 | 0.0258 |
| Boreal Plains | Fine | 163 | 0.0180 | 467 | 0.0231 | 630 | 0.0283 | -163 | 0.0180 | -467 | 0.0231 | -630 | 0.0283 |
| Boreal Shield East | Coarse | 277 | 0.0295 | 665 | 0.0268 | 941 | 0.0242 | -277 | 0.0295 | -665 | 0.0268 | -941 | 0.0242 |
| Boreal Shield East | Medium | 238 | 0.0266 | 311 | 0.0230 | 549 | 0.0193 | -238 | 0.0266 | -311 | 0.0230 | -549 | 0.0193 |
| Boreal Shield East | Fine | 206 | 0.0228 | 235 | 0.0178 | 441 | 0.0127 | -206 | 0.0228 | -235 | 0.0178 | -441 | 0.0127 |
| Mixedwood Plains | Coarse | 181 | 0.0307 | 435 | 0.0300 | 616 | 0.0293 | -181 | 0.0307 | -435 | 0.0300 | -616 | 0.0293 |
| Mixedwood Plains | Medium | 173 | 0.0262 | 264 | 0.0256 | 437 | 0.0250 | -173 | 0.0262 | -264 | 0.0256 | -437 | 0.0250 |

|  |  | Tillage practice change |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | From intensive tillage to reduced tillage |  | From reduced tillage to no tillage |  | From intensive tillage to no tillage |  | From reduced tillage to intensive tillage |  | From no tillage to reduced tillage |  | From no tillage to intensive tillage |  |
| Reporting Zone | Soil texture | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ |
| Mixedwood Plains | Fine | 197 | 0.0208 | 207 | 0.0216 | 404 | 0.0223 | -197 | 0.0208 | -207 | 0.0216 | -404 | 0.0223 |
| Semiarid Prairies | Coarse | 183 | 0.0226 | 316 | 0.0239 | 499 | 0.0252 | -183 | 0.0226 | -316 | 0.0239 | -499 | 0.0252 |
| Semiarid Prairies | Medium | 233 | 0.0193 | 261 | 0.0230 | 495 | 0.0266 | -233 | 0.0193 | -261 | 0.0230 | -495 | 0.0266 |
| Semiarid Prairies | Fine | 268 | 0.0149 | 193 | 0.0194 | 462 | 0.0240 | -268 | 0.0149 | -193 | 0.0194 | -462 | 0.0240 |
| Montane Cordillera | Coarse | 51 | 0.0141 | 289 | 0.0138 | 340 | 0.0135 | -51 | 0.0141 | -289 | 0.0138 | -340 | 0.0135 |
| Montane Cordillera | Medium | 446 | 0.0163 | 115 | 0.0159 | 561 | 0.0155 | -446 | 0.0163 | -115 | 0.0159 | -561 | 0.0155 |
| Montane Cordillera | Fine | 31 | 0.0073 | 581 | 0.0101 | 613 | 0.0129 | -31 | 0.0073 | -581 | 0.0101 | -613 | 0.0129 |
| Pacific Maritime | Coarse | 105 | 0.0175 | 638 | 0.0153 | 743 | 0.0132 | -105 | 0.0175 | -638 | 0.0153 | -743 | 0.0132 |
| Pacific Maritime | Medium | 763 | 0.0120 | 807 | 0.0131 | 1570 | 0.0143 | -763 | 0.0120 | -1256 | 0.0219 | -1570 | 0.0143 |
| Pacific Maritime | Fine | 533 | 0.0091 | 778 | 0.0106 | 1311 | 0.0121 | -533 | 0.0091 | -441 | 0.0310 | -1311 | 0.0121 |
| Subhumid Prairies | Coarse | 256 | 0.0230 | 411 | 0.0266 | 667 | 0.0302 | -256 | 0.0230 | -411 | 0.0266 | -667 | 0.0302 |
| Subhumid Prairies | Medium | 331 | 0.0271 | 320 | 0.0287 | 651 | 0.0302 | -331 | 0.0271 | -320 | 0.0287 | -651 | 0.0302 |
| Subhumid Prairies | Fine | 196 | 0.0203 | 189 | 0.0230 | 385 | 0.0257 | -196 | 0.0203 | -189 | 0.0230 | -385 | 0.0257 |

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**Table A4-5. *LumC$_{max}$* and *k* values for fallow practice change.**

| | | Fallow practice change | | | |
|---|---|---|---|---|---|
| | | From fallow cropping to continuous cropping | | From continuous cropping to fallow cropping | |
| Reporting zone | Soil texture | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ |
| Boreal Shield West | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Boreal Shield West | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Boreal Shield West | Fine | 1314 | 0.0305 | -1314 | 0.0305 |
| Atlantic Maritime | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Atlantic Maritime | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Atlantic Maritime | Fine | 1314 | 0.0305 | -1314 | 0.0305 |
| Boreal Plains | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Boreal Plains | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Boreal Plains | Fine | 1314 | 0.0305 | -1314 | 0.0305 |
| Boreal Shield East | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Boreal Shield East | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Boreal Shield East | Fine | 1314 | 0.0305 | -1314 | 0.0305 |
| Mixedwood Plains | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Mixedwood Plains | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Mixedwood Plains | Fine | 1314 | 0.0305 | -1314 | 0.0305 |
| Semiarid Prairies | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Semiarid Prairies | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Semiarid Prairies | Fine | 1314 | 0.0305 | -1314 | 0.0305 |
| Montane Cordillera | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Montane Cordillera | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Montane Cordillera | Fine | 1314 | 0.0305 | -1314 | 0.0305 |
| Pacific Maritime | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Pacific Maritime | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Pacific Maritime | Fine | 1314 | 0.0305 | -1314 | 0.0305 |
| Subhumid Prairies | Coarse | 1314 | 0.0305 | -1314 | 0.0305 |
| Subhumid Prairies | Medium | 1314 | 0.0305 | -1314 | 0.0305 |
| Subhumid Prairies | Fine | 1314 | 0.0305 | -1314 | 0.0305 |

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**Table A4-6. $LumC_{max}$ and $k$ values for perennial cropping change.**

| | | Perennial cropping change | | | |
|---|---|---|---|---|---|
| | | Increase in perennial crop area | | Decrease in perennial crop area | |
| Reporting zone | Soil texture | $lumC_{max}$ | $k$ | $lumC_{max}$ | $k$ |
| Boreal Shield West | Coarse | 1942 | 0.0350 | -1942 | 0.0350 |
| Boreal Shield West | Medium | 2757 | 0.0253 | -2757 | 0.0253 |
| Boreal Shield West | Fine | 3532 | 0.0218 | -3532 | 0.0218 |
| Atlantic Maritime | Coarse | 3769 | 0.0254 | -3769 | 0.0254 |
| Atlantic Maritime | Medium | 4813 | 0.0190 | -4813 | 0.0190 |
| Atlantic Maritime | Fine | 5281 | 0.0222 | -5281 | 0.0222 |
| Boreal Plains | Coarse | 2080 | 0.0296 | -2080 | 0.0296 |
| Boreal Plains | Medium | 3241 | 0.0216 | -3241 | 0.0216 |
| Boreal Plains | Fine | 4107 | 0.0179 | -4107 | 0.0179 |
| Boreal Shield East | Coarse | 3115 | 0.0299 | -3115 | 0.0299 |
| Boreal Shield East | Medium | 4945 | 0.0215 | -4945 | 0.0215 |
| Boreal Shield East | Fine | 5586 | 0.0165 | -5586 | 0.0165 |
| Mixedwood Plains | Coarse | 3001 | 0.0299 | -3001 | 0.0299 |
| Mixedwood Plains | Medium | 3691 | 0.0241 | -3691 | 0.0241 |
| Mixedwood Plains | Fine | 4865 | 0.0215 | -4865 | 0.0215 |
| Semiarid Prairies | Coarse | 1639 | 0.0336 | -1639 | 0.0336 |
| Semiarid Prairies | Medium | 2519 | 0.0289 | -2519 | 0.0289 |
| Semiarid Prairies | Fine | 3750 | 0.0218 | -3750 | 0.0218 |
| Montane Cordillera | Coarse | 2231 | 0.0197 | -2231 | 0.0197 |
| Montane Cordillera | Medium | 3787 | 0.0174 | -3787 | 0.0174 |
| Montane Cordillera | Fine | 4803 | 0.0108 | -4803 | 0.0108 |
| Pacific Maritime | Coarse | 3043 | 0.0167 | -3043 | 0.0167 |
| Pacific Maritime | Medium | 6071 | 0.0123 | -6071 | 0.0123 |
| Pacific Maritime | Fine | 5193 | 0.0113 | -5193 | 0.0113 |
| Subhumid Prairies | Coarse | 1756 | 0.0298 | -1756 | 0.0298 |
| Subhumid Prairies | Medium | 2735 | 0.0249 | -2735 | 0.0249 |
| Subhumid Prairies | Fine | 3036 | 0.0187 | -3036 | 0.0187 |

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# 3 Beef cattle $CH_4$ and $N_2O$ emissions

If changes in cattle or management occur (e.g., diet change, feeding activity change, lactation, manure management), calculate emissions for each management period and sum emissions for the year.

## 3.1 *Enteric $CH_4$*

Enteric $CH_4$ calculations should be completed for each cattle class (except calves).

$$avg\_wt = \frac{initial\_wt + final\_wt}{2} \tag{3.1}$$

| | |
|---|---|
| *avg_wt* | Average weight (kg $head^{-1}$) |
| *initial_wt* | Initial weight (kg $head^{-1}$) (Table A4-7, by cattle class) |
| *final_wt* | Final weight (kg $head^{-1}$) (Table A4-7, by cattle class) |

### 3.1.1 Net energy requirements

$$NE_{maintenance} = C_f * (avg\_wt)^{0.75} \tag{3.2}$$

IPCC 2006

| | |
|---|---|
| $NE_{maintenance}$ | Net energy for maintenance (MJ $head^{-1}$ $day^{-1}$) |
| $C_f$ | Maintenance coefficient (Mj $day^{-1}$ $kg^{-1}$) (Table A4-7, by cattle class) |

$$NE_{activity} = C_a * NE_{maintenance} \tag{3.3}$$

IPCC 2006

| | |
|---|---|
| $NE_{activity}$ | Net energy for activity (MJ $head^{-1}$ $day^{-1}$) |
| $C_a$ | Feeding activity coefficient (Table A4-8, by activity type) |

**For lactating beef cows only (use only when cows are lactating):**

$$NE_{lactation} = [milk\_production * (1.47 + 0.40 * fat\_content)] \tag{3.4}$$

IPCC 2006

| | |
|---|---|
| $NE_{lactation}$ | Net energy for lactation (MJ $head^{-1}$ $day^{-1}$) |
| *milk_production* | Milk production (kg $head^{-1}$ $day^{-1}$) |
| *fat_content* | Fat content (%) |

Holos uses 8 kg $day^{-1}$ for *milk_production* and 4% for *fat_content*. *Fat_content* is entered as a percentage (e.g. as 4 not 0.04).

**For pregnant beef cows only:**

$$NE_{pregnancy} = 0.10 * NE_{maintenance} \tag{3.5}$$

IPCC 2006

| | |
|---|---|
| $NE_{pregnancy}$ | Net energy for pregnancy (MJ $head^{-1}$ $day^{-1}$) |

This equation averages pregnancy energy requirements over the entire year.

### 3.1.2 Average daily gain, net energy for gain

$$NE_{required}\_Mcal = NE_{required} / 4.184 \tag{3.6}$$

| | |
|---|---|
| $NE_{required}\_Mcal$ | Total net energy required (Mcal head$^{-1}$ day$^{-1}$) |
| 4.184 | Conversion from Mcal to MJ |

$$Feed\_NE_m = (0.0305 * DE) - 0.5058 \tag{3.7}$$

National Research Council 2000

| | |
|---|---|
| $Feed\_NE_m$ | Net energy in feed for maintenance (Mcal kg$^{-1}$) |
| $DE$ | Percent digestible energy in feed (Table A4-9, by diet) |

DE value is to be entered as a percentage (e.g. as 81 not 0.81).

$$Feed\_NE_g = (0.877 * Feed\_NE_m) - 0.41 \tag{3.8}$$

National Research Council 2000

| | |
|---|---|
| $Feed\_NE_g$ | Net energy in feed for gain (Mcal kg$^{-1}$) |

$$Feed_m = NE_{required}\_Mcal / Feed\_NE_m \tag{3.9}$$

| | |
|---|---|
| $Feed_m$ | Feed for maintenance (kg head$^{-1}$ day$^{-1}$) |

**For mature beef cattle (cows and bulls) only:**

$$NE_m intake = (avg\_wt)^{0.75} * [(0.04997 * Feed\_NE_m{}^2) + 0.04631] \tag{3.10}$$

National Research Council 2000

**For growing beef cattle (steers and heifers) only:**

$$NE_m intake = (avg\_wt)^{0.75} * [(0.2435 * Feed\_NE_m) - (0.0466 * Feed\_NE_m{}^2) - 0.0869] \tag{3.11}$$

National Research Council 2000

| | |
|---|---|
| $NE_m intake$ | Net energy intake for maintenance (Mcal head$^{-1}$ day$^{-1}$) |

$$DMI = NE_m intake / Feed\_NE_m \tag{3.12}$$

National Research Council 2000

| | |
|---|---|
| $DMI$ | Dry matter intake (kg head$^{-1}$ day$^{-1}$) |

$$Feed_g = DMI - Feed_m \tag{3.13}$$

National Research Council 2001

| | |
|---|---|
| $Feed_g$ | Feed available for gain (kg head$^{-1}$ day$^{-1}$) |

$$NE_g available = Feed_g * Feed\_NE_g \tag{3.14}$$

| | |
|---|---|
| $NE_g available$ | Net energy available for gain (Mcal head$^{-1}$ day$^{-1}$) |

$$EQSBW = (478 \ / \ final\_wt) \ * \ avg\_wt \quad (3.15)$$

National Research Council 2000

| | |
|---|---|
| *EQSBW* | Equivalent shrunk body weight (kg) |

**For mature beef cattle (cows and bulls) only:**

$$ADG = 0 \quad (3.16)$$

**For growing beef cattle (steers and heifers) only:**

$$ADG = 13.91 \ * \ NE_g available^{0.9116} * EQSBW^{-0.6837} \quad (3.17)$$

National Research Council 2000

| | |
|---|---|
| *ADG* | Average daily gain (kg head$^{-1}$ day$^{-1}$)<br>Note: If ADG is known, use the known value. |

$$NE_{gain} \ = \ 22.02 \ * \left( \frac{avg\_wt}{C_d \ * \ 658} \right)^{0.75} \ * \ ADG^{1.097} \quad (3.18)$$

IPCC 2006

| | |
|---|---|
| $NE_{gain}$ | Net energy for gain (MJ head$^{-1}$ day$^{-1}$) |
| 658 | Mature live weight of adult female in moderate body condition (kg) (D. Gibb 2007 personal communication) |
| $C_d$ | Gain coefficient (Table A4-7, by cattle class) |

### 3.1.3 Ratios of net energy available to digestible energy

$$REM = 1.123 - \left(4.092 \ x \ 10^{-3} * DE\right) + \left(1.126 \ x \ 10^{-5} * DE^2\right) - \left(\frac{25.4}{DE}\right) \quad (3.19)$$

IPCC 2006

| | |
|---|---|
| *REM* | Ratio of net energy available in diet for maintenance to digestible energy consumed |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

$$REG = 1.164 - \left(5.160 \ x \ 10^{-3} * DE\right) + \left(1.308 \ x \ 10^{-5} * DE^2\right) - \left(\frac{37.4}{DE}\right) \quad (3.20)$$

IPCC 2006

| | |
|---|---|
| *REG* | Ratio of net energy available in diet for gain to digestible energy consumed |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

### 3.1.4 Gross energy

$$GE = \frac{\left[\left(\frac{NE_{maintenance} + NE_{activity} + NE_{lactation} + NE_{pregnancy}}{REM}\right) + \left(\frac{NE_{gain}}{REG}\right)\right]}{\frac{DE}{100}} \qquad (3.21)$$

IPCC 2006

| | |
|---|---|
| *GE* | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

**If ADG and feed:gain are known, use equations to (3.22) and (3.23) to calculate gross energy.**

$$DMI = ADG * feed{:}gain \qquad (3.22)$$

$$GE = DMI * 18.45 \qquad (3.23)$$

IPCC 2006

| | |
|---|---|
| *feed:gain* | Feed efficiency as feed:gain ratio (kg kg$^{-1}$) |
| 18.45 | Conversion factor for gross energy per kg of dry matter (MJ kg$^{-1}$) |

### 3.1.5 $CH_4$ emission

$$CH_{4enteric}\_rate = GE * \frac{Y_m}{55.65} * \left(1 - \frac{AR}{100}\right) \qquad (3.24)$$

IPCC 2006

| | |
|---|---|
| $Y_m$ | Methane conversion factor (Table A4-9, by diet) |
| 55.65 | Energy content of $CH_4$ (MJ kg$^{-1}$ $CH_4$) |
| *AR* | Additive reduction factor (Table A4-10, by additive) |
| $CH_{4enteric}\_rate$ | Enteric $CH_4$ emission rate (kg head$^{-1}$ day$^{-1}$) |

$$CH_{4enteric} = CH_{4enteric}\_rate * \#cattle * \#days \qquad (3.25)$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$) |
| *#cattle* | Number of cattle |
| *#days* | Number of days in period |

## 3.2 Manure $CH_4$

Manure $CH_4$ calculations should be completed for each cattle class (except calves).

### 3.2.1 Volatile solids

$$VS = \left[ GE * \left( 1 - \frac{DE}{100} \right) + (0.04 * GE) \right] * \left( 1 - \frac{Ash}{100} \right) * \frac{1}{18.45} \qquad (3.26)$$

IPCC 2006

| | |
|---|---|
| *VS* | Volatile solids (kg head$^{-1}$ day$^{-1}$) |
| *GE* | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |
| *DE* | Percent digestible energy in feed (Table A4-9, by diet) |
| *Ash* | Ash content of manure (%) |
| 18.45 | Conversion factor for gross energy per kg of dry matter (MJ kg$^{-1}$) |

Holos uses 8 for the ash content (IPCC 2006). *DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

### 3.2.2 $CH_4$ emission

$$CH_{4manure}\_rate = VS * B_o * MCF * 0.67 \qquad (3.27)$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}\_rate$ | Manure $CH_4$ emission rate (kg head$^{-1}$ day$^{-1}$) |
| $B_o$ | Methane producing capacity |
| *MCF* | Methane conversion factor (Table A4-11, by handling system) |
| 0.67 | Conversion factor from volume to mass (kg m$^{-3}$) |

Holos uses 0.19 for $B_o$ (IPCC 2006).

$$CH_{4manure} = CH_{4manure}\_rate * \#cattle * \#days \qquad (3.28)$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}$ | Manure $CH_4$ emission (kg $CH_4$) |
| *#cattle* | Number of cattle |
| *#days* | Number of days in period |

## 3.3 Manure $N_2O$

Enteric $N_2O$ calculations should be completed for each cattle class (except calves).

### 3.3.1 Nitrogen excretion

$$PI = \frac{GE}{18.45} * protein\_content \qquad (3.29)$$

IPCC 2006

| | |
|---|---|
| *PI* | Protein intake (kg $head^{-1}$ $day^{-1}$) |
| *GE* | Gross energy intake (MJ $head^{-1}$ $day^{-1}$) |
| 18.45 | Conversion factor for gross energy per kg of dry matter (MJ $kg^{-1}$) |
| *protein_content* | Protein content (kg $kg^{-1}$) (Table A4-9, by diet) |

**For pregnant beef cows only:**

$$PR_{fetal} = \frac{5}{\#days} \qquad (3.30)$$

| | |
|---|---|
| $PR_{fetal}$ | Protein retained for pregnancy (kg $head^{-1}$ $day^{-1}$) |
| 5 | Protein retained per pregnancy (kg $head^{-1}$) (National Research Council 2000) |
| *#days* | Number of days in period |

This equation averages pregnancy protein retained over the gestation period.

**For lactating beef cows only (use only when cows are lactating):**

$$PR_{lactation} = milk\_production * 0.035 \qquad (3.31)$$

IPCC 2006

| | |
|---|---|
| $PR_{lactation}$ | Protein retained for lactation (kg $head^{-1}$ $day^{-1}$) |
| *milk_production* | Milk production (kg $head^{-1}$ $day^{-1}$) |
| 0.035 | Protein content of milk (kg $kg^{-1}$) |

**For growing beef cattle (steers and heifers) only:**

$$EBW = avg\_wt * 0.891 \qquad (3.32)$$

National Research Council 2000

| | |
|---|---|
| *EBW* | Empty body weight (kg $head^{-1}$) |
| *avg_wt* | Average weight (kg $head^{-1}$) |

**For growing beef cattle (steers and heifers) only:**

$$EBG = ADG * 0.956 \qquad (3.33)$$

National Research Council 2000

| | |
|---|---|
| *EBG* | Empty body gain (kg $head^{-1}$ $day^{-1}$) |
| *ADG* | Average daily gain (kg $head^{-1}$ $day^{-1}$)<br>Note: If ADG is known, use the known value. |

**For growing beef cattle (steers and heifers) only:**

$$RE = 0.0635 * EBW^{0.75} * EBG^{1.097} \tag{3.34}$$

National Research Council 2000

| | |
|---|---|
| *RE* | Retained energy (Mcal head$^{-1}$ day$^{-1}$) |

$$PR_{gain} = ADG * \frac{268 - \left(29.4 * \frac{RE}{ADG}\right)}{1000} \tag{3.35}$$

National Research Council 2000

| | |
|---|---|
| $PR_{gain}$ | Protein retained for gain (kg head$^{-1}$ day$^{-1}$) |

$$N_{excretion}\_rate = \frac{PI}{6.25} - \left(\frac{PR_{fetal}}{6.25} + \frac{PR_{lactation}}{6.38} + \frac{PR_{gain}}{6.25}\right) \tag{3.36}$$

Derived from IPCC 2006

| | |
|---|---|
| $N_{excretion}\_rate$ | N excretion rate (kg head$^{-1}$ day$^{-1}$) |
| 6.25 | Conversion from dietary protein to dietary N |
| 6.38 | Conversion from milk protein to milk N |

## 3.3.2 N$_2$O emission

### *3.3.2.1 Direct emission*

$$N_2O\text{-}N_{direct}\_rate = N_{excretion}\_rate * EF_{direct} \tag{3.37}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{direct}\_rate$ | Manure direct N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $EF_{direct}$ | Emission factor [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-11, by handling system) |

$$N_2O\text{-}N_{directmanure} = N_2O\text{-}N_{direct}\_rate * \#cattle * \#days \tag{3.38}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N) |
| *#cattle* | Number of cattle |
| *#days* | Number of days in period |

### *3.3.2.2 Indirect emissions – volatilization and leaching/runoff*

$$N_2O\text{-}N_{volatilization}\_rate = N_{excretion}\_rate * Frac_{volatilization} * EF_{volatilization} \tag{3.39}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}\_rate$ | Manure volatilization N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Frac_{volatilization}$ | Volatilization fraction (Table A4-11, by handling system) |
| $EF_{volatilization}$ | Emission factor for volatilization [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-11, by handling system) |

$$N_2O\text{-}N_{volatilization} = N_2O\text{-}N_{volatilization}\_rate * \#cattle * \#days$$

(3.40)
IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{leaching}\_rate = N_{excretion}\_rate * Frac_{leach} * EF_{leaching}$$

(3.41)
IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}\_rate$ | Manure leaching N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Frac_{leach}$ | Leaching fraction (Table A4-11, by handling system) |
| $EF_{leaching}$ | Emission factor for leaching [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-11, by handling system) |

$$N_2O\text{-}N_{leaching} = N_2O\text{-}N_{leaching}\_rate * \#cattle * \#days$$

(3.42)
IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{indirectmanure} = N_2O\text{-}N_{volatilization} + N_2O\text{-}N_{leaching}$$

(3.43)

| | |
|---|---|
| $N_2O\text{-}N_{indirectmanure}$ | Manure indirect N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{manure} = N_2O\text{-}N_{directmanure} + N_2O\text{-}N_{indirectmanure}$$

(3.44)

| | |
|---|---|
| $N_2O\text{-}N_{manure}$ | Manure N emission (kg $N_2O$-N) |

### *3.3.2.3 N available for land application*

**For cattle manure from handling systems (do not use if manure is deposited on pasture or paddock). Backgrounder cattle manure only.**

$$N_{landmanure} = (N_{excretion}\_rate * \#cattle * \#days) * [1 - (Frac_{volatilization} + Frac_{leach})]$$

(3.45)
IPCC 2006

| | |
|---|---|
| $N_{landmanure}$ | Manure available for land application (kg N) |

## For calves

The following equations are used to calculate emissions from beef calves.

## *3.4 Enteric $CH_4$ - calves*

$$DMI = \frac{(avg\_wt_{cow} * 0.4)}{2} * 0.01$$

(3.46)

| | |
|---|---|
| $DMI$ | Dry matter intake (kg head$^{-1}$ day$^{-1}$) |
| $avg\_wt_{cow}$ | Average weight of cow (kg head$^{-1}$) |

$$GE = DMI * 18.45 \tag{3.47}$$

IPCC 2006

| | |
|---|---|
| $GE$ | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |
| 18.45 | Conversion factor for gross energy per kg of dry matter (MJ kg$^{-1}$) |

Use equations (3.24) and (3.25) to calculate enteric $CH_4$ emissions.

## 3.5 Manure $CH_4$ - calves

Use equations (3.26) to (3.28) to calculate manure $CH_4$ emissions.

## 3.6 Manure $N_2O$ - calves

$$PI_{solid} = DMI * protein\_content \tag{3.48}$$

Janzen *et al.* 2006

| | |
|---|---|
| $PI_{solid}$ | Calf protein intake from solid food (kg head$^{-1}$ day$^{-1}$) |
| $DMI$ | Dry matter intake (kg head$^{-1}$ day$^{-1}$) |
| $protein\_content$ | Protein content (kg kg$^{-1}$) (Table A4-9, by diet) |

$$PI_{milk} = milk\_production * 0.035 \tag{3.49}$$

| | |
|---|---|
| $PI_{milk}$ | Calf protein intake from milk (kg head$^{-1}$ day$^{-1}$) |
| $milk\_production$ | Milk production (kg head$^{-1}$ day$^{-1}$ ) |
| 0.035 | Protein content of milk (kg kg$^{-1}$) |

$$PI = PI_{solid} + PI_{milk} \tag{3.50}$$

| | |
|---|---|
| $PI$ | Calf protein intake (kg head$^{-1}$ day$^{-1}$) |

$$PR_{solid} = PI_{solid} * 0.20 \tag{3.51}$$

| | |
|---|---|
| $PR_{solid}$ | Calf protein retained from solid feed (kg head$^{-1}$ day$^{-1}$) |

$$PR_{milk} = PI_{milk} * 0.40 \tag{3.52}$$

| | |
|---|---|
| $PR_{milk}$ | Calf protein retained from milk (kg head$^{-1}$ day$^{-1}$) |

$$PR = PR_{solid} + PR_{milk} \tag{3.53}$$

| | |
|---|---|
| $PR$ | Protein retained (kg head$^{-1}$ day$^{-1}$) |

$$N_{excretion}\_rate = \frac{PI}{6.25} - \frac{PR}{6.25} \tag{3.54}$$

Derived from IPCC 2006

| | |
|---|---|
| $N_{excretion}\_rate$ | N excretion rate (kg head$^{-1}$ day$^{-1}$) |
| 6.25 | Conversion from dietary protein to dietary N |
| 6.38 | Conversion from milk protein to milk N |

Use equations (3.37) to (3.44) to calculate manure $N_2O$ emissions.

## 3.7 Total emissions

Emissions should be summed for all cattle classes and changes in management.

$$Total\_CH_{4enteric} = \sum_{allscenariocattle} CH_{4enteric} \tag{3.55}$$

| | |
|---|---|
| $Total\_CH_{4enteric}$ | Total enteric $CH_4$ emission from beef cattle (kg $CH_4$ year$^{-1}$) |
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$) |

$$Total\_CH_{4manure} = \sum_{allscenariocattle} CH_{4manure} \tag{3.56}$$

| | |
|---|---|
| $Total\_CH_{4manure}$ | Total manure $CH_4$ emission from beef cattle (kg $CH_4$ year$^{-1}$) |
| $CH_{4manure}$ | Manure $CH_4$ emission (kg $CH_4$) |

$$Total\_N_2O\text{-}N_{directmanure} = \sum_{allscenariocattle} N_2O\text{-}N_{directmanure} \tag{3.57}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from beef cattle (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{volatilization} = \sum_{allscenariocattle} N_2O\text{-}N_{volatilization} \tag{3.58}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{volatilization}$ | Total manure volatilization N emission from beef cattle (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{leaching} = \sum_{allscenariocattle} N_2O\text{-}N_{leaching} \tag{3.59}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{leaching}$ | Total manure leaching N emission from beef cattle (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{indirectmanure} = Total\_N_2O\text{-}N_{volatilization} + Total\_N_2O\text{-}N_{leaching} \tag{3.60}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from beef cattle (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O\text{-}N_{manure} = Total\_N_2O\text{-}N_{directmanure} + Total\_N_2O\text{-}N_{indirectmanure} \tag{3.61}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{manure}$ | Total manure N emission from beef cattle (kg $N_2O$-N year$^{-1}$) |

$$Scenario\_N_{landmanure} = \sum_{allscenariocattle} N_{landmanure} \quad (3.62)$$

| | |
|---|---|
| *Scenario_N*$_{landmanure}$ | Scenario manure available for land application (kg N) |
| *N*$_{landmanure}$ | Manure available for land application (kg N) |

*Scenario_N*$_{landmanure}$ is inserted into the Soil $N_2O$ equations (Equation (1.12)) and Energy $CO_2$ equations (Equation (10.24)).

## 3.8 Conversion from $N_2O$-N to $N_2O$

$$Total\_N_2O_{directmanure} = Total\_N_2O\text{-}N_{directmanure} * \frac{44}{28} \quad (3.63)$$

| | |
|---|---|
| *Total_N*$_2$*O*$_{directmanure}$ | Total manure direct $N_2O$ emission from beef cattle (kg $N_2O$ year$^{-1}$) |
| *Total_N*$_2$*O-N*$_{directmanure}$ | Total manure direct N emission from beef cattle (kg $N_2O$-N year$^{-1}$) |
| 44/28 | Conversion from $N_2O$-N to $N_2O$ |

$$Total\_N_2O_{indirectmanure} = Total\_N_2O\text{-}N_{indirectmanure} * \frac{44}{28} \quad (3.64)$$

| | |
|---|---|
| *Total_N*$_2$*O*$_{indirectmanure}$ | Total manure indirect $N_2O$ emission from beef cattle (kg $N_2O$ year$^{-1}$) |
| *Total_N*$_2$*O-N*$_{indirectmanure}$ | Total manure indirect N emission from beef cattle (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O_{manure} = Total\_\ N_2O\text{-}N_{manure} * \frac{44}{28} \quad (3.65)$$

| | |
|---|---|
| *Total_N*$_2$*O*$_{manure}$ | Total manure $N_2O$ emission from beef cattle (kg $N_2O$ year$^{-1}$) |
| *Total_N*$_2$*O-N*$_{manure}$ | Total manure N emission from beef cattle (kg $N_2O$-N year$^{-1}$) |

**Table A4-7. Beef cattle coefficients.**

| Cattle class | $C_f$* (MJ d$^{-1}$ kg$^{-1}$) | $C_d$ | *initial_wt* (kg) | *final_wt* (kg) |
|---|---|---|---|---|
| Beef cow lactating | 0.494 | 0.80 | 600 | 600 |
| Beef cow dry | 0.430 | 0.80 | 600 | 600 |
| Bull | 0.478 | 1.20 | 820 | 820 |
| Backgrounding steer | 0.430 | 1.00 | 225 | 350 |
| Backgrounding heifer | 0.430 | 0.80 | 225 | 350 |
| Finishing steer | 0.430 | 1.00 | 350 | 625 |
| Finishing heifer | 0.430 | 0.80 | 325 | 575 |
| Source: | IPCC 2006 | IPCC 2006 | D. Gibb and F. Van Herk, personal communication | D. Gibb and F. Van Herk, personal communication |

*$C_f$ values have been adjusted to reflect an average winter temperature of -2.5EC.

**Table A4-8. Feeding activity coefficients for beef cattle.**

| Activity | $C_a$ |
|---|---:|
| Confined | 0.00 |
| Enclosed pasture | 0.17 |
| Open range or hills | 0.36 |

IPCC 2006.

**Table A4-9. Diet coefficients for beef cattle.**

| Diet | *DE* (%) | *Protein_content* (kg $kg^{-1}$) | $Y_m$ |
|---|---:|---:|---:|
| Barley finishing | 81 | 0.125 | 0.040 |
| Corn finishing | 83 | 0.13 | 0.030 |
| Backgrounding | 70 | 0.12 | 0.065 |
| Good quality forage | 65 | 0.18 | 0.065 |
| Average quality forage | 55 | 0.12 | 0.070 |
| Poor quality forage* | 45 | 0.06 | 0.080 |

These values were obtained from expert opinion (Darryl Gibb, Karen Beauchemin, Sean McGinn, AAFC).
*Poor quality forage will lead to a negative ADG with growing animals due to the DE value (45%).

**Table A4-10. Additive reduction factors for beef cattle.**

| Additive | *AR* (%) |
|---|---:|
| No additives | 0 |
| Ionophore | 20*30/#days H |
| Fat | 20 |
| Ionophore + fat | 20 + 0.5 * 20 * 30/ #days |

These values were obtained from expert opinion (Darryl Gibb, Karen Beauchemin, Sean McGinn, AAFC).
H The effect of ionophores is reduced over time. This calculation prorates the reduction over the time period.

**Table A4-11. Methane conversion factors and $N_2O$ emission factors for beef cattle.**

| Handling system | *MCF* | $EF_{direct}$ [kg $N_2O$-N (kg N)$^{-1}$] | $Frac_{volatilization}$ | $EF_{volatilization}$ [kg $N_2O$-N (kg N)$^{-1}$] | $Frac_{leach}$ | $EF_{leach}$ [kg $N_2O$-N (kg N)$^{-1}$] |
|---|---|---|---|---|---|---|
| Pasture/range/ paddock-beef | 0.010 | 0.02 | 0.20 | 0.01 | calculated* | 0.0075 |
| Solid storage-beef | 0.020 | 0.005 | 0.45 | 0.01 | 0 | 0.0075 |
| Compost - intensive windrow-beef | 0.005 | 0.1 | 0.45 | 0.01 | 0 | 0.0075 |
| Compost - passive windrow-beef | 0.005 | 0.01 | 0.45 | 0.01 | 0 | 0.0075 |
| Deep bedding > 1 month, no mixing -beef | 0.170 | 0.01 | 0.30 | 0.01 | 0 | 0.0075 |

IPCC 2006.

*Pasture manure value calculated in soil $N_2O$ emissions, equation (1.22).

# 4 Dairy cattle $CH_4$ and $N_2O$ emissions

If changes in cattle or management occur (e.g., diet change, feeding activity change, lactation, manure management), calculate emissions for each management period and sum emissions for the year.

## 4.1 *Enteric $CH_4$*

Enteric $CH_4$ calculations should be completed for each cattle class (except calves).

$$avg\_wt = \frac{initial\_wt + final\_wt}{2} \tag{4.1}$$

| | |
|---|---|
| *avg_wt* | Average weight (kg $head^{-1}$) |
| *initial_wt* | Initial weight (kg $head^{-1}$) (Table A4-12, by cattle class) |
| *final_wt* | Final weight (kg $head^{-1}$) (Table A4-12, by cattle class) |

### 4.1.1 Net energy requirements

$$NE_{maintenance} = C_f * (avg\_wt)^{0.75} \tag{4.2}$$

IPCC 2006

| | |
|---|---|
| $NE_{maintenance}$ | Net energy for maintenance (MJ $head^{-1}$ $day^{-1}$) |
| $C_f$ | Maintenance coefficient (MJ $day^{-1}$ $kg^{-1}$) (Table A4-12, by cattle class) |

$$NE_{activity} = C_a * NE_{maintenance} \tag{4.3}$$

IPCC 2006

| | |
|---|---|
| $NE_{activity}$ | Net energy for activity (MJ $head^{-1}$ $day^{-1}$) |
| $C_a$ | Feeding activity coefficient (Table A4-13, by activity type) |

**For lactating dairy cows only (use only when cows are lactating):**

$$NE_{lactation} = [milk\_production * (1.47 + 0.40 * fat\_content)] \tag{4.4}$$

IPCC 2006

| | |
|---|---|
| $NE_{lactation}$ | Net energy for lactation (MJ $head^{-1}$ $day^{-1}$) |
| *milk_production* | Milk production (kg $head^{-1}$ $day^{-1}$) (Table A4-12, by breed) |
| *fat_content* | Fat content (%)(Table A4-12, by breed)<br>Note: If milk production or fat content is known, use the known value. |

*Fat_content* is entered as a percentage (e.g. as 4 not 0.04).

**For mature dairy cows only:**

$$NE_{pregnancy} = 0.10 * NE_{maintenance} \quad (4.5)$$

IPCC 2006

| | |
|---|---|
| $NE_{pregnancy}$ | Net energy for pregnancy (MJ head$^{-1}$ day$^{-1}$) |

This equation averages pregnancy energy requirements over the entire year.

### 4.1.2 Average daily gain, net energy for gain

$$NE_{required}\_Mcal = NE_{required} \ / \ 4.184 \quad (4.6)$$

| | |
|---|---|
| $NE_{required}\_Mcal$ | Total net energy required (Mcal head$^{-1}$ day$^{-1}$) |
| 4.184 | Conversion from Mcal to MJ |

$$Feed\_NE_m = (0.0305 * DE) - 0.5058 \quad (4.7)$$

National Research Council 2001

| | |
|---|---|
| $Feed\_NE_m$ | Net energy in feed for maintenance (Mcal kg$^{-1}$) |
| $DE$ | Percent digestible energy in feed (Table A4-14, by diet)<br>Equal to Total Digestible Nutrients (*TDN*)<br>Note: If *DE/TDN* or $NE_L$ is known, use the known value. |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

**To convert $NE_L$ to *DE/TDN*:**

$$DE / TDN = \frac{(NE_L + 0.12)}{0.0245} \quad (4.8)$$

National Research Council 2001

| | |
|---|---|
| $NE_L$ | Net energy of lactation (Mcal kg$^{-1}$) |

$$Feed\_NE_g = (0.877 * Feed\_NE_m) - 0.41 \quad (4.9)$$

National Research Council 2001

| | |
|---|---|
| $Feed\_NE_g$ | Net energy in feed for gain (Mcal kg$^{-1}$) |

$$Feed_m = NE_{required}\_Mcal \ / \ Feed\_NE_m \quad (4.10)$$

| | |
|---|---|
| $Feed_m$ | Feed for maintenance (kg head$^{-1}$ day$^{-1}$) |

**For mature dairy cows only:**

$$DMI = 0.372 * milk\_production + 0.0968 * avg\_wt^{0.75} \quad (4.11)$$

National Research Council 2001

| | |
|---|---|
| $DMI$ | Dry matter intake (kg head$^{-1}$ day$^{-1}$) |

**For dairy bulls only:**

$$NE_m intake = (avg\_wt)^{0.75} * [(0.04997 * Feed\_NE_m{}^2) + 0.04631] \tag{4.12}$$

National Research Council 2000

**For dairy replacement heifers only:**

$$NE_m intake = (avg\_wt)^{0.75} * [(0.2435 * Feed\_NE_m) - (0.0466 * Feed\_NE_m{}^2) - 0.0869] \tag{4.13}$$

National Research Council 2001

| | |
|---|---|
| $NE_m intake$ | Net energy intake for maintenance (Mcal head$^{-1}$ day$^{-1}$) |

**For dairy bulls and replacement heifers only:**

$$DMI = NE_m intake \ / \ Feed\_NE_m \tag{4.14}$$

National Research Council 2000

$$Feed_g = DMI - Feed_m \tag{4.15}$$

National Research Council 2000

| | |
|---|---|
| $Feed_g$ | Feed available for gain (kg head$^{-1}$ day$^{-1}$) |

$$NE_g available = Feed_g * Feed\_NE_g \tag{4.16}$$

| | |
|---|---|
| $NE_g available$ | Net energy available for gain (Mcal head$^{-1}$ day$^{-1}$) |

$$EQSBW = (478 \ / \ final\_wt) * avg\_wt \tag{4.17}$$

National Research Council 2000

| | |
|---|---|
| $EQSBW$ | Equivalent shrunk body weight (kg) |

**For mature dairy cattle (cows and bulls) only:**

$$ADG = 0 \tag{4.18}$$

**For dairy replacement heifers only:**

$$ADG = 13.91 * NE_g available^{0.9116} * EQSBW^{-0.6837} \tag{4.19}$$

National Research Council 2000

| | |
|---|---|
| $ADG$ | Average daily gain (kg head$^{-1}$ day$^{-1}$) |

$$NE_{gain} = 22.02 * \left( \frac{avg\_wt}{C_d * final\_wt_{milkcow}} \right)^{0.75} * ADG^{1.097} \tag{4.20}$$

IPCC 2006

| | |
|---|---|
| $NE_{gain}$ | Net energy for gain (MJ head$^{-1}$ day$^{-1}$) |
| $final\_wt_{milkcow}$ | Final weight of milk cow (kg) (Table A4-12, by breed) |
| $C_d$ | Gain coefficient (Table A4-12, by cattle class) |

### 4.1.3 Ratios of net energy available to digestible energy

$$REM = 1.123 - \left(4.092\ x\ 10^{-3} * DE\right) + \left(1.126\ x\ 10^{-5} * DE^{2}\right) - \left(\frac{25.4}{DE}\right) \tag{4.21}$$

IPCC 2006

| | |
|---|---|
| *REM* | Ratio of net energy available in diet for maintenance to digestible energy consumed |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

$$REG = 1.164 - \left(5.160\ x\ 10^{-3} * DE\right) + \left(1.308\ x\ 10^{-5} * DE^{2}\right) - \left(\frac{37.4}{DE}\right) \tag{4.22}$$

IPCC 2006

| | |
|---|---|
| *REG* | Ratio of net energy available in diet for gain to digestible energy consumed |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

### 4.1.4 Gross energy

$$GE = \frac{\left[\left(\frac{NE_{maintenance} + NE_{activity} + NE_{lactation} + NE_{pregnancy}}{REM}\right) + \left(\frac{NE_{gain}}{REG}\right)\right]}{\frac{DE}{100}} \tag{4.23}$$

IPCC 2006

| | |
|---|---|
| *GE* | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

### 4.1.5 $CH_4$ emission

$$CH_{4enteric}\_rate = GE * \frac{Y_m}{55.65} * \left(1 - \frac{AR}{100}\right) \tag{4.24}$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}\_rate$ | Enteric $CH_4$ emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Y_m$ | Methane conversion factor (Table A4-14, by diet) |
| 55.65 | Energy content of $CH_4$ (MJ kg$^{-1}$ $CH_4$) |
| *AR* | Additive reduction factor (Table A4-15, by additive) |

$$CH_{4enteric} = CH_{4enteric}\_rate * \#cattle * \#days \tag{4.25}$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$) |
| *#cattle* | Number of cattle |
| *#days* | Number of days in period |

## 4.2 Manure $CH_4$

Manure $CH_4$ calculations should be completed for each cattle class (except calves).

### 4.2.1 Volatile solids

$$VS = \left[\left(GE * \left(1 - \frac{DE}{100}\right) + (0.04 * GE)\right) * \left(1 - \frac{Ash}{100}\right) * \frac{1}{18.45}\right] \qquad (4.26)$$

IPCC 2006

| | |
|---|---|
| *VS* | Volatile solids (kg head$^{-1}$ day$^{-1}$) |
| *GE* | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |
| *DE* | Percent digestible energy in feed (Table A4-14, by diet) |
| *Ash* | Ash content of manure (%) |
| 18.45 | Conversion factor for gross energy per kg of dry matter (MJ kg$^{-1}$)<br>Note: If DE or $NE_L$ is known, use known value. |

Holos uses 8 for the ash content (IPCC 2006). *DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

### 4.2.2 $CH_4$ emission

$$CH_{4manure}\_rate = VS * B_o * MCF * 0.67 \qquad (4.27)$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}\_rate$ | Manure $CH_4$ emission rate (kg head$^{-1}$ day$^{-1}$) |
| $B_o$ | Methane producing capacity |
| *MCF* | Methane conversion factor (Table A4-16 or Table A4-17, by handling system, province, season of application) |
| 0.67 | Conversion factor from volume to mass (kg m$^{-3}$) |

Holos uses 0.24 for $B_o$ (IPCC 2006).

$$CH_{4manure} = CH_{4manure}\_rate * \#cattle * \#days \qquad (4.28)$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}$ | Manure $CH_4$ emission (kg $CH_4$) |
| *#cattle* | Number of cattle |
| *#days* | Number of days in period |

## 4.3 Manure $N_2O$

Manure $N_2O$ calculations should be completed for each cattle class (except calves).

### 4.3.1 Nitrogen excretion

$$PI = \frac{GE}{18.45} * protein\_content \tag{4.29}$$

IPCC 2006

| | |
|---|---|
| *PI* | Protein intake (kg head$^{-1}$ day$^{-1}$) |
| *GE* | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |
| 18.45 | Conversion factor for gross energy per kg of dry matter (MJ kg$^{-1}$) |
| *protein_content* | Protein content (kg kg$^{-1}$) (Table A4-9, by diet)<br>Note: If protein content is known, use the known value. |

**For mature dairy cows only:**

$$PR_{fetal} = \frac{5}{\#days} \tag{4.30}$$

| | |
|---|---|
| $PR_{fetal}$ | Protein retained for pregnancy (kg head$^{-1}$ day$^{-1}$) |
| 5 | Protein retained per pregnancy (kg head$^{-1}$) (National Research Council 2000) |
| *#days* | Number of days in period |

This equation averages pregnancy protein retained over the gestation period.

**For lactating dairy cows only (use only when cows are lactating):**

$$PR_{lactation} = milk\_production * 0.035 \tag{4.31}$$

IPCC 2006

| | |
|---|---|
| $PR_{lactation}$ | Protein retained for lactation (kg head$^{-1}$ day$^{-1}$) |
| *milk_production* | Milk production (kg head$^{-1}$ day$^{-1}$ )<br>Note: If milk production is known, use the known value. |
| 0.035 | Protein content of milk (kg kg$^{-1}$) |

**For replacement dairy heifers only:**

$$EBW = avg\_wt * 0.891 \tag{4.32}$$

National Research Council 2000

| | |
|---|---|
| *EBW* | Empty body weight (kg head$^{-1}$) |
| *avg_wt* | Average weight (kg head$^{-1}$) |

**For replacement dairy heifers only:**

$$EBG = ADG * 0.956 \tag{4.33}$$

National Research Council 2000

| | |
|---|---|
| *EBG* | Empty body gain (kg head$^{-1}$ day$^{-1}$) |
| *ADG* | Average daily gain (kg head$^{-1}$ day$^{-1}$) |

**For replacement dairy heifers only:**

$$RE = 0.0635 * EBW^{0.75} * EBG^{1.097} \tag{4.34}$$

National Research Council 2000

| | |
|---|---|
| $RE$ | Retained energy (Mcal head$^{-1}$ day$^{-1}$) |

$$PR_{gain} = ADG * \frac{268 - \left(29.4 * \dfrac{RE}{ADG}\right)}{1000} \tag{4.35}$$

National Research Council 2000

| | |
|---|---|
| $PR_{gain}$ | Protein retained for gain (kg head$^{-1}$ day$^{-1}$) |

$$N_{excretion}\_rate = \frac{PI}{6.25} - \left(\frac{PR_{fetal}}{6.25} + \frac{PR_{lactation}}{6.38} + \frac{PR_{gain}}{6.25}\right) \tag{4.36}$$

Derived from IPCC 2006

| | |
|---|---|
| $N_{excretion}\_rate$ | N excretion rate (kg head$^{-1}$ day$^{-1}$) |
| 6.25 | Conversion from dietary protein to dietary N |
| 6.38 | Conversion from milk protein to milk N |

## 4.3.2 $N_2O$ emission

### *4.3.2.1 Direct emission*

$$N_2O\text{-}N_{direct}\_rate = N_{excretion}\_rate * EF_{direct} \tag{4.37}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{direct}\_rate$ | Manure direct N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $EF_{direct}$ | Emission factor [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-16 or Table A4-17, by handling system, province, season of application) |

$$N_2O\text{-}N_{directmanure} = N_2O\text{-}N_{direct}\_rate * \#cattle * \#days \tag{4.38}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N) |
| *#cattle* | Number of cattle |
| *#days* | Number of days in period |

### *4.3.2.2 Indirect emissions – volatilization and leaching/runoff*

$$N_2O\text{-}N_{volatilization}\_rate = N_{excretion}\_rate * Frac_{volatilization} * EF_{volatilization} \tag{4.39}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}\_rate$ | Manure volatilization N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Frac_{volatilization}$ | Volatilization fraction (Table A4-16 or Table A4-17, by handling system, province, season of application) |
| $EF_{volatilization}$ | Emission factor for volatilization [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-16 or Table A4-17, by handling system, province, season of application) |

$$N_2O\text{-}N_{volatilization} = N_2O\text{-}N_{volatilization}\_rate * \#cattle * \#days \tag{4.40}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{leaching}\_rate = N_{excretion}\_rate * Frac_{leach} * EF_{leaching} \tag{4.41}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}\_rate$ | Manure leaching N emission rate (kg $head^{-1}$ $day^{-1}$) |
| $Frac_{leach}$ | Leaching fraction (Table A4-16 or Table A4-17, by handling system, province, season of application) |
| $EF_{leaching}$ | Emission factor for leaching [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-16 or Table A4-17, by handling system, province, season of application) |

$$N_2O\text{-}N_{leaching} = N_2O\text{-}N_{leaching}\_rate * \#cattle * \#days \tag{4.42}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{indirectmanure} = N_2O\text{-}N_{volatilization} + N_2O\text{-}N_{leaching} \tag{4.43}$$

| | |
|---|---|
| $N_2O\text{-}N_{indirectmanure}$ | Manure indirect N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{manure} = N_2O\text{-}N_{direct} + N_2O\text{-}N_{indirect} \tag{4.44}$$

| | |
|---|---|
| $N_2O\text{-}N_{manure}$ | Manure N emission (kg $N_2O$-N) |

#### *4.3.2.3 N available for land application*

**For cattle manure from handling systems (do not use if manure is deposited on pasture or paddock).**

$$N_{landmanure} = (N_{excretion}\_rate * \#cattle * \#days) * [1 - (Frac_{volatilization} + Frac_{leach})] \tag{4.45}$$

IPCC 2006

| | |
|---|---|
| $N_{landmanure}$ | Manure available for land application (kg N) |

# For calves

The following equations are used to calculate emissions from dairy calves.

## *4.4 Enteric $CH_4$ - calves*

$$CH_{4enteric} = 0 \tag{4.46}$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$) |

IPCC 2006 recommends using a methane conversion factor ($Y_m$) of zero for milk-fed calves. Therefore, there are no enteric $CH_4$ emissions associated with milk-fed calves.

## 4.5 Manure $CH_4$ - calves

$$VS = 1.42 \tag{4.47}$$

Marinier *et al.* 2004

| | |
|---|---|
| $VS$ | Volatile solids (kg head$^{-1}$ day$^{-1}$) |

Use equations (4.27) and (4.28) to calculate manure $CH_4$ emissions.

## 4.6 Manure $N_2O$ - calves

$$N_{excretion}\_rate = 0.057 \tag{4.48}$$

IPCC 2006

| | |
|---|---|
| $N_{excretion}\_rate$ | N excretion rate (kg head$^{-1}$ day$^{-1}$) |

This value is based on an average calf weight of 130 kg (40 kg birth weight, 220 kg slaughter weight).

Use equations (4.37) to (4.45) to calculate manure $N_2O$ emissions.

## 4.7 Total emissions

Emissions should be summed for all cattle classes and changes in management.

$$Total\_CH_{4enteric} = \sum_{allscenariocattle} CH_{4enteric} \tag{4.49}$$

| | |
|---|---|
| $Total\_CH_{4enteric}$ | Total enteric $CH_4$ emission from dairy cattle (kg $CH_4$ year$^{-1}$) |
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$) |

$$Total\_CH_{4manure} = \sum_{allscenariocattle} CH_{4manure} \tag{4.50}$$

| | |
|---|---|
| $Total\_CH_{4manure}$ | Total manure $CH_4$ emission from dairy cattle (kg $CH_4$ year$^{-1}$) |
| $CH_{4manure}$ | Manure $CH_4$ emission (kg $CH_4$) |

$$Total\_N_2O\text{-}N_{directmanure} = \sum_{allscenariocattle} N_2O\text{-}N_{directmanure} \tag{4.51}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from dairy cattle (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{volatilization} = \sum_{allscenariocattle} N_2O\text{-}N_{volatilization} \tag{4.52}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{volatilization}$ | Total manure volatilization N emission from dairy cattle (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{leaching} = \sum_{allscenariocattle} N_2O\text{-}N_{leaching} \tag{4.53}$$

| | |
|---|---|
| *Total_*$N_2O\text{-}N_{leaching}$ | Total manure leaching N emission from dairy cattle (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{indirectmanure} = Total\_N_2O\text{-}N_{volatilization} + Total\_N_2O\text{-}N_{leaching} \tag{4.54}$$

| | |
|---|---|
| *Total_*$N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from dairy cattle (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O\text{-}N_{manure} = Total\_N_2O\text{-}N_{directmanure} + Total\_N_2O\text{-}N_{indirectmanure} \tag{4.55}$$

| | |
|---|---|
| *Total_*$N_2O\text{-}N_{manure}$ | Total manure N emission from dairy cattle (kg $N_2O$-N year$^{-1}$) |

$$Scenario\_N_{landmanure} = \sum_{allscenariocattle} N_{landmanure} \tag{4.56}$$

| | |
|---|---|
| *Scenario_*$N_{landmanure}$ | Scenarios manure available for land application (kg N) |
| $N_{landmanure}$ | Manure available for land application (kg N) |

*Scenario_*$N_{landmanure}$ is inserted into the Soil $N_2O$ equations (Equation (1.12)) and Energy $CO_2$ equations (Equation (10.21) or (10.24)).

## *4.8 Conversion from $N_2O$-N to $N_2O$*

$$Total\_N_2O_{directmanure} = Total\_N_2O\text{-}N_{directmanure} * \frac{44}{28} \tag{4.57}$$

| | |
|---|---|
| *Total_*$N_2O_{directmanure}$ | Total manure direct $N_2O$ emission from dairy cattle (kg $N_2O$ year$^{-1}$) |
| *Total_*$N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from dairy cattle (kg $N_2O$-N year$^{-1}$) |
| 44/28 | Conversion from $N_2O$-N to $N_2O$ |

$$Total\_N_2O_{indirectmanure} = Total\_N_2O\text{-}N_{indirectmanure} * \frac{44}{28} \tag{4.58}$$

| | |
|---|---|
| *Total_*$N_2O_{indirectmanure}$ | Total manure indirect $N_2O$ emission from dairy cattle (kg $N_2O$ year$^{-1}$) |
| *Total_*$N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from dairy cattle (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O_{manure} = Total\_N_2O\text{-}N_{manure} * \frac{44}{28} \tag{4.59}$$

| | |
|---|---|
| *Total_*$N_2O_{manure}$ | Total manure $N_2O$ emission from dairy cattle (kg $N_2O$ year$^{-1}$) |
| *Total_*$N_2O\text{-}N_{manure}$ | Total manure N emission from dairy cattle (kg $N_2O$-N year$^{-1}$) |

**Table A4-12. Dairy cattle coefficients.**

| Cattle class | $C_f$ (MJ $d^{-1}$ $kg^{-1}$) | $C_d$ | *initial_wt* (kg) | *final_wt* (kg) | *milk_ production* (L $d^{-1}$) | *fat_ content* (%) |
|---|---:|---:|---:|---:|---:|---:|
| Holstein cow - milking | 0.386 | 0.8 | 650 | 650 | 27 | 3.71 |
| Holstein cow - dry | 0.322 | 0.8 | 650 | 650 | 0 | 0 |
| Holstein replacement | 0.322 | 0.8 | 468 | 650 | 0 | 0 |
| Holstein bull | 0.37 | 1.2 | 1200 | 1200 | 0 | 0 |
| Jersey cow - milking | 0.386 | 0.8 | 450 | 450 | 20 | 4.83 |
| Jersey cow - dry | 0.322 | 0.8 | 450 | 450 | 0 | 0 |
| Jersey replacement | 0.322 | 0.8 | 324 | 450 | 0 | 0 |
| Jersey bull | 0.37 | 1.2 | 1200 | 1200 | 0 | 0 |
| Source: | IPCC 2006 | IPCC 2006 | | | Dairy Farmers of Ontario | Canadian Dairy Information Centre |

**Table A4-13. Feeding activity coefficients for dairy cattle.**

| Activity | $C_a$ |
|---|---:|
| Confined | 0.00 |
| Enclosed pasture | 0.17 |

IPCC 2006.

**Table A4-14. Diet coefficients for dairy cattle.**

| Diet | *DE* (%) | *Protein_content* (kg $kg^{-1}$) | $Y_m$ |
|---|---:|---:|---:|
| Dairy lactation diet | 70 | 0.16 | 0.065 |
| Dairy dry diet | 60 | 0.12 | 0.065 |

These values were obtained from expert opinion (Darryl Gibb, Karen Beauchemin, Sean McGinn, AAFC).

**Table A4-15. Additive reduction factors for dairy cattle.**

| Additive | *AR* (%) |
|---|---:|
| No additives | 0 |
| Ionophore | 20*30/#days H |
| Fat | 5 * %addedfat § |
| Ionophore + fat | (5 * %addedfat) + 0.5 * ( 20 * 30/ #days) |

These values were obtained from expert opinion (Darryl Gibb, Karen Beauchemin, Sean McGinn, AAFC).

H The effect of ionophores is reduced over time. This calculation prorates the reduction over the time period.

§ Up to 6% added fat possible.

**Table A4-16. Methane conversion factors and $N_2O$ emission factors for dairy cattle.**

| Handling system | $MCF$ | $EF_{direct}$ [kg $N_2O$-N (kg N)$^{-1}$] | $Frac_{volatilization}$ | $EF_{volatilization}$ [kg $N_2O$-N (kg N)$^{-1}$] | $Frac_{leach}$ | $EF_{leach}$ [kg $N_2O$-N (kg N)$^{-1}$] |
|---|---|---|---|---|---|---|
| Pasture/range/ paddock-dairy | 0.010 | 0.02 | 0.20 | 0.01 | calculated* | 0.0075 |
| Daily spread-dairy | 0.001 | 0 | 0.07 | 0.01 | 0 | 0.0075 |
| Solid storage-dairy | 0.020 | 0.005 | 0.30 | 0.01 | 0 | 0.0075 |
| Compost - intensive windrow-dairy | 0.005 | 0.1 | 0.30 | 0.01 | 0 | 0.0075 |
| Compost - passive windrow-dairy | 0.005 | 0.01 | 0.30 | 0.01 | 0 | 0.0075 |
| Deep bedding > 1 month, no mixing-dairy | 0.170 | 0.01 | 0.30 | 0.01 | 0 | 0.0075 |
| Liquid/slurry, with natural crust cover-dairy | See Table A4-17 | 0.005 | 0.40 | 0.01 | 0 | 0.0075 |
| Liquid/slurry, without natural crust cover-dairy | See Table A4-17 | 0 | 0.40 | 0.01 | 0 | 0.0075 |
| Anaerobic digester-dairy | 0.01 | 0 | 0.40 | 0.01 | 0 | 0.0075 |

IPCC 2006.

*Pasture manure value calculated in soil $N_2O$ emissions, equation (1.22).

**Table A4-17. Liquid/slurry methane conversion factors based on season of application.**

| Handling system | | *MCF* | | | | |
|---|---|---|---|---|---|---|
| | Province | spring | summer | fall | winter | spring & fallH |
| Liquid/slurry, with natural crust cover* | NB NS PE NF | 0.131 | 0.188 | 0.197 | 0.160 | 0.109 |
| | QC | 0.140 | 0.202 | 0.202 | 0.161 | 0.116 |
| | ON | 0.140 | 0.210 | 0.210 | 0.168 | 0.116 |
| | MB | 0.130 | 0.196 | 0.195 | 0.157 | 0.108 |
| | SK | 0.128 | 0.191 | 0.191 | 0.154 | 0.106 |
| | AB | 0.127 | 0.191 | 0.183 | 0.149 | 0.105 |
| | BC | 0.130 | 0.182 | 0.186 | 0.151 | 0.108 |
| Liquid/slurry, without natural crust cover | NB NS PE NF | 0.219 | 0.313 | 0.329 | 0.267 | 0.182 |
| | QC | 0.233 | 0.337 | 0.336 | 0.269 | 0.193 |
| | ON | 0.233 | 0.350 | 0.350 | 0.280 | 0.193 |
| | MB | 0.216 | 0.327 | 0.325 | 0.262 | 0.179 |
| | SK | 0.214 | 0.319 | 0.318 | 0.257 | 0.178 |
| | AB | 0.211 | 0.319 | 0.305 | 0.249 | 0.175 |
| | BC | 0.216 | 0.304 | 0.310 | 0.252 | 0.179 |

Vergé *et al.* 2006.

*40% reduction in MCF values for liquid/slurry with a natural crust cover (IPCC 2006).

HSpring & fall application values are 83% of spring only value.

# 5 Swine $CH_4$ and $N_2O$ emissions

## 5.1 *Enteric $CH_4$*

Enteric $CH_4$ calculations should be completed for each pig class.

$$CH_{4enteric}\_rate = \frac{1.5}{365} \tag{5.1}$$

| | |
|---|---|
| $CH_{4enteric}\_rate$ | Enteric $CH_4$ emission rate (kg head$^{-1}$ day$^{-1}$) |
| 1.5 | Yearly enteric $CH_4$ emission rate (IPCC 2006) |

$$CH_{4enteric} = CH_{4enteric}\_rate * \# pigs * \# days \tag{5.2}$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$ year$^{-1}$) |
| *#pigs* | Number of pigs |
| *#days* | Number of days (Table A4-18, by pig class, scenario) |

Using the number of days as in Table A4-18 will calculate emissions for one year using the method and scenarios that Holos utilizes.

## 5.2 *Manure $CH_4$*

Manure $CH_4$ calculations should be completed for each pig class.

### 5.2.1 Volatile solids

$$VS_{adjusted} = VS_{excretion} * VS_{adjustment} \tag{5.3}$$

Greenhouse Gas System Pork Protocol 2006

| | |
|---|---|
| $VS_{adjusted}$ | Volatile solid adjusted |
| $VS_{excretion}$ | Volatile solid excretion (kg kg$^{-1}$) (Table A4-19, by pig class, province) |
| $VS_{adjustment}$ | Volatile solid adjustment factor (kg kg$^{-1}$) (Table A4-20, by diet) |

$$VS = feed\_intake * VS_{adjusted} \tag{5.4}$$

Greenhouse Gas System Pork Protocol 2006

| | |
|---|---|
| *VS* | Volatile solids (kg head$^{-1}$ day$^{-1}$) |
| *feed_intake* | Feed intake (kg head$^{-1}$ day$^{-1}$) (Table A4-21, by pig class, province) |

### 5.2.2 $CH_4$ emission

$$CH_{4manure}\_rate = VS * B_o * MCF * 0.67 \tag{5.5}$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}\_rate$ | Manure $CH_4$ emission rate (kg head$^{-1}$ day$^{-1}$) |
| $B_o$ | Methane producing capacity |
| $MCF$ | Methane conversion factor (Table A4-22 or Table A4-23, by handling system, province, season of application) |
| 0.67 | Conversion factor from volume to mass (kg m$^{-3}$) |

Holos uses 0.48 for $B_o$ (IPCC 2006).

$$CH_{4manure} = CH_{4manure}\_rate * \#pigs * \#days \tag{5.6}$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}$ | Manure $CH_4$ emission (kg $CH_4$ year$^{-1}$) |
| $\#pigs$ | Number of pigs |
| $\#days$ | Number of days (Table A4-18, by pig class, scenario) |

Using the number of days as in Table A4-18 will calculate emissions for one year using the method and scenarios that Holos utilizes.

## 5.3 Manure $N_2O$

Manure $N_2O$ calculations should be completed for each pig class.

### 5.3.1 Nitrogen excretion

$$PI = feed\_intake * protein\_content \tag{5.7}$$

Greenhouse Gas System Pork Protocol 2006

| | |
|---|---|
| $PI$ | Protein intake (kg head$^{-1}$ day$^{-1}$) |
| $feed\_intake$ | Feed intake (kg head$^{-1}$ day$^{-1}$) (Table A4-21, by pig class, province) |
| $protein\_content$ | Protein content (kg kg$^{-1}$) (Table A4-24, by pig class, province) |

$$PR = 0.30 \tag{5.8}$$

IPCC 2006

| | |
|---|---|
| $PR$ | Protein retained (kg (kg protein intake)$^{-1}$) |

$$N_{excretion}\_rate = \frac{PI * (1 - PR)}{6.25} * Nexcreted_{adjustment} \tag{5.9}$$

Derived from IPCC 2006

| | |
|---|---|
| $N_{excretion}\_rate$ | N excretion rate (kg head$^{-1}$ day$^{-1}$) |
| 6.25 | Conversion from dietary protein to dietary N |
| $Nexcreted_{adjustment}$ | N excreted adjustment factor (kg kg$^{-1}$) (Table A4-20, by diet) |

## 5.3.2 $N_2O$ emission

### *5.3.2.1 Direct emission*

$$N_2O\text{-}N_{direct}\_rate = N_{excretion}\_rate * EF_{direct} \tag{5.10}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{direct}\_rate$ | Manure direct N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $EF_{direct}$ | Emission factor [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-22 or Table A4-23, by handling system, province, season of application) |

$$N_2O\text{-}N_{directmanure} = N_2O\text{-}N_{direct}\_rate * \#\, pigs * \#\, days \tag{5.11}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N year$^{-1}$) |
| *#pigs* | Number of pigs |
| *#days* | Number of days (Table A4-18, by pig class, scenario) |

Using the number of days as in Table A4-18 will calculate emissions for one year using the method and scenarios that Holos utilizes.

### *5.3.2.2 Indirect emissions – volatilization and leaching/runoff*

$$N_2O\text{-}N_{volatilization}\_rate = N_{excretion}\_rate * Frac_{volatilization} * EF_{volatilization} \tag{5.12}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}\_rate$ | Manure volatilization N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Frac_{volatilization}$ | Volatilization fraction (Table A4-22 or Table A4-23, by handling system, province, season of application) |
| $EF_{volatilization}$ | Emission factor for volatilization [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-22 or Table A4-23, by handling system, province, season of application) |

$$N_2O\text{-}N_{volatilization} = N_2O\text{-}N_{volatilization}\_rate * \#\, pigs * \#\, days \tag{5.13}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N year$^{-1}$) |

$$N_2O\text{-}N_{leaching}\_rate = N_{excretion}\_rate * Frac_{leach} * EF_{leaching} \tag{5.14}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}\_rate$ | Manure leaching N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Frac_{leach}$ | Leaching fraction (Table A4-22 or Table A4-23, by handling system, province, season of application) |
| $EF_{leaching}$ | Emission factor for leaching [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-22 or Table A4-23, by handling system, province, season of application) |

$$N_2O\text{-}N_{leaching} = N_2O\text{-}N_{leaching}\_rate * \#\, pigs * \#\, days \tag{5.15}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N year$^{-1}$) |

$$N_2O\text{-}N_{indirectmanure} = N_2O\text{-}N_{volatilization} + N_2O\text{-}N_{leaching} \qquad (5.16)$$

| | |
|---|---|
| $N_2O\text{-}N_{indirectmanure}$ | Manure indirect N emission (kg $N_2O$-N $year^{-1}$) |

$$N_2O - N_{manure} = N_2O - N_{directmanure} + N_2O - N_{indirectmanure} \qquad (5.17)$$

| | |
|---|---|
| $N_2O\text{-}N_{manure}$ | Manure N emission (kg $N_2O$-N $year^{-1}$) |

#### 5.3.2.3 N available for land application

**For pig manure from handling systems.**

$$N_{landmanure} = (N_{excretion}\_rate * \# pigs * \# days) * [1 - (Frac_{volatilization} + Frac_{leach})] \qquad (5.18)$$

IPCC 2006

| | |
|---|---|
| $N_{landmanure}$ | Manure available for land application (kg N) |

## 5.4 Total emissions

Emissions should be summed for all pig classes.

$$Total\_CH_{4enteric} = \sum_{allscenariopigs} CH_{4enteric} \qquad (5.19)$$

| | |
|---|---|
| $Total\_CH_{4enteric}$ | Total enteric $CH_4$ emission from swine (kg $CH_4$ $year^{-1}$) |
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$ $year^{-1}$) |

$$Total\_CH_{4manure} = \sum_{allscenariopigs} CH_{4manure} \qquad (5.20)$$

| | |
|---|---|
| $Total\_CH_{4manure}$ | Total manure $CH_4$ emission from swine (kg $CH_4$ $year^{-1}$) |
| $CH_{4manure}$ | Manure $CH_4$ emission (kg $CH_4$ $year^{-1}$) |

$$Total\_N_2O\text{-}N_{directmanure} = \sum_{allscenariopigs} N_2O\text{-}N_{directmanure} \qquad (5.21)$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from swine (kg $N_2O$-N $year^{-1}$) |
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N $year^{-1}$) |

$$Total\_N_2O\text{-}N_{volatilization} = \sum_{allscenariopigs} N_2O\text{-}N_{volatilization} \qquad (5.22)$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{volatilization}$ | Total manure volatilization N emission from swine (kg $N_2O$-N $year^{-1}$) |
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N $year^{-1}$) |

$$Total\_N_2O\text{-}N_{leaching} = \sum_{allscenariopigs} N_2O\text{-}N_{leaching} \qquad (5.23)$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{leaching}$ | Total manure leaching N emission from swine (kg $N_2O$-N $year^{-1}$) |
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N $year^{-1}$) |

$$Total\_N_2O\text{-}N_{indirectmanure} = Total\_N_2O\text{-}N_{volatilization} + Total\_N_2O\text{-}N_{leaching} \quad (5.24)$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from swine (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O\text{-}N_{manure} = Total\_N_2O\text{-}N_{direct} + Total\_N_2O\text{-}N_{indirect} \quad (5.25)$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{manure}$ | Total manure N emission from swine (kg $N_2O$-N year$^{-1}$) |

$$Scenario\_N_{landmanure} = \sum_{allscenariopigs} N_{landmanure} \quad (5.26)$$

| | |
|---|---|
| $Scenario\_N_{landmanure}$ | Manure available for land application (kg N) |
| $N_{landmanure}$ | Manure available for land application (kg N) |

$Scenario\_N_{landmanure}$ is inserted into the Soil $N_2O$ equations (Equation (1.12)) and Energy $CO_2$ equations (Equation (10.21) or (10.24)).

## 5.5 Conversion from $N_2O$-N to $N_2O$

$$Total\_N_2O_{directmanure} = Total\_N_2O\text{-}N_{directmanure} * \frac{44}{28} \quad (5.27)$$

| | |
|---|---|
| $Total\_N_2O_{directmanure}$ | Total manure direct $N_2O$ emission from swine (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from swine (kg $N_2O$-N year$^{-1}$) |
| 44/28 | Conversion from $N_2O$-N to $N_2O$ |

$$Total\_N_2O_{indirectmanure} = Total\_N_2O\text{-}N_{indirectmanure} * \frac{44}{28} \quad (5.28)$$

| | |
|---|---|
| $Total\_N_2O_{indirectmanure}$ | Total manure indirect $N_2O$ emission from swine (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from swine (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O_{manure} = Total\_N_2O\text{-}N_{manure} * \frac{44}{28} \quad (5.29)$$

| | |
|---|---|
| $Total\_N_2O_{manure}$ | Total manure $N_2O$ emission from swine (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{manure}$ | Total manure N emission from swine (kg $N_2O$-N year$^{-1}$) |

**Table A4-18. Number of days for each pig class, by Holos scenario.**

| | *#days* | | | |
|---|---|---|---|---|
| Pig class | Scenario 1 - Farrow to finish | Scenario 2 - Farrow to wean | Scenario 3 - Finishing operation | Scenario 4 - Nursery operation |
| Starter | 68 | 0 | 0 | 365 |
| Grower | 94 | 0 | 159 | 0 |
| Finisher | 108 | 0 | 183 | 0 |
| Sow-lactating | 46 | 46 | 0 | 0 |
| Sow-dry | 319 | 319 | 0 | 0 |
| Boar | 365 | 365 | 0 | 0 |

Developed from Greenhouse Gas System Pork Protocol 2006 swine operation barn cycles.

**Table A4-19. Volatile solid excretion for performance standard diets for each pig class, by province.**

| | $VS_{excretion}$ (kg VS $kg^{-1}$ feed, as fed) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pig class | BC | AB | SK | MB | ON | QB | NF | NS | NB | PE |
| Starter | 0.1446 | 0.1504 | 0.1292 | 0.1034 | 0.0985 | 0.0845 | 0.0936 | 0.0886 | 0.0949 | 0.0966 |
| Grower | 0.1391 | 0.1389 | 0.1539 | 0.1514 | 0.1034 | 0.1097 | 0.1354 | 0.1478 | 0.1525 | 0.1470 |
| Finisher | 0.1391 | 0.1389 | 0.1539 | 0.1514 | 0.1034 | 0.1097 | 0.1354 | 0.1478 | 0.1525 | 0.1470 |
| Sow-dry and boar | 0.1227 | 0.1228 | 0.1321 | 0.1406 | 0.0712 | 0.1053 | 0.1232 | 0.1243 | 0.1278 | 0.1243 |
| Sow-lactating | 0.1227 | 0.1228 | 0.1321 | 0.1406 | 0.0712 | 0.1053 | 0.1232 | 0.1243 | 0.1278 | 0.1243 |

Greenhouse Gas System Pork Protocol 2006

**Table A4-20. Volatile solid and nitrogen excretion adjustment factors, by diet.**

| Diet | $VS_{adjustment}$ (kg $kg^{-1}$) | $Nexcreted_{adjusment}$ (kg $kg^{-1}$) |
|---|---|---|
| Standard diet | 1 | 1 |
| Reduced protein diet | 0.99 | 0.70 |
| Highly digestible feed diet | 0.95 | 0.95 |

Greenhouse Gas System Pork Protocol 2006.

**Table A4-21. Daily feed intake (as fed) for each pig class, by province.**

| | *feed_intake* (kg head $^{-1}$ day$^{-1}$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pig class | BC | AB | SK | MB | ON | QB | NF | NS | NB | PE |
| Starter | 0.70 | 0.70 | 0.70 | 0.70 | 0.65 | 0.65 | 0.70 | 0.70 | 0.70 | 0.70 |
| Grower | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Finisher | 3.00 | 3.00 | 3.00 | 3.00 | 2.80 | 2.80 | 3.00 | 3.00 | 3.00 | 3.00 |
| Sow-dry and boar | 2.55 | 2.55 | 2.55 | 2.55 | 2.45 | 2.45 | 2.55 | 2.55 | 2.55 | 2.55 |
| Sow-lactating | 6.11 | 6.11 | 6.11 | 6.11 | 5.85 | 5.85 | 6.11 | 6.11 | 6.11 | 6.11 |

Greenhouse Gas System Pork Protocol 2006.

**Table A4-22. Methane conversion factors and $N_2O$ emission factors for swine.**

| Handling system | *MCF* | $EF_{direct}$ [kg $N_2O$-N (kg N)$^{-1}$] | $Frac_{volatilization}$ | $EF_{volatilization}$ [kg $N_2O$-N (kg N)$^{-1}$] | $Frac_{leach}$ | $EF_{leach}$ [kg $N_2O$-N (kg N)$^{-1}$] |
|---|---|---|---|---|---|---|
| Solid storage-swine | 0.020 | 0.005 | 0.45 | 0.01 | 0 | 0.0075 |
| Liquid/slurry, with natural crust cover-swine | See Table A4-23 | 0.005 | 0.48 | 0.01 | 0 | 0.0075 |
| Liquid/slurry, without natural crust cover-swine | See Table A4-23 | 0 | 0.48 | 0.01 | 0 | 0.0075 |
| Anaerobic digester-swine | 0.01 | 0 | 0.48 | 0.01 | 0 | 0.0075 |
| Deep pit under barn-swine | 0.3514H | 0.002 | 0.25 | 0.01 | 0 | 0.0075 |

IPCC 2006.

HThis assumes a constant temperature of 15EC and that manure is directly land applied (no external storage).

**Table A4-23. Liquid/slurry methane conversion factors based on season of application.**

| Handling system |  | *MCF* |  |  |  |  |
|---|---|---|---|---|---|---|
|  | Province | spring | summer | fall | winter | spring & fallH |
| Liquid/slurry, with natural crust cover* | NB NS PE NF | 0.131 | 0.188 | 0.197 | 0.160 | 0.109 |
|  | QC | 0.140 | 0.202 | 0.202 | 0.161 | 0.116 |
|  | ON | 0.140 | 0.210 | 0.210 | 0.168 | 0.116 |
|  | MB | 0.130 | 0.196 | 0.195 | 0.157 | 0.108 |
|  | SK | 0.128 | 0.191 | 0.191 | 0.154 | 0.106 |
|  | AB | 0.127 | 0.191 | 0.183 | 0.149 | 0.105 |
|  | BC | 0.130 | 0.182 | 0.186 | 0.151 | 0.108 |
| Liquid/slurry, without natural crust cover | NB NS PE NF | 0.219 | 0.313 | 0.329 | 0.267 | 0.182 |
|  | QC | 0.233 | 0.337 | 0.336 | 0.269 | 0.193 |
|  | ON | 0.233 | 0.350 | 0.350 | 0.280 | 0.193 |
|  | MB | 0.216 | 0.327 | 0.325 | 0.262 | 0.179 |
|  | SK | 0.214 | 0.319 | 0.318 | 0.257 | 0.178 |
|  | AB | 0.211 | 0.319 | 0.305 | 0.249 | 0.175 |
|  | BC | 0.216 | 0.304 | 0.310 | 0.252 | 0.179 |

Vergé *et al.* 2006.

*40% reduction in MCF values for liquid/slurry with a natural crust cover (IPCC 2006).

HSpring & fall application values are 83% of spring only value.

**Table A4-24. Protein content in feed, as fed, for each pig class, by province.**

|  | *Protein_content* (kg protein $kg^{-1}$ feed, as fed) |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| Pig class | BC | AB | SK | MB | ON | QB | NF | NS | NB | PE |
| Starter | 0.220 | 0.220 | 0.220 | 0.220 | 0.210 | 0.210 | 0.220 | 0.220 | 0.220 | 0.220 |
| Grower | 0.180 | 0.180 | 0.180 | 0.180 | 0.175 | 0.175 | 0.180 | 0.180 | 0.180 | 0.180 |
| Finisher | 0.155 | 0.155 | 0.155 | 0.155 | 0.135 | 0.135 | 0.155 | 0.155 | 0.155 | 0.155 |
| Sow-dry and boar | 0.145 | 0.145 | 0.145 | 0.145 | 0.135 | 0.135 | 0.145 | 0.145 | 0.145 | 0.145 |
| Sow-lactating | 0.200 | 0.200 | 0.200 | 0.200 | 0.185 | 0.185 | 0.200 | 0.200 | 0.200 | 0.200 |

Greenhouse Gas System Pork Protocol 2006.

# 6 Sheep $CH_4$ and $N_2O$ emissions

If changes in sheep or management occur (e.g., diet change, feeding activity change, lactation, manure management), calculate emissions for each management period and sum emissions for the year.

## 6.1 *Enteric $CH_4$*

Enteric $CH_4$ calculations should be completed for each sheep class.

$$avg\_wt = \frac{initial\_wt + final\_wt}{2} \qquad (6.1)$$

| | |
|---|---|
| *avg_wt* | Average weight (kg head$^{-1}$) |
| *initial_wt* | Initial weight (kg head$^{-1}$) (Table A4-25, by sheep class) |
| *final_wt* | Final weight (kg head$^{-1}$) (Table A4-25, by sheep class) |

### 6.1.1 Net energy requirements

$$NE_{maintenance} = C_f * (avg\_wt)^{0.75} \qquad (6.2)$$

IPCC 2006

| | |
|---|---|
| $NE_{maintenance}$ | Net energy for maintenance (MJ head$^{-1}$ day$^{-1}$) |
| $C_f$ | Maintenance coefficient (MJ day$^{-1}$ kg$^{-1}$) (Table A4-25, by sheep class) |

$$NE_{activity} = C_a * avg\_wt \qquad (6.3)$$

IPCC 2006

| | |
|---|---|
| $NE_{activity}$ | Net energy for activity (MJ head$^{-1}$ day$^{-1}$) |
| $C_a$ | Feeding activity coefficient (MJ kg$^{-1}$) (Table A4-26, by activity type) |

**For lactating ewes only (use only when ewes are lactating):**

$$NE_{lactation} = \left[5*0.6*\frac{\%twins}{100}\right] + \left[5*0.4*\left(1-\frac{\%twins}{100}\right)\right]*EV_{milk} \qquad (6.4)$$

Derived from IPCC 2006

| | |
|---|---|
| $NE_{lactation}$ | Net energy for lactation (MJ head$^{-1}$ day$^{-1}$) |
| *%twins* | Percentage of twin births |
| $EV_{milk}$ | Energy required to produce 1 L of milk (MJ kg$^{-1}$) |

This is based on a combined weight gain of twins of 0.6 kg day$^{-1}$ and a weight gain of single lambs of 0.4 kg day$^{-1}$ (Helgason *et al.* 2005). $EV_{milk}$ is 4.6 MJ kg$^{-1}$ (IPCC 2006).

**For pregnant ewes only:**

$$NE_{pregnancy} = \left\{ \left[ 0.126 * \frac{\%twins}{100} \right] + \left[ 0.077 * \left( 1 - \frac{\%twins}{100} \right) \right] \right\} * NE_{maintenance} \tag{6.5}$$

Derived from IPCC 2006

| | |
|---|---|
| $NE_{pregnancy}$ | Net energy for pregnancy (MJ head$^{-1}$ day$^{-1}$) |
| 0.126 | Pregnancy constant for twin births (IPCC 2006) |
| 0.077 | Pregnancy constant for single births (IPCC 2006) |

This equation averages pregnancy energy requirements over the entire year and takes into account single lambs and twins.

**For ewes and rams only:**

$$NE_{wool} = \frac{EV_{wool} * wool\_production}{\# days} \tag{6.6}$$

IPCC 2006

| | |
|---|---|
| $NE_{wool}$ | Net energy for wool production (MJ head$^{-1}$ day$^{-1}$) |
| $EV_{wool}$ | Energy value of 1 kg of wool (MJ kg$^{-1}$) |
| *wool_production* | Wool production (kg year$^{-1}$) (Table A4-25, by sheep class) |
| *#days* | Number of days in period |

$EV_{wool}$ is 24 MJ kg$^{-1}$ (IPCC 2006).

$$NE_{gain} = \frac{(final\_wt - initial\_wt) * \left[ a + 0.5b (initial\_wt + final\_wt) \right]}{\# days} \tag{6.7}$$

IPCC 2006

| | |
|---|---|
| $NE_{gain}$ | Net energy for gain (MJ head$^{-1}$ day$^{-1}$) |
| *a* | Coefficient a (MJ kg$^{-1}$) (Table Table A4-25, by sheep class) |
| *b* | Coefficient a (MJ kg$^{-2}$) (Table Table A4-25, by sheep class) |

### 6.1.2 Ratios of net energy available to digestible energy

$$REM = 1.123 - \left(4.092\ x\ 10^{-3} * DE\right) + \left(1.126\ x\ 10^{-5} * DE^{2}\right) - \left(\frac{25.4}{DE}\right) \quad (6.8)$$

IPCC 2006

| | |
|---|---|
| *REM* | Ratio of net energy available in diet for maintenance to digestible energy consumed |
| *DE* | Percent digestible energy in feed (Table A4-27, by diet) |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

$$REG = 1.164 - \left(5.160\ x\ 10^{-3} * DE\right) + \left(1.308\ x\ 10^{-5} * DE^{2}\right) - \left(\frac{37.4}{DE}\right) \quad (6.9)$$

IPCC 2006

| | |
|---|---|
| *REG* | Ratio of net energy available in diet for gain to digestible energy consumed |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

### 6.1.3 Gross energy

$$GE = \frac{\left[\left(\frac{NE_{maintenance} + NE_{activity} + NE_{lactation} + NE_{pregnancy}}{REM}\right) + \left(\frac{NE_{gain} + NE_{wool}}{REG}\right)\right]}{\frac{DE}{100}} \quad (6.10)$$

IPCC 2006

| | |
|---|---|
| *GE* | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |

*DE* value is to be entered as a percentage (e.g. as 81 not 0.81).

### 6.1.4 CH$_4$ emission

$$CH_{4enteric}\_rate = GE * \frac{Y_m}{55.65} \quad (6.11)$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}\_rate$ | Enteric CH$_4$ emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Y_m$ | Methane conversion factor (Table A4-25, by sheep class) |
| 55.65 | Energy content of CH$_4$ (MJ kg$^{-1}$ CH$_4$) |

$$CH_{4enteric} = CH_{4enteric}\_rate * \#sheep * \#days \quad (6.12)$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}$ | Enteric CH$_4$ emission (kg CH$_4$) |
| *#sheep* | Number of sheep |
| *#days* | Number of days in period |

## 6.2 Manure $CH_4$

Manure $CH_4$ calculations should be completed for each sheep class.

### 6.2.1 Volatile solids

$$VS = \left[ GE * \left( 1 - \frac{DE}{100} \right) + \left( 0.04 * GE \right) \right] * \left( 1 - \frac{Ash}{100} \right) * \frac{1}{18.45} \tag{6.13}$$

IPCC 2006

| | |
|---|---|
| *VS* | Volatile solids (kg head$^{-1}$ day$^{-1}$) |
| *GE* | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |
| *DE* | Percent digestible energy in feed (Table A4-27, by diet) |
| *Ash* | Ash content of manure (%) |
| 18.45 | Conversion factor for gross energy per kg of dry matter (MJ kg$^{-1}$) |

Holos uses 8 for the ash content (IPCC 2006).

### 6.2.2 $CH_4$ emission

$$CH_{4manure}\_rate = VS * B_o * MCF * 0.67 \tag{6.14}$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}\_rate$ | Manure $CH_4$ emission rate (kg head$^{-1}$ day$^{-1}$) |
| $B_o$ | Methane producing capacity |
| *MCF* | Methane conversion factor (Table A4-28, by handling system) |
| 0.67 | Conversion factor from volume to mass (kg m$^{-3}$) |

Holos uses 0.19 for $B_o$ (IPCC 2006).

$$CH_{4manure} = CH_{4manure}\_rate * \#sheep * \#days \tag{6.15}$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}$ | Manure $CH_4$ emission (kg $CH_4$) |
| *#sheep* | Number of sheep |
| *#days* | Number of days in period |

## 6.3 Manure $N_2O$

Enteric $N_2O$ calculations should be completed for each sheep class.

### 6.3.1 Nitrogen excretion

$$PI = \frac{GE}{18.45} * protein\_content \tag{6.16}$$

IPCC 2006

| | |
|---|---|
| *PI* | Protein intake (kg head$^{-1}$ day$^{-1}$) |
| *GE* | Gross energy intake (MJ head$^{-1}$ day$^{-1}$) |
| *protein_content* | Protein content (kg kg$^{-1}$) (Table A4-27, by diet) |

$$PR = 0.10$$

(6.17)
IPCC 2006

| | |
|---|---|
| *PR* | Protein retained (kg (kg protein intake)$^{-1}$) |

$$N_{excretion}\_rate = \frac{PI * (1 - PR)}{6.25}$$

(6.18)

Derived from IPCC 2006

| | |
|---|---|
| $N_{excretion}\_rate$ | N excretion rate (kg head$^{-1}$ day$^{-1}$) |
| 6.25 | Conversion from dietary protein to dietary N |

## 6.3.2 $N_2O$ emission

### 6.3.2.1 *Direct emission*

$$N_2O\text{-}N_{direct}\_rate = N_{excretion}\_rate * EF_{direct}$$

(6.19)
IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{direct}\_rate$ | Manure direct N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $EF_{direct}$ | Emission factor [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-28, by handling system) |

$$N_2O\text{-}N_{directmanure} = N_2O\text{-}N_{direct}\_rate * \#sheep * \#days$$

(6.20)
IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N) |
| *#sheep* | Number of sheep |
| *#days* | Number of days in period |

### 6.3.2.2 *Indirect emissions – volatilization and leaching/runoff*

$$N_2O\text{-}N_{volatilization}\_rate = N_{excretion}\_rate * Frac_{volatilization} * EF_{volatilization}$$

(6.21)
IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}\_rate$ | Manure volatilization N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Frac_{volatilization}$ | Volatilization fraction (Table A4-28, by handling system) |
| $EF_{volatilization}$ | Emission factor for volatilization [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-28, by handling system) |

$$N_2O\text{-}N_{volatilization} = N_2O\text{-}N_{volatilization}\_rate * \#sheep * \#days$$

(6.22)
IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{leaching}\_rate = N_{excretion}\_rate * Frac_{leach} * EF_{leaching} \tag{6.23}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}\_rate$ | Manure leaching N emission rate (kg head$^{-1}$ day$^{-1}$) |
| $Frac_{leach}$ | Leaching fraction (Table A4-28, by handling system) |
| $EF_{leaching}$ | Emission factor for leaching [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-28, by handling system) |

$$N_2O\text{-}N_{leaching} = N_2O\text{-}N_{leaching}\_rate * \#sheep * \#days \tag{6.24}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{indirectmanure} = N_2O\text{-}N_{volatilization} + N_2O\text{-}N_{leaching} \tag{6.25}$$

| | |
|---|---|
| $N_2O\text{-}N_{indirectmanure}$ | Manure indirect N emission (kg $N_2O$-N) |

$$N_2O\text{-}N_{manure} = N_2O\text{-}N_{directmanure} + N_2O\text{-}N_{indirectmanure} \tag{6.26}$$

| | |
|---|---|
| $N_2O\text{-}N_{manure}$ | Manure N emission (kg $N_2O$-N) |

### *6.3.2.3 N available for land application*

**For sheep manure from handling systems (do not use if manure is deposited on pasture).**

$$N_{landmanure} = (N_{excretion}\_rate * \#sheep * \#days) * [1 - (Frac_{volatilization} + Frac_{leach})] \tag{6.27}$$

IPCC 2006

| | |
|---|---|
| $N_{landmanure}$ | Manure available for land application (kg N) |

## *6.4 Total emissions*

Emissions should be summed for all sheep classes and changes in management.

$$Total\_CH_{4enteric} = \sum_{allscenariosheep} CH_{4enteric} \tag{6.28}$$

| | |
|---|---|
| $Total\_CH_{4enteric}$ | Total enteric $CH_4$ emission from sheep (kg $CH_4$ year$^{-1}$) |
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$) |

$$Total\_CH_{4manure} = \sum_{allscenariosheep} CH_{4manure} \tag{6.29}$$

| | |
|---|---|
| $Total\_CH_{4manure}$ | Total manure $CH_4$ emission from sheep (kg $CH_4$ year$^{-1}$) |
| $CH_{4manure}$ | Manure $CH_4$ emission (kg $CH_4$) |

$$Total\_N_2O\text{-}N_{directmanure} = \sum_{allscenariosheep} N_2O\text{-}N_{directmanure} \tag{6.30}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from sheep (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{volatilization} = \sum_{allscenariosheep} N_2O\text{-}N_{volatilization} \tag{6.31}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{volatilization}$ | Total manure volatilization N emission from sheep (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{leaching} = \sum_{allscenariosheep} N_2O\text{-}N_{leaching} \tag{6.32}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{leaching}$ | Total manure leaching N emission from sheep (kg $N_2O$-N year$^{-1}$) |
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N) |

$$Total\_N_2O\text{-}N_{indirectmanure} = Total\_N_2O\text{-}N_{volatilization} + Total\_N_2O\text{-}N_{leaching} \tag{6.33}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from sheep (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O\text{-}N_{manure} = Total\_N_2O\text{-}N_{direct} + Total\_N_2O\text{-}N_{indirect} \tag{6.34}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{manure}$ | Total manure N emission from sheep (kg $N_2O$-N year$^{-1}$) |

$$Scenario\_N_{landmanure} = \sum_{allscenariosheep} N_{landmanure} \tag{6.35}$$

| | |
|---|---|
| $Scenario\_N_{landmanure}$ | Manure available for land application (kg N) |
| $N_{landmanure}$ | Manure available for land application (kg N) |

$Scenario\_N_{landmanure}$ is inserted into the Soil $N_2O$ equations (Equation (1.12)) and Energy $CO_2$ equations (Equation (10.24)).

## 6.5 Conversion from $N_2O$-N to $N_2O$

$$Total\_N_2O_{directmanure} = Total\_N_2O\text{-}N_{directmanure} * \frac{44}{28} \tag{6.36}$$

| | |
|---|---|
| $Total\_N_2O_{directmanure}$ | Total manure direct $N_2O$ emission from sheep (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from sheep (kg $N_2O$-N year$^{-1}$) |
| 44/28 | Conversion from $N_2O$-N to $N_2O$ |

$$Total\_N_2O_{indirectmanure} = Total\_N_2O\text{-}N_{indirectmanure} * \frac{44}{28} \tag{6.37}$$

| | |
|---|---|
| $Total\_N_2O_{indirectmanure}$ | Total manure indirect $N_2O$ emission from sheep (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from sheep (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O_{manure} = Total\_N_2O\text{-}N_{manure} * \frac{44}{28} \quad (6.38)$$

| | |
|---|---|
| $Total\_N_2O_{manure}$ | Total manure $N_2O$ emission from sheep (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{manure}$ | Total manure N emission from sheep (kg $N_2O$-N year$^{-1}$) |

**Table A4-25. Sheep coefficients.**

| Sheep class | $C_f$ (MJ d$^{-1}$ kg$^{-1}$) | *a* (MJ kg$^{-1}$) | *b* (MJ kg$^{-2}$) | *initial_wt* (kg) | *final_wt* (kg) | *wool_production* (kg year$^{-1}$) | $Y_m$ |
|---|---|---|---|---|---|---|---|
| Ewe | 0.217 | 2.1 | 0.45 | 70 | 70 | 4 | 0.065 |
| Ram | 0.250 | 2.5 | 0.35 | 125 | 125 | 4 | 0.065 |
| Weaned lamb | 0.236 | 3.25 | 0.385 | 30 | 50 | 0 | 0.045 |
| Source: | IPCC 2006 | IPCC 2006 | IPCC 2006 | Helgason *et al.* 2005 | Helgason *et al.* 2005 | Helgason *et al.* 2005 | IPCC 2006 |

**Table A4-26. Feeding activity coefficients for sheep.**

| Activity | $C_a$ (MJ d$^{-1}$kg$^{-1}$) |
|---|---|
| Confined | 0.0067 |
| Flat pasture | 0.0107 |
| Hilly pasture or open range | 0.0240 |

IPCC 2006.

**Table A4-27. Diet coefficients for sheep.**

| Diet | *DE* (%) | *Protein_content* (kg kg-1) |
|---|---|---|
| Good quality forage | 65 | 0.18 |
| Average quality forage | 55 | 0.12 |
| Poor quality forage | 45 | 0.06 |

These values were obtained from expert opinion (Darryl Gibb, Karen Beauchemin, Sean McGinn, AAFC).

**Table A4-28. Methane conversion factors and $N_2O$ emission factors for sheep.**

| Handling system | *MCF* | $EF_{direct}$ [kg $N_2O$-N (kg N)$^{-1}$] | $Frac_{volatilization}$ | $EF_{volatilization}$ [kg $N_2O$-N (kg N)$^{-1}$] | $Frac_{leach}$ | $EF_{leach}$ [kg $N_2O$-N (kg N)$^{-1}$] |
|---|---|---|---|---|---|---|
| Pasture/range/ paddock - sheep | 0.010 | 0.01 | 0.20 | 0.01 | calculated* | 0.0075 |
| Solid storage-sheep | 0.020 | 0.005 | 0.12 | 0.01 | 0 | 0.0075 |
| Compost - intensive windrow - sheep | 0.005 | 0.1 | 0.12 | 0.01 | 0 | 0.0075 |
| Compost - passive windrow - sheep | 0.005 | 0.01 | 0.12 | 0.01 | 0 | 0.0075 |
| Deep bedding > 1 month, no mixing-sheep | 0.170 | 0.01 | 0.25 | 0.01 | 0 | 0.0075 |

IPCC 2006.

*Pasture manure value calculated in soil $N_2O$ emissions, equation (1.22).

# 7 Poultry $CH_4$ and $N_2O$ emissions

## 7.1 *Enteric $CH_4$*

Enteric $CH_4$ calculations should be completed for each poultry type.

$$CH_{4enteric} = CH_{4enteric}\_rate * barn\_capacity \tag{7.1}$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}\_rate$ | Enteric $CH_4$ emission rate (kg head$^{-1}$ year$^{-1}$) (Table A4-29, by poultry type) |
| $barn\_capacity$ | Capacity of barn |
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$ year$^{-1}$) |

$$Total\_CH_{4enteric} = \sum_{allpoultry} CH_{4enteric} \tag{7.2}$$

| | |
|---|---|
| $Total\_CH_{4enteric}$ | Total enteric $CH_4$ emission from poultry (kg $CH_4$ year$^{-1}$) |

## 7.2 *Manure $CH_4$*

Manure $CH_4$ calculations should be completed for each poultry type.

$$CH_{4manure} = CH_{4manure}\_rate * barn\_capacity \tag{7.3}$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}\_rate$ | Manure $CH_4$ emission rate (kg head$^{-1}$ year$^{-1}$) (Table A4-29, by poultry type) |
| $barn\_capacity$ | Capacity of barn |
| $CH_{4manture}$ | Manure $CH_4$ emission (kg $CH_4$ year$^{-1}$) |

$$Total\_CH_{4manure} = \sum_{allpoultry} CH_{4manure} \tag{7.4}$$

| | |
|---|---|
| $Total\_CH_{4manture}$ | Total manure $CH_4$ emission from poultry (kg $CH_4$ year$^{-1}$) |

## 7.3 *Manure $N_2O$*

Manure $N_2O$ calculations should be completed for each poultry type.

### 7.3.1 Nitrogen excretion

$$N_{manure} = N_{excretion}\_rate * barn\_capacity \tag{7.5}$$

IPCC 2006

| | |
|---|---|
| $N_{excretion}\_rate$ | N excretion rate (kg head$^{-1}$ year$^{-1}$) (Table A4-29, by poultry type) |
| $barn\_capacity$ | Capacity of barn |
| $N_{manture}$ | Manure N (kg N year$^{-1}$) |

## 7.3.2 $N_2O$ emission

### *7.3.2.1 Direct emission*

$$N_2O\text{-}N_{directmanure} = N_{manure} * EF_{direct} \tag{7.6}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N year$^{-1}$) |
| $N_{manture}$ | Manure N (kg N year$^{-1}$) |
| $EF_{direct}$ | Emission factor [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-29, by poultry type) |

$$Total\_N_2O\text{-}N_{directmanure} = \sum_{allpoultry} N_2O\text{-}N_{directmanure} \tag{7.7}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from poultry (kg $N_2O$-N year$^{-1}$) |

### *7.3.2.2 Indirect emissions – volatilization and leaching/runoff*

$$N_2O\text{-}N_{volatilization} = N_{manure} * Frac_{volatilization} * EF_{volatilization} \tag{7.8}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N year$^{-1}$) |
| $Frac_{volatilization}$ | Volatilization fraction |
| $EF_{volatilization}$ | Emission factor for volatilization [kg $N_2O$-N (kg N)$^{-1}$] |

Holos uses 0.4 for $Frac_{volatilization}$ and 0.01 for $EF_{volatilization}$ (IPCC 2006).

$$Total\_N_2O\text{-}N_{volatilization} = \sum_{allpoultry} N_2O\text{-}N_{volatilization} \tag{7.9}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{volatilization}$ | Total manure volatilization N emission from poultry (kg $N_2O$-N year$^{-1}$) |

$$N_2O\text{-}N_{leaching} = N_{manure} * Frac_{leach} * EF_{leaching} \tag{7.10}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N year$^{-1}$) |
| $Frac_{leach}$ | Leaching fraction |
| $EF_{leaching}$ | Emission factor for leaching [kg $N_2O$-N (kg N)$^{-1}$] |

Holos uses 0 for $Frac_{leach}$ and 0.0075 for $EF_{leaching}$ (IPCC 2006).

$$Total\_N_2O\text{-}N_{leaching} = \sum_{allpoultry} N_2O\text{-}N_{leaching} \tag{7.11}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{leaching}$ | Total manure leaching N emission from poultry (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O\text{-}N_{indirectmanure} = Total\_N_2O\text{-}N_{volatilization} + Total\_N_2O\text{-}N_{leaching} \tag{7.12}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from poultry (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O\text{-}N_{manure} = Total\_N_2O\text{-}N_{directmanure} + Total\_N_2O\text{-}N_{indirectmanure} \quad (7.13)$$

| | |
|---|---|
| *Total_N*$_2$*O-N*$_{manure}$ | Total manure N emission from poultry (kg $N_2O$-N year$^{-1}$) |

### 7.3.2.3 N available for land application

**For poultry manure from handling systems.**

$$N_{landmanure} = N_{manure} * [1 - (Frac_{volatilization} + Frac_{leach})] \quad (7.14)$$

IPCC 2006

| | |
|---|---|
| *N*$_{landmanure}$ | Manure available for land application (kg N) |

$$Scenario\_N_{landmanure} = \sum_{allpoultry} N_{landmanure} \quad (7.15)$$

| | |
|---|---|
| *Scenario_N*$_{landmanure}$ | Scenario manure available for land application (kg N) |

*Scenario_N*$_{landmanure}$ is inserted into the Soil $N_2O$ equations (Equation (1.12)) and Energy $CO_2$ equations (Equation (10.21) or (10.24)).

## 7.4 Conversion from $N_2O$-N to $N_2O$

$$Total\_N_2O_{directmanure} = Total\_N_2O\text{-}N_{directmanure} * \frac{44}{28} \quad (7.16)$$

| | |
|---|---|
| *Total_N*$_2$*O*$_{directmanure}$ | Total manure direct $N_2O$ emission from poultry (kg $N_2O$ year$^{-1}$) |
| *Total_N*$_2$*O-N*$_{directmanure}$ | Total manure direct N emission from poultry (kg $N_2O$-N year$^{-1}$) |
| 44/28 | Conversion from $N_2O$-N to $N_2O$ |

$$Total\_N_2O_{indirectmanure} = Total\_N_2O\text{-}N_{indirectmanure} * \frac{44}{28} \quad (7.17)$$

| | |
|---|---|
| *Total_N*$_2$*O*$_{indirectmanure}$ | Total manure indirect $N_2O$ emission from poultry (kg $N_2O$ year$^{-1}$) |
| *Total_N*$_2$*O-N*$_{indirectmanure}$ | Total manure indirect N emission from poultry (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O_{manure} = Total\_N_2O\text{-}N_{manure} * \frac{44}{28} \quad (7.18)$$

| | |
|---|---|
| *Total_N*$_2$*O*$_{manure}$ | Total manure $N_2O$ emission from poultry (kg $N_2O$ year$^{-1}$) |
| *Total_N*$_2$*O-N*$_{manure}$ | Total manure N emission from poultry (kg $N_2O$-N year$^{-1}$) |

**Table A4-29. $CH_4$ and $N_2O$ emission rates for poultry.**

| Poultry type | $CH_{4enteric}\_rate$ (kg head$^{-1}$ year$^{-1}$) | $CH_{4manure}\_rate$ (kg head$^{-1}$ year$^{-1}$) | $Nexcretion\_rate$ (kg head$^{-1}$ year$^{-1}$) | $EF_{direct}$ [kg $N_2O$-N (kg N)$^{-1}$] |
|---|---|---|---|---|
| Layers (dry manure) | 0 | 0.03 | 0.55 | 0.001 |
| Layers (wet manure) | 0 | 1.20 | 0.55 | 0.001 |
| Broilers | 0 | 0.02 | 0.36 | 0.001 |
| Turkeys | 0 | 0.09 | 1.84 | 0.001 |
| Ducks & geese* | 0 | 0.02 | 0.82 | 0.001 |

IPCC 2006.

*Geese were added to this category.

# 8 Other animals $CH_4$ and $N_2O$ emissions

## 8.1 *Enteric $CH_4$*

Enteric $CH_4$ calculations should be completed for each animal type.

$$CH_{4enteric} = CH_{4enteric}\_rate * \#animals \tag{8.1}$$

IPCC 2006

| | |
|---|---|
| $CH_{4enteric}\_rate$ | Enteric $CH_4$ emission rate (kg head$^{-1}$ year$^{-1}$) (Table A4-30, by animal type) |
| $\#animals$ | Number of animals |
| $CH_{4enteric}$ | Enteric $CH_4$ emission (kg $CH_4$ year$^{-1}$) |

$$Total\_CH_{4enteric} = \sum_{allanimals} CH_{4enteric} \tag{8.2}$$

| | |
|---|---|
| $Total\_CH_{4enteric}$ | Total enteric $CH_4$ emission from other animals (kg $CH_4$ year$^{-1}$) |

## 8.2 *Manure $CH_4$*

Manure $CH_4$ calculations should be completed for each animal type.

$$CH_{4manure} = CH_{4manure}\_rate * \#animals \tag{8.3}$$

IPCC 2006

| | |
|---|---|
| $CH_{4manure}\_rate$ | Manure $CH_4$ emission rate (kg head$^{-1}$ year$^{-1}$) (Table A4-30, by animal type) |
| $\#animals$ | Number of animals |
| $CH_{4manture}$ | Manure $CH_4$ emission (kg $CH_4$ year$^{-1}$) |

$$Total\_CH_{4manure} = \sum_{allanimals} CH_{4manure} \tag{8.4}$$

| | |
|---|---|
| $Total\_CH_{4manture}$ | Total manure $CH_4$ emission from other animals (kg $CH_4$ year$^{-1}$) |

## 8.3 *Manure $N_2O$*

Manure $N_2O$ calculations should be completed for each animal type.

### 8.3.1 Nitrogen excretion

$$N_{manure} = N_{excretion}\_rate * \#animals \tag{8.5}$$

IPCC 2006

| | |
|---|---|
| $N_{excretion}\_rate$ | N excretion rate (kg head$^{-1}$ year$^{-1}$) (Table A4-30, by animal type) |
| $\#animals$ | Number of animals |
| $N_{manture}$ | Manure N (kg N year$^{-1}$) |

## 8.3.2 $N_2O$ emission

### *8.3.2.1 Direct emission*

$$N_2O\text{-}N_{directmanure} = N_{manure} * EF_{direct} \tag{8.6}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{directmanure}$ | Manure direct N emission (kg $N_2O$-N year$^{-1}$) |
| $N_{manture}$ | Manure N (kg N year$^{-1}$) |
| $EF_{direct}$ | Emission factor [kg $N_2O$-N (kg N)$^{-1}$] (Table A4-30, by animal type) |

$$Total\_N_2O\text{-}N_{directmanure} = \sum_{allanimals} N_2O\text{-}N_{directmanure} \tag{8.7}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from other animals (kg $N_2O$-N year$^{-1}$) |

### *8.3.2.2 Indirect emissions – volatilization and leaching/runoff*

$$N_2O\text{-}N_{volatilization} = N_{manure} * Frac_{volatilization} * EF_{volatilization} \tag{8.8}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{volatilization}$ | Manure volatilization N emission (kg $N_2O$-N year$^{-1}$) |
| $Frac_{volatilization}$ | Volatilization fraction |
| $EF_{volatilization}$ | Emission factor for volatilization [kg $N_2O$-N (kg N)$^{-1}$] |

Holos uses 0.2 for $Frac_{volatilization}$ and 0.01 for $EF_{volatilization}$ (IPCC 2006).

$$Total\_N_2O\text{-}N_{volatilization} = \sum_{allanimals} N_2O\text{-}N_{volatilization} \tag{8.9}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{volatilization}$ | Total manure volatilization N emission from other animals (kg $N_2O$-N year$^{-1}$) |

$$N_2O\text{-}N_{leaching} = N_{manure} * Frac_{leach} * EF_{leaching} \tag{8.10}$$

IPCC 2006

| | |
|---|---|
| $N_2O\text{-}N_{leaching}$ | Manure leaching N emission (kg $N_2O$-N year$^{-1}$) |
| $Frac_{leach}$ | Leaching fraction - calculated in soil $N_2O$ emissions, equation (1.22) |
| $EF_{leaching}$ | Emission factor for leaching [kg $N_2O$-N (kg N)$^{-1}$] |

Holos uses 0.0075 for $EF_{leaching}$ (IPCC 2006). All other animal manure is deposited on pasture. Therefore, $Frac_{leach}$ is calculated.

$$Total\_N_2O\text{-}N_{leaching} = \sum_{allanimals} N_2O\text{-}N_{leaching} \tag{8.11}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{leaching}$ | Total manure leaching N emission from other animals (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O\text{-}N_{indirectmanure} = Total\_N_2O\text{-}N_{volatilization} + Total\_N_2O\text{-}N_{leaching} \tag{8.12}$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from other animals (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O\text{-}N_{manure} = Total\_N_2O\text{-}N_{directmanure} + Total\_N_2O\text{-}N_{indirectmanure} \quad (8.13)$$

| | |
|---|---|
| $Total\_N_2O\text{-}N_{manure}$ | Total manure N emission from other animals (kg $N_2O$-N year$^{-1}$) |

#### 8.3.2.3 N available for land application

$$Scenario\_N_{landmanure} = 0 \quad (8.14)$$

| | |
|---|---|
| $Scenario\_N_{landmanure}$ | Scenario manure available for land application (kg N) |

***Scenario_N$_{landmanure}$ = 0 because manure location is pasture!***

## 8.4 Conversion from $N_2O$-N to $N_2O$

$$Total\_N_2O_{directmanure} = Total\_N_2O\text{-}N_{directmanure} * \frac{44}{28} \quad (8.15)$$

| | |
|---|---|
| $Total\_N_2O_{directmanure}$ | Total manure direct $N_2O$ emission from other animals (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{directmanure}$ | Total manure direct N emission from other animals (kg $N_2O$-N year$^{-1}$) |
| 44/28 | Conversion from $N_2O$-N to $N_2O$ |

$$Total\_N_2O_{indirectmanure} = Total\_N_2O\text{-}N_{indirectmanure} * \frac{44}{28} \quad (8.16)$$

| | |
|---|---|
| $Total\_N_2O_{indirectmanure}$ | Total manure indirect $N_2O$ emission from other animals (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{indirectmanure}$ | Total manure indirect N emission from other animals (kg $N_2O$-N year$^{-1}$) |

$$Total\_N_2O_{manure} = Total\_N_2O\text{-}N_{manure} * \frac{44}{28} \quad (8.17)$$

| | |
|---|---|
| $Total\_N_2O_{manure}$ | Total manure $N_2O$ emission from other animals (kg $N_2O$ year$^{-1}$) |
| $Total\_N_2O\text{-}N_{manure}$ | Total manure N emission from other animals (kg $N_2O$-N year$^{-1}$) |

**Table A4-30. $CH_4$ and $N_2O$ emission rates for other animals.**

| Animal type | $CH_{4enteric}\_rate$ (kg head$^{-1}$ year$^{-1}$) | $CH_{4manure}\_rate$ (kg head$^{-1}$ year$^{-1}$) | *Nexcretion_rate* (kg head$^{-1}$ year$^{-1}$) | $EF_{direct}$ [kg $N_2O$-N (kg N)$^{-1}$] |
|---|---:|---:|---:|---:|
| Goats | 5 | 0.13 | 6.6 | 0.01 |
| Llamas and alpacas | 8 | 0.19§ | 10.0§ | 0.01 |
| Deer and elk* | 20 | 0.22 | 18.4§ | 0.01 |
| Horses | 18 | 1.56 | 60.2 | 0.01 |
| Mules | 10 | 0.76 | 26.8 | 0.01 |
| BisonH | 53 | 1 | 69.2 | 0.02 |

IPCC 2006.

*Elk were added to this category.

HValues for “other cattle” were used (with an average weight of 612 kg).

§These values were estimated as suggested by IPCC 2006, Section 10.2.

# 9 Shelterbelt and lineal tree planting carbon storage

## 9.1 *Storage of carbon in tree biomass – conifers and deciduous trees*

**For trees over 2 years of age (otherwise $C_{tree} = 0$).**

$$C_{tree} = \left[a*(age-2)\right]^{b} \tag{9.1}$$

Kort and Turnock 1998

| | |
|---|---|
| $C_{tree}$ | Annual C accumulation per tree (kg C year$^{-1}$) |
| *a* | Coefficient a (Table A4-31, by soil type, tree species) |
| *b* | Coefficient b (Table A4-31, by soil type, tree species) |
| *age* | Age of shelterbelt (years) |

$$C_{planting} = C_{tree} * \frac{length}{planting\_space} * \#rows \tag{9.2}$$

Kort and Turnock 1998

| | |
|---|---|
| $C_{planting}$ | Annual C accumulation per linear planting (kg C year$^{-1}$) |
| *length* | Length of row (m) |
| *planting_space* | Planting space (Table A4-31, by tree species) |
| *#rows* | Number of rows |

## 9.2 *Storage of carbon in tree biomass – caragana*

**For caragana over 2 years of age (otherwise $CO_2$-$C_{tree} = 0$).**

$$C_{tree} = \left[a*(age)\right]^{b} \tag{9.3}$$

Kort and Turnock 1998

| | |
|---|---|
| $C_{tree}$ | Annual C accumulation per tree (kg C year$^{-1}$) |
| *a* | Coefficient a (Table A4-31, by soil type, tree species) |
| *b* | Coefficient b (Table A4-31, by soil type, tree species) |
| *age* | Age of shelterbelt (years) |

$$C_{planting} = C_{tree} * \frac{length}{10} * \#rows \tag{9.4}$$

Kort and Turnock 1998

| | |
|---|---|
| $C_{planting}$ | Annual C accumulation per lineal planting (kg C year$^{-1}$) |
| *length* | Length of row (m) |
| *#rows* | Number of rows |

## 9.3 Total carbon in shelterbelt/ lineal tree plantings

$$Total\_C_{shelterbelt} = \sum_{allplantings} C_{planting} \qquad (9.5)$$

| | |
|---|---|
| $Total\_C_{shelterbelt}$ | Total annual C accumulation in lineal tree plantings/shelterbelt (kg C year$^{-1}$) |
| $C_{planting}$ | Annual C accumulation per lineal planting (kg C year$^{-1}$) |

## 9.4 Convert C to $CO_2$ and emission

$$Total\_CO_{2shelterbelt} = Total\_C_{shelterbelt} * \frac{44}{12} * -1 \qquad (9.6)$$

| | |
|---|---|
| $Total\_CO_{2shelterbelt}$ | Total $CO_2$ emissions from tree plantings/shelterbelt (kg $CO_2$ year$^{-1}$) |
| $Total\_C_{shelterbelt}$ | Total annual C accumulation in shelterbelt (kg C year$^{-1}$) |
| 44/12 | Conversion from C to $CO_2$ |

Multiplying by -1 converts the result to an emission. (Positive value is an emission, negative value is sequestration.)

**Table A4-31. Coefficients for annual carbon accumulation for shelterbelt tree species.**

| Species | Brown chernozem soil | | Dark brown chernozem soil | | Black chernozem & Eastern Canada soilH | | *Planting_ space* (m) |
|---|---|---|---|---|---|---|---|
| | *a* | *b* | *a* | *b* | *a* | *b* | |
| Green ash | 0.5218 | 0.2932 | 0.7284 | 0.2932 | 1.1391 | 0.2932 | 2.5 |
| Manitoba maple | 0.0916 | 1.0568 | 0.0654 | 1.0568 | 0.1177 | 1.0568 | 2.5 |
| Poplar | 0.2089 | 0.9651 | 0.3232 | 0.9651 | 0.7679 | 0.9651 | 2.5 |
| Siberian elm | 1.6595 | 0.2551 | 2.0672 | 0.2551 | 2.6801 | 0.2551 | 2.5 |
| Colorado spruce | 0.8193 | 0.4560 | 0.9950 | 0.4560 | 1.0394 | 0.4560 | 3.5 |
| White spruce | 0.1633 | 0.8970 | 0.1345 | 0.8970 | 0.2318 | 0.8960 | 3.5 |
| Scots pine | 0.2266 | 0.6716 | 0.2895 | 0.6716 | 0.3159 | 0.6716 | 3.5 |
| Caragana* | 0.4017 | 0.6446 | 0.4511 | 0.6446 | 0.5987 | 0.6446 | n/a |

Kort and Turnock 1998.

*Annual carbon accumulation expresses in kg 10m$^{-1}$ for a linear shelterbelt (i.e. all above ground biomass was sampled in a 10 m length).

HFor locations in Eastern Canada, the coefficients for the Black Chernozem soil zone were used.

# 10 Energy $CO_2$ emissions

## *10.1 Cropping emissions*

These equations are used to calculate emissions from fuel use. Use equations (10.1) to (10.3) for cropped land, including annual crops and perennial forages, and equation (10.4) for fallow land.

### 10.1.1 $CO_2$ from fuel use

#### *10.1.1.1 Cropped land*

**For Western Canada only:**

$$Total\_CO_{2cropfuel} = E_{fuel} * area_{crop} * 75 \tag{10.1}$$

| | |
|---|---|
| $Total\_CO_{2cropfuel}$ | Total $CO_2$ emissions from cropping fuel use (kg $CO_2$ year$^{-1}$) |
| $E_{fuel}$ | Energy from fuel use (GJ ha$^{-1}$) (Table A4-32, by region, soil type, tillage, crop type (in Western Canada use "crops", in Eastern Canada use crop type based on Table A4-33)) |
| $area_{crop}$ | Area of crop (ha) (include annual crops and perennial forages) |
| 75 | Conversion of GJ of diesel to kg $CO_2$ (National Inventory Report 1990-2005, Bioenergy Feedstock Information Network) |

**For Eastern Canada only:**

$$CO_{2cropfuel} = E_{fuel} * area_{crop} * 75 \tag{10.2}$$

| | |
|---|---|
| $CO_{2cropfuel}$ | $CO_2$ emissions from cropping fuel use (kg $CO_2$ year$^{-1}$) |

$$Total\_CO_{2cropfuel} = \sum_{allcrops} CO_{2cropfuel} \tag{10.3}$$

#### *10.1.1.2 Fallow land*

**For Western Canada (fallow land) only:**

$$Total\_CO_{2\,fallowfuel} = E_{fuel} * area_{fallow} * 75 \tag{10.4}$$

| | |
|---|---|
| $Total\_CO_{2fallowfuel}$ | Total $CO_2$ emissions from fallowing fuel use (kg $CO_2$ year$^{-1}$) |
| $E_{fuel}$ | Energy from fuel use (GJ ha$^{-1}$) (Table A4-32, by region, soil type, tillage, "fallow" as crop type) |
| $area_{fallow}$ | Area of fallow (ha) |

### 10.1.2 CO$_2$ from herbicide production

These equations are used to calculate emissions from herbicide production. Use equations (10.5) to (10.7) for cropped land, including annual crops and perennial forages, and equation (10.8) for fallow land.

#### *10.1.2.1 Cropped land*

**For Western Canada only:**

$$Total\_CO_{2cropherbicide} = E_{herbicide} * area_{crop} * 5.8 \tag{10.5}$$

| | |
|---|---|
| $Total\_CO_{2cropherbicide}$ | Total CO$_2$ emissions from cropping herbicide production (kg CO$_2$ year$^{-1}$) |
| $E_{herbicide}$ | Energy for herbicide production (GJ ha$^{-1}$) (Table A4-32, by region, soil type, tillage, crop type (in Western Canada use “crops”, in Eastern Canada use crop type based on Table A4-33)) |
| 5.8 | Conversion of GJ for herbicide production to kg CO$_2$ (Dyer and Desjardins 2007) |

**For Eastern Canada only:**

$$CO_{2cropherbicide} = E_{herbicide} * area_{crop} * 5.8 \tag{10.6}$$

| | |
|---|---|
| $CO_{2cropherbicide}$ | CO$_2$ emissions from cropping herbicide production (kg CO$_2$ year$^{-1}$) |

$$Total\_CO_{2cropherbicide} = \sum_{allcrops} CO_{2cropherbicide} \tag{10.7}$$

#### *10.1.2.2 Fallow land*

**For Western Canada (fallow land) only:**

$$Total\_CO_{2fallowherbicide} = E_{herbicide} * area_{fallow} * 5.8 \tag{10.8}$$

| | |
|---|---|
| $Total\_CO_{2fallowherbicide}$ | Total CO$_2$ emissions from fallow herbicide production (kg CO$_2$ year$^{-1}$) |
| $E_{herbicide}$ | Energy for herbicide production (GJ ha$^{-1}$) (Table A4-32, by region, soil type, tillage, “fallow” as crop type) |

### 10.1.3 CO$_2$ from nitrogen and phosphorus fertilizer production

These equations are used to calculate emissions from nitrogen and phosphorous fertilizer production. Use these equations for each fertilized crop, including annual crops, perennial forage and improved pasture.

#### *10.1.3.1 Nitrogen fertilizer production*

$$CO_{2Nfertilizer} = N\_fert\_applied * area * 3.59 \tag{10.9}$$

| | |
|---|---|
| $CO_{2Nfertilizer}$ | CO$_2$ emissions from N fertilizer production (kg CO$_2$ year$^{-1}$) |
| $N\_fert\_applied$ | N fertilizer applied (kg ha$^{-1}$) |
| $area$ | Area of crop fertilized (ha) (include annual crops and perennial forages and improved pasture if fertilized) |
| 3.59 | Conversion of N fertilizer production kg to kg CO$_2$ (Nagy 2000) |

$$Total\_CO_{2Nfertilizer} = \sum_{allcrops} CO_{2Nfertilizer} \tag{10.10}$$

| | |
|---|---|
| $Total\_CO_{2Nfertilizer}$ | Total $CO_2$ emissions from N fertilizer production (kg $CO_2$ year$^{-1}$) |

#### *10.1.3.2 Phosphorus fertilizer production*

$$CO_{2Pfertilizer} = P_2O_{5rate} * area * 0.5699 \tag{10.11}$$

| | |
|---|---|
| $CO_{2Pfertilizer}$ | $CO_2$ emissions from $P_2O_5$ fertilizer production (kg $CO_2$ year$^{-1}$) |
| $P_2O_{5rate}$ | $P_2O_5$ fertilizer rate (kg ha$^{-1}$) |
| 0.5699 | Conversion of $P_2O_5$ fertilizer production kg to kg $CO_2$ (Nagy 2000) |

$$Total\_CO_{2Pfertilizer} = \sum_{allcrops} CO_{2Pfertilizer} \tag{10.12}$$

| | |
|---|---|
| $Total\_CO_{2Pfertilizer}$ | Total $CO_2$ emissions from $P_2O_5$ fertilizer production (kg $CO_2$ year$^{-1}$) |

### 10.1.4 $CO_2$ from irrigation

This equation is used to calculate emissions from irrigation use.

$$Total\_CO_{2irrigation} = area * 370 \tag{10.13}$$

| | |
|---|---|
| $Total\_CO_{2irrigation}$ | Total $CO_2$ emissions from irrigation (kg $CO_2$ year$^{-1}$) |
| *area* | area of crop irrigated (ha) (include annual crops and perennial forages and improved pasture if irrigated) |
| 370 | Conversion of area irrigated to kg $CO_2$ |

## *10.2 Livestock emissions*

### 10.2.1 $CO_2$ from dairy

This equation is used to calculate emissions for dairy based on the number of dairy cows.

$$Total\_CO_{2dairy} = \#cows * 968 * 0.220 \tag{10.14}$$

| | |
|---|---|
| $Total\_CO_{2dairy}$ | Total $CO_2$ emissions from dairy operations (kg $CO_2$ year$^{-1}$) |
| *#cows* | Number of dairy cows |
| 968 | kWh per dairy cow per year for electricity (Vergé *et al.* 2007) |
| 0.220 | Conversion of kWh of electricity to kg $CO_2$ emissions (National Inventory Report 1990-2005) |

### 10.2.2 $CO_2$ from swine

This equation is used to calculate emissions for swine based on the number of sows and boars or starters or finishers, depending on scenario.

**Number of pigs for Scenario 1 - Farrow to finish and Scenario 2 - Farrow to wean:**

$$\#pigs = \#sows + \#boars \tag{10.15}$$

**Number of pigs for Scenario 3 - Finishing operation:**

$$\#pigs = \#finishers \tag{10.16}$$

**Number of pigs for Scenario 4 - Nursery operation:**

$$\#pigs = \#starters \tag{10.17}$$

| | |
|---|---|
| $\#pigs$ | Number of pigs |
| $\#sows$ | Number of sows |
| $\#boars$ | Number of boars |
| $\#finishers$ | Number of finishers |
| $\#starters$ | Number of starters |

$$Total\_CO_{2swine} = \#pigs * 1.06 * 0.220 \tag{10.18}$$

| | |
|---|---|
| $Total\_CO_{2swine}$ | Total $CO_2$ emissions from swine operations (kg $CO_2$ year$^{-1}$) |
| 1.06 | kWh per pig per year for electricity (Dyer and Desjardins 2006) |
| 0.220 | Conversion of kWh of electricity to kg $CO_2$ emissions (National Inventory Report 1990-2005) |

### 10.2.3 $CO_2$ from poultry

This equation is used to calculate emissions for poultry based on the barn capacity.

$$Total\_CO_{2poultry} = barn\_capacity * 2.88 * 0.220 \tag{10.19}$$

| | |
|---|---|
| $Total\_CO_{2poultry}$ | Total $CO_2$ emissions from poultry operations (kg $CO_2$ year$^{-1}$) |
| $barn\_capacity$ | Barn capacity |
| 2.88 | kWh per poultry placement per year for electricity (Dyer and Desjardins 2006) |
| 0.220 | Conversion of kWh of electricity to kg $CO_2$ emissions (National Inventory Report) |

### 10.2.4 CO$_2$ from housed beef

This equation is used to calculate emissions for housed beef cattle based on the number of cattle.

$$Total\_CO_{2housedbeef} = \#cattle * 65.7 * 0.220 \tag{10.20}$$

| | |
|---|---|
| $Total\_CO_{2housedbeef}$ | Total CO$_2$ emissions from housed beef operations (kg CO$_2$ year$^{-1}$) |
| $\#cattle$ | Number of housed cattle |
| 65.7 | kWh per cattle per year for electricity (Dyer and Desjardins 2006) |
| 0.220 | Conversion of kWh of electricity to kg CO$_2$ emissions (National Inventory Report 1990-2005) |

## 10.3 Manure spreading emissions

### 10.3.1 CO$_2$ from manure spreading

These equations are used to calculate emissions for fuel use in manure spreading.

#### *10.3.1.1 For liquid manure spreading*

$$Volume_{manure} = \frac{Scenario\_N_{landmanure}(liquid)}{N\_concentration} \tag{10.21}$$

| | |
|---|---|
| $Volume_{manure}$ | Volume of liquid manure (1000 litres) |
| $Scenario\_N_{landmanure}(liquid)$ | Total N from **liquid** land applied manure (from each scenario – dairy, swine and poultry) (kg N)<br>(from equations (4.56), (5.26) and/ or(7.15)) |
| $N\_concentration$ | N concentration of liquid manure based on animal type (kg N 1000 litre$^{-1}$)<br>(Table A4-34, by animal type) |

$$CO_{2liquidmanure} = Volume_{manure} * 0.0248 * 75 \tag{10.22}$$

| | |
|---|---|
| $CO_{2liquidmanure}$ | CO$_2$ emissions from liquid manure spreading (kg CO$_2$ year$^{-1}$) |
| 0.0248 | GJ of energy per 1000 litres of liquid manure applied (M. Wiens, La Broquerie project, University of Manitoba, personal communication) |
| 75 | Conversion of GJ of diesel to kg CO$_2$ (National Inventory Report 1990-2005, Bioenergy Feedstock Information Network) |

$$Total\_CO_{2liquidmanure} = \sum_{all\ animals} CO_{2liquidmanure} \tag{10.23}$$

| | |
|---|---|
| $Total\_CO_{2liquidmanure}$ | Total CO$_2$ emissions from liquid manure spreading (kg CO$_2$ year$^{-1}$) |

#### 10.3.1.2 For solid manure spreading

$$Volume_{manure} = \frac{Scenario\_N_{landmanure}(solid)}{N\_concentration} \tag{10.24}$$

| | |
|---|---|
| $Volume_{manure}$ | Volume of solid manure (litres) |
| $Scenario\_N_{landmanure}(solid)$ | Total N from **solid** land applied manure (from each scenario - beef, dairy, swine, sheep and poultry) (kg N)<br>(from equations (3.62), (4.56), (5.26), (6.35) and/ or (7.15)) |
| $N\_concentration$ | N concentration of solid manure based on animal type (kg litre$^{-1}$) (Table A4-35, by animal type) |

$$CO_{2solidmanure} = Volume_{manure} * 0.0248 * 75 \tag{10.25}$$

| | |
|---|---|
| $CO_{2solidmanure}$ | $CO_2$ emissions from solid manure spreading (kg $CO_2$ year$^{-1}$) |

$$Total\_CO_{2solidmanure} = \sum_{all\ animals} CO_{2solidmanure} \tag{10.26}$$

| | |
|---|---|
| $Total\_CO_{2solidmanure}$ | Total $CO_2$ emissions from solid manure spreading (kg $CO_2$ year$^{-1}$) |

## 10.4 Total emissions

$$\begin{aligned} & Total\_CO_{2energy} = \\ & Total\_CO_{2cropfuel} + Total\_CO_{2fallowfuel} + Total\_CO_{2cropherbicide} + Total\_CO_{2fallowherbicide} + Total\_CO_{2Nfertilizer} + \\ & Total\_CO_{2Pfertilizer} + Total\_CO_{2irrigation} + Total\_CO_{2dairy} + Total\_CO_{2swine} + Total\_CO_{2poultry} + \\ & Total\_CO_{2housedbeef} + Total\_CO_{2liquidmanure} + Total\_CO_{2solidmanure} \end{aligned} \tag{10.27}$$

| | |
|---|---|
| $Total\_CO_{2energy}$ | Total $CO_2$ emissions from energy use (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2cropfuel}$ | Total $CO_2$ emissions from cropping fuel use (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2fallowfuel}$ | Total $CO_2$ emissions from fallowing fuel use (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2cropherbicide}$ | Total $CO_2$ emissions from cropping herbicide production (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2fallowherbicide}$ | Total $CO_2$ emissions from fallow herbicide production (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2Nfertilizer}$ | Total $CO_2$ emissions from N fertilizer production (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2Pfertilizer}$ | Total $CO_2$ emissions from $P_2O_5$ fertilizer production (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2irrigation}$ | Total $CO_2$ emissions from irrigation (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2dairy}$ | Total $CO_2$ emissions from dairy operations (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2swine}$ | Total $CO_2$ emissions from swine operations (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2poultry}$ | Total $CO_2$ emissions from poultry operations (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2housedbeef}$ | Total $CO_2$ emissions from housed beef operations (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2liquidmanure}$ | Total $CO_2$ emissions from liquid manure spreading (kg $CO_2$ year$^{-1}$) |
| $Total\_CO_{2solidmanure}$ | Total $CO_2$ emissions from solid manure spreading (kg $CO_2$ year$^{-1}$) |

**Table A4-32. Energy requirement estimates for common cropping systems in different regions of Canada.**

| Region* | Soil type | Tillage system | Crop typeH | $E_{fuel}$ (GJ ha$^{-1}$) | $E_{herbicide}$ (GJ ha$^{-1}$) |
|---|---|---|---|---:|---:|
| W. Canada | Brown | Intensive | Crop | 2.02 | 0.16 |
| W. Canada | Brown | Intensive | Fallow | 1.62 | 0 |
| W. Canada | Brown | Minimum | Crop | 1.78 | 0.23 |
| W. Canada | Brown | Minimum | Fallow | 1.16 | 0.07 |
| W. Canada | Brown | No-till | Crop | 1.42 | 0.46 |
| W. Canada | Brown | No-till | Fallow | 0.34 | 0.78 |
| W. Canada | Dark brown | Intensive | Crop | 2.02 | 0.16 |
| W. Canada | Dark brown | Intensive | Fallow | 1.62 | 0 |
| W. Canada | Dark brown | Minimum | Crop | 1.78 | 0.23 |
| W. Canada | Dark brown | Minimum | Fallow | 1.16 | 0.07 |
| W. Canada | Dark brown | No-till | Crop | 1.42 | 0.46 |
| W. Canada | Dark brown | No-till | Fallow | 0.34 | 0.78 |
| W. Canada | Black | Intensive | Crop | 2.63 | 0.16 |
| W. Canada | Black | Intensive | Fallow | 2.35 | 0.06 |
| W. Canada | Black | Minimum | Crop | 2.39 | 0.23 |
| W. Canada | Black | Minimum | Fallow | 1.71 | 0.11 |
| W. Canada | Black | No-till | Crop | 1.43 | 0.46 |
| W. Canada | Black | No-till | Fallow | 0.93 | 0.6 |
| E. Canada | Eastern Canada | Intensive | Type 1 | 3.29 | 0.08 |
| E. Canada | Eastern Canada | Intensive | Type 2 | 3.11 | 0.08 |
| E. Canada | Eastern Canada | Intensive | Type 3 | 2.83 | 0.16 |
| E. Canada | Eastern Canada | Intensive | Type 4 | 0.81 | 0 |
| E. Canada | Eastern Canada | Minimum | Type 1 | 2.30 | 0.12 |
| E. Canada | Eastern Canada | Minimum | Type 2 | 2.13 | 0.12 |
| E. Canada | Eastern Canada | Minimum | Type 3 | 1.80 | 0.24 |
| E. Canada | Eastern Canada | Minimum | Type 4 | 0.81 | 0 |
| E. Canada | Eastern Canada | No-till | Type 1 | 1.90 | 0.12 |
| E. Canada | Eastern Canada | No-till | Type 2 | 1.72 | 0.12 |
| E. Canada | Eastern Canada | No-till | Type 3 | 1.34 | 0.24 |
| E. Canada | Eastern Canada | No-till | Type 4 | 0.81 | 0 |

W. Canada - Elwin Smith, personal communication.

E. Canada - Jim Dyer, Farm Fieldwork and Fossil Fuel Energy and Emissions (F4E2) model ($E_{fuel}$) or Dyer and Desjardins 2004 ($E_{herbicide}$)

* W. Canada includes BC, AB, SK, MB. E. Canada includes ON, QB, NB, NS, PE, NF.

H Use Table A4-33 to determine crop type in Eastern Canada.

**Table A4-33. Crop type table for Eastern Canada, used to determine $E_{fuel}$ and $E_{herbicide}$ value.**

| Crop | Crop type |
|---|---:|
| Barley | 3 |
| Buckwheat | 3 |
| Canary Seed | 3 |
| Canola | 3 |
| Chickpeas | 2 |
| Coloured, white, faba beans | 2 |
| Dry Peas | 2 |
| Flaxseed | 3 |
| Fodder Corn | 1 |
| Grain Corn | 1 |
| Hay and forage seed | 4 |
| Hay-grass | 4 |
| Hay-legume | 4 |
| Hay-mixed | 4 |
| Lentils | 2 |
| Mixed Grain | 3 |
| Mustard seed | 3 |
| Oats | 3 |
| Potatoes | 1 |
| Rye | 3 |
| Safflower | 3 |
| Soybeans | 2 |
| Spring wheat, durum | 3 |
| Sunflower seed | 3 |
| Triticale | 3 |
| Winter wheat | 3 |

**Table A4-34. Nitrogen concentrations of liquid manure.**

| Animal type | *N_concentration* (kg N 1000 $\text{litre}^{-1}$) |
|---|---:|
| Swine | 3.5 |
| Dairy cattle | 3.4 |
| Poultry | 6.0 |

Agricultural Operation Practices Act (2001) as cited in Ormann 2005 & Tri-Provincial Manure Application and Use Guidelines 2004.

**Table A4-35. Nitrogen concentrations of solid manure.**

| Animal type | *N_concentration* (kg 1000 litre$^{-1}$) |
|---|---:|
| Swine | 8.0 |
| Dairy cattle | 5.0 |
| Poultry | 24.1 |
| Beef | 10.0 |
| Sheep | 10.0 |

Agricultural Operation Practices Act (2001) as cited in Ormann 2005.

# 11 Summations

Following are the equations to sum emissions from all sources and to convert these emissions to $CO_2$ equivalents (Mg) based on their global warming potential (Table A4-36).

## 11.1 Soil $N_2O$

$N_2O$ emissions from land applied manure are included here.

### 11.1.1 Direct soil $N_2O$

$$N_2O_{directsoil}(CO_2eq) = \frac{N_2O_{directsoil} * 296}{1000} \tag{11.1}$$

| | |
|---|---|
| $N_2O_{directsoil}(CO_2eq)$ | Direct $N_2O$ emissions from soils (Mg $CO_2$ eq year$^{-1}$) |
| $N_2O_{directsoil}$ | Direct $N_2O$ emissions from soils (kg $N_2O$ year$^{-1}$) (from equation (1.29)) |
| 296 | Global warming potential conversion factor |
| 1000 | Conversion from kg to Mg |

### 11.1.2 Indirect soil $N_2O$

$$N_2O_{indirectsoil}(CO_2eq) = \frac{N_2O_{indirectsoil} * 296}{1000} \tag{11.2}$$

| | |
|---|---|
| $N_2O_{indirectsoil}(CO_2eq)$ | Indirect $N_2O$ emissions from soils (Mg $CO_2$ eq year$^{-1}$) |
| $N_2O_{directsoil}$ | Indirect $N_2O$ emissions from soils (kg $N_2O$ year$^{-1}$) (from equation (1.30)) |

## 11.2 Soil carbon

$$CO_{2soil}(CO_2eq) = \frac{CO_{2soil}}{1000} \tag{11.3}$$

| | |
|---|---|
| $CO_{2soil}(CO_2eq)$ | $CO_2$ emissions from soils (Mg $CO_2$ eq year$^{-1}$) |
| $CO_{2soil}$ | $CO_2$ emissions from soils (kg $CO_2$ year$^{-1}$) (from equation (2.17)) |
| 1000 | Conversion from kg to Mg |

## 11.3 Shelterbelt and linear plantings carbon

$$CO_{2shelterbelt}(CO_2eq) = \frac{Total\_CO_{2shelterbelt}}{1000} \tag{11.4}$$

| | |
|---|---|
| $CO_{2shelterbelt}(CO_2eq)$ | $CO_2$ emissions from tree plantings/shelterbelt (Mg $CO_2$ eq year$^{-1}$) |
| $Total\_CO_{2shelterbelt}$ | Total $CO_2$ emissions from tree plantings/shelterbelt (kg $CO_2$ year$^{-1}$) (from equation (9.6)) |
| 1000 | Conversion from kg to Mg |

## 11.4 Energy $CO_2$

$$CO_{2energy}(CO_2eq) = \frac{Total\_CO_{2energy}}{1000} \tag{11.5}$$

| | |
|---|---|
| $CO_{2energy}(CO_2eq)$ | $CO_2$ emissions from energy use (Mg $CO_2$ eq year$^{-1}$) |
| $Total\_CO_{2energy}$ | Total $CO_2$ emissions from energy use (kg $CO_2$ year$^{-1}$) (from equation (10.27)) |
| 1000 | Conversion from kg to Mg |

## 11.5 Enteric $CH_4$

$$CH_{4enteric}(CO_2eq) = \frac{\sum_{all\_livestock\_operations} Total\_CH_{4enteric} * 23}{1000} \tag{11.6}$$

| | |
|---|---|
| $CH_{4enteric}(CO_2eq)$ | Enteric $CH_4$ emission from livestock (Mg $CO_2$ eq year$^{-1}$) |
| $Total\_CH_{4enteric}$ | Total enteric $CH_4$ emission from livestock (kg $CH_4$ year$^{-1}$) (from equations (3.55), (4.49), (5.19), (6.28), (7.2) and/or (8.2)) |
| 23 | Global warming potential conversion factor |
| 1000 | Conversion from kg to Mg |

## 11.6 Manure $CH_4$

$$CH_{4manure}(CO_2eq) = \frac{\sum_{all\_livestock\_operations} Total\_CH_{4manure} * 23}{1000} \tag{11.7}$$

| | |
|---|---|
| $CH_{4manure}(CO_2eq)$ | Manure $CH_4$ emission from livestock (Mg $CO_2$ eq year$^{-1}$) |
| $Total\_CH_{4manure}$ | Total manure $CH_4$ emission from livestock (kg $CH_4$ year$^{-1}$) (from equations (3.56), (4.50), (5.20), (6.29), (7.4) and/or (8.4)) |
| 23 | Global warming potential conversion factor |
| 1000 | Conversion from kg to Mg |

## 11.7 Manure $N_2O$

### 11.7.1 Direct manure $N_2O$

$$N_2O_{directmanure}(CO_2eq) = \frac{\sum_{all\_livestock\_operations} Total\_N_2O_{directmanure} * 296}{1000} \tag{11.8}$$

| | |
|---|---|
| $N_2O_{directmanure}(CO_2eq)$ | Manure direct $N_2O$ emission from livestock (Mg $CO_2$ eq year$^{-1}$) |
| $Total\_N_2O_{directmanure}$ | Total manure direct $N_2O$ emission from livestock (kg $N_2O$ year$^{-1}$) (from equations (3.63), (4.57), (5.27), (6.36), (7.16) and/or (8.15)) |
| 296 | Global warming potential conversion factor |
| 1000 | Conversion from kg to Mg |

### 11.7.2 Indirect manure $N_2O$

$$N_2O_{indirectmanure}(CO_2eq) = \frac{\sum_{all\_livestock\_operations} Total\_N_2O_{indirect\,manure} * 296}{1000} \qquad (11.9)$$

| | |
|---|---|
| $N_2O_{indirectmanure}(CO_2eq)$ | Manure indirect $N_2O$ emission from livestock (Mg $CO_2$ eq year$^{-1}$) |
| $Total\_N_2O_{indirectmanure}$ | Total manure indirect $N_2O$ emission from livestock (kg $N_2O$ year$^{-1}$) (from equations (3.64), (4.58), (5.28), (6.37), (7.17) and/or (8.16)) |

## *11.8 Indirect $N_2O$ – soils and manure*

$$N_2O_{indirect}(CO_2eq) = N_2O_{indirectsoil}(CO_2eq) + N_2O_{indirectmanure}(CO_2eq) \qquad (11.10)$$

| | |
|---|---|
| $N_2O_{indirect}(CO_2eq)$ | Indirect $N_2O$ emissions from farm (Mg $CO_2$ eq year$^{-1}$) |
| $N_2O_{indirectsoil}(CO_2eq)$ | Indirect $N_2O$ emissions from soils (Mg $CO_2$ eq year$^{-1}$) |
| $N_2O_{indirectmanure}(CO_2eq)$ | Manure indirect $N_2O$ emission from livestock (Mg $CO_2$ eq year$^{-1}$) |

## *11.9 Total emissions per farm*

$$\begin{aligned} CO_{2eqfarm} &= \\ &N_2O_{directsoil}(CO_2eq) + CO_{2soil}(CO_2eq) + CO_{2shelterbelt}(CO_2eq) + CO_{2energy}(CO_2eq) + \\ &CH_{4enteric}(CO_2eq) + CH_{4manure}(CO_2eq) + N_2O_{directmanure}(CO_2eq) + N_2O_{indirect}(CO_2eq) \end{aligned} \qquad (11.11)$$

| | |
|---|---|
| $CO_2eq$ | Total annual farm $CO_2$ eq emissions (Mg $CO_2$ eq year$^{-1}$) |
| $N_2O_{directsoil}(CO_2eq)$ | Direct $N_2O$ emissions from soils (Mg $CO_2$ eq year$^{-1}$) |
| $CO_{2soil}(CO_2eq)$ | $CO_2$ emissions from soils (Mg $CO_2$ eq year$^{-1}$) |
| $CO_{2shelterbelt}(CO_2eq)$ | $CO_2$ emissions from tree plantings/shelterbelt (Mg $CO_2$ eq year$^{-1}$) |
| $CO_{2energy}(CO_2eq)$ | $CO_2$ emissions from energy use (Mg $CO_2$ eq year$^{-1}$) |
| $CH_{4enteric}(CO_2eq)$ | Enteric $CH_4$ emission from livestock (Mg $CO_2$ eq year$^{-1}$) |
| $CH_{4manure}(CO_2eq)$ | Manure $CH_4$ emission from livestock (Mg $CO_2$ eq year$^{-1}$) |
| $N_2O_{directmanure}(CO_2eq)$ | Manure direct $N_2O$ emission from livestock (Mg $CO_2$ eq year$^{-1}$) |
| $N_2O_{indirect}(CO_2eq)$ | Indirect $N_2O$ emissions from farm (Mg $CO_2$ eq year$^{-1}$) |

**Table A4-36. Global warming potential of emissions.**

| Greenhouse gas | Conversion factor |
|---|---|
| $CO_2$ | 1 |
| $CH_4$ | 23 |
| $N_2O$ | 296 |

These conversion factors are the Direct Global Warming Potentials (mass basis) relative to carbon dioxide (for gases for which the lifetimes have been adequately characterised). The time horizon is 100 years (IPCC 2006).

**Table A4-37. Conversion factors from atomic weight to molecular weight.**

| To convert from: | To: | Multiply by: |
|---|---|---|
| $CO_2$-C | $CO_2$ | 44/12 |
| $CH_4$-C | $CH_4$ | 16/12 |
| $N_2O$-N | $N_2O$ | 44/28 |

**These conversions were done in earlier equations.**

# 12 Expression of Uncertainty

## 12.1 *Uncertainty associated with each emission category*

An estimate of uncertainty was developed based on expert opinion for each of the categories of emission given in the Holos output (Table A4-38). A categorization system was developed and is listed in Table A4-39.

## 12.2 *Uncertainty estimate for net emission*

To determine the overall uncertainty for the estimate of net GHG emissions from a specified set of farm conditions, the following equation was used.

$$Uncertainty = \frac{\left[ (A * a)^2 + (B * b)^2 + \ldots \right]^{0.5}}{\left( A^2 + B^2 + \ldots \right)^{0.5}} \qquad (13.1)$$

| | |
|---|---|
| *Uncertainty* | Uncertainty associated with net farm emission estimate |
| *A* | Emission estimate for each emissions category (Mg $CO_2$ equivalent – calculated in Summations section, equations (11.1) to (11.10)) |
| *a* | Uncertainty estimate (Table A4-39, by uncertainty category associated with emission category and relative uncertainty in Table A4-38) |

**Table A4-38. Relative uncertainties for each emission category.**

| Emission category | Relative uncertainty |
|---|---|
| Soil $N_2O$ - direct | High |
| Soil C | Medium |
| Enteric $CH_4$ | Low |
| Manure $N_2O$ - direct | Medium |
| Indirect $N_2O$ – soils & manure | Very High |
| Manure $CH_4$ | Low |
| Energy use $CO_2$ | Medium |
| Lineal tree planting C | Low |

**Table A4-39. Uncertainty categories and associated estimates.**

| Relative uncertainty | Uncertainty | Uncertainty estimate "*a*" |
|---|---|---|
| Low | ± <20% | 1 |
| Medium | ± <40% | 2 |
| High | ± <60% | 3 |
| Very High | ± >60% | 4 |

# 13 Equation references

Bioenergy Feedstock Information Network (BFIN). Undated. Energy Conversion Factors. [Online]
Available: http://bioenergy.ornl.gov/papers/misc/energy_conv.html [accessed 5 May 2008].

Canadian Dairy Information Centre - Agriculture and Agri-Food Canada. Milk production by breed. [Online]
Available: http://www.dairyinfo.gc.ca/_english/dff/dff_2/dff_2b_e.htm [accessed 1 November 2007].

Dairy Farmers of Ontario Dairy cattle breeds. [Online]
Available: http://www.milk.org/Corporate/view.aspx?content=Students/DairyCattleBreeds
[accessed 1 November 2007].

Dyer, J.A. and R.L. Desjardins. 2004, The Impact of Energy use in Canadian Agriculture on the Sector's Greenhouse Gas (GHG) Emissions. Research Branch, Agriculture and Agri-Food Canada, Technical Report, 17pp.
Website: http://www.canren.gc.ca/re-farms/documents/elecPub.cfm

Dyer, J.A. and R.L. Desjardins. 2006. An integrated index of electrical energy use in Canadian agriculture with implications for greenhouse gas emissions. Biosystems Engineering 95 (3): 449-460.

Dyer, J.A. and R.L. Desjardins. 2007. Energy based GHG emissions from Canadian agriculture. Journal of the Energy Institute 80(2): 93-95.

Greenhouse Gas System Pork Protocol: The Innovative Feeding of Swine and Storing and Spreading of Swine Manure (Draft) dated July 31, 2006. Prepared by the Pork Technical Working Group (PTWG), a sub-committee of the National Offsets Quantification Team (NOQT).

Helgason, B.L., 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. Agriculture and Agri-Food Canada.

IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme, H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara and K. Tanabe. (Eds). IGES, Japan.
Available: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm

Janzen, H.H., K.A. Beauchemin, Y. Bruinsma, C.A. Campbell, R.L. Desjardins, B.H. Ellert and E.G. Smith. 2003. The fate of nitrogen in agroecosystems: An illustration using Canadian estimates. Nutrient Cycling in Agroecosystems 67: 85-102.

Janzen, H. H., D. A Angers, M. Boehm, M. Bolinder, R.L. Desjardins, J.A. Dyer, B.H. Ellert, D.J. Gibb, E.G. Gregorich, B.L. Helgason, R. Lemke, D. Massé, S.M. McGinn, T.A. McAllister, N. Newlands, E. Pattey, P. Rochette, W. Smith, A.J. VandenBygaart and H. Wang. 2006. A proposed approach to estimate and reduce net greenhouse gas emissions from whole farms. Canadian Journal of Soil Science 86: 401–418.

Kort, J. and R. Turnock. 1998. Annual carbon accumulations in agroforestry plantations. Agriculture and Agri-Food Canada, PFRA Shelterbelt Centre, Indian Head, Canada. 7 pp.
Available: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1199722936936&lang=e

Marinier, M., K. Clark and C. Wagner-Riddle. 2004. Determining manure management practices for major domestic animals in Canada. Environment Canada Greenhouse Gas Inventory Project Final Report. 30 pp.

Marshall, I.B., P Schut and M. Ballard (compilers). 1999. A National Ecological Framework for Canada: Attribute Data. Environmental Quality Branch, Ecosystems Science Directorate, Environment Canada and Research Branch, Agriculture and Agri-Food Canada, Ottawa/Hull, Canada.
Available: http://sis.agr.gc.ca/cansis/nsdb/ecostrat/data_files.html

McConkey, B.G., D.A. Angers, M. Bentham, M. Boehm, T. Brierley, D. Cerkowniak, C. Liang, P. Collas, H. de Gooijer, R. Desjardins, S. Gameda, B. Grant, E. Huffman, J. Hutchinson, L. Hill, P. Krug, T. Martin, G. Patterson, P. Rochette, W. Smith, B. VandenBygaart, X. Vergé, and D. Worth. 2007. Canadian Agricultural Greenhouse Gas Monitoring Accounting and Reporting System: Methodology and greenhouse gas estimates for agricultural land in the LULUCF sector for NIR 2006. Agriculture and Agri-Food Canada, Ottawa, Canada.

Nagy, C.N. 2000. Energy and greenhouse gas emissions coefficients for inputs used in agriculture. Report to the Prairie Adaptation Research Collaborative, 11 pp.

National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990-2005. 2007. Prepared by the Greenhouse Gas Division, Environment Canada. Environment Canada, Gatineau, Canada. 611 pp.
Available: http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/tdm-toc_eng.cfm

National Research Council. 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. National Academy Press, Washington, USA.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle: Seventh Revised Edition: Update 2001. National Academy Press, Washington, USA.

Ormann, T. 2005. Manure Nutrient Value: Wisdom Gained from Experience in Southern Alberta. County of Lethbridge, Canada.
Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw8709?opendocument

Rochette, P., D.E. Worth, R.L. Lemke, B.G. McConkey, D.J. Pennock, C. Wagner-Riddle and R.L. Desjardins. 2008. Estimation of $N_2O$ emissions from agricultural soils in Canada. I. Development of a country-specific methodology. Canadian Journal of Soil Science 88: 641-654.

Tri-Provincial Manure Application and Use Guidelines. 2004. Prepared by The Prairie Province's Committee on Livestock Development and Manure Management.
Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw8709?opendocument

Vergé, X, D. Worth, J. Hutchinson and R. Desjardins. 2006. Greenhouse gas emission from Canadian Agro-ecosystems. Cat. no.: AAFC-10181E. 38 pp.

Vergé, X.P.C., J.A. Dyer, R.L. Desjardins and D. Worth. 2007. Greenhouse gas emissions from the Canadian dairy industry in 2001. Agricultural Systems 94: 683-693.