Farming in a Changing Climate in Manitoba

Climate Change Connection

A GUIDE TO SUSTAINABLE CROPPING SYSTEMS - APRIL 2013

Assiniboine Credit Union

Manitoba Hydro Power Smart

Manitoba

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CLIMATE CHANGE CONNECTION IS A MULTI-STAKEHOLDER PROJECT, MANAGED BY THE MANITOBA ECO-NETWORK:

Our vision is for a future in which Manitobans will be aware of climate change facts related to Manitoba and will take action to reduce their greenhouse gas (GHG) emissions, both individually and as a community

CONTACT US:

- Tel: 204-943-4836
- Fax: 1-866-237-3130
- E-mail: climate.connection@mymts.net
- Web site: www.climatechangeconnection.org

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Can You Make a Difference?

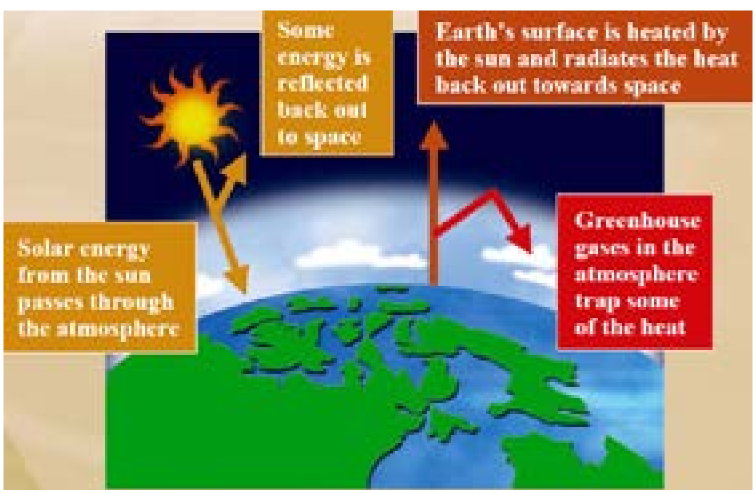
This guide is intended for Manitoba crop producers. This guide is not meant to be prescriptive; it provides ideas to consider. This guide suggests farming practices that are practical and reduce greenhouse gas (GHG) emissions. Many of these practices have been shown to maintain or increase yields, often with fewer inputs. By considering them, you will be part of a positive movement to pass on a healthier environment and healthier land to future generations

This guide includes the following topics related to crop production on the Prairies:

- A brief introduction to climate change on the Prairies
- Predicted changed for Manitoba's climate
- Impacts of climate change on crop production in Manitoba
- Farm contributions to climate change
- Recommendations on how to reduce greenhouse gas emission from crop production
- A list of information resources

What is Climate Change?

The earth has always acted as a greenhouse system, retaining some of the sun's warmth through the buildup of naturally occurring greenhouse gases (GHG), namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_20) in the atmosphere. This natural greenhouse effect ensures that not all energy arriving from the sun escapes directly back into space. Without this warming effect, Earth's average temperature would be too cold to support life as we know it. The greenhouse effect is necessary for life on Earth.



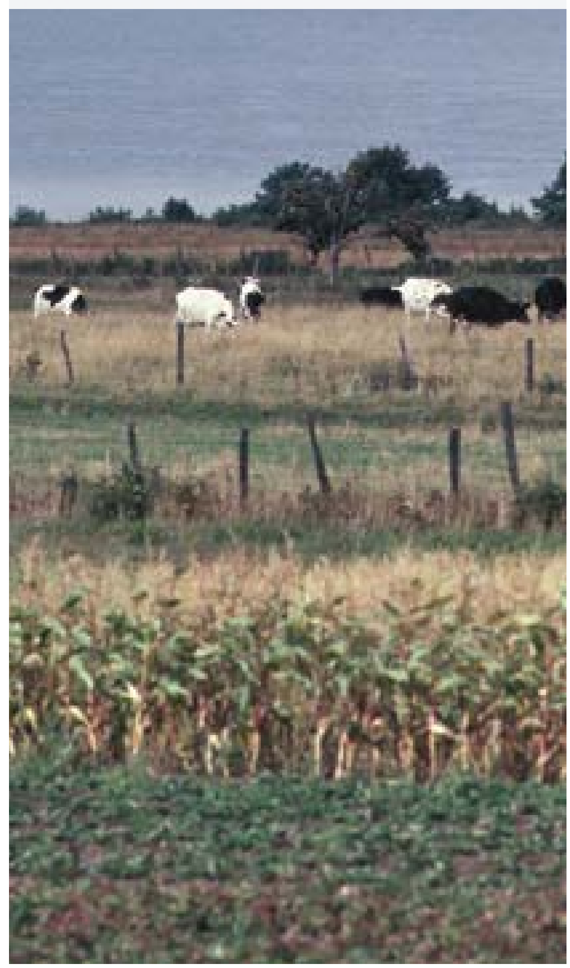
"Warming of the climate system is unequivocal, as it is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

-Intergovernmental Panel on Climate Change, 2007

In Manitoba...

Agriculture plays a significant role in contributing emissions.

- It accounts for 33 percent of Manitoba's total greenhouse gas emissions, excluding vehicle fuel and commercial heat.
- Manitoba's agricultural emissions increased 30.7 percent between 1990 and 2010.
- Of Manitoba's agricultural emissions in 2010, 63 percent came from agricultural soils, 27 percent from enteric fermentation and 9 percent from manure management.*
- In Canada, agriculture-related GHG emissions contributed 10 percent of total emissions in 2010, an increase of 27 percent above 1990 levels. *



With the occurrence of the industrial revolution around 1750, humans began contributing to the rising amount of greenhouse gases in the atmosphere. Increased GHG sources and the removal of existing sinks (e.g. old growth forests and tall grass prairie) have increased global atmospheric GHG levels by 39 percent since the start of the Industrial Revolution.[1]

The increase in greenhouse gas emissions means a thicker blanket of greenhouse gases in the atmosphere. The "blanket" of gases traps more heat leading to global warming. Global warming leads to a changing climate. Here are some global warming facts:[2]

- Temperatures have increased by 0.76°C during the twentieth century
- The 10 hottest years in the instrument temperature record have all occurred since 1998
- A further rise of between 1.1 to 6.4°C is expected by the year 2100

Global warming, in turn, affects other aspects of the earth's climate. Here are some possible impacts of global warming on the climate and environment[3 4],

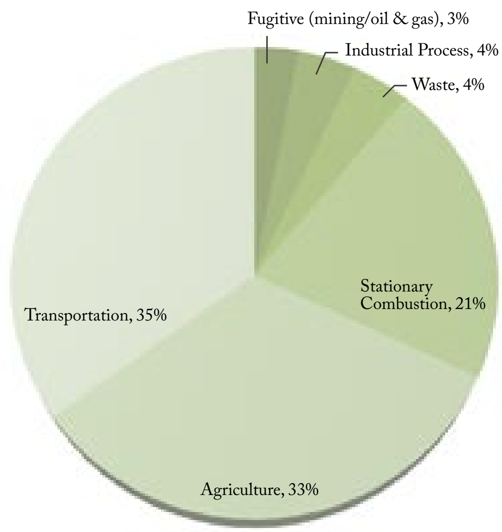
- Changing weather and rainfall patterns
- Melting polar ice cover, snow, and permafrost
- Rising sea level
- Increasing occurrence of extreme weather events, such as drought or flooding
- Habitat loss

The most significant man-made GHGs are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon dioxide is the most common GHG, but not the most environmentally damaging. Methane and nitrous oxide have 25 and 298 times,[5] respectively, the Global Warming Potential (GWP) of CO_2. This means that these two gases have a much greater environmental impact per molecule of gas than CO_2. Greenhouse gas emissions data are usually normalized to CO_2-equivalents.[6]

How Does Agriculture Contribute to Climate Change?

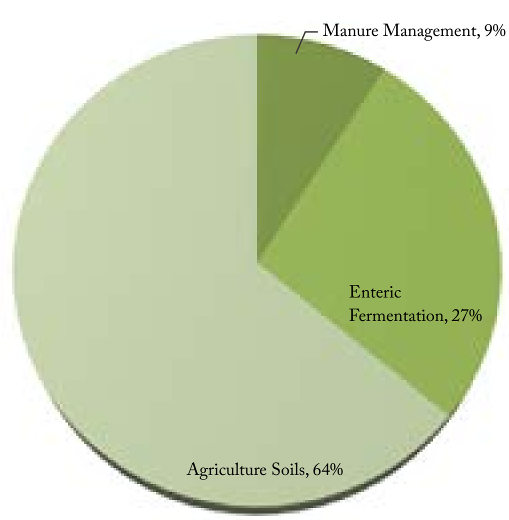
Farming activities such as manure storage, use of nitrogen fertilizers, and ruminant enteric fermentation (i.e. livestock burps), account for one-third of Manitoba's total greenhouse gas emissions. This is about equal to the contribution from burning fossil fuels for transportation. Although carbon dioxide (CO_2) is the primary gas emitted by fossil fuel combustion, the main greenhouse gases (GHG) from agriculture are nitrous oxide (N_20) and methane (CH_4).[7 8]

FIGURE 1: MANITOBA GHG EMISSIONS



In Manitoba, enteric fermentation of ruminant livestock (sheep, goat, and cow burps) emits about 27 percent of the provincial agricultural GHG emissions, mostly in the form of methane (CH_4). Anaerobic (without oxygen) decomposition of organic matter in wet soils and riparian zones, as well as manure storage, also contributes CH_4 in lesser amounts. Manure storage and management contributes both nitrous oxide (N_2O) and CO_2 at about 9 percent.[9]

FIGURE 2: MANITOBA AGRICULTURAL GHG EMISSIONS



Nitrous oxide is created by the denitrification (anaerobic microbial respiration in wet soils) of synthetic fertilizers and soil nitrogen, as well as from the nitrification of ammonium nitrate. Together these add up to about 64 percent of Manitoba's agriculturally-produced gases.

With the proper techniques and crop production practices, farmers have the potential to improve their economic and production efficiency, and reduce the amount of GHGs going into the atmosphere.

Table 1 gives a handy breakdown of greenhouse gases and some of the ways that agricultural practices contribute them. Home heating and farm machinery are still considered sources of CO_2 but are categorized separately from agricultural emissions in Manitoba GHG statistics.

TABLE 1: GHG SOURCES FROM AGRICULTURE

GREENHOUSE GAS	GLOBAL WARMING POTENTIAL	AGRICULTURAL SOURCE	CAUSES
Carbon dioxide (CO_2)	1:1 (CO_2 equivalent)	• Soils • Fossil fuel combustion	• Tillage, which accelerates organic matter decomposition • Clearing woodlots and soil drainage • Operating farm machinery • Heating farm buildings • Crop residue burning
Methane (CH_4)	21:1 (21 times more potent than CO_2)	• Ruminant livestock (the major source) • Manure • Soils	• Digestion of feeds by ruminants • Decomposition of manure during storage and application • Methane production by bacteria in poorly drained soils
Nitrous oxide (N_2O)	310:1 (310 times more potent than CO_2)	• Manure storage • Nitrification (oxidation of ammonia) • Denitrification (conversion of plant-available nitrate-nitrogen to gases) in the soil	• Saturated soil conditions with warm soil temperatures and the presence of carbon • Production of N_2O during manure storage • Immediate loss to atmosphere shortly after fertilizer application • Use of excess amounts of nitrogen fertilizers • No or delayed incorporation of manure

Source: Ontario Ministry of Agriculture, Food and Rural Affairs
100-year Global Warming Potential (GWP)

What Changes are Predicted for Manitoba?

As every farmer knows, it's difficult to predict weather for any given day. So how can scientists possibly predict climate change?

Climate and weather are two very different things. Weather is the specific condition of the atmosphere at a particular place and time. Climate, in contrast, is much less specific. It refers to weather patterns and probabilities averaged over a long period.

Manitoba's central location in North American, combined with its northerly latitude, means that climate change affects are likely to be felt sooner and more severely than in other parts of the world. [10]

Predicted changes for Manitoba's agricultural regions over the next century include the following: [11]

- Not much change in average annual precipitation in Manitoba's south-west
- Slightly more annual average precipitation in Manitoba's far north-east
- A shift in when precipitation occurs - slightly more in winter and less in summer
- More extreme weather, including droughts, heat waves, heavy precipitation events and flooding
- Fewer extreme cold spells
- More intense winter storms
- More winter precipitation falling as rain and freezing rain rather than snow

How Will Climate Change Affect Manitoba Crop Production?

A changed climate will significantly affect agriculture in Manitoba. Higher levels of CO_2, changing rain patterns, higher temperatures and greater occurrence of extreme weather events will all modify crop production in Manitoba.

Climate change is in the forecast however, detailed predictions about how crop production will be affected are less clear. Higher levels of CO_2 may affect the growth rate and yield of crops, whereas higher temperatures or lack of precipitation may influence growing season length, crop type, or pests found in fields.[12] [13] Generally, climate change models predict an uncertain future for agriculture in Manitoba, with potential benefits most likely being offset by major drawbacks.[14]

The following sections will help clarify the potential benefits and drawbacks of climate change on crop production in Manitoba.

GROWING SEASON

Predicted increases in Manitoba's temperatures could result in a longer growing season due to more frost-free days and earlier seeding times for most crops. For every 1°C increase in average temperature, the growing season could lengthen by 10 days on the Canadian Prairies.[15] Warmer winter temperatures could either reduce the amount of winterkill in fall-seeded crops, or decrease the thickness of snow cover and result in greater amounts of winterkill when cold temperatures are experienced.[16]

CROP YIELD

Warming temperatures, particularly higher spring temperatures, mean that crops may be planted earlier. In Alberta, spring is arriving approximately 26 days earlier than it was a century ago. Earlier seeding could mean increased yields in regions where there is adequate soil moisture, due to greater crop growth during spring rains. However, the forecasted reduction in precipitation could result in more frequent drought conditions and loss of yield.[17]

Crop yield may also be influenced by the increased amount of CO_2 in the atmosphere. Crop species vary in their response to CO_2 levels. C3 plants, such as wheat, canola, and soybeans, as well as many pasture grasses and forage species (i.e. alfalfa, clover, fescue, Kentucky bluegrass) grow better when CO_2 levels are higher. C4 plants, such as corn, millet, and big bluestem are less responsive to higher CO_2 levels.[18,19] However, C4 plants have an advantage with higher temperatures, metabolizing CO_2 better when temperatures are over 32°C.[20] Field trials in Illinois have found there may be negligible growth effects on plant species at higher atmospheric CO_2 levels.[21]

WATER RESOURCES

Although overall growing season precipitation on the Prairies is expected to decrease, (especially into Alberta) precipitation is anticipated to occur in intense events. Crops depend on the quantity and timing of precipitation, meaning that water stress during a critical growth phase may be detrimental to yield goals. Warmer temperatures and longer dry spells between rain events will likely increase drought severity and frequency.[22] Water-stressed areas will expand to include drier areas of the province where seasonal lack of water is already a concern.[23]

Lack of water will place increased demands on available water resources, affecting water quality and quantity on a seasonal basis. Mild winters and limited snowfall may also decrease water availability. Water stress may affect water basin and lake levels, increasing the need for alternative irrigation sources when necessary.[24] Water storage systems may become important for farmers.

INSECTS, DISEASE, AND WEEDS

The exact affects of climate change on insects and pathogens are somewhat uncertain; some changes may be favorable, while others may be negative. Beneficial changes may include the introduction of new predatory insects and faster crop residue decomposition. Negative changes might include increased pests capable of surviving the milder Manitoba winters, increased insect and disease susceptibility or ineffective herbicides and pesticides on new pests. Most evidence, however, indicates an overall increase in the number of outbreaks of a wider variety of insects and pathogens.[25]

SOIL QUALITY

Warmer air and soil temperatures increase soil microbial activity that speeds up the natural breakdown of organic matter. Organic matter is an important component of soil that is a natural plant fertilizer. Climate change might impact the fertility of Manitoba soils by breaking down organic matter faster than the crops can use the available nutrients. However, a longer growing season with more vegetative mass produced may offset the increased breakdown of organic matter.[26]

The drought conditions and extreme weather events predicted are expected to increase the risk of soil erosion. Greater precipitation during rainfall events and an increased likelihood of flooding and heavy winds during the growing season will be some risks for soil erosion. It may be necessary to take steps to ensure adequate ground cover at key periods throughout the growing season. Manitoba Agriculture (MAFRI) currently recommends that 60 percent of the soil surface be covered with crop residue to prevent erosion.[28]

How to Reduce Greenhouse Gas Emissions from Crop Production

Because some degree of climate change is now inevitable, changes to agricultural practices are critical to climate change adaptation. A focus needs to be on the implementation of farming practices that develop soil health, exercise sustainable nutrient management and encourage environmental sustainability. Manitoba agriculture is in a good position to influence greenhouse gas (GHG) emissions, because farming practices can be modified to become part of the climate change solution. [29]

There are practical on-farm techniques that can be implemented to help reduce GHG emissions. Management practices such as conservation tillage, crop rotation selection or type of fertilizer used can promote long-term soil productivity while maintaining water quality and preserving profitability.
This section includes suggestions in the following areas of operation:

- Build and manage healthier soil
- Manage synthetic and natural fertilizers
- Choose effective crop rotations and tillage techniques
- Use trees to enhance soil carbon storage
- Reduce emissions from farm vehicles and equipment use
- Increase the energy efficiency of farm buildings

HEALTHY SOIL MANAGEMENT

Healthy soils are a key step towards reducing GHG emissions from agriculture. A balanced mixture of minerals, organic matter, living organisms, plant roots, water and gases are ingredients for a healthy soil. When soil components are in healthy equilibrium, nutrients will be available to provide food for the crop and micro-organisms alike. Natural nutrient cycling will limit the need for farmers to apply excess amounts of fertilizers and keep nutrients in forms that are good for the environment.[30] Soil with a wide diversity of soil organisms and nutrients will be more productive and sequester carbon (C) from the atmosphere.

The quality of soil is essential to efficient crop production and environmental health because it plays many key roles for the ecosystem:[31] Soil contributes to agro-ecological health by

- Supporting plant growth
- Controlling water loss, use, and cleanliness
- Acting as a recycling system by decomposing plant and organic residue
- Providing habitats to small mammals, reptiles, and micro-organisms
- Strongly influencing the cycling of gases between the soil and the atmosphere

One of the best indicators of soil quality is earthworm populations. Earthworms increase soil fertility and improve soil physical properties.[32] Worms create burrows that act as water drainage tunnels, aerate the soil and create pathways for crop roots to reach deeply stored nutrients. A minimum of 5 earthworms in a shovelful of soil under cool, moist soil conditions indicates a good worm population in agricultural systems.[33] Other large soil organisms in a healthy soil include nematodes and insects, or micro-organisms, such as bacteria, fungi or algae that live in the soil water and provide nutrients to plant roots.[34]

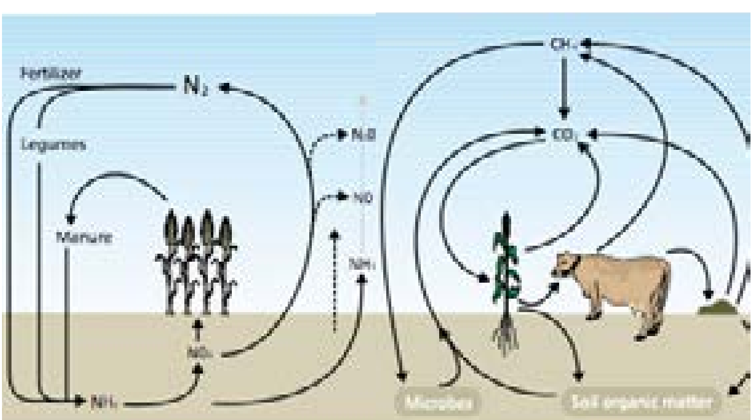
In agricultural systems, specific forms of nitrogen (N) and carbon (C) are the culprits that create atmospheric greenhouse gases. Farming practices have increased the amount of C and N cycling in the environment, leading to greater amounts of carbon dioxide (CO_2) and nitrous oxide (N_2O) in the atmosphere. Limited nutrients stay in the soil system, lessening soil organic matter and plant available N forms in the soil. Awareness of the cycling of these two nutrients is important to understanding how crop production can reduce GHG emissions.

NITROGEN

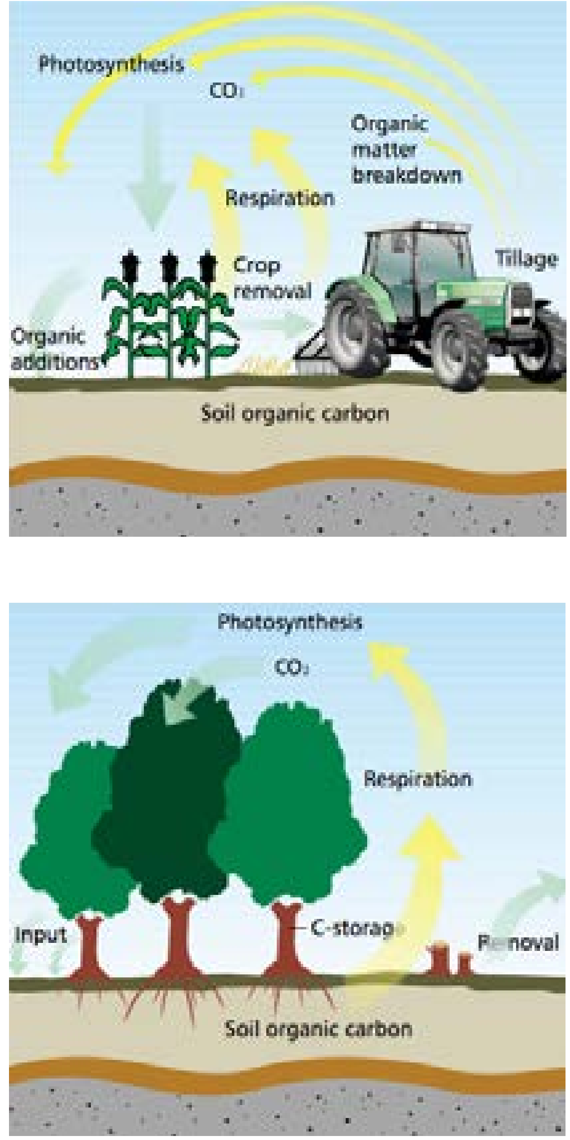
Nitrogen is a naturally occurring element that is essential for strong root growth and plant development. Small amounts of N are moved into the soil by biological nitrogen fixation and lightning strikes, replenishing only a portion of N soil reserves. Decomposing organic material provides most of the natural N found in the soil.[35]

To ensure that adequate amounts of N are available for the crop, farmers must apply N fertilizers. Good soil and crop management will ensure that sufficient N forms and amounts are available to the crop throughout the growing season. Simply adding N fertilizer to a cropping system at planting will not ensure adequate and efficient use of the nutrient. For plant uptake, N needs to be in the form of ammonium (NH_4 +) or nitrate (NO_3-). Synthetic fertilizers, such as anhydrous ammonia, urea and UAN that rapidly convert into these forms of N are generally used.[36]

A healthy soil will promote complete N cycling, reducing the likelihood of nitrous oxide (N_2O) creation. Nitrous oxide is a potent greenhouse gas that is the by-product of an incomplete nitrogen cycle and a major greenhouse gas.



Nitrogen Cycle



Carbon Cycle

CARBON

Agricultural soils act as both a source of atmospheric carbon dioxide (CO_2) gas and as a sink to store carbon (C).[37] Although various farming practices influence C cycling differently, sustainable and healthy soil management should moderate the amount of C leaving the cropping system and aim to enhance the amount of C that remains.

When forests, wetlands or pastures are converted into cropland huge amounts of natural C are released to the atmosphere as CO_2 gas. The conversion of these systems releases C stored within the soil or in the plant biomass.[38] The tillage that occurs in farming systems is a major agricultural source of C. Tillage allows more air and microbes to access soil organic matter (SOM) on a regular basis. Decomposition rates are increased, releasing huge amounts of CO_2 to the atmosphere that would otherwise remain in the soil as organic matter.[39]

Bob McNabb: Conservation Tillage

Bob McNabb is one of the pioneers of zero-till in Manitoba, sowing his first crop into the previous year's stubble in 1978. "At that time I was motivated more by perceived economic advantages than by a strong environmental thought," he says.

But over the years the environmental advantages became increasingly evident—soil retention during windstorms, greater soil moisture, excellent earthworm activity, and, most recently, carbon storage. "Ag Canada did an extensive three-year program on my farm to test carbon. We were sinking more carbon than conventional farmers," Bob says.

With just one pass needed to seed his 2500 acres, he's also using a lot less fuel. And since he's not digging deep into the soil, he can pull wider equipment using the same horsepower—representing more fuel savings.

The Minnedosa farmer, however, recognizes he makes an environmental trade-off. Despite using a low disturbance hoe press drill for seeding, he still faces greater weed growth with zero till than with other production systems. And that means he reluctantly uses more pesticides. Still, he's confident the environmental benefits of conservation tillage far outweigh the negatives.

Soil acts as a C sink when CO_2 is sequestered into the system. Using photosynthesis, plants store C in their foliage, seeds or roots. Some of the plant C will decompose to become part of the SOM, portions of which can be considered long-term storage. Organic matter is the component of soil that acts as a natural plant fertilizer and is fundamental to healthy soil.

Besides storing more organic matter and lowering GHG emissions, good soil management will provide economic benefits to a farmer by increasing crop productivity, improving nutrient use efficiency, and enhancing air and water quality.[40 41] Numerous farming practices can be implemented to improve soil health and enhance crop production. Several methods are discussed in the following sections.

ADOPT CONSERVATION TILLAGE

Conservation tillage, where crops are planted directly into the previous year's stubble, limit the amount of carbon (C) loss and increase the amount of plant material returned to the soil. Conservation tillage also encourages plant root growth, helping hold soil particles together, improving soil structure and almost eliminating the risk of wind and water erosion. Also known as reduced-till or zero-till, these soil management practices have been shown to sequester C over time. [42 43]

The Soil Conservation Council of Canada estimates that conservation tillage, depending on weather and moisture conditions, can help store between 0.3 and 0.5 tonnes of C per hectare per year in the soil.[44] Research from Saskatchewan has shown there is more available organic nitrogen (N) in long-term zero tillage fields than in fields tilled using conventional methods.[45]

Conservation tillage is done using narrow, low disturbance openers (knives or discs). These openers have the advantage of minimal seedbed disturbance (less than 33 percent of the total surface area), encouraging sparser weed growth and improved crop production. Benefits also include moisture conservation, erosion control, and reduced labour and fossil fuel costs. Crop stubble that is left standing over the winter will help trap snow, increasing spring soil moisture and permitting the survival of over-wintering crops.[46]

CHOOSE EFFECTIVE CROP ROTATIONS

The best crop rotations should not only manage soil nutrients and reduce pest problems, but also improve soil quality. While the environmental benefits of certain crop rotations are clear, market demand or production constraints may limit which crops can be grown.

Here are some suggestions to improve crop rotation quality:

- Include legume and pulse crops in crop rotations to fix N. Perennial legumes, such as alfalfa or clover, provide valuable nutrients to subsequent crops and encourage the increase of SOM. Pulse crops, such as beans, peas or lentils, are also biological nitrogen fixers and encourage N accumulation in plant roots.
- Use crops with high N requirements, such as corn or cereals, as a follow-up to legumes. These crops need much N to grow and using the fixed N in the soil will help reduce the amount of fertilizer required at planting.[47]
- Remove surplus N by planting a winter cereal (i.e. winter wheat or fall rye) or a cover crop, such as mustard, vetch, or clover after harvest. Cover crops provide nutrients for subsequent crops, reduce weeds, host beneficial insects and improve soil quality.[48]
- Try planting multi-species crop mixtures, such as alfalfa-brome grass, or clover-winter wheat when using cover crops. Crop mixtures help mimic a natural system and use soil nutrients more efficiently, reducing their potential to be lost to the environment.[50]
- Consider forages for their numerous indirect benefits on grain production. Perennial forages trap more atmospheric carbon dioxide (CO_2) because they have extensive roots systems and grow for more months of the year than annual crops. Forage production not only improves the soil by increasing organic C, it suppresses pests, increases subsequent crop yield and quality and uses surplus soil nutrients.[51] Capable of absorbing excess water, forages are great for managing high water tables or soil salinity, by lowering the water table.[52] Reducing soil moisture also limits the risk of N losses by denitrification, cutting down the amount of N_2O emitted to the atmosphere.

INCREASE SOIL COVER

Improving crop rotation quality can also be achieved by eliminating the use of summer fallow. Besides leaving fields susceptible to wind and water erosion, fallow reduces the amount of plant residues returned to the soil and encourages residue decomposition by soil animals and microorganisms.[53] Rather, a green manure cover crop or legume can be used in the crop rotation to increase the N and C content of the soil. The cover crop would be returned to the soil or left as surface mulch in mid-July when there are peak nutrients in the plant tissues. The nutritional residues reduce the need for synthetic fertilizer addition the following spring. Cover crops also limit the risk of wind or water erosion.[54]

MANAGE CROP RESIDUE

Properly managing crop residue can enhance soil organic matter and nutrients or improve soil moisture. Depending upon production practices, time and labour constraints, or equipment availability, there are different options to managing crop residues.

Opportunities for removing residues from the field include either stubble burning or baling. Stubble burning is strongly discouraged for many reasons:

- More than 90 percent of crop residue C is lost (mostly as CO2) when it is burned, returning little nutrients or organic matter back to the soil[55]
- Burning can turn into a health hazard, when smoke remains close to the ground and moves towards residential areas

Consider alternate uses for cereal straw such as chopping and spreading it back on fields or baling the straw to be sold for profit. Cattle farmers can either graze or bale the straw to be used for livestock bedding and feed.

A farmer may choose to incorporate crop residue. Under drought conditions or on soils prone to erosion, increasing crop residue is favorable. On heavy clay soils or during wet conditions, fewer residues are ideal otherwise soils can take longer to warm up in the spring.[56] Harvest methods will influence the amount of residue left on the field. To effectively encourage straw and chaff residue decomposition, combine settings should be set so that straw is finely chopped and spread over the maximum amount of the width of cut.[57] Crop residue will slowly decompose, providing nutrients to subsequent crops and improving organic matter in the soil.

If a farmer chooses to leave crop stubble standing on the field from harvest to seeding, there are several benefits that can be achieved. Between 30 and 60 percent crop residue cover is recommended to prevent wind erosion. Crop residues also encourage the trapping of snow over the winter months. Adequate snow cover encourages the survival of over-wintering crops and increases the amount of spring soil moisture.[58]

MANAGE SOIL DRAINAGE

Saturated conditions during the growing season are more prone to producing nitrous oxide (N_2O) through denitrification. Saturated soils also increase water stress for the plant, resulting in unhealthy, stunted plant shoots and roots from lack of oxygen.[59] Improving soil drainage will encourage efficient crop growth, increase nutrient and fertilizer uptake and may even extend the crop production season. [60]

Surface drainage of fields in the province is done using small drainage ditches within fields and large, deeper, permanent ditches around field edges. Proper drainage should remove excess ponding from the field within 24-48 hours of a precipitation event. Rapid water removal will reduce the potential for crop damage. Sometimes a high water table can be an issue, resulting in extended, saturated soil conditions. In these scenarios, an increase in SOM to improve water infiltration, diversifying the crop rotation or planting perennial forage crops are management strategies recommended to improve drainage. A good indicator that inadequate surface drainage may be an issue can be local weeds. Indicator weeds that thrive in wet environments include horsetail, chickweed, and marsh smartweed. Even though retention ponds are a great idea for water conservation, it is not a viable option for farmers. They would have to purchase irrigation equipment, etc and it is not worth the money for most prairie crops. This could be a possible option for potatoes or veggie crops.[61]

REMOVE MARGINAL LAND FROM PRODUCTION

Maintaining or improving soil drainage removes the need for the conversion of marginal land into agriculture. Flood-prone property or lands with excess moisture require the same inputs as productive crop land, but produce lower yields. Marginal land, such as wetlands and marshes, are beneficial to the environment. They recharge groundwater, filter and recycle nutrients, and provide wildlife habitat. These lands should be protected from agricultural development when possible. When marginal lands have little environmental value, they can be planted to perennial cover to improve profit margins, creating a carbon sink, and provide a wildlife habitat.

CONSIDER ORGANIC FARMING METHODS

Organic farming adopts a whole-system management approach, with the farmer making decisions based on the farm ecosystem as a whole. Many organic farming methods have the potential to mitigate climate change by reducing greenhouse gas emissions and sequestering carbon dioxide (CO_2). While numerous variables make it difficult to confidently say that organic systems are more environmentally sustainable than conventional systems, there are some key practices that favour organic agriculture. Conventional farms will also benefit from many of these organic practices:

- The use of legumes has the potential to reduce agricultural emissions of greenhouse gases by reducing the need for synthetic fertilizers. Growing perennial legumes, such as alfalfa, is a proven way of replacing the need for synthetic N fertilizer in Prairie cropping systems.[62]
- A Manitoba study that compared two crop rotation types with organic and conventional production found that energy usage was 40-50 percent lower on organic farms. The major factor affecting energy use between the two systems was the use of inorganic (synthetic) fertilizer in the conventional system. Energy efficiency was determined higher in the organic system.[63]
- Organic agriculture sustains soil fertility by enhancing nutrient cycles, building soil organic matter and promoting biological activity.[64] The increased use of green and animal manure, intercropping and cover cropping, perennial forage crops and composting techniques may result in carbon (C) gains and help reduce soil erosion.
- A further benefit in organically farmed soils is increased water content. Soils with higher C content can capture more water, providing necessary water to plants. In a 12-year study in north-eastern U.S.A., water volumes were found to be substantially higher in two organic systems compared to a conventional agro-ecosystem. Ability to conserve water might make this organic management practice important for adapting to climate change. However, the impact of greater moisture retention on emissions of N_2O should also be considered.

TABLE 2: BEST MANAGEMENT PRACTICES FOR SOIL & CROPS

BEST MANAGEMENT PRACTICE	CARBON SEQUESTRATION POTENTIAL (PER HA BASIS)	ADDITIONAL GHG BENEFITS	SOIL, WATER & OTHER ENVIRONMENTAL BENEFITS
No-till	• Soils • Fossil fuel combustion	• Reduces amount of fossil fuels that are burned • Could decrease N_2O release by improving spring drainage	• Minimizes erosion and runoff • Improves soil quality
Other Conservation Tillage (reduced tillage)	• Low	• Reduces amount of fossil fuels that are burned	• Minimizes erosion and runoff • Improves soil quality
Appropriate Use of Manures & Other Organic Materials (e.g. spring application rates)	• Medium	• Lessens need for additional commercial nitrogen fertilizers • May lessen available N for N_2O release	• Improves soil quality • Can reduce nitrate leaching
Pasture Management (permanent & improved)	• Medium	• Decreases N loss to atmosphere assuming less fertilizer is added	• Improves soil quality • Minimizes erosion
Crop Rotation	• Low	• Maximizes yield (more residue) • Lowers need for additional N fertilizers if legumes are included in rotation	• Reduces disease and weed pressures • Improves soil quality
Winter Cover Crop	• Low	• By trapping available N, leaching and N2O emissions are reduced (if left live over winter and killed in spring)	• Minimizes erosion • Improves soil quality

Source: Ontario Ministry of Agriculture, Food and Rural Affairs
100-year Global Warming Potential (GWP)

Nutrient Management

Sustainable nutrient management revolves around the non-excessive use of synthetic or natural fertilizers. This practice benefits both the farmer and the environment when proper techniques are used. Improving the efficiency of fertilizers should lower application rates and costs, while reducing the amount of nutrients that can be lost to the environment through leaching, denitrification, or volatilization. Of the four major nutrients (nitrogen-N, phosphorous-P, potassium-K, and sulfur-S) applied as synthetic fertilizer, N is the nutrient most easily lost. Nitrogen causes the most environmental damage and economic loss to the farmer.

Nitrous oxide (N_2O) is the most potent agricultural greenhouse gas (GHG), having 298 times more environmental impact per one molecule of gas than carbon dioxide (CO_2). In Manitoba, N_2O accounts for 66 percent of all agricultural GHG emissions.[66] Nitrogen is lost through many pathways, increasing the chance of loss to the environment.[67] Most losses happen when too much N fertilizer is applied and denitrification occurs. This nutrient can also be lost to groundwater or volatilized into the atmosphere.[68]

Any fertilizer sources, such as decomposing manure, synthetic fertilizer or soil N can contribute to N losses. The placement, timing, application method and rate of fertilizer or manure applied to a field will influence the amount of N available to the plant or lost to the environment. Only about 50 percent of the N is used by the crop in the year of application. What happens to the remaining N is unclear. Depending on environmental conditions and fertilizer placement and timing, the remaining N could be immobilized (taken up) by the soil or lost to leaching, denitrification and volatilization. On average, 2.7 percent of applied fertilizer is lost as N_2O. In the Red River Valley, losses were found to be as low as 0.8 percent. [69]

Following good management practices for both manure and fertilizers can help lower greenhouse gas emissions and represent economic savings for the farmer. Some nutrient management techniques to lower N_2O emissions include the following:

- Soil testing
- Avoiding excessive fertilizer application
- Immediately incorporating fertilizer
- Optimizing fertilizer application timing
- Using precision farming techniques

SOIL TESTING

The first step toward reducing nitrous oxide emissions from crop land is testing soil for residual nutrient levels. Some nutrients, such as N and S, can vary greatly from year to year, and from location to location. A soil test will provide an account of field fertility and help determine appropriate nutrient application rates to maximize yield.[70] Soil testing is recommended at least every two years.[71] For the Canadian Prairies, soil testing usually occurs in the fall, once soil temperatures are low. Proper sampling techniques and information can be found in the Manitoba *Soil Fertility Guide.*[72]

AVOID EXCESSIVE FERTILIZER APPLICATION

Crops have varying nutrient requirements. Matching the nitrogen (N) requirements to the needs of a particular crop decreases the chance that excess N will be applied and lost. Proper application rates are beneficial for the farmer's pocketbook by optimizing crop response, reducing lodging and lowering fertilizer costs. Adequate fertilizer will also lower nutrient losses to run-off or to the atmosphere.[73] To avoid excessive fertilizer or manure application, manure and annual soil tests are suggested (see point above). Realistic crop nutrient requirements and yield targets are also important. Applying fertilizers based on an unreasonable target yield will ensure loss of nutrients.[74]

IMMEDIATELY INCORPORATE FERTILIZER

Injecting or immediately incorporating broadcast fertilizers or manures will limit atmospheric losses. If injection or immediate incorporation is used, no volatilization losses are assumed. When fertilizer or manure is incorporated within 24 hours, the N loss can jump to 25 percent. For every additional day that fertilizer is not incorporated, approximately 5 percent N is lost. Up to 90 percent of applied broadcast fertilizer N can be lost within 5 days when environmental conditions are warm and dry.[75] This is extremely inefficient nutrient management for the farmer and it releases N gases to the environment.

OPTIMIZE FERTILIZER APPLICATION TIMING

Ideally, fertilizers should be applied when the crops require the nutrients. Spring-applied fertilizer is typically 20 percent more efficient than fall-applied. Spring applications will reduce the presence of nitrate-N during wet, spring-thaw conditions when denitrification, leaching and run-off potential is higher. Even though potential N loss exists with spring-thaw, late fall applications of fertilizer or manure are acceptable in the province, once the soil is cool and microorganisms are less active. In a practical sense, fertilizer application should not only be based on crop nutrient requirements and potential soil losses, but also on the farm management system. Fertilizer application that creates a good seed bed, conserves soil moisture, prevents soil erosion, permits efficient machinery operation, and maximizes returns to the farmer is also valued.[76]

USE PRECISION FARMING TECHNIQUES

Nutrient application is more efficient when using precision agriculture because the technology allows fertilizers to be applied only where they are needed and at the appropriate application rate.[77] Guidance systems, such as GPS (global positioning systems) and GIS (geographic information systems) decrease the amount of equipment overlap, reducing applied fertilizers and costs.

Manure Management

Because manure is such a volatile substance, many nutrients are easily lost and contribute to the high levels of nitrous oxide in the atmosphere. The following practices suggest some manure management adaptations that can further reduce GHG emissions from agriculture.

MANURE TESTING

Manure testing should be done routinely to determine the amount of plant-available nutrients, particularly N and P. Current legislation states that manure application be based on soil phosphorus levels. When soil Olsen-P levels are between 60 and 180 ppm, manure can be applied no more than five times the annual crop removal rate of phosphate (P_2O_5). Additionally, nitrate-N levels can be no more than 140 lbs per acre (157.1 kg/ha) of soil class 1 to 3.[78] Because both nutrient levels are important, manure testing is a cost-effective farming practice.

CALIBRATE APPLICATION EQUIPMENT

To ensure the target application rate of manure is applied, application equipment should be calibrated. For liquid manure, this can be done with drag-line or tanker application systems equipped with flow-rate monitors.[79] Spreading of solid manure is harder to accurately control. Manure testing should be done prior to application and spreading rates based on manure phosphorus levels. Manure spreaders should be properly maintained to ensure uniform spreading. Uniform spreading will lower risk of nutrient loss to the environment and is important for optimal crop response.[80]

ELIMINATE WINTER SPREADING

Winter manure application should be eliminated to prevent manure runoff at spring-thaw and to reduce spring-thaw N_2O emissions. Effective November 10, 2013, the spreading of livestock manure between November 10 and April 10 in Manitoba will be prohibited under The Environment Act: Livestock Manure and Mortalities Management Regulation, unless otherwise noted.[81 82] When manure is applied in the spring or after crop emergence, the developing crop uses the manure nutrients as they become plant-available. This minimizes the risk of loss to the environment.[83] Should moving manure during the winter be necessary, it is recommended that the manure be stockpiled in the field and spread following spring-melt.

Synthetic Fertilizers

Management practices directly related to synthetic fertilizer application continue to be adapted by industry to lower risk loss and reduce GHG emissions. The following suggestions are some forms of nutrient management practices that can enhance fertilizer use efficiency and limit GHG creation.

BAND YOUR FERTILIZER

The best method for applying N fertilizer to a crop is banding. Banding in or near the seed row ensures that the fertilizer is accessible to the crop roots when they need it most. When applied in a concentrated band, less fertilizer surface area is accessible to soil microorganisms, preserving the fertilizer in ammonium (NH_4^+) form for longer. This reduces leaching and denitrification potential. When banding is not possible, fertilizer should be incorporated into the soil shortly after application. In the case of perennial crops or winter wheat, where incorporated or injection is not an option, N fertilizer is best broadcast shortly before a rainfall.[84]

USE SLOW-RELEASE NITROGEN FERTILIZER

Slow release fertilizers do just that - release nutrients slowly over time, making N available to the crop when it is most needed. Crop roots develop slowly after seeding and slow-release fertilizers gradually break down, supplying nutrients in synchrony with crop growth. Fertilizer loss is lowered due to less leaching or denitrification risk because growing roots consume almost all N. Slow-release fertilizers are more expensive, so economics may limit their use to high value crops.[85]

USE UREASE INHIBITORS AND NITRIFICATION INHIBITORS

Urease inhibitors prevent volatilization of surface-applied area or UAN solutions. A nitrification inhibitor slows the conversion of ammonia-N to nitrate-N, keeping the fertilizer in an inaccessible form for a longer period of time. Urease and nitrification inhibitors reduce the risk of N losses from a variety of paths, including N_2O emissions from denitrification. Inhibitors are an affordable solution for farmers to improve the efficiency of N uptake when broadcast applications are necessary. [86]

Use Trees to Make Your Farm More Climate Friendly

Trees can be extremely valuable resources to farmers, although over the last couple decades many trees have been torn down on the Prairies to enlarge fields.

When trees are grown together with crops and livestock, as an integrated production unit, numerous benefits can be observed. Trees have been shown to indirectly increase crop yields, improve soil and water quality, increase biodiversity, reduce greenhouse gas (GHG) emissions, and increase carbon (C) sequestration.[87,88] Trees, shrubs, or bushes act as natural buffers, filtering the air and water, reducing blowing wind, and can even minimize the spread of air-born crop diseases and pests.[89] These plants can be easily incorporated onto your farm and are aesthetically pleasing, as well.

PLANT SHELTERBELTS

Shelterbelts consist of one or more rows of strategically planted trees and/or bushes. Traditionally, shelterbelts were found around farmyards to shelter farm buildings and livestock, but they are also now used along highways or between fields. The trees help reduce wind, limit soil erosion and nutrient loss, control and trap blowing snow and conserve water.[90] Crop yields can increase with the use of shelterbelts. Trees physically protect young plants and reduce moisture losses by protecting crops from drying winds, and. A 20 percent yield increase was observed for alfalfa planted beside a shelterbelt.[91]

Shelterbelts can also help fight climate change because they remove carbon dioxide (CO_2) from the atmosphere and store it as carbon. Studies at the Agroforestry Development Centre, formerly known as the Prairie Farm Rehabilitation Administration (PFRA) Shelterbelt Centre, show that the leaves and branches of a mature poplar tree can store about 970 kg of CO_2.[92] The leaves and branches alone can save the equivalent amount of driving a car approximately 4600 kilometres![93] Tree roots are thought to store 50 to 75 percent more C than that stored above ground.[94]

Despite the numerous benefits of shelterbelts, trees compete with crops for water and nutrients, and increase the amount of shade. With increasing equipment size and growing value of crops, Prairie farmers continue to push down shelterbelts to expand field size and increase land available for crop production.

PLANT RIPARIAN BUFFERS

Riparian buffers consist of trees, shrubs or grasses planted between cultivated crop land and a waterway, such as river, pond, or dugout. The main benefits of these buffers are to filter surface run-off before it enters the water, to protect water edges from erosion, and to sequester C.[95] Run-off may contain sediments, nutrients, and/or pesticides, which can be damaging to the water quality and the animals that live there.[96] Without adequate buffering areas, nutrient and sediment filtering cannot take place which encourages the eutrophication (algal blooms) and sedimentation of local waterways.[97]

Sheldon Wiebe: Inorganic Fertilizer Management

Sheldon Wiebe doesn't like to see fertilizer go to waste. He knows it's costly to him and to the environment. That's why he employs the latest technology to ensure he's applying the right amount of fertilizer to his soils at the right time of year.

First thing in spring, Sheldon hires a soil agronomist to test his soils at the 0–6 inch and 6–24 inch depths. "We GPS the point and go back to the same spot every year for the tests. It keeps a consistency from year to year. That way we can better tell if the soil is changing. And it means we don't put a blanket rate on every field," he says.

He soil tests throughout his McGregor farm's 800 acres of wheat, 800 acres of canola, and 1000 acres of potatoes. But for the potatoes he also goes one step further. He takes a petiole sample during the growing season to have analyzed for nutrient levels in the plant itself. That gives him an even better guide for fertilizing his potatoes.

The soil testing he's been doing for years. The GPS system he introduced in recent years. And this year he's going one step further.

Last year Sheldon used satellite imagery during the growing season to examine crop density. With that information in hand, he tested soil in areas of low density to determine nutrient levels. With the data inputted into his on-tractor GPS unit, he'll apply variable rates of fertilizer this spring.

He says the cost of soil testing based on these density zones will be a third of doing grid sampling because it requires much less labour. And applying variable rates of fertilizer makes economic sense too.

"Our application rates are different on different fields. Some fields may require more fertilizer but others less. It's better for the soil and better for the crop. We try to be very good stewards of the land. And it's just not cost effective to over-apply."

Sieg Peters: Manure Injection

As far as Sieg Peters is concerned, manure is a precious commodity. “We have a lot of land, so we want to get as much coverage out of our manure as possible,” he says. “We need the nitrogen so there’s no point losing half of it. That’s why we directly inject it into the ground.”

Sieg, who farms with his brother and their sons near Steinbach, was never that impressed with sprinkler systems. There was too much nitrogen loss. And the odours and view weren’t pleasant. So seven years ago he started hiring a custom applicator to come in and inject the manure directly—some of which is pumped through hoses from his storage lagoon three to four miles away.

As part of a large farm—they crop about 3000 acres, and have a 12,000 feeder hog operation—they use all the manure they produce. That means they’re reluctant to see any go to waste.

But the environment ranks high on their priorities too. “We know if we put it in the ground it’s less likely to leach off, to run off the field. That’s a huge consideration.”

CONSIDER ALLEY CROPPING

Alley cropping is a form of tree production that mixes trees with agricultural crops. The trees are planted in widely spaced rows with agricultural crops in alleys between the trees. The shelterbelts minimize soil erosion and nutrient loss, trap snow, and create warmer microclimates for crops.[98 99]

DIVERSIFY INTO AGRO WOODLOTS

Growing trees is becoming a popular way of bringing marginal land or small, irregular shaped sections of land into production. Fast growing wood crops, such as hybrid poplars, provide environmental benefits to the land, increasing soil organic matter and creating oxygen. Trees have high rates of nutrient uptake and can store large amounts of C over rotation lengths as short as 15 years. The Agro Woodlot Program of Manitoba recommends growing a combination of fast and slow growing trees to provide monetary benefits over a longer time.[100] Biomass from the trees can be used as timber or as an alternative fuel (bioenergy).

Cut Greenhouse Gas Emissions from Vehicles and Equipment

Farm practices that reduce the need for equipment and vehicles without productivity losses, have benefits for both farm budgets and the environment. Rationalizing the use of vehicles and equipment and making fuel-efficient choices will reduce GHG and improve profits. Enhancing the energy efficiency of farm homes and buildings can also reduce demand for fossil fuels. Some suggestions for alternative energy management are outlined below.

FUEL-SAVING STRATEGIES

Adopting fuel-saving strategies can be a huge step towards lowering GHG emissions from farms. In 2009, almost 5 percent of all GHGs created in Canada were from off-road gasoline and diesel transportation.[101] In 2003, Manitoba passed the Biofuels Act, mandating the availability of at least 8.5 percent of gasoline sold to be an ethanol blend. Similar legislation came into event for biodiesel in 2009, where 2 percent of all diesel fuel must be biodiesel.[102] Because agriculture is highly dependent on fuel consumption, using biofuels are already helping to reduce GHG emissions created by the province. The Biofuel Acts are thought to have reduced GHG emissions by the equivalent of taking more than 63,000 vehicles off the road every year.[103]

Regular machinery maintenance will ensure that equipment is operating at peak efficiency. Correct tire pressure can use up to 20 percent less fuel and improve productivity by more than 5 percent. Keeping fuel and air systems clean and selectively using the throttle during farm operations can also help with fuel efficiency. Reducing tillage or limiting field passes by performing multiple operations in one pass will reduce fuel consumption.[104] Limiting idling times will also save fuel and cut emissions.

BIOGAS USE

Biogas is the use of organic wastes to produce gas for generating heat and power. On-farm biogas production offers the benefits of nutrient management, odour control and pathogen reduction. However, current biogas technologies are expensive and not an easy alternative for most farmers. Research is being undertaken by the University of Manitoba to further education and implementation opportunities in the province. [105]

ENERGY EFFICIENCY FOR FARM BUILDINGS

Energy efficiency in farm homes, work sheds or barns can reduce energy demands, saving money and lowering carbon dioxide emissions. Farm yards can easily be protected from cold winter winds by shelterbelts or windbreaks, reducing heating costs by as much as 25 percent.[106] Alternate energy sources, such as geothermal heat, solar, wind, biogas or waste heat can also be used to heat farm buildings and lower heating demands.

TABLE 3: BEST MANAGEMENT PRACTICES FOR GREENHOUSE GAS REDUCTION

BEST MANAGEMENT PRACTICE	WHAT'S INVOLVED	GHG BENEFITS
NUTRIENT MANAGEMENT Nitrogen management	• Use pre-sidedress N test • Optimize N availability at key times of crop need and uptake ability • Test manure • Increase spring application, avoid fall/winter application • Credit N from other sources (e.g. cover crops, previous crops, legumes, manure) • Incorporate pre-plant applications within 1 day	• Minimize residual soil N • Reduces N inputs • Limits excess soil N, especially during spring and winter thaw when plant uptake does not occur • Reduces indirect N loss and atmospheric loss • Avoids over-application of N and excess soil N • Reduces direct N_2O loss
Livestock management	• Modify livestock rations to reduce dry matter	• Reduces CH_4^+, which is released as by-product of digestion
SOIL MANAGEMENT Buffer strips	• Establish buffers or enhance existing buffers with trees, shrubs and ground cover along field borders and stream banks	• Reduces indirect N losses (removes excess N from soil, reduces leaching) • Intercepts surface and ground water flow containing N compounds • Fixes carbon
Retirement of marginal land	• Plant marginal and fragile lands to permanent cover	• Removes soil from intensive cultivation • Eliminates nutrient inputs to land • Allows buildups of soil organic matter • Fixes carbon in the perennial vegetation before it reaches watercourses • Allows uptake of nutrients in buffer vegetation
Cover crops and crop rotations	• Maintain live cover crops over winter following high use N crops • Use crops with high N requirements after forages (e.g. corn), high N producing crops or residues	• Minimizes residual N • Reduces fertilizer requirements by accounting for precious crop N contributions
No-till and conservation tillage	• Practise no-till: leave residue on field surface until spring	• Increase soil organic matter • Reduces CO_2 loss • Sequesters carbon
MANURE MANAGEMENT	• Eliminate or minimize winter spreading of manure	• Reduces amount of excess N available during spring when potential N_2O losses are greatest
AGROFORESTRY • Windbreaks (<5 trees wide) • Shelterbelts (5 or more trees wide) • Riparian buffers (in stream banks and floodplain areas)	• Increase number, length, width, and tree species diversity • Practise good forest management and harvest selectively	• Fixes or "sequesters" carbon + requires no fertilization • Reduces indirect N losses • Can offset long-term sequestration costs (e.g. tree planting, removal of land from cultivation)

Source: Ontario Ministry of Agriculture, Food and Rural Affairs
100-year Global Warming Potential (GWP)

More Information

For more information on climate change and sustainable farming practices in Manitoba, please check out the following Web sites:

GOVERNMENT OF MANITOBA WEB SITES

Agricultural Sustainability Initiative
http://www.gov.mb.ca/agriculture/research/asi/index.html
The program provides funding to Manitoba producer groups and provincial commodity organizations to carry out sustainable agriculture demonstration or technology transfer projects throughout the province.

Beyond Kyoto – Province of Manitoba Climate Change Action Plan
http://www.gov.mb.ca/beyond_kyoto/index.html
Manitoba's plan for achieving our Kyoto commitments

Energy Development Initiative
http://www.gov.mb.ca/est/energy/index.html
Manitoba Energy, Science and Technology's guide to alternative energy, such as agri-energy, ethanol, and wind energy.

Environmental Farm Plan
http://www.gov.mb.ca/agriculture/soilwater/farmplan/fpp00s01.html
Environmental farm planning is a voluntary, self-assessment process designed to help farm managers identify the environmental strengths and weaknesses of their operations.

Manitoba Agriculture, Food and Rural Initiatives
http://www.gov.mb.ca/agriculture/index.shtml

OTHER USEFUL SITES

Agri-Environment Services Branch
http://www4.agr.gc.ca/AAFC-AAC/display-afficherdo?id=1187362338955&lang=eng
Guides to clean air, clean water, healthy soils and biodiversity.

Agroforestry Development Centre
http://www4.agr.gc.ca/AAFC-AAC/display-afficherdo?id=1186517615847&lang=eng
Shelterbelt research, programs and numerous resources.

C-CIARN Agriculture
http://www.c-ciarn.uoguelph.ca
Clearinghouse of current information on climate change risks and adaptation for the Canadian agri-food sector.

Climate and Farming
http://www.climateandfarming.org/index.php
Resource materials to help farmers make practical and profitable responses to climate changes.

Climate Change and Agriculture
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/cl9706
Alberta's guide to farming and climate change.

Climate Change Central
http://www.climatechangecentral.com
A public-private partnership based in Alberta that promotes the development of innovative responses to global climate change and its impacts.

Climate Change Connection
http://www.climatechangeconnection.org
Public education and outreach on climate change issues for Manitoba.

Manitoba Hydro – PowerSmart for Farms
http://www.hydro.mb.ca/your_business/farm/index.shtml
Information on energy efficiency for farm owners.

Manitoba Zero Tillage Research Association
http://www.mbzerotill.com
Farmer-directed research information on zero tillage production systems.

PAMI (Prairie Agricultural Machinery Institute)
http://www.pami.ca
An applied research, development, and testing organization serving manufacturers and farmers.

Soil Conservation Council of Canada
http://www.soilcc.ca
Wide-ranging producer information from the Greenhouse Gas Mitigation Program for Canadian agriculture, as well as soil conservation knowledge.

University of Manitoba - Natural Systems Agriculture
http://www.umanitoba.ca/outreach/naturalagriculture/index.html
Information on cropping systems based on processes found in nature - specifically the natural grassland ecosystem of prairie Canada.

References

*Intergovernmental Panel on Climate Change. 2011. Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA. Online: http://srren.ipcc-wg3.de/report

[1] Intergovernmental Panel on Climate Change. 2011. Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA. Online: http://srren.ipcc-wg3.de/report

[2] Intergovernmental Panel on Climate Change. 2011. Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA. Online: http://srren.ipcc-wg3.de/report

[3] Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., editors. 2008. From Impacts to Adaptation: Canada in a Changing Climate 2007. Government of Canada, Ottawa, ON. 448p

[4] MAFRI (Manitoba Agriculture, Food and Rural Initiatives). 2008. Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[5] Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4), Working Group 1 (WG1), Chapter 2, Changes in Atmospheric Constituents and in Radiative Forcing, Table 2.14, page 212. Online: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

[6] Environment Canada. 2012. National Inventory Report 1990-2009 Part 3: Greenhouse Gas Sources and Sinks in Canada. The Canadian Government's Submission to the UN Framework Convention on Climate Change. Online: http://ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1

[7] Environment Canada. 2012. National Inventory Report 1990-2009 Part 3: Greenhouse Gas Sources and Sinks in Canada. The Canadian Government's Submission to the UN Framework Convention on Climate Change. Online: http://ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1

[8] Environment Canada. 2012. National Inventory Report 1990-2009 Part 3: Greenhouse Gas Sources and Sinks in Canada. The Canadian Government's Submission to the UN Framework Convention on Climate Change. Online: http://ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1

[9] Environment Canada. 2012. National Inventory Report 1990-2009 Part 3: Greenhouse Gas Sources and Sinks in Canada. The Canadian Government's Submission to the UN Framework Convention on Climate Change. Online: http://ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1

[10] IISD (International Institute for Sustainable Development). 2010. The Manitoba Challenge: Linking Water and Land Management for Climate Adaptation. Online: http://www.iisd.org/publications/pub.aspx?pno=1220

[11] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[12] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[13] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[14] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[15] UNEP (United Nations Environment Programme). 1990. The Impacts of Climate Change on Agriculture. United Nations Environment Programme Information Unit for Climate Change Fact Sheet 101. Nairobi, Kenya: United Nations Environment Programme (UNEP) Information Unit for Climate Change (IUCC)

[16] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[17] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[18] [UNEP, 1990]

[19] Stock Seed Farms. 2011. Pasture and Forage Mixes. Online: http://www.stockseed.com/pasture_default.asp

[20] Botkin, D.B., Keller, E.A, and Heathcote, I.W. 2006. Environmental Science: earth as a living planet. Canadian Edition. John Wiley & Sons Cda, Ltd

[21] Science journal, June 30, 2006 issue, http://www.ars.usda.gov/is/pr/2006/060630.htm

[22] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[23] International Institute for Sustainable Development (IISD), 2010, The Manitoba Challenge: Linking Water and Land Management for Climate Adaptation. Online: http://www.iisd.org/publications/pub.aspx?pno=1220

[24] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[25] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[26] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[27] Sauchyn, D., and Kulshreshtha, S., (2008): Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., Government of Canada, Ottawa, ON. p. 275-328

[28] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[29] Murphy, D., McCandless, M., and Drexhage, J. 2010. Expanding Agriculture's Role in the International Climate Change Regime: Capturing the opportunities. International Institute for Sustainable Development, Winnipeg, MB. 36p

[30] Brady, N.C., and Weil, R.R. 2008. The Nature and Properties of Soil. Revised 14th Edition. Pearson Education Inc., Upper Saddle River, NJ, USA

[31] Brady, N.C., and Weil, R.R. 2008. The Nature and Properties of Soil. Revised 14th Edition. Pearson Education Inc., Upper Saddle River, NJ, USA

[32] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2011, Agro Woodlot Program. Online: http://www.gov.mb.ca/agriculture/woodlot/

[33] Brady, N.C., and Weil, R.R. 2008. The Nature and Properties of Soil. Revised 14th Edition. Pearson Education Inc., Upper Saddle River, NJ, USA

[34] Brady, N.C., and Weil, R.R. 2008. The Nature and Properties of Soil. Revised 14th Edition. Pearson Education Inc., Upper Saddle River, NJ, USA

[35] Brady, N.C., and Weil, R.R. 2008. The Nature and Properties of Soil. Revised 14th Edition. Pearson Education Inc., Upper Saddle River, NJ, USA

[36] Brady, N.C., and Weil, R.R. 2008. The Nature and Properties of Soil. Revised 14th Edition. Pearson Education Inc., Upper Saddle River, NJ, USA

[37] OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2001. Carbon Sequestration and Ontario Agriculture, Infosheet #2. Online: https://ospace.scholarsportal.info/bitstream/1873/8317/1/10298422.pdf

[38] OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2001. Carbon Sequestration and Ontario Agriculture, Infosheet #2. Online: https://ospace.scholarsportal.info/bitstream/1873/8317/1/10298422.pdf

[39] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[40] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[41] Murphy, D., McCandless, M., and Drexhage, J. 2010. Expanding Agriculture's Role in the International Climate Change Regime: Capturing the opportunities. International Institute for Sustainable Development, Winnipeg, MB. 36p

[42] 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, 2007a. "Agriculture" in: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press

[43] Murphy, D., McCandless, M., and Drexhage, J. 2010. Expanding Agriculture's Role in the International Climate Change Regime: Capturing the opportunities. International Institute for Sustainable Development, Winnipeg, MB. 36p

[44] SCCC (Soil Conservation Council of Canada). 2006. Greenhouse Gas Mitigation Program for Canadian Agriculture Soils and Nutrient Management Sector: Report to Canadian Producers. Indian Head, SK. Online: www.soilcc.ca/downloads/ggmp_section.pdf

[45] McConkey, B.G., Curtin, D., Campbell, C.A., Brandt, S.A., and Selles, F. 2002. Crop and Soil Nitrogen Status of Tilled and No-tillage Systems in Semiarid Regions of Saskatchewan. Canadian Journal of Soil Science, 82: 489-498.

[46] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html]

[47] SCCC (Soil Conservation Council of Canada). 2003. Global Warming and Agriculture: Best Management Practices for Coarse Grains. Vol.2. No.6. Indian Head, SK. Online: http://www.soilcc.ca/downloads/factsheets/Coarse percent20Grains percent20Eng6.pdf

[48] Brady, N.C., and Weil, R.R. 2008. The Nature and Properties of Soil. Revised 14th Edition. Pearson Education Inc., Upper Saddle River, NJ, USA

[49] SCCC (Soil Conservation Council of Canada). 2003. Global Warming and Agriculture: Best Management Practices for Coarse Grains. Vol.2. No.6. Indian Head, SK. Online: http://www.soilcc.ca/downloads/factsheets/Coarse percent20Grains percent20Eng6.pdf

[50] Malhi, S.S., Zentner, R.P., and Heier, K. 2002. Effectiveness of Alfalfa in Reducing Fertilizer N Input for Optimum Forage Yield, Protein Concentration, Returns and Energy Performance of Bromegrass-Alfalfa Mixtures. Nutrient Cycling in Agroecosystems, 62: 219-227

[51] Entz, M.H. 2011. Natural Systems Agriculture website. University of Manitoba. Online: http://umanitoba.ca/outreach/naturalagriculture/

[52] SCCC (Soil Conservation Council of Canada). 2000. Global Warming and Agriculture: The Carbon Cycle. Vol.1. No.2. Indian Head, SK. Online: http://www.soilcc.ca/downloads/factsheets/Factsheet percent202 percent20- percent20CO2.pdf

[53] SCCC (Soil Conservation Council of Canada). 2000. Global Warming and Agriculture: The Carbon Cycle. Vol.1. No.2. Indian Head, SK. Online: http://www.soilcc.ca/downloads/factsheets/Factsheet percent202 percent20- percent20CO2.pdf

[54] Brady, N.C., and Weil, R.R. 2008. The Nature and Properties of Soil. Revised 14th Edition. Pearson Education Inc., Upper Saddle River, NJ, USA.

[55] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[56] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[57] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[58] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html]

[59] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html]

[60] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html]

[61] Royer, F. and Dickinson, R. 1999. Weeds of Canada and the Northern United States. University of Alberta Press, Edmonton, AB. 434p.

[62] Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Aviles-Vazquez, K., Samulon, A., and Perfecto, I. 2006. Organic Agriculture and the Global Food Supply. Renewable Agriculture and Food Systems, 22: 86-108. Online: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=1091304&fulltextType=RA&fileId=S174217050
7001640

[63] Hoeppner, J.W., Entz, M.H., McConkey, B.G., Zentner, R.P., and Nagy, C.N. 2006. Energy Use and Efficiency in two Cnaadian Organic and Conventional Crop Production Systems. Renewable Agriculture and Food Systems, 21: 60-67. Online: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=692948&fulltextType=RA&fileId=S174217050600007X

[64] Dwwyor, L., Heise, E., Macey, A., Simmons, K., and Wallace, J. 2005. Gaining Ground – Making a Successful Transition to Organic Farming. Canadian Organic Growers, Ottawa, Ontario. 311p.

[65] Pimental, D., Hepperly, P., Hanson, J., Douds, D., and Seidel, R. 2005. Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. BioScience, 55: 573-582 Online: http://www.bioone.org/perlserv/?request=getabstract&doi=10.1641%2F0006-3568%282005%29055%5B0573%3AEEAECO%5D2.0.CO%3B2html

[66] Environment Canada. 2012. National Inventory Report 1990-2009 Part 3: Greenhouse Gas Sources and Sinks in Canada. The Canadian Government's Submission to the UN Framework Convention on Climate Change. Online: http://ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1

[67] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[68] Environment Canada. 2012. National Inventory Report 1990-2009 Part 3: Greenhouse Gas Sources and Sinks in Canada. The Canadian Government's Submission to the UN Framework Convention on Climate Change. Online: http://ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1

[69] Burton, D.L., Li, X. and Grant, C.A. 2008. Influence of fertilizer nitrogen source and management practices on N2O emissions from two Black Chernozemic soils. Can. J. Soil Sci. 88, 219-227.

[70] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[71] Manitoba Agriculture, Food and Rural Initiatives MAFRI. 2007. Manitoba Soil Fertility Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/nutrient/pdf/soil_fertility_guide.pdf

[72] Manitoba Agriculture, Food and Rural Initiatives MAFRI. 2007. Manitoba Soil Fertility Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/nutrient/pdf/soil_fertility_guide.pdf

[73] OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs). 2001. On-Farm Nutrients and Greenhouse Gas Opportunities for Ontario Agriculture, Infosheet #3. Online: https://ozone.scholarsportal.info/bitstream/1873/8069/1/10298452.pdf

[74] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[75] The Prairie Provinces' Committee on Livestock Development and Manure Management, 2004, Tri-Provincial Manure Application and Use Guidelines. Online: http://www.gov.mb.ca/agriculture/livestock/beef/pdf/baa08s01a.pdf

[76] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[77] SCCC (Soil Conservation Council of Canada). 2006. Greenhouse Gas Mitigation Program for Canadian Agriculture Soils and Nutrient Management Sector: Report to Canadian Producers. Indian Head, SK. Online: www.soilcc.ca/downloads/ggmp_section.pdf

[78] The Prairie Provinces' Committee on Livestock Development and Manure Management, 2004, Tri-Provincial Manure Application and Use Guidelines. Online: http://www.gov.mb.ca/agriculture/livestock/beef/pdf/baa08s01a.pdf

[79] MacLeod, C. 2005. Greenhouse Gas Mitigation Program – Canadian Pork Council. In: Advances in Pork Production, Vol 16., pg. 67. Online: http://www.banffpork.ca/proc/2005pdf/BO02-MacLeodC.pdf

[80] PPCLDMM (The Prairie Provinces' Committee on Livestock Development and Manure Management. 2004. Tri-Provincial Manure Application and Use Guidelines. Online: http://www.gov.mb.ca/agriculture/livestock/beef/pdf/baa08s01a.pdf

[81] Manitoba Government. 1998. The Environment Act (C.C.S.M. c. E125): Livestock Manure and Mortalities Management Regulation. Online: http://web2.gov.mb.ca/laws/regs/pdf/e125-042.98.pdf

[82] Manitoba Government. 2010. Recent changes to the Livestock Manure and Mortalities Management Regulation. Online: http://manure.mb.ca/projects/pdfs/Changes percent20to percent20LMMMR percent20- percent20ENG percent20June percent202010.pdf

[83] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[84] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html

[85] Havlin, J.L., Beaton, J.D., Tisdale, S.L., and Nelson, W.L. 2005. Soil Fertility and Fertilizers : An Introducation to Nutrient Management, 7th Ed. Pearson Education, Inc., Upper Saddle River, NJ. 515p.

[86] Havlin, J.L., Beaton, J.D., Tisdale, S.L., and Nelson, W.L. 2005. Soil Fertility and Fertilizers : An Introducation to Nutrient Management, 7th Ed. Pearson Education, Inc., Upper Saddle River, NJ. 515p.

[87] PFT (Private Forests Tasmania). 2007. Farm Shelter: Technical Information Sheet No.9, Level 2. Online: http://www.privateforests.tas.gov.au/files/active/0/9FarmShelter2.pdf

[88] ADC (Agroforestry Development Centre). 2010. Agroforestry – A Sink for Carbon. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1186580878442&lang=eng

[89] ADC (Agroforestry Development Centre). 2011. Shelterbelts – A Tool for Climate Change. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1198780151759&lang=eng.

[90] ADC (Agroforestry Development Centre). 2011. Shelterbelts – A Tool for Climate Change. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1198780151759&lang=eng.

[91] ADC (Agroforestry Development Centre). 2007. Livestock Benefit from Shelterbelts. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1192562636367&lang=eng

[92] ADC (Agroforestry Development Centre). 2011. Shelterbelts – A Tool for Climate Change. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1198780151759&lang=eng

[93] Rutland County Council. 2011. What's a Tonne of CO2? Online: http://www.rutland.gov.uk/climate_change/act_on_co2_and_your_footprint/whats_a_tonne_of_co2.aspx

[94] ADC (Agroforestry Development Centre). 2011. Shelterbelts – A Tool for Climate Change. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1198780151759&lang=eng.

[95] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html]

[96] ADC (Agroforestry Development Centre). 2010. Agroforestry – A Sink for Carbon. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1186580878442&lang=eng

[97] Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2008, Soil Management Guide. Online: http://www.gov.mb.ca/agriculture/soilwater/soilmgmt/index.html]

[98] ADC (Agroforestry Development Centre). 2010. Agroforestry – A Sink for Carbon. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1186580878442&lang=eng

[99] MAFRI (Manitoba Agriculture, Food and Rural Initiatives). 2011 Agro Woodlot Program. Online: http://www.gov.mb.ca/agriculture/woodlot/

[100] MAFRI (Manitoba Agriculture, Food and Rural Initiatives). 2011 Agro Woodlot Program. Online: http://www.gov.mb.ca/agriculture/woodlot/

[101] Environment Canada. 2012. National Inventory Report 1990-2009 Part 3: Greenhouse Gas Sources and Sinks in Canada. The Canadian Government's Submission to the UN Framework Convention on Climate Change. Online: http://ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1

[102] CRFA (Canadian Renewable Fuels Association). 2010. Growing Beyond Oil, Delivering Our Energy Future: A Report Card on the Canadian Renewable Fuels Industry. Online: http://www.greenfuels.org/uploads/documents/crfareportcardenglish2010final.pdf

[103] MAFRI. (Manitoba Agriculture, Food and Rural Initiatives). 2010. Growing Green: The Manitoba Bioproducts Strategy. Online: http://www.gov.mb.ca/agriculture/pdf/the_manitoba_bioproducts_strategy.pdf

[104] CFBF (California Farm Bureau Federation). 2011. Fuel Efficiency on the Farm. Online: http://www.cfbf.com/issues/energy/flex.cfm

[105] MAFRI. (Manitoba Agriculture, Food and Rural Initiatives). 2010. Growing Green: The Manitoba Bioproducts Strategy. Online: http://www.gov.mb.ca/agriculture/pdf/the_manitoba_bioproducts_strategy.pdf

[106] ADC (Agroforestry Development Centre). 2011. Shelterbelts – A Tool for Climate Change. Online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1198780151759&lang=eng

CLIMATE CHANGE CONNECTION
3RD FLOOR- 303 PORTAGE AVENUE
WINNIPEG, MB R3B 2B4

Tel: 204-943-4836 Fax: 1-866-237-3130
E-mail: climate.connection@mymts.net
Web site: www.climatechangeconnection.org