

Climate Change and Agriculture

[LIVING OFF THE LAND](#)
[GROWING EMISSIONS](#)
[AGRICULTURAL GHGS](#)

[IMPACTS ON AGRICULTURE](#)

[A DELICATE BALANCE](#)
[SIX MAJOR IMPACTS OF CLIMATE CHANGE](#)

[REDUCING AGRICULTURAL EMISSIONS](#)

[SOILS AS SINKS FOR CARBON](#)
[CARBON-FRIENDLY FARMING](#)
[BENEFITS BEYOND CLIMATE CHANGE](#)
[LESS NITROGEN IS BETTER](#)
[DOUBLE TROUBLE](#)
[FERTILE GROUNDS FOR CHANGE](#)
[LIVESTOCK AND GHG EMISSIONS](#)
[SOMETHING TO CHEW ON](#)
[NOTHING TO SNIFF AT](#)

[DOING OUR BIT](#)

CLIMATE CHANGE AND AGRICULTURE

Living Off the Land

A short drive outside any town or city in south-central Manitoba reveals where much of the province's wealth lies: in fertile farmland. Over 33,000 people are directly employed in Manitoba's agricultural industryⁱ. Another 18,300 Manitobans are employed indirectly by agricultureⁱⁱ. Farming, since the birth of our province, has continued to sustain and drive our economy.

Growing Emissions

Agriculture accounted for 33% of Manitoba's climate-changing emissions in 1999ⁱⁱⁱ. No one agricultural sector is solely responsible for these emissions. Livestock and crop production in Manitoba both contribute to climate change.

Agricultural GHGs

The most basic agricultural activities create climate-changing emissions. Clearing forests, draining wetlands, burning stubble, raising livestock and fertilizing with nitrogen all release GHG's into the atmosphere^{iv}. *Agriculture and Agri-Food Canada* has identified the three most important greenhouse gases produced by agriculture^v:

- **Carbon dioxide (CO₂)**: Massive global increases have been produced from the widespread combustion of fossil fuels and other materials. It is also released by natural processes such as plant and animal respiration, and the decay of organic matter. CO₂ is currently responsible for over 60% of the enhanced greenhouse effect.
- **Methane (CH₄)**: Methane is produced from the decay of organic matter without oxygen. Major sources include ruminant digestive processes, and manure storage and handling. Although there is less methane in the atmosphere, it is a more effective heat-trapping gas than CO₂.
- **Nitrous oxide (N₂O)**: Soil cultivation, fertilizer and manure application, and the combustion of fossil fuels and organic matter produce N₂O emissions. Soils and oceans naturally release N₂O. It is over 300 times more effective than CO₂ in greenhouse warming.

IMPACTS ON AGRICULTURE

A Delicate Balance

Agriculture on the Canadian Prairies is sensitive to the vagaries of climate. Throughout the history of Manitoba, droughts, floods, early frosts and hail have all taken their toll on crops and livestock^{vi}. It is not difficult to imagine that climate change will have a major impact the agriculture industry. **Climate change models predict an uncertain future for agriculture in Manitoba, with potential benefits offset by powerful drawbacks.**

Six Major Impacts of Climate Change^{vii}

1. More carbon dioxide.

Crop Productivity Boosted

Crop species vary in their response to carbon dioxide. C₃ plants such as wheat, rice and soybeans, respond readily to increases in CO₂. They step up photosynthesis rates, converting more CO₂ to sugars, starches and cellulose. Increased CO₂ also tends to suppress photo-respiration in these plants, making them more water-efficient^{viii}.

Corn, sorghum and millet, plus many pasture and forage grasses are C₄ plants^{ix}. They are less responsive to higher levels of CO₂.

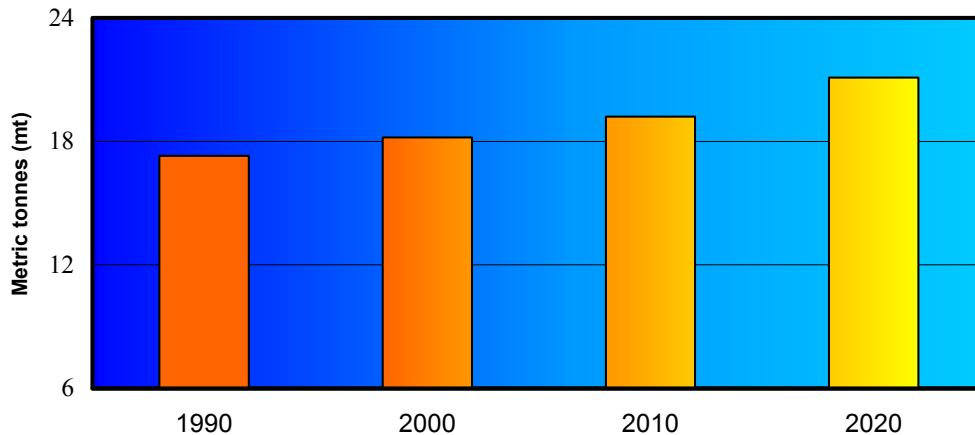


Figure 1: Past, present and projected future carbon dioxide emissions in Manitoba.
 Source: Natural Resources Canada.

2. Higher temperatures.

Growing Larger

At middle and higher latitudes, climate change will extend the growing season^x. Earlier planting and harvesting may allow for more than one cropping cycle per season. For every 1°C increase in average temperature, the growing season may lengthen by 10 days on the Canadian Prairies^{xi}.

Crop-producing areas may expand northward, though yields will be lower due to less fertile soils. Many crops are adapted to specific growing-season daylengths of middle and lower latitudes. These plants may respond poorly to the longer days of high-latitude summers.

Too Hot To Grow

At lower latitudes, increased temperatures may exceed optimal conditions for growth. In the same way that overheated people become sluggish and unproductive, plants respond with a steep drop in net growth and yield. High temperatures also accelerate development, resulting in early maturation and reduced yield.

Overheated Livestock

Livestock would also be more susceptible to the effects of high temperatures. Heat stressed dairy cattle produce less milk and are less fertile^{xii}. Hogs and fowl are especially susceptible to heat-related injury and death because they have no sweat glands. The demand – and cost - for water and cooling systems will grow.

Cows sweat at only 10 percent the rate of humans^{xiii}.

3. Less water.

Feast or Famine

Climate change models predict 10 to 20 percent declines in summer precipitation in Manitoba^{xiv}. What rain does fall will more likely be released during intense weather events. The duration of dry periods between deluges is predicted to increase^{xv}. Coupled with warmer temperatures, Prairie farmers can expect more droughts^{xvi}.

Thirsty Crops

In addition to rainfall, evaporation, runoff and soil moisture will also be influenced by climate change. Warmer temperatures will increase the rate of evapotranspiration, draining both the soil and crops of water. Wheat, corn and soybeans are very sensitive to moisture stress – particularly during flowering, pollination and grain-filling^{xvii}. A greater demand for irrigation would place a strain on limited water supplies and increase N₂O emissions.

4. Extreme weather events.

Hold on to Your Hat

Climate change will affect the frequency, severity and duration of extreme weather events^{xviii}. Spells of high temperature, heavy rainfall, high winds and droughts disrupt crop production. The *International Institute for Sustainable Development* has projected possible increases in the following weather events:

- prolonged heat spells
- thunderstorms and straight-line winds
- hailstorms
- tornadoes
- heavy rainfall
- intense winter storms.

Hail is the most destructive weather event in Canada, causing an average of \$450 million dollars a year in damage^{xix}.

Winds of Change

Long term changes in the pattern of water and air movement may change as the greenhouse gases alter the dynamics of the atmosphere. Major changes in atmospheric circulation could occur, altering storm tracks, rainfall distribution and wind patterns. In turn, climate change would affect the way that rivers and streams run. Lake levels would either rise or fall dramatically with alterations in input.

As greenhouse gas concentrations continue to rise – doubling, tripling and quadrupling current values – climate patterns would not have a chance to stabilize. **Climate-changing emissions would constantly alter the flow of air and water through the atmosphere.** Things would never be the same.

5. Soil fertility and erosion

Less Soil Organic Matter

Climate change will also impact soil quality. Warmer temperatures increase soil respiration^{xx}, speeding the natural breakdown of organic matter and other processes that affect fertility. Adequate soil organic matter is critical to fertility, water retention, crop production and carbon sequestration^{xxi}.

More chemical fertilization may offset soil quality losses, but at a cost to air and water quality. Nitrogen-based fertilizers are also a chief source of N₂O emissions, another important greenhouse gas.

The Root of the Problem

Plants take up nitrogen, a key nutrient, through their roots. Greater root development indicates healthy rates of nitrogen uptake. If soil moisture is not limiting, warmer air temperatures will increase nutrient uptake.

Unfortunately, climate change models predict hotter, dryer summers. Increases in evapotranspiration and evaporation will remove water from soil. Nitrogen uptake will be suppressed, slowing root growth and decomposition. Without the anchor of well-developed root systems, fertile Prairie soils will be more vulnerable to wind erosion. Dry spells broken up by heavy rainfall increase the likelihood of water erosion as well.

Yields from severely eroded soils may be 50-100% lower than those from stable soil in the same field^{xxii}.

6. Pests and diseases

What is Good for the Goose...

Agricultural pests, pathogens and weeds are all affected by climate^{xxiii}. Warming can affect the range of pest species, while extreme weather events provide opportunity for infestation^{xxiv}. They will respond in a variety of undesirable ways to climate change events:

1. **Longer growing seasons** – insects such as grasshoppers and flies will be able to complete a greater number of reproductive cycles during the spring, summer and autumn. Warm-season weed species may also benefit from balmy weather^{xxv}.
2. **Warmer winter temperatures** – the range of many pest species is limited by cold temperatures. With milder winters, larvae could survive overwintering, causing greater infestation the following spring.
3. **Altered wind patterns** – different wind patterns could change the spread of wind-borne pest insects, bacteria and fungi that cause crop and livestock disease.
4. **Elevated CO₂ levels** – crops aren't the only plants that will increase productivity. Many weed species would benefit from carbon dioxide fertilization.

Some 500 insect pests, 270 weed species and 150 plant diseases are now resistant to one or more pesticides^{xxvi}.

REDUCING AGRICULTURAL EMISSIONS

Soils As Sinks for Carbon

Carbon – in the form of organic matter – is a key element to healthy soil. Some of the carbon previously stored in fertile Manitoban soils has been lost. The conversion of natural habitats to cropland and pasture, and unsustainable land practices such as excessive tillage, frees carbon from organic matter, releasing it to the atmosphere as CO₂^{xxvii}. Depleted of organic carbon, soils develop a “carbon deficit”.

Soils can regain lost carbon by reabsorbing it from the atmosphere. This process is called “carbon sequestration”. Through photosynthesis, plants convert CO₂ to sugars, starch and cellulose, also known as carbohydrates. These are organic forms of carbon. In natural habitats, carbon from plants is deposited in the soil through roots and plant residues, such as fallen leaves.

Carbon-Friendly Farming

When crops are harvested, much of the carbon-containing plant mass is removed. How can farmers refill the soil carbon sink and still produce crops for food and industry?

The following farming practices can slow carbon loss and increase long-term soil organic carbon (SOC):

1. **Conservation tillage or no-till farming** - reduces soil disturbance and fossil fuel emissions from farm machinery^{xxviii}.
2. **Regrowth of native or perennial vegetation** – increases SOC in previously cultivated soils^{xxix}. Converted marginal croplands can also act as shelterbelts and oases of natural habitat.
3. **Reducing summer fallow** – continuous cropping leaves soils with a higher SOC than those with a high frequency of fallow^{xxx}.
4. **Including perennial forages** –they have longer growing seasons than annual crops. Regularly including perennial forages in crop rotations increases SOC^{xxxi}.

Benefits Beyond Climate Change

Many of these practices produce benefits beyond reducing GHG emissions and increasing SOC. They also contribute to environmental sustainability and economic savings. *Agriculture and Agri-Food Canada* have identified the extra perks of climate-friendly farming practices:

- Increased water conservation
- Reduced wind and water erosion

- Enhanced wildlife habitat and protection
- Increased biodiversity
- Reduced machinery use and fuel consumption
- Improved yields

Less Nitrogen is Better

Nitrogen (N) is the fourth most common element in living tissues and necessary for life^{xxxii}. Earth's atmosphere is 78% nitrogen (N₂). However, most plants and animals cannot use N gas directly from the air like oxygen or carbon dioxide. They must wait for nitrogen to be “fixed” – pulled from the air and bonded into molecules with hydrogen or oxygen – before they can use it^{xxxiii}.

Before human activities began to alter the release of nitrogen into the atmosphere, nitrogen was a rare and precious commodity. It served as an important limiting resource that controlled the biodiversity and function of many ecosystems^{xxxiv}.

Double Trouble

Nitrous oxide (N₂O) is a powerful greenhouse gas, with a global warming potential 310 times that of carbon dioxide^{xxxv}. **It also long-lived in the atmosphere, trapping Earth's heat for about 120 years once released.** It eventually converts to nitric oxide (NO), a gas that breaks down ozone (O₃) in the upper stratosphere. Ozone filters out harmful UV radiation from the sun.

Fertile Grounds for Change

Almost 70% of N₂O released is from agricultural activities^{xxxvi}. The inefficient use of nitrogen-based fertilizers is greatest source of GHG emissions. Plant uptake is often only 50% of the nitrogen (N) applied – a huge economic loss for producers^{xxxvii}. Such poor uptake is caused by leaching, runoff, erosion and gaseous emissions^{xxxviii}.

Timing and technique of fertilizer application can help dramatically reduce rates of N₂O release to the atmosphere^{xxxix}.

1. **Match fertilizer additions to plant needs** – apply just enough N so crops reach maximum yield without leftovers.
2. **Cut the poop** – heavily manured lands emit a lot of N₂O. Like nitrogen-based fertilizers, manure should be applied only as needed.
3. **Perfect timing**– fertilizers and manure should be applied as quickly as possible just prior to the maximum uptake by the crop^{xl}.
4. **Improve soil aeration** – the chemical reactions that produce N₂O occur in low-oxygen conditions. Managing soils prone to water logging, avoiding excess irrigation and using tillage practices that improve soil structure will reduce emissions.
5. **All fertilizers are not created equal** – some forms of fertilizers emit more GHG's than others. Anhydrous ammonia produces the highest emissions^{xli}, whereas forms containing NO₃ produce the lowest.
6. **Lime acid soils** - emissions can be suppressed by applying neutralizing lime to acid soils, which favour the production of N₂O.

Livestock and GHG Emissions

Methane is responsible for about 18% of the enhanced greenhouse effect^{xliii}. Its concentration in the atmosphere is increasing^{xliiii}. Although there is considerably less methane than CO₂ in the atmosphere, it is still a serious problem. **Methane is 21 times more effective than CO₂ at trapping heat.**

According to the *Intergovernmental Panel on Climate Change*, methane concentrations now are at their highest levels in 420 000 years.

Something to Chew On

The majority of methane emissions are from the digestive processes of ruminant livestock, such as cattle, sheep, buffalo and goats. These animals have a rumen or large “fore-stomach”. Microorganisms live in the rumen and break down food into nutrients the animal can absorb. This is called enteric fermentation. During microbial fermentation, methane is produced, which is exhaled or burped up by the animal.

A variety of climate-friendly livestock feed management practices decrease enteric methane production^{xliv}:

1. **High quality forages** –steers grazing on high-quality pasture emit 50% less methane than those feeding on matured pastures^{xlv}.
2. **Legumes in grazing rotations** – fewer methane emissions were observed from animals grazing alfalfa-grass pastures than grass-only pastures^{xlvi}.
3. **Feed additives** –use of ionophores can reduce methane emissions by 28%^{xlvii}, but only in the short-term, as digestive microbes adapt to the additives.
4. **Adding fat to grain diets** – methane emissions can drop by one-third when canola oil is added to feed^{xlviii}. However, fat should not comprise more than 5% of the diet. Too much fat depresses fibre digestion.
5. **Feed and animal management** –methane released from an animal represents lost energy. Improved efficiency reduces methane emissions and improves a farm’s bottom line:
 - Rotational grazing instead of continuous grazing
 - Penning and grouping strategies to meet nutrient needs (age, sex, etc.)
 - Grinding and pelleting food
 - Use of high grain to forage ratios
 - Formulate diets to avoid overfeeding and underfeeding of nutrients
 - Adjust diet to life cycle stage to reduce excess nutrients and manure volume.

Nothing to Sniff At

Manure in storage and on land is also a significant source of methane emissions. If manure decomposes in the absence of oxygen – such as in stockpiling or liquid storage – much of the carbon in the manure

is converted to methane gas^{xlix}. When oxygen is present, decomposing manure releases nitrous oxide (N₂O), another potent greenhouse gas.

**A full-grown pig produces 4.5 kg or 10 lbs of manure a day,
while a cow produces 54.5 kg or 120 lbs!**

Manitoba's livestock industry is growing. The sale of Manitoban hogs alone increased from 4.3 million to 5.3 million head from 1999 to 2000. To do their bit, farmers can use the following management options to reduce methane and nitrous oxide emissions from manure^{li}:

1. **Reduced dietary protein** – about 50% of the total nitrogen excreted by pigs can be reduced by adjusting amino acid composition of the diet^{lii}.
2. **Improved feed efficiency** – better quality nutrition means less manure and less nitrogen excreted in the manure. Easy as pie...
3. **Manure handling systems** – liquid or slurry systems support anaerobic (oxygen-free) decomposition, producing more methane than other systems.
4. **Manure storage systems** – composting is the most climate-friendly method of storing manure. It emits up to 17 times less GHG's than slurry storage, and 2-3 times less than stockpiling.
5. **Type of land application** – Injecting manure directly into the soil or cultivating directly after surface spreading reduces nitrogen release compared to other application techniques.^{liiii}

DOING OUR BIT

Over one third of Manitoba's greenhouse gas emissions are produced by agricultural activities. These emissions will ultimately force farmers to change the way they produce food and agricultural products. As the climate changes, Manitoban farmers will have to adapt to new conditions – for better or for worse.

To avoid such a scenario, Manitobans must do their bit to reduce climate-changing emissions from the agriculture sector today. It is far easier to make sustainable farm management choices now instead of waiting for the inevitable losses that will accompany a changing, unpredictable climate.

Rachel Van Caesele. September 2002.



-
- ⁱ Manitoba Agriculture and Food. 2001. Impact of Agriculture on the Provincial Economy. Manitoba Agricultural Review. 4 pp.
- ⁱⁱ IBID.
- ⁱⁱⁱ <http://www.gov.mb.ca/conservation/climatechange/inventory/overview.html>
- ^{iv} Rosenzweig, C and D, Hillal. 1995. Potential impacts of climate change on agriculture and food supply. Consequences, 1(2): 1-11.
- ^v Agriculture and Agri-Food Canada. 2000. Agricultural Greenhouse Gases. Environment Bureau. 2 pp. http://www.agr.gc.ca/policy/environment/eb/public_html/ebe/c_gases.html
- ^{vi} Chiotti, Q., A. Tyrchniewicz and M.Meyer. 1997. Agriculture and Climate Change: A Prairie Perspective. A Working Paper of the International Institute for Sustainable Development. 22 pp.
- ^{vii} Rosenzweig, C and D, Hillal. 1995. Potential impacts of climate change on agriculture and food supply. Consequences, 1(2): 1-11.
- ^{viii} UNEP. 1990. The impacts of climate change on agriculture. United Nations Environment Programme Information Unit for Climate Change Fact Sheet 101. UNEP Information Unit for Climate Change.
- ^{ix} IBID.
- ^x Keeling, C.D., J.F.S. Chin and T.P. Whorf. 1996. Increased activity of northern vegetation inferred from atmospheric CO₂ measurements. Science, 382:146-149.
- ^{xi} UNEP. 1990. The impacts of climate change on agriculture. United Nations Environment Programme Information Unit for Climate Change Fact Sheet 101. UNEP Information Unit for Climate Change.
- ^{xii} Keown, J.K. and R.J. Grant. 1991. How to reduce heat stress in cattle. NebGuide G91-1063-A. Institute of Agriculture and Natural Resources and the University of Nebraska-Lincoln.
- ^{xiii} IBID.
- ^{xiv} Manitoba Clean Environment Commission. 2001. Manitoba and Climate Change: A Primer. International Institute for Sustainable Development. 28 pp.
- ^{xv} IBID.
- ^{xvi} Williams, G.D.V., R.A. Faultey, K.H. Jones, R.B. Stewart and E.E. Wheaton. 1988. Estimating the effects of climatic change on agriculture in Saskatchewan. In The Impacts of Climatic Variations on Agriculture, Vol. I: Assessments in Cool, Temperate and Cold Regions. Eds. Parry, M.L., T.R. carter and N.T. Konjin. Academic Publishers, Dordrecht. Pp. 219-379.
- ^{xvii} Rosenzweig, C and D, Hillal. 1995. Potential impacts of climate change on agriculture and food supply. Consequences, 1(2): 1-11.
- ^{xviii} Herrington, R. et al. 1999. Prairie Adaptation: Background, Prairie Adaptation Research Co-operative.
- ^{xix} Street, R., D. Elkins and D. Phillips. 1997. Weather Impacts in Canada. Workshop on the Social and Economic Impacts of Weather. Boulder, Colorado.
- ^{xx} Keeling, C.D., J.F.S. Chin and T.P. Whorf. 1996. Increased activity of northern vegetation inferred from atmospheric CO₂ measurements. Science, 382:146-149.
- ^{xxi} Schlesinger, W.H. 2000. Carbon sequestration in soils: Some cautions amidst optimism. Agriculture, Ecosystems and Environment, 82:121-127.
- ^{xxii} Wall et al. 1995.
- ^{xxiii} Epstein, P.R. 2000. Global Warming: Health and Disease. Campaign for Climate Change, World Wildlife Fund.
- ^{xxiv} IBID.
- ^{xxv} Shriner, D.S. and R.B. Street. 2000. The Regional Impacts of Climate Change: North America. Intergovernmental Panel on Climate Change.
- ^{xxvi} UNEP. 2002. North America, Past and Present: 1972 to 2002. Fact Sheet. Global Environment Outlook-3.
- ^{xxvii} Rosenzweig, C and D, Hillal. 1995. Potential impacts of climate change on agriculture and food supply. Consequences, 1(2): 1-11.
- ^{xxviii} Schlesinger, W.H. 2000. Carbon sequestration in soils: Some cautions amidst optimism. Agriculture, Ecosystems and Environment, 82:121-127.
- ^{xxix} Janzen, H.H., C.A. Campbell, R.C. Izaurralde, B.H. Ellert, N. Juma, W.B. McGill and R.P. Zentner. 1998. Management effects on soil C storage on the Canadian Prairies. Soil and Tillage Research, 47:181-195.
- ^{xxx} Juma, N.G., R.C. Izaurralde, J.A. Roberston, and W.B. McGill. 1997. Crop yield and soil organic matter trends over 60 years in a typical Cryoboralf at Breton, Alberta. In Soil Organic Matter in Temperate Agroecosystems: Long-Term Experiments in North America. Eds. Paul, E.A., K. Paustian, E.T. Elliott and C.V. Cole. Lewis Publishers, CRC Press, Boca Raton, Florida. Pp. 273-281.
- ^{xxxi} Janzen, H.H., C.A. Campbell, R.C. Izaurralde, B.H. Ellert, N. Juma, W.B. McGill and R.P. Zentner. 1998. Management effects on soil C storage on the Canadian Prairies. Soil and Tillage Research, 47:181-195.
- ^{xxxii} Vitousek, P.M., J. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger and G.D. Tilman. 1997. Human Alteration of the Global Nitrogen Cycle: Causes and Consequences. Issues in Ecology, 1: 1-15.
- ^{xxxiii} IBID.

^{xxxiv} IBID.

^{xxxv} Janzen, H.H., R.L. Desjardins, J.M.R. Asselin and B. Grace. 1998. The Health of Our Air: Towards Sustainable Agriculture in Canada. No. 1981/E. Research Branch, Agriculture and Agri-Food Canada.

^{xxxvi} IBID.

^{xxxvii} FAO and IFA. 2001. Global Estimates of Gaseous Emissions of NH₃, NO and N₂O from Agricultural Land. International Fertilizer Industry Association and the Food and Agriculture Organization of the United Nations. Rome. 105 pp.

^{xxxviii} IBID.

^{xxxix} Janzen, H.H., R.L. Desjardins, J.M.R. Asselin and B. Grace. 1998. The Health of Our Air: Towards Sustainable Agriculture in Canada. No. 1981/E. Research Branch, Agriculture and Agri-Food Canada

^{xl} FAO and IFA. 2001. Global Estimates of Gaseous Emissions of NH₃, NO and N₂O from Agricultural Land. International Fertilizer Industry Association and the Food and Agriculture Organization of the United Nations. Rome. 105 pp.

^{xli} IBID.

^{xlii} Lockyer, D.R. 1997. Methane emissions from grazing sheep and calves. *Agriculture, Ecosystems and Environment*, 66:11-18.

^{xliii} Rodhe, H. 1990. A comparison of the contribution of various gases to the greenhouse effect. *Science*, 248:1217-1219.

^{xliv} Wittenberg, K. and D. Boadi. 2001. Reducing Greenhouse Gas Emissions from Livestock Agriculture in Manitoba. Manitoba Climate Change Task Force, Public Consultation Sessions.

^{xlv} Boadi, D., K.M. Wittenberg and W.P. McCaughey. 2000. Effect of energy supplementation on methane production in grazing steers. *Proceedings of Forage-Ruminant Workshop, Winnipeg, July 20-21, 2000.*

^{xlvi} McCaughey, W.P., K. Wittenberg, and D. Corrigan. 1999. Impact of pasture type on methane production by lactating beef cows. *Canadian Journal Animal Science*, 79: 221-226.

^{xlvii} Kinsmen, R.G., F.D. Sauer, H.A. Jackson, H.K. Patni, D.I. Masse, M. Wolynetz and J.A. Munroe. 1997. Methane and carbon dioxide emissions from lactating Holsteins. Dairy and Research Report, Centre for Food and Animal Research, Agriculture and Agri-Food Canada.

^{xlviii} Mathison, G.W., T.A. McAllister, K.J. Cheng, Y. Dong, J. Galbraith and O. Dmytruk. 1997. Methane emissions from farm animals. *Workshop on Greenhouse Gases Research in Agriculture, Saint-Foy, March 12-14.*

^{xlix} Wittenberg, K. and D. Boadi. 2001. Reducing Greenhouse Gas Emissions from Livestock Agriculture in Manitoba. Manitoba Climate Change Task Force, Public Consultation Sessions

^l *Livestock Waste Facilities Handbook*. 1985. Midwest Plan Service #18.

^{li} Wittenberg, K. and D. Boadi. 2001. Reducing Greenhouse Gas Emissions from Livestock Agriculture in Manitoba. Manitoba Climate Change Task Force, Public Consultation Sessions

^{lii} Pomar, C. 1998. Potential for reducing GHG emissions from domestic monogastric animals. *Agriculture and Agri-Food Table Climate Change Workshop*. Montreal, November 12-14.

^{liii} Janzen, H.H., R.L. Desjardins, J.M.R. Asselin and B. Grace. 1998. The Health of Our Air: Towards Sustainable Agriculture in Canada. No. 1981/E. Research Branch, Agriculture and Agri-Food Canada.