GREENHOUSE GASES AND CARBON SEQUESTRATION: WHERE THEY FIT WITH THE FERTILIZER INDUSTRY

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Background – Climate Change and the Kyoto Protocol

Few things elicit more debate than the weather, and whether it is changing. Farmers in Nebraska are fully convinced that global warming is real, while farmers in Michigan and Ontario aren't nearly as sure after this growing season. I am not going to debate whether climate change is real, or whether it is good or bad, but rather provide some background on the whole issue and how farmers and the fertilizer industry may be affected.

Current scientific consensus is that greenhouse gas levels in the atmosphere are increasing, and this either is, or has the potential to, increase the mean global temperature. International agreements to stabilize emissions of greenhouse gases were first made in 1992 at the Earth Summit in Rio de Janiero. These had little effect, and more binding agreements were made in Kyoto in 1997.

The Kyoto protocol includes specific targets for greenhouse gas emissions, intended to reduce global GHG emissions to 5.2% below 1990 levels by 2012. The target for the USA is for a 7% reduction, while Canada's target is a 6% reduction. Both countries have signed the Kyoto protocol, but neither has formally ratified the treaty.

As with any international agreement, the hardest part is working out the myriad details of exactly how the agreement will be interpreted, and what actions will be considered as appropriate in carrying out the intent of the treaty. In the case of the Kyoto protocol, the most hotly contested issue is whether the sequestration of carbon in agricultural soils to offset other GHG emissions is acceptable or not. I will stick my neck out and speculate that, if C sequestration in agricultural soils is not officially recognized by the signatories to Kyoto, both countries will declare their intention to meet the Kyoto targets, but including carbon sequestration in the calculations.

Greenhouse Gases and Emissions

What are Greenhouse Gases?

The greenhouse effect, or radiative forcing, is necessary for life on earth. Solar energy that is intercepted by the earth is radiated back towards space as infrared radiation (heat). The greenhouse gases in the atmosphere trap some of this infrared radiation and reflect it back to the earth. It has been calculated that the mean global temperature without radiative forcing would be about -18°C. The current concern is that the level of GHG's in the atmosphere is increasing to the point where unacceptable climate change will occur.

There are three gases responsible for the majority of radiative forcing: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Other gases such as chlorinated flourocarbons (CFC's, HCFC's) play a minor role as GHG's, but are not important in agriculture. The importance of each gas in climate change is calculated from the potential for each gas to trap infrared radiation, and the residence time of each gas in the atmosphere. To provide a comparable measure of the global warming potential from each gas, they are often expressed as carbon equivalents. Methane has 21 times the global warming potential of carbon dioxide, and nitrous oxide is 310 times as potent as carbon dioxide.

Total Emissions

The greenhouse gas present in the greatest quantity is carbon dioxide (Figure 4). Concentration of carbon dioxide in the atmosphere has increased from a pre-industrial concentration of 280 parts per million by volume (ppmv), to a current concentration of 358 ppmv (US-EPA, 2000). Combustion of fossil fuels is the largest source of carbon dioxide, for power generation, transportation, and domestic and industrial uses (Figure 1). Total North American emissions of carbon dioxide in 1997, the most recent year with complete statistics, were 1646 million metric tonnes of carbon equivalents. This is a 5% increase from 1990.

Methane is the second most common greenhouse gas, representing about 27% of the total North American emissions on a Carbon equivalent basis. Methane is produced in the anaerobic digestion of organic materials, so while the largest single source is from landfills, there are significant emissions from the energy industries (coal mines, and incomplete combustion of fossil fuels), and from agriculture (enteric fermentation in ruminant livestock, manure storage, and rice paddies) (Figure 2).

Nitrous oxide makes up a small, but increasing, part of the total greenhouse gases. Atmospheric concentrations of nitrous oxide are about a thousand times less than carbon dioxide. The largest source of nitrous oxide is from agriculture, both from denitrification in soils, and from manure (Figure 3).

There are a number of other greenhouse gases. Water vapour is actually a greenhouse gas, but it is not normally considered in the global warming equation because man's impact on water evaporation is relatively small. The whole family of halocarbon compounds are greenhouse gases, but are released in very small quantities so their total effect is small. In addition, these compounds are already being reduced in the environment because of their detrimental effect on the ozone layer.

GHG Emissions from Agriculture

The pattern of greenhouse gas emission from agriculture is quite different from the total emissions. Methane is by far the largest agricultural emission, followed by nitrous oxide, and the net emission of carbon dioxide is a small part of the total (Figure 5).

Agriculture is both a source and a sink for carbon dioxide. The breakdown of soil organic matter, and the respiration of plants and animals, both release carbon dioxide into the air. On the other hand, photosynthesis fixes carbon dioxide out of the air and converts it into organic matter. The balance of these sources and sinks determines whether agriculture is a net source or sink of CO_2. While it is likely that agriculture was a net source when the virgin soils were first cultivated, and organic matter levels began to decline, agricultural soils are now considered to be a minor source of carbon dioxide at most. There is considerable discussion about the potential use of agricultural soils to sequester carbon dioxide. The emission of carbon dioxide from the burning of fossil fuels as part of agricultural production is normally included with the energy sector's totals, rather than agriculture's.

Methane emissions from agriculture are chiefly from enteric fermentation, animal waste and rice paddies, with a smaller amount from crop residue burning. Growing plants have been observed to absorb and oxidize a significant amount of methane, and can represent a large sink for this particular GHG (Robertson et al, 2000).

Nitrous oxide emissions come primarily from the application of nitrogen fertilizers, both synthetic and organic, to agricultural soils. Nitrous oxide (N_2O) is one of the natural byproducts of denitrification, and as the amount of nitrate in the soil increases, the probability of N_2O release also increases. The average release of N_2O is about 1.25% of the total nitrogen applied as fertilizer or manure (US-EPA, 2000), although measured releases of N_2O have varied by more than an order of magnitude in either direction from this figure. Soil conditions, and particularly how aerobic or anaerobic the soil is, will have a significant impact on the release of N_2O. A Scottish study found a ten fold increase in N_2O emissions from the furrows in a potato field than from the adjacent ridges (Smith et al, 1997). There is also a significant seasonal effect on N_2O emissions, particularly in soils subject to freezing. In one study, between 40 and 75% of the annual flux of N_2O occurred immediately following the spring thaw, although the mechanism causing this flux is unclear (Wagner-Riddle et al, 1997).

Uncertainties in Emission Estimates

The science of measuring greenhouse gas emissions is, relatively speaking, in its infancy. Carbon dioxide emissions can be measured with the greatest precision, both because there is a widespread network of measuring sites, and because it is relatively simple to calculate carbon dioxide emissions from a mass balance. Methane measurements are less certain, and actual nitrous oxide emissions have been estimated to vary by more than ten times the mean (US-EPA, 2000).

Adding to this is the uncertainty about the effectiveness of the various reduction options. Much of the assessment of various options is done through empirical models. These models are only as good as the coefficients used, which range from accurate measurements to educated guesses. It will be a challenge to direct a politically driven process so that it is flexible enough to accommodate advances in the science of GHG measurement and reduction.

Options for Greenhouse Gas Emission Reduction

Many of the options for GHG reduction will focus on the major sources of carbon dioxide: transportation, power plants and industrial sources. I will focus, instead, on the potential reductions which will directly affect agriculture, and, in particular, crop production. In assessing any GHG reduction strategy, it is important to look at the net effect of the strategy on all the greenhouse gases.

Nitrogen Rates:
With the link between nitrogen application and nitrous oxide emission, the simplest way to reduce N_2O would be to limit nitrogen fertilizer rates. This could also have significant detrimental impacts on the production of many crops, and result in much less fixation of carbon dioxide because of reduced crop growth. The reduction of N_2O release does, however, provide an additional reason to target the optimum nitrogen fertilizer rate rather than applying "insurance" rates of nitrogen fertilizer.

Nitrogen Timing:
Nitrogen which is part of living plant tissue is not available to be lost as nitrous oxide, so applying nitrogen fertilizer as close as possible to the time of plant uptake should reduce the amount of soil nitrate that could be denitrified. With the large fluxes recorded at spring thaw (Wagner-Riddle et al, 1997), it appears that eliminating the fall application of both manure and nitrogen fertilizer would significantly reduce the emission of N_2O.

Increased use of Organic Nitrogen Sources:
Increasing the inclusion of legume crops in the rotation has the potential to reduce the emission of nitrous oxide by reducing the application of nitrogen fertilizers, as well as increasing the opportunity for sequestering carbon in the soil. This will only be effective, of course, if it is actually accompanied by a decrease in fertilizer rates. On the other side of the balance, there is a greater risk of nitrification late in the season, after crop uptake of N has slowed or stopped, from organic sources of N. This late season nitrate could contribute to an early spring flush of nitrous oxide.

Remove Marginal Land from Agricultural Production:
The greatest net reduction in GHG emissions occurred when agricultural soils were retired from production and planted to permanent cover (sod and/or trees) (Robertson et al, 2000). This resulted from increased tie-up of carbon dioxide in the biomass, increased absorption of methane, and reduced emission of N_2O because of lower fertilizer rates. It is important to note that the net absorption of GHG's slowed as the permanent cover matured, and reached a new equilibrium.

Ruminant Diets:
Methane release from ruminant livestock can be reduced by increasing the digestibility of the diet. This can be achieved by increasing the energy content of the diet by adding grains or edible oils, harvesting the forage portion of the diet at an earlier stage, and using ionophores to change the rumen bacterial population (Jantzen et al, 1998)

Biomass Fuels:
Replacing fossil fuels with newly fixed carbon sources short circuits the increase in carbon dioxide by recycling the CO_2 back into more plant tissue. Net CO_2 emissions from using 10% ethanol-blended gasoline have been shown to be about 3% less than from burning regular unleaded fuel (Jantzen et al, 1998). Most ethanol produced today is from high starch materials, but research is underway on using cellulosic materials to produce ethanol or methanol.

Carbon Sequestration:
Most of our agricultural soils have lost a large proportion of the organic matter that was present when they were first cultivated, and have reached a new equilibrium. By reducing the amount and intensity of tillage, there is potential to increase the amount of soil organic matter, and sequester carbon in the soil, and such increases have been measured quite consistently (Paustian et al, 1997). Adjusting the crop rotation to include more high-residue producing crops, or more cover crops, also increased the amount of soil carbon. It is important to remember, however, that the level of soil organic matter will only increase until a new equilibrium is reached. There will not be an indefinite increase in soil organic matter.

Carbon Credit Trading:
If it is uncertain whether carbon sequestration in agricultural soils will be acceptable under Kyoto, it is even less certain if the trading of Carbon Emission Credits will be recognized. Nonetheless, a consortium of Canadian energy companies have undertaken a project to buy carbon credits from farmers in Iowa. (GEMCo, 1999) The basis of carbon trading is that reductions in GHG emissions purchased from farmers can be used to offset the GHG emission by the purchaser. In other words, it is cheaper to pay farmers to sequester carbon than for the energy companies to reduce outputs. The current value of carbon credits is $1 to $3 per acre, although that could rise to $3 to $4 per acre if a good benchmarking system is developed (NACD, 2000).

There are several questions about carbon credit trading, beyond the uncertainty whether it will be accepted by the international community. Who has control over the carbon, and what are the consequences if a no-till field gets plowed up? What level of precision is there in the measurement of soil carbon? What are the precise impacts of increased carbon sequestration on the emission of other greenhouse gases? And looking beyond the immediate monetary benefit, I am concerned that farmers may have used up their most economical GHG reduction, and still be called on to meet GHG reduction targets from the rest of their operations. Carbon credit trading is certainly worth investigating, but it should not be approached blindly.

Impacts on Agriculture and the Fertilizer Industry

Predicting the impacts of GHG reductions, with the current level of knowledge, is a bit like shoveling fog. It is certain, however, that there will be an impact. There will certainly be pressure to reduce nitrogen fertilizer rates, which will affect the whole supply chain from the manufacturer to the farmer. There will also be pressures on the manufacturers to tighten up their procedures to reduce the emission of GHG's during the manufacturing process. Offsetting this will be opportunities at the retail end for supplying agronomic services to help the farmer fine-tune his rates.

A much larger impact on the fertilizer industry would come from a ban on fall nitrogen application. The capitalization required for new anhydrous storage, transportation and application would certainly increase the price of fertilizer, to the point that trying to reduce rates would not be a problem.

The other options for GHG reductions would have mixed effects on agriculture and the fertilizer industry. Options which favor the reduction in grain acres (increased use of legume N, retirement of marginal land) could be offset by options which encourage the production of more grain (increased energy in ruminant diets, more use of ethanol). As with any change, it will be important to assess the dominant influences in the marketplace, and act accordingly.

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Figure 1

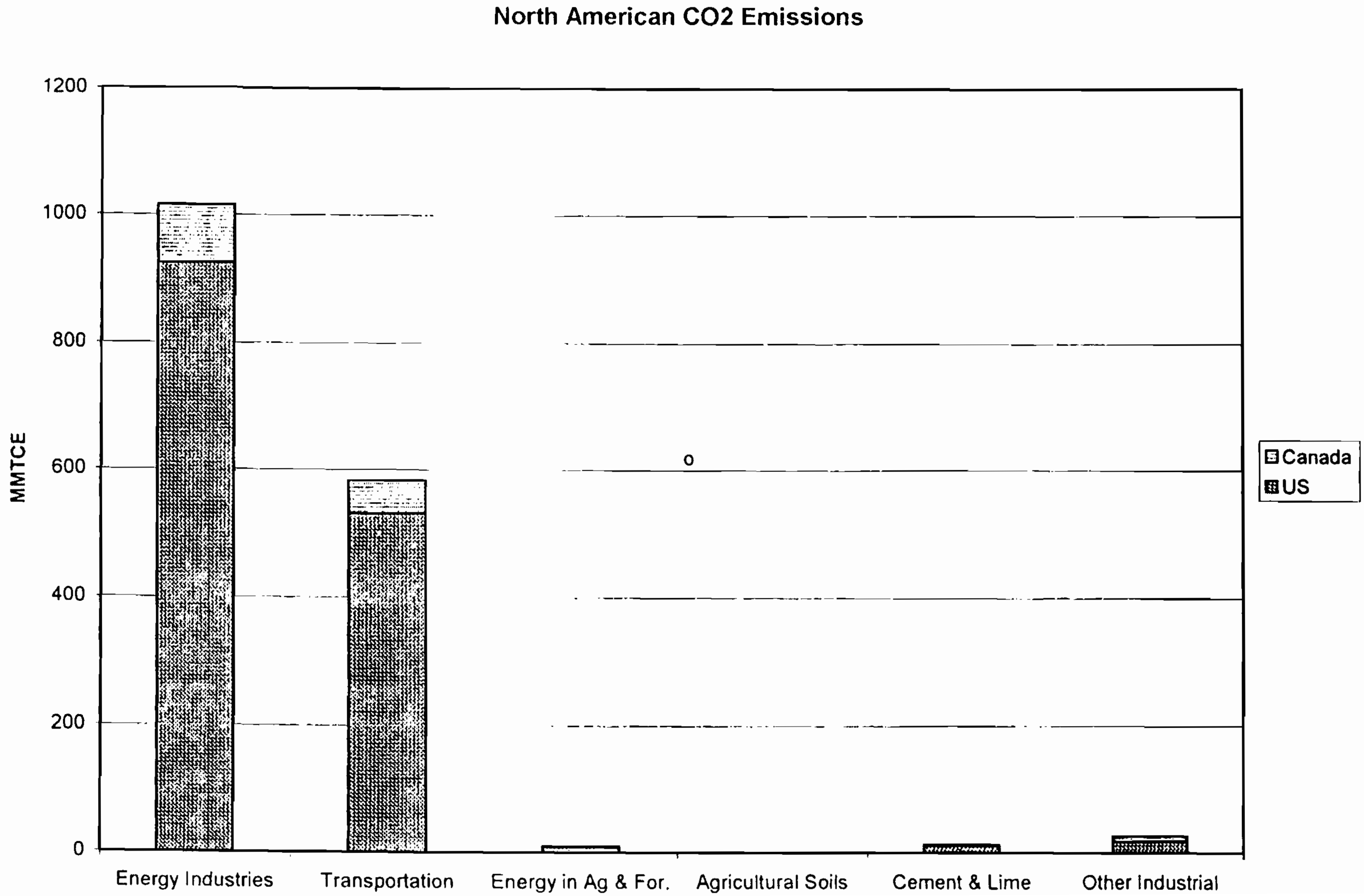

North American CO2 Emissions
MMTCE
1200
1000
800
600
400
200
0
o
Energy Industries
Transportation
Energy in Ag & For.
Agricultural Soils
Cement & Lime
Other Industrial
Canada
US

Figure 2

North American CH4 Emissions

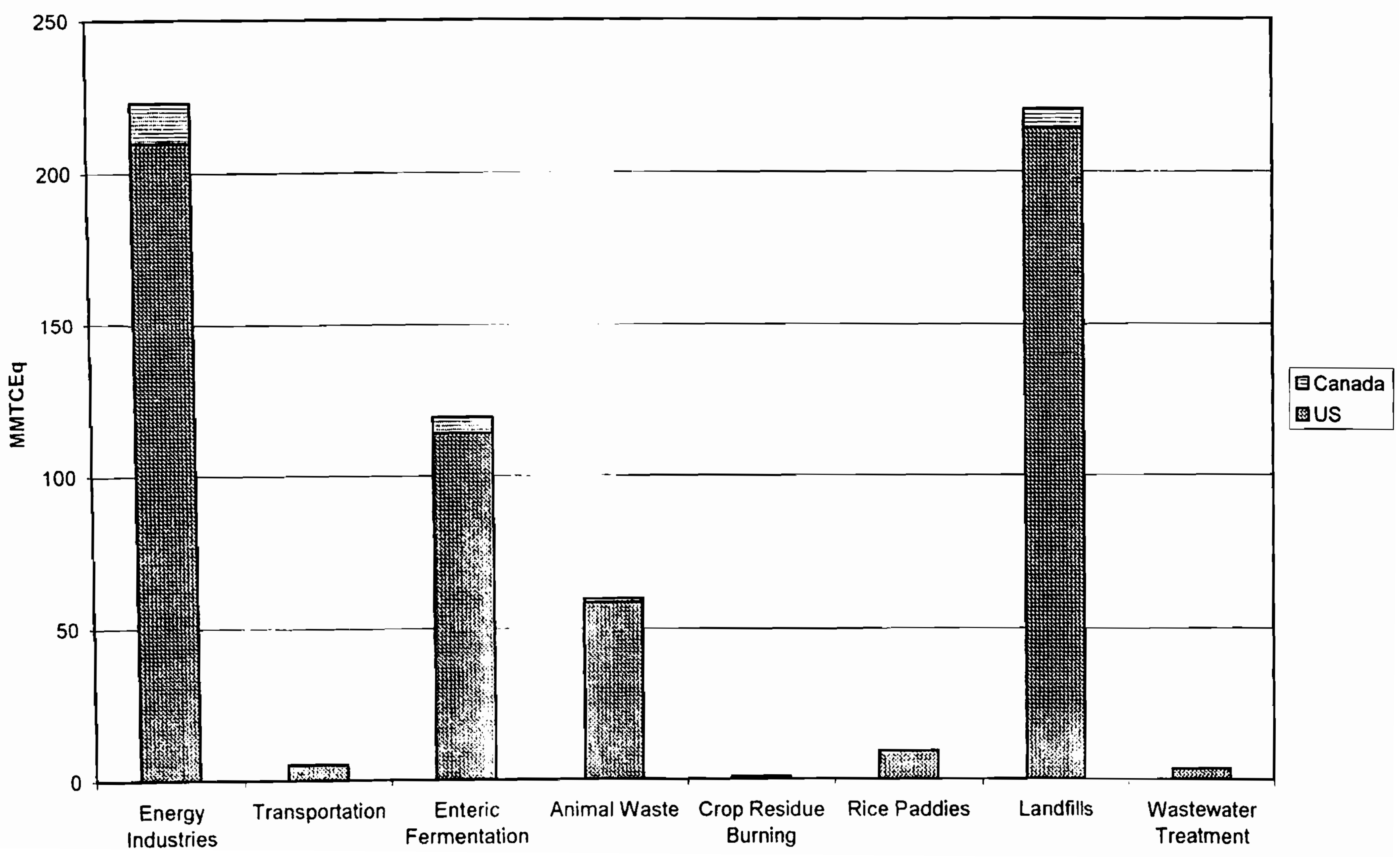


Figure 3

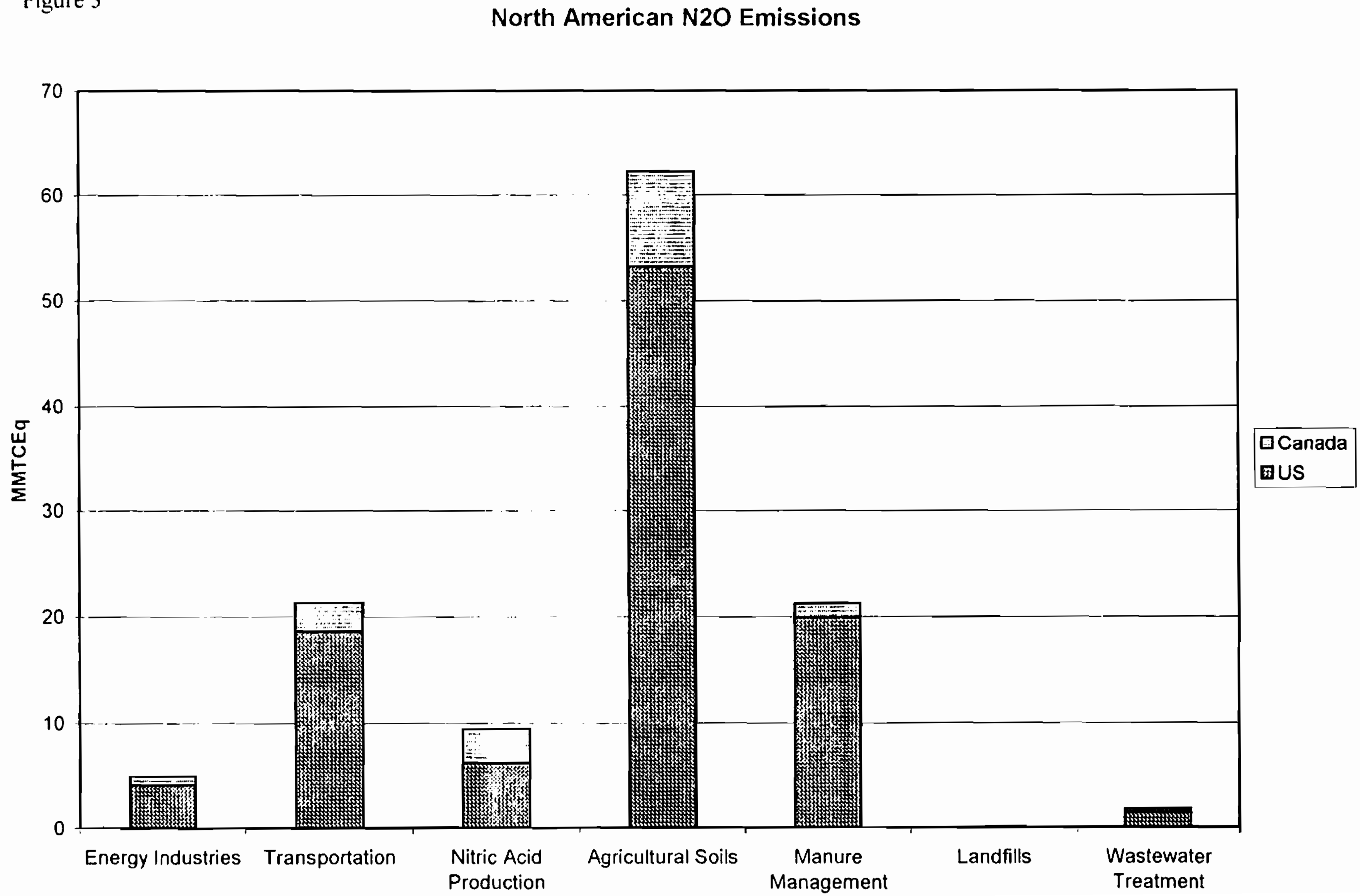

North American N2O Emissions
MMTCEq
70
60
50
40
30
20
10
0
Energy Industries
Transportation
Nitric Acid Production
Agricultural Soils
Manure Management
Landfills
Wastewater Treatment
Canada
US

Figure 4

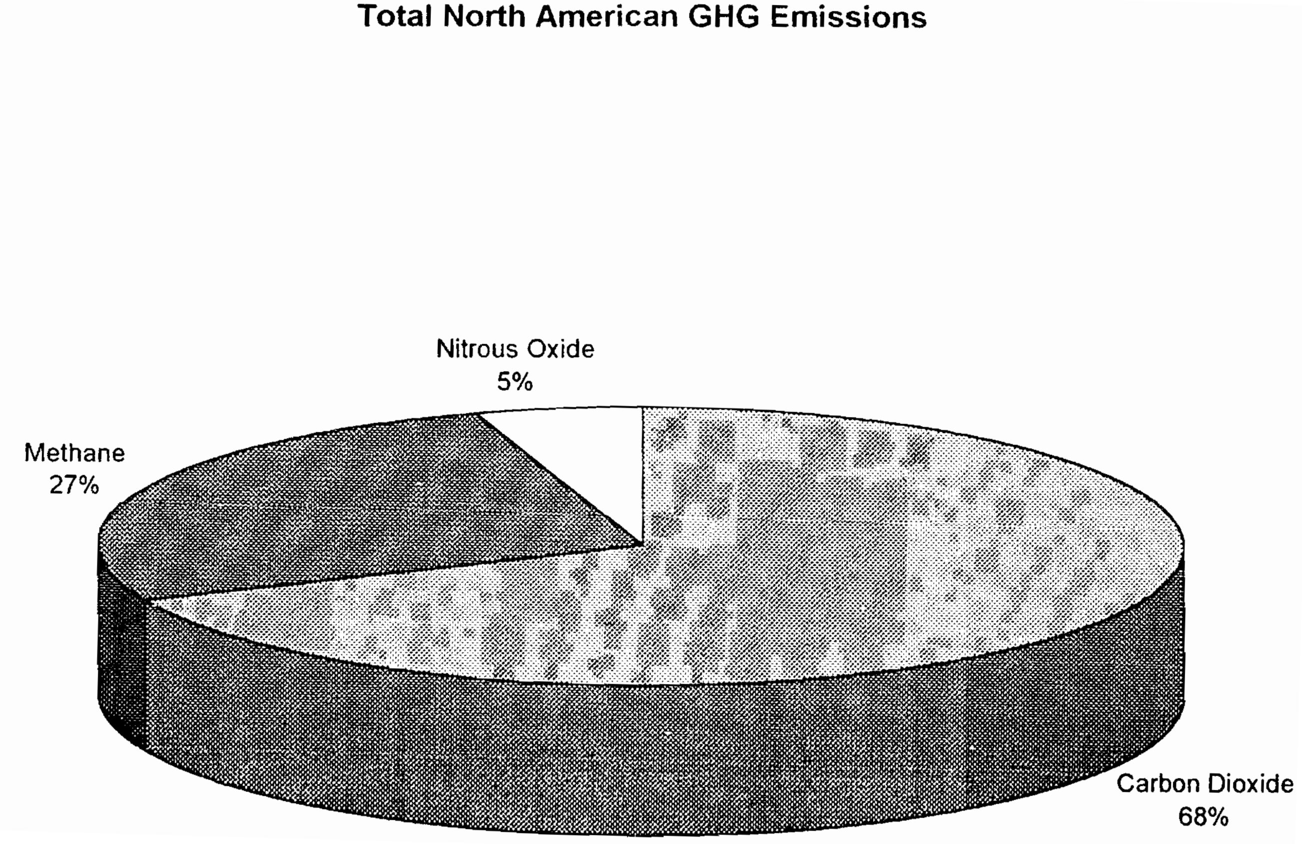
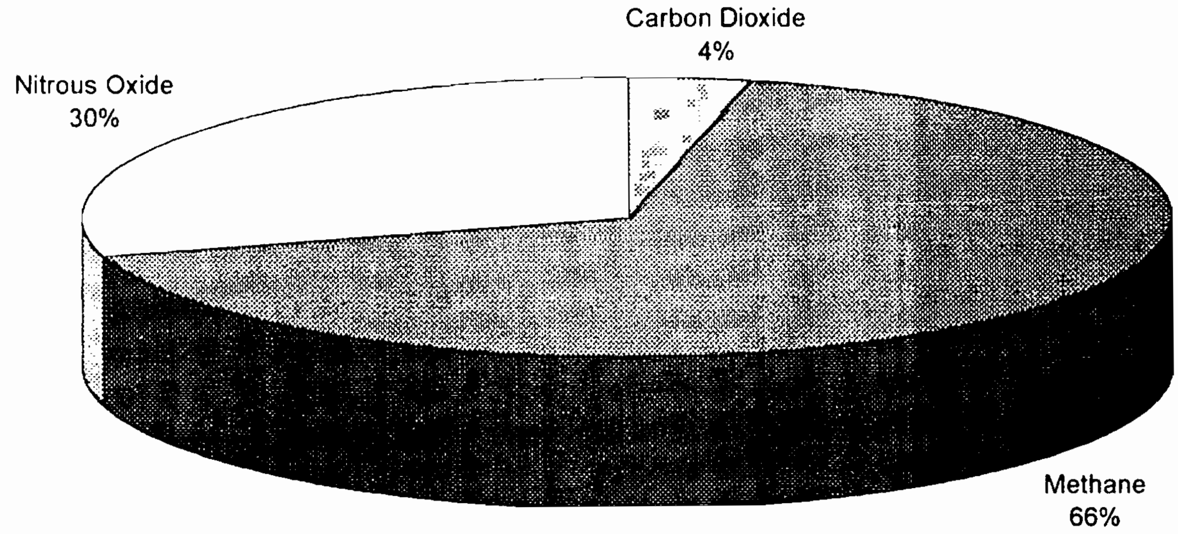

Total North American GHG Emissions
Nitrous Oxide
5%
Methane
27%
Carbon Dioxide
68%

Figure 5

North American Agricultural GHG Emissions



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