Nitrous Oxide Emissions and Prairie Agriculture

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Summary

There's nothing funny about laughing gas when it comes to global warming. Nitrous Oxide (N_2O), best known as laughing gas, a colourless, odourless gas sometimes used as an anaesthetic by dentists, is also a powerful greenhouse gas. While carbon dioxide (CO_2) is the main human-generated greenhouse gas, N_2O is approximately 300 times more effective at trapping heat in the atmosphere. Farm activity, especially emissions from agricultural soils, is by far the largest source of human-induced N_2O emissions. In 2005 Canadian farmers were responsible for 70% of all of Canada's N_2O emissions[3]; industrial processes and the combustion of fossil fuels produced the remaining 30%. This article looks at how prairie agriculture contributes N_2O to the atmosphere and identifies some possible strategies to help minimize those emissions.

Properties and Potency of Nitrous Oxide

Nitrous oxide (N_2O) is a colourless, almost odourless gas formed when two nitrogen atoms bond to an oxygen atom. The way these atoms join together makes the N_2O molecule very effective at absorbing heat radiating from the surface of the earth as infrared energy. Molecules, like N_2O, trap some of this heat energy and prevent it from radiating into deep space. Some of this absorbed heat is then re-radiated back towards the earth, increasing the earth's average temperature[1].

The atmospheric concentration of CO_2 is over a thousand times greater than that of N_2O (~ 380 ppmv versus ~ 0.320 ppmv) [ppmv=parts per million by volume]. However, molecules of N_2O are both more effective at absorbing infrared radiation and are very long lived. They will remain in the atmosphere for up to 120 years, thus a single molecule of N_2O entering the atmosphere has the same effect on the earth's energy balance as about three hundred CO_2 molecules. Nitrous oxide accounts for about 6% of the global warming caused by greenhouse gases produced from human activities.

Increasing the amount of N_2O entering the earth's atmosphere not only contributes to global warming, it's also very harmful to the earth's ozone layer. This layer of ozone in the stratosphere (portion of the atmosphere approximately 10-50 km above the earth's surface), protects the earth's surface from harmful ultraviolet radiation from the sun. When N_2O reaches this layer it can undergo a series of reactions that ultimately result in deterioration of the ozone layer[2].

Applying only the amount of commercial fertilizer that a crop can utilize at the proper time in the growing season, as well as no-till farming, are a couple of methods prairie farmers employ to reduce nitrous oxide emissions.

Photo credit: Thom Weir

Major sources of Nitrous Oxide

If it wasn't for humans there would only be trace amounts of N_2O in the atmosphere. Some N_2O is generated directly in the atmosphere through a complex series of chemical reactions, and much larger amounts are produced by microbial activities in terrestrial and aquatic ecosystems.

Human activities are causing a rapid increase in the concentration of atmospheric N_2O. Nitrous oxide is released directly into the atmosphere during combustion of fossil fuels, when used as a propellant for aerosols, and during the production of nitric and adipic acids required for making nylon, polyurethane, and nitrogen fertilizers. Other activities increase N_2O emissions indirectly. Activities such as human waste disposal and pollution from the combustion of fossil fuels for transportation, heat, electrical power generation and industrial processes have increased the amount of nitrogen entering many natural ecosystems; this in turn increases the microbial activities that generate N_2O emissions. However, agriculture is the largest source of human induced N_2O emissions.

Agricultural Sources of Nitrous Oxide

Agricultural activities on the Canadian Prairies are responsible for both direct and indirect emissions of N_2O to the atmosphere (Figure 1).

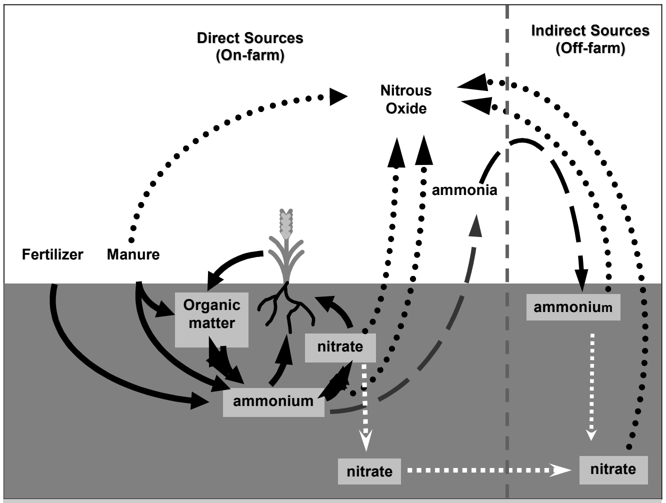

Figure 1. Simplified diagram outlining the passage of nitrogen through the soil and indicating the direct and indirect sources of N2O emissions from farming activities.

Direct Sources

Agricultural soils are the single largest source of human-induced N_2O emissions. Natural ecosystems do contribute N_2O to the atmosphere, but agricultural soils emit more N_2O on an area basis than a comparable soil in a natural ecosystem. In general, N_2O emissions from soils on the Canadian prairies are quite low, ranging from a few hundred to a few thousand grams per hectare per year. However, there are millions of hectares of agricultural soil on the prairies and on a cumulative basis, these emissions are substantial.

Numerous biological pathways can generate N_2O emissions from soil, but nitrification and denitrification predominate. In simplest terms, nitrification is a microbial process that converts ammonium into nitrate. In general, conditions that favour crop growth also favour nitrification. Nitrification can be very rapid when soils are warm and moist (but not too wet), and contain a ready supply of ammonium. Under favourable conditions the amount of N_2O produced during nitrification is usually quite small; often 0.1% or less of the nitrogen in ammonium being lost as N_2O. However, cumulative losses over the course of a growing season can be substantial.

Farming practices that increase the amount of ammonium nitrified will increase N_2O losses. Applying ammonium-based commercial fertilizers, such as urea or anhydrous ammonia, directly increases the amount of ammonium entering the soil and, hence, the amount of ammonium nitrified. Ammonium also is released during decomposition of organic materials such as crop residues, livestock manures and soil organic matter. Soil tillage, summerfallowing, and the plow-down of green manure crops and forage legumes increases the amount of organic material that is decomposed, increasing the amount of ammonium available for nitrification. Livestock manures contain a combination of ammonium and organic material. Therefore soil application of livestock manure will immediately increase the amount of available ammonium in the soil; with additional ammonium being released over the longer term as the organic portion of the manure decomposes.

Excess water greatly reduces the amount of oxygen in the soil. A limited oxygen supply will slow, or even halt, nitrification, but favours denitrification. Denitrification is the microbial conversion of nitrate to N_2O and/or nitrogen gas (N_2). Warm, wet soils, with a good supply of nitrate and soluble carbon, are conducive to rapid denitrification. Under these conditions, large amounts of nitrogen can be lost through denitrification and substantial amounts of N_2O released.

In general, daily N_2O emissions from agricultural soils on the Canadian prairies can be characterized as small and fairly continuous, with intermittent high emission "episodes" that result from specific soil and climatic conditions. The former are likely emissions arising largely from nitrification and their magnitude is related to total N turnover. Bursts of N_2O emissions are generally triggered by high soil-water contents after rainfall, irrigation, or snow melt, and are most likely the result of denitrification. Particularly intense emission events can occur after wetting of a dry soil or thawing of frozen soil. However if the supply of nitrate is limited, emissions may be minimal even under these conditions.

On the Canadian prairies, the seasonal pattern of N_2O emissions reflects the interaction between soil temperature and soil water. Little to no N_2O emission activity occurs while soils are frozen, and very little activity occurs when soils are dry. The spatial pattern of N_2O emissions is also largely governed by soil water content.

Precipitation inputs, evaporation, and transpiration losses by the growing crop determine soil water content. In broad terms this means that drier regions of the prairies have lower N_2O losses than moister regions. On a smaller scale, soil water content is influenced by factors such as soil texture, drainage, and slope position. Emissions from lower slope positions in a field (positions where water collects), can be many times higher than emissions from the upper slope positions (positions where water runs off)[4].

The storage and handling of livestock manures is another source of direct emissions. The same microbial processes responsible for generating N_2O in soils, nitrification and denitrification, are also responsible for the N_2O generated during the handling and storage of livestock manure. There are a wide variety of manure handling and storage systems but in general they can be grouped into solid and liquid storage systems. Solid waste systems are usually associated with beef cattle feedlots where manure accumulates in holding areas or is moved and stored in piles pending field application. Urine and feces are rich sources of carbon, nitrogen, and numerous other nutrients that stimulate microbial activity. Depending on conditions, substantial N_2O emissions can occur during storage and handling of solid manure. Oxygen is usually available in the outer layers of the manure pack allowing nitrification to proceed. This not only generates N_2O, but also nitrate which can then be used by denitrifiers in the deeper layers of the manure pack where oxygen is limited.

Manure (feces and urine) from intensive hog operations is normally washed from the barns into holding tanks or lagoons. Emissions occurring during storage and handling of liquid manures are usually comparatively low. The high water content of this manure excludes oxygen and limits nitrification. This means that little to no N_2O is produced during nitrification, but more importantly, no nitrate is produced to support denitrification. Due to the large numbers of cattle and hogs on the Canadian prairies, emissions during manure handling and storage contribute substantially to total N_2O losses from the region. In Alberta for example, N_2O emissions from manure handling and storage represented about 16% of total provincial

Innovations Reduce Nitrous Oxide Emissions

Soil management and new technology have had a profound effect on nitrous oxide (N_2O) emissions from agricultural soils on the prairies. If N_2O emissions had been measured in the early 1980's, and compared to modern emissions, this dramatic reduction would be clearly evident.

Management

According to the 2006 Census of Agriculture, 60% of the annual cropped land in Saskatchewan is in a no-till system with 48% in Alberta and 21% in Manitoba. This approach has dramatically reduced soil degradation from wind and water erosion and in the process has greatly improved overall soil quality. Improved soil quality lowers nitrogen fertilizer requirements, which means less potential for N_2O emissions.

Prairie farmers have also drastically reduced summerfallow area. The 2006 Census of Agriculture shows a 64% reduction in Saskatchewan since 1981 and an 80% reduction in Alberta and Manitoba. Reducing the area in fallow has a direct influence in reducing N_2O emissions.

The introduction of grain legume crops, like dry pea, lentil, and chick pea, in prairie cropping systems has also reduced N_2O emissions. These crops fix their own nitrogen and require no additional nitrogen fertilizer.

Technology

Advances in no-till seeding technology have lead to the widespread adoption of one-pass seeding and fertilizing systems. The time between nitrogen application and crop uptake is greatly reduced thereby reducing the opportunity for losses from denitrification and potential N_2O emissions.

The merits of starter-N combined with in-crop applications of nitrogen are being investigated with new optical sensor technology. This enables the farmer to more efficiently match nitrogen fertilizer use with crop needs. In doing so, there is less potential for nitrogen losses through N_2O emissions.

A number of specialized nitrogen fertilizer products are also available that use urease and nitrification inhibitors, as well as slow release polymer coated urea fertilizer. The concept is to target the release of nitrogen to crop growth stages where uptake is very rapid thereby minimizing the potential for losses, some of which would be as N_2O.

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human-induced N_2O emissions in 2005[3].

Indirect sources

Nitrogen that inadvertently "escapes" during farm operations can later be deposited onto adjacent areas, often non-agricultural ecosystems, causing increased emission of N_2O in these areas. This increased N_2O loss is deemed an indirect emission and is attributed to the farming activity that was the original source of the nitrogen. For example, application of nitrogen fertilizers and livestock manures greatly increases the localized concentration of ammonium in the soil. Under the right soil and climatic conditions, a significant portion of this ammonium can be lost (volatilized) to the atmosphere as ammonia gas. Much of this ammonia will be absorbed by soil, water, or other surfaces only a short distance from the application point, but a portion can be transported long distances in the upper atmosphere. In either case, when this ammonia is deposited it will almost certainly undergo microbial transformations (nitrification and denitrification) causing further increases in N_2O emissions.

Similarly, nitrate can accumulate in the soil after fertilizer or manure applications or after a fallow period. If there is a concurrent flow of water through the soil because of excessive rainfall, irrigation, or after the spring snow melt, nitrate can be transported into sloughs, streams, rivers, or lakes as surface runoff or through groundwater flow. Some of this nitrate will eventually be subjected to microbial transformations that result in N_2O emissions.

Can Nitrous Oxide Emissions from Agriculture be Reduced to a Minimum?

Knowing that the greatest losses of N_2O occur when high levels of nitrate coincide with high soil-water contents, clearly suggests that managing our farming practices to avoid this occurrence will reduce emissions. Precipitation patterns are beyond our control, leaving us with the option of managing nitrogen in such a way as to minimize the accumulation of nitrates.

In general, any management that increases the nitrogen use efficiency of a crop should translate into reduced N_2O emissions. This is true for both direct and indirect emissions of N_2O. If more N is applied to a field than the crop requires, an accumulation of nitrate will likely occur. This increases the potential for both direct and indirect N_2O loss. This is particularly true for the lower positions of the landscape where soils are more frequently wet. Similarly, applying nitrogen as close as possible to the time when crops will rapidly take it up, minimizes the availability of this nitrogen for microbial transformations and N_2O production.

Nitrogen applied in the fall, when soil temperatures are still warm and nitrification can proceed, results in an accumulation of nitrate that remains in the soil over winter. This can cause substantial N_2O emissions during the following spring thaw period. Studies indicate that this is particularly true with livestock manure[5]. Livestock manure, particularly liquid manure, not only contains a ready source of nitrogen, but also important amounts of soluble carbon that stimulates the denitrification process. Therefore proper management of nitrogen containing fertilizers and livestock manures is the key to minimizing N_2O emissions.

Recent work indicates that substituting a pulse crop for a cereal or oilseed crop in a rotation reduces the overall N_2O loss from that rotation. Nitrogen fertilizer induced N_2O emissions are avoided in the year that the pulse crop is grown because no nitrogen fertilizer is applied. The reduction in N_2O emissions is proportional to the frequency of pulse crops in the rotation cycle, and to the N_2O loss potential of the location[6]. Soil tillage strongly influences soil aeration, temperature and humidity, and the distribution of fertilizer, crop residues and organic amendments in the soil profile. All these in turn will impact potential N_2O losses. Comparisons of tillage systems on the Canadian prairies indicate that, more often than not, N_2O emissions are reduced when no-till production practices are adopted[7].

Summerfallowing is a common management practice in drier regions of the Canadian prairies. No fertilizer is applied during the fallow year so there are no fertilizer-induced N_2O emissions. However, because soil water content and nitrates increase during the fallow period, due to lack of crop uptake, N_2O emissions are as high on fallow as on continuously cropped and fertilized stubble[7]. This means that cropping intensity can be increased (fallow frequency reduced) without a concomitant increase in N_2O emissions in the drier areas of the prairies. Reducing fallow frequency will also result in improved soil quality and higher levels of soil organic carbon.

What More Do We Need to Learn?

Soil emissions of N_2O are extremely variable over space and time. We need to better understand the causes of this variability before we can predict, with acceptable confidence, the magnitude of emissions at any specific place and time. This will only be possible with the development of simulation models that deal better with the complexities involved. Certainly more can be learned about the effective use of fertilizer nitrogen to optimize crop production and minimize N_2O emissions, including an assessment of specialized products such as nitrification inhibitors and polymer-coated urea. Further research is also needed to develop strategies to make effective use of the nutrients in livestock manures for crop production while minimizing N_2O emissions. Similarly, alternative approaches to legume forage termination, and the management of green manures, are needed to reduce N_2O emissions associated with these practices.

Concluding Remarks

Moisture is the factor that most often limits crop production on the Canadian prairies and it is also the factor that most often influences the extent of N_2O emissions. As a result, emissions from the Canadian prairies - on a per area basis -are typically lower than from other agricultural regions of Canada. For example, average fertilizer - induced emissions (the amount of fertilizer nitrogen lost as N_2O) for eastern Canada are currently estimated at about 1.7%, while estimates for the prairies range between 0.2 and 0.8 %.

While prairie agriculture is fortunate to have environmental conditions that limit N_2O emissions, the large land base means that the combined contribution from farm activities on the prairies is significant at a national level. Inappropriate management of nitrogen fertilizers and particularly livestock manure can result in greatly increased N_2O emissions. Conversely, employing no-till production practices, reducing the use of summer-fallow, including pulses in crop rotations, and carefully planning the amount and timing of fertilizer or manure N applications to match as closely as possible the needs of the crop will all help to minimize N_2O emissions from crop production on the prairies.

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