Nitrous oxide Emissions From the Farm: Can Anything be Done?

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Should we care about nitrous oxide emissions from farms?

The atmospheric build-up of radiatively active trace gases (greenhouse gases) is affecting the global energy balance and, in the case of N_2O, accelerating the deterioration of the stratospheric ozone layer. Agricultural activities contribute about 10% of Canada's anthropogenic greenhouse gases. Nearly two-thirds of the greenhouse gases arising from agricultural activities are nitrous oxide. It is important to identify farming practices that will minimize N_2O emissions.

What is the source of N_2O emitted from Prairie farms?

Nitrous oxide emissions are produced during the handling and storage of livestock manures, and are emitted during biological transformation of nitrogen (N) in soil. The latter is the unavoidable consequence of N cycling that occurs naturally in all soils. Farm practices that alter the amount, temporal pattern and/or rate of N being cycled will affect the net emission of N_2O. Application of commercial N fertilizers and livestock manures, increasing the amount of biologically fixed N (e.g. introducing legumes into cereal based rotations) and increasing soil mineralization rates by increasing tillage intensity or altering moisture regimes (irrigation) are all examples of practices that will likely increase net N_2O emission from soils. Nitrous oxide emissions from handling and storage of livestock manures will not be discussed in this paper.

What controls the amount of N_2O produced from soil?

In general, any farming practice that increases the amount of N cycled through soil over a particular period of time will increase N_2O emissions. However, this is only part of the story. The increase in N_2O emissions relative to the increase in N being cycled is strongly influenced by the prevailing soil environmental conditions. Most N_2O emissions are generated by two biological processes - nitrification and denitrification. The amount of N_2O released per unit of N nitrified is normally very small, although on an annual basis the cumulative production is not insignificant. On the other hand, denitrification can produce a large amount of N_2O over a short period of time. Denitrification occurs only when soils are quite wet, thus N_2O emissions from denitrification are episodic, usually associated with periods of high soil-water content after rainfall or irrigation. Emissions can be particularly intense after wetting of a dry soil or after snow melt in the spring. Hence soil-water content strongly governs the magnitude of soil-emitted N_2O.

Can we minimize N_2O emissions from farming activities?

Reducing Tillage Intensity

Adoption of No Till (NT) practices has been widely promoted for its "environmentally friendly" profile including its soil organic carbon sequestering potential. Compared to conventional tillage, NT affects several factors that influence N_2O production including decomposition of soil organic matter, soil C and N availability, soil density and water content. Comparative field studies have returned conflicting results with N_2O emissions under NT being reported as greater, smaller, and approximately equal to emissions under more intensively tilled systems. In a recent review of Canadian studies, Helgason et al. (2004) reported that N_2O emissions on the Canadian prairies were lower on NT compared to CT in 63% of the observations. This situation was reversed for the more humid sites in eastern Canada. Rochette et al. (2007) revisited the data currently available, and concluded that N_2O emissions would be, on average, 20% lower on NT compared to CT on the prairies and 10% higher for eastern Canada.

Matching N applications to Crop N requirements

Research conducted on the Canadian prairies indicates that there is very little difference in total N_2O emissions between N application systems (e.g. mid-row versus side-row banded N) or between fertilizer N forms (urea versus anhydrous ammonia). Results do indicate that manure or fertilizer N application rates that exceed crop requirements increase the potential for N_2O emissions. For example, research has shown a reasonable relationship between cumulative N_2O emissions during the spring thaw period and soil nitrate levels in the previous fall. Thus residual fertilizer N left in the soil at the end of the growing season could contribute substantially to N_2O loss during the following spring if soils become very wet after snow melt. In general, any practice that increases fertilizer N use efficiency should help to minimize the N_2O emissions associated with the use of that fertilizer.

Avoiding Fall Fertilizer or Manure Applications

As indicated in the previous section, research has shown a reasonable relationship between cumulative N_2O emissions during the spring thaw period and soil nitrate levels in the previous fall. It would seem reasonable to expect that applying fertilizer N or manure in the fall could increase N availability and would increase N_2O emissions during the following spring. The story appears to be a bit more complex. Studies that compare N_2O emissions from fall applied versus spring applied fertilizer N show that emissions are often similar, but on occasion emissions can be substantially higher from fall compared to spring applied N (Table 1). The determining factor is likely whether or not the fertilizer application increases soil nitrate levels. Ammonium based fertilizers are used on the prairies. If these fertilizers are applied close to soil freeze-up so that the ammonium is not converted to nitrate, then the increased risk of N_2O emissions is likely minimal. Of course, if soils are dry and snow cover is light, then the risk of N_2O emissions is likewise minimal. Weather conditions in the fall are unpredictable and it is not always easy for farmers with large acreages of land to fertilize to ensure that applications are done just prior to freeze-up. Based on current information, it is reasonable to conclude that fall applied fertilizer N or manure increases the risk of substantial N_2O loss during the following spring thaw and avoiding fall applications would minimize N_2O emissions.

Table 1. Estimated N_2O emissions from coated versus uncoated and fall versus spring applied urea at a study site near Melfort, SK.

Time of N Application	**Urea**	**Coated Urea**
	kg N_2O-N ha^{-1}	
2005 Season		
Fall	na*	na
Spring	0.9	0.9
2006 Season		
Fall	2.5	1.7
Spring	1.7	1.3

* not available

“New Generation” Fertilizer Management

On the Canadian prairies, all fertilizer N requirements are normally applied either late in the fall, or at or just before the crop is seeded in spring. At best it will be several weeks after the fertilizer is applied before there is a high uptake of fertilizer N by the growing crop. During the intervening period, that fertilizer N is susceptible to gaseous loss if soil conditions allow. If, for example, a heavy rain occurs soon after the fertilizer is applied considerable losses could occur via denitrification. Methods that slow the conversion of ammonium to nitrate could help better match N availability to crop demand and reduce the risk of N_2O loss if soils become wet soon after fertilizer application (ammonium isn’t susceptible to loss via denitrification). Products such as nitrapyrin, dicyandiamide, or acetylene inhibit the microbes that convert ammonium to nitrate. Delaying the release of fertilizer N into the soil environment can also be accomplished using polymer coatings. Both approaches have shown promise in reducing N_2O emissions, but research under prairie conditions is extremely limited. Some recent work being conducted at a field study near Melfort showed no difference in N_2O emissions from spring applied coated versus uncoated urea in 2005, but a clear reduction in N_2O emissions from coated versus uncoated urea for both spring and fall applications in 2006 (Table 1). In 2005, fertilizer N application did not significantly increase N_2O emissions compared to the control (control = 0.8 kg ha^{-1}) leaving no opportunity for the coated product to minimize emissions. This underscores the point that the benefit of nitrification inhibitors or coated products for reducing N_2O emissions will only be realized when the potential for N_2O loss is high. Much more study will be needed determine if and how these technologies can be effectively employed to reduce N_2O emissions for dry land cropping on the Canadian prairies.

Growing Pulse Crops

There are two questions to ask when considering how growing a pulse rather than a fertilized cereal or oilseed crop may affect N_2O emissions. Firstly, does the presence of the pulse crop itself change net annual emissions? In other words, will emissions during the growing season be different on the pulse compared to cereal or oilseed crops? Secondly, will pulse residues affect

N_2O emissions differently than cereal or oilseed residues in the following spring and growing season?

There is limited data available for the Canadian prairies, but in a recent summary Lemke et al. (2006) reported that growing season N_2O emissions from field pea or lentil crops were significantly lower than from fertilized cereal crops and were comparable to estimated background emissions (Table 2). Similarly, Zhong et al., (2004) compared inoculated lentils and field pea, fertilized non-inoculated lentil and field pea, and fertilized and unfertilized wheat. Emissions were comparable amongst crops receiving fertilizer, while emissions from inoculated crops were much lower and comparable to the control treatments. The available data indicates that emissions from pulse crops grown on the Canadian prairies tend to be lower than emissions from their fertilized cereal counterparts.

Table 2. Estimated cumulative (May-October) N_2O loss measured from pulse and fertilized spring wheat plots at Three Hills, AB and Swift Current, SK.

Crop	2000	2001	2002	Mean
	(kg N ha^{-1})			
	Three Hills			
P	0.4	0.6	0.4	0.5
Ws	1.0	1.4	0.8	1.1
	Swift Current			
Lentil	na	> 0.0	0.1	0.1
Spring Wheat	na	0.1	0.2	0.2

Crop residues with a low C:N ratio can stimulate N_2O emissions as they are both a source of N for nitrification and potentially denitrification, and a source of easily decomposable C. Accordingly, pulse residues could result in higher N_2O losses compared to cereal crop residues. However, Lemke et al. (2006) reported that emissions from wheat grown on pulse stubble (pea or lentil) were comparable or lower than emissions from fertilized monoculture wheat at two sites in western Canada (data not shown). However, some ongoing research at Indian Head, SK suggests that emissions on wheat grown on field pea stubble are higher than wheat grown on wheat stubble (Hunter et al. 2006). The increase does not appear great enough to offset the lower emissions measured during the pea crop phase. Based on the information currently at hand it appears that growing a pulse crop in place of a well-fertilized cereal will result in a small reduction in N_2O emissions, but there is still considerable uncertainty surrounding this conclusion.

Summerfallow

Fertilizer is not applied during summerfallow periods, thus reducing the frequency of summerfallow (increasing the number of crops grown over a given period of time) means that N fertilizer will need to be applied more often in order to maintain soil fertility levels. This undoubtedly means that there will be more "fertilizer-induced" N_2O emissions. However, the higher soil water contents normally associated with summerfallow increases soil organic matter decomposition releasing mineral N. Without a growing crop to utilize it, this available N will be highly susceptible to denitrification. Particularly high N_2O emissions from summerfallow fields have been reported after snow melt in the spring. A summary of the available literature suggests that annual N_2O emissions from summerfallow fields are comparable to their counterparts that are fertilized and seeded to cereal or oilseed crops (Table 3). If summerfallow is replaced with a fertilized cereal or oilseed crop then N_2O emissions will likely not increase or decrease. This is important to note as there may be other environmental and/or economic reasons for reducing summerfallow frequency. If summerfallow is replaced with a pulse crop then net N_2O emissions may be slightly reduced.

Table 3. Estimated N_2O emissions from fertilized cropland compared to summerfallow at five locations on the Canadian prairies.

Location	**Fertilized Cropland**	**Summerfallow**
	kg N_2O-N ha^{-1}	
Swift Current, SK	0.2*	0.1
Three Hills, AB	1.4	1.7
Ellerslie, AB	1.4	1.2
Breton, AB	0.5	0.5
Cooking Lake, AB	1.2	0.8
Overall Mean	0.9	0.9

* All values presented are the mean of 3 - 4 years except for Cooking Lake which is the mean of 2 years.

Summary

Decisions such as reducing tillage intensity, avoiding fall application of nitrogen fertilizer or manure, and incorporating pulse crops into cereal-based rotations will likely realize small reductions in overall soil-emitted N_2O. Reducing summerfallow frequency will likely be neutral in terms of overall N_2O emissions, but may be desirable for other environmental and economic considerations. Technologies such as coated urea or the use of nitrification inhibitors show some promise for minimizing N_2O emissions but require more study to determine their best fit for Canadian prairie agriculture. In addition, more consideration needs to be given to the total greenhouse gas impact of each of these specific farming practices to ensure that reductions in N_2O emissions aren't negated by increases in other greenhouse gases.

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