

## Impacts of Agriculture on Air Quality (with emphasis on CO<sub>2</sub> and N<sub>2</sub>O)

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### What are the impacts of agriculture on air quality?

Agriculture adds many substances into the air. Table 1 summarizes the major air quality concerns related to agriculture.

Table 1. Air quality concerns related to primary agriculture.

Air Quality Concern	Agricultural Sources	Impact	Range of Impact
Particulate Matter	Soil erosion by wind, dust raised during soil tillage; Burning farm wastes, bush piles, and crop residues; Diesel engines; Grain and feed processing and handling; Driving on dirt and gravel roads; Pollen	Crop damage for particles >10 microns, especially greater than 1000 microns (“sand blasting”); Animal and human health for particles ≤10 microns (PM10), especially < 2.5 microns (PM2.5), organic particulates more harmful to health than inorganic particulates; Some particulates are allergens; Impaired visibility for driving	Local(0-10 km) for large particulate matter to regional (0-1000 km) to global (0-1000s km) for fine particulate matter
Odour	Livestock generally especially Intensive Livestock Operations (ILO); Manure storage, handling, and land application; Dead animal storage and handling	Nuisance	Local
Ammonia	Manure storage, handling, and land application; Losses during nitrogen fertilizer handling and application	Precursor to formation of various toxic compounds and aerosols that are also PM2.5; Irritant; Nutrient pollutant	Local to regional
Pesticides	Pesticide application and handling, drift during application and volatilization after application or from spills	Damage to sensitive plants and aquatic organisms; Humans with chemical sensitivities; Aerosols that are PM2.5	Local to global
Nitrous oxide	Nitrogen inputs on agricultural land from animal manures, N-rich crop residues, and fertilizer – released from nitrification of ammonia to nitrate and denitrification of nitrate.	Destroys stratospheric ozone; Climate change from additions of this potent greenhouse gas	Global
Carbon dioxide	Sources are fossil fuel burning and net decay of soil organic matter	Climate change from additions of this greenhouse gas	Global
Methane	Animal digestion, especially ruminants; Manure storage and handling	Climate change from additions of this greenhouse gas	Global

## Which air quality concern is most important?

This depends on where you are and your perspective. From an immediate human health perspective, there is widespread agreement that fine particulate matter is the most serious concern. Table 2 summarizes the differences in particulate sizes from several agriculture-related sources of particulate matter. Because it is primarily very fine particles, smoke is clearly the greatest particulate matter concern from agriculture on the prairies. In other parts of Canada, such as the Fraser Valley in BC, ammonia emission (as a precursor to the formation of particulate matter), is considered a greater particulate matter concern from agriculture. The public has pressured government to enact regulation of particulate matter sources and more regulations can be expected. For example, there is movement to declare ammonia a controlled toxic substance, which will affect both nitrogen fertilizer use and livestock operations, primarily because of its particulate matter-forming properties.

Table 2. Size fractions for several agricultural sources of dust and smoke.

Source of particulate matter	Proportion of Emitted Particulate Matter that is	
	≤ 10 micron (PM10)	≤2.5 micron (PM2.5)
Dust from wind erosion or tillage	45	10
Dust from gravel road	59	11
Smoke from burning straw	96	95
Smoke from brush fire	96	85
Grain and feed handling	29	1
Diesel engine exhaust	100	92

Source: CALIFORNIA EMISSION INVENTORY AND REPORTING SYSTEM (CEIDARS), <http://www.arb.ca.gov/emisinv/speciate/speciate.htm>

From a quality of life perspective, many people living downwind of an intensive livestock operation would list odour as the biggest air quality concern. Similarly, a family with a member who has acute chemical sensitivities might list pesticide loss into the atmosphere their biggest air quality concern related to agriculture.

However, many people and scientists rate the most serious agricultural air quality concern as its contribution to the recent build-up of greenhouse gases that can cause climate change. Globally, agriculture directly accounts for about 14% of greenhouse gas emissions and much more indirectly from deforestation to develop new agricultural lands. Unlike most other air pollutants, the effects of greenhouse gases are very long-lived so the greenhouse gases emitted today will affect the climate for centuries. The impacts of climate change could be disastrous for many peoples living at the ecological or economic margins. Rapid climatic changes could outstrip the ability of industrialized nations like Canada to adapt.

## Surely you are not suggesting farmers are responsible for air pollution?

It is true that agriculture is only a relatively small contributor of many air pollutants. However, society has decided on a fundamental principle of “polluter pays”. As mentioned earlier, particulate matter is widely regarded as the greatest immediate human health air quality concern. Essentially every Canadian contributes particulate matter to the atmosphere. A finger-pointing exercise to single out who should first address atmospheric particulate matter would be unproductive. The problem will only be solved with all contributors making changes to reduce particulate matter emissions due to their activities. Tempering the “polluter pays” principle is a pragmatic realization that the most cost-effective methods to reduce an air pollution problem

should be implemented preferentially. For example, there are no restrictions on diesel engine use on farms for control of particulate matter as that control cost is judged prohibitive, but there are restrictions on burning crop residue and brush since those control measures are considered reasonable, and desirable for other reasons. Giving preference to least-cost control measures is highly formalized for some air pollutants such as sulfur dioxide. In much of North America, the total allowable emission of this pollutant is set by governments. The large polluters then trade entitlements to emit sulfur dioxide. If it is less costly to make in-house reductions in emissions than to purchase emission entitlements on the market, then accomplishing those in-house emission reductions makes economic sense. If many large polluters find this so, then the market value of the emission entitlement will fall until it makes more sense for some polluters to purchase emission entitlements. In this way, the market works to ensure that only the most cost-effective emission reductions are undertaken to reach a specific emission target. A form of this highly successful market mechanism for air pollution is being proposed for making reductions in net greenhouse gas emissions.

### **What are the greenhouse gases?**

For agriculture, there are three important greenhouse gases: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). Since the start of the industrial revolution, the concentration of atmospheric CO<sub>2</sub> has increased 31%, CH<sub>4</sub> has increased 151%, and N<sub>2</sub>O has increased 17% (IPCC 2001). These gases are called greenhouse gases because they reduce the net radiation from the earth, warming the earth's surface. Along with other world citizens, Canadians have become concerned about climate change from the human additions of greenhouse gases to the atmosphere. Reflecting this concern, Canada pledged in the Kyoto Protocol to reduce its average annual greenhouse gas emission during 2008-2012 to 6% less than its emissions during 1990. In 2002, Canada ratified the Kyoto Protocol and will be bound by this international treaty when other developed countries with sufficient emissions, such as Russia, also ratify.

### **What is meant by CO<sub>2</sub>-equivalent?**

Compared to CO<sub>2</sub>, methane has 21 times more warming effect, and nitrous oxide 310 times more warming effect when compared on a 100 year time frame. Because of these differences, it is useful and common practice to express greenhouse gas emissions as CO<sub>2</sub>-equivalents (i.e. the equivalent warming effect if all emissions were CO<sub>2</sub>).

### **What is a source and sink?**

A source is an emission to the atmosphere and a sink is a removal from the atmosphere. Generally, agricultural land acts as a sink for all its air quality problems. Particulate matter that falls onto agricultural land becomes incorporated into the soil and thereby removed from air. The smelly volatile organic compounds from manure will be consumed by soil microbes and converted into soil organic matter when it diffuses into the soil (or the manure is incorporated into the soil). Ammonia from the atmosphere is absorbed by agricultural crops and soils. (In fact, it is because the land is such a good sink for ammonia that this represents another air quality concern. The additional N from absorbed ammonia alters the nutrient balance in natural ecosystems and native plants are displaced by invasive species that are better adapted to the more N-rich environment). Methane and nitrous oxide from the atmosphere diffuses into the soil where it is consumed by soil microbes. Similarly, soil also acts as a sink for pesticides that enter the soil from the air.

However, by far the greatest source-sink interplay occurs for CO<sub>2</sub>, discussed below.

**Describe the soil source-sink for CO<sub>2</sub>.**

Photosynthesizing plants grow by converting inorganic C in CO<sub>2</sub> into organic forms. The organic residues from these plants become soil organic matter. This organic matter is continually being consumed by soil fauna and microbes who convert organic C into CO<sub>2</sub>, which is then returned to the atmosphere. The balance between new organic carbon additions from plants and the loss of organic matter from decomposition determines whether the soil is a source or sink of CO<sub>2</sub>. If the losses over several years exceed the additions, then the soil is a source of CO<sub>2</sub>. Conversely if the additions exceed the losses, then the soil is a sink for CO<sub>2</sub>. A soil sink for CO<sub>2</sub> necessarily requires that soil organic matter is increasing. Soil C sequestration is another term used for soil C sink. However, decomposition usually increases as soil organic matter increases. Therefore, a soil sink will not occur indefinitely; it eventually stops when the rate of C loss from decomposition balances the rate of C addition. When that balance is obtained the soil organic matter is at a steady-state or equilibrium and the soil is neither a net source nor sink of CO<sub>2</sub>. In practice, soils probably never reach a perfect steady-state because of year-to-year changes in weather and other factors; instead soil carbon fluctuates near an equilibrium.

When the prairie soils were first broken for agriculture, they were rich in soil organic matter – the result of millennia of C additions under native vegetation. The conversion to agriculture changed the balance between C input and loss so that much (15-35%) of the original soil organic matter was lost as CO<sub>2</sub> (soil organic matter is typically considered 58% C by mass). This soil organic matter was lost because: 1) the tillage exposed the native soil organic matter to more decomposition, 2) the annual crops returned fewer residues than the native prairie (in particular, summerfallow added no residue except weeds), 3) moister soil accelerated decomposition since annual crops did not keep the soil as dry as the native vegetation did, and 4) farming is specifically designed to export from the field large portions of the plant carbon (e.g., wheat grain) so that inputs to soil are reduced. When soil organic matter is lost, the carbon in that soil organic matter returns to the atmosphere as CO<sub>2</sub>. Each tonne of carbon lost from soil organic matter releases 3.667 tonnes of CO<sub>2</sub>. Similarly, each tonne of soil organic carbon increase removes 3.667 tonnes of CO<sub>2</sub> from the atmosphere.

Presently, we estimate that soil organic matter in prairie soils cultivated for decades is near a steady-state that have been under long-term cultivation. If we change agricultural management so that soil organic matter increases, CO<sub>2</sub> is removed from the atmosphere and sequestered as soil organic matter. As shown in Figure 1, carbon sequestration is essentially recapturing carbon from the atmosphere that had been emitted from the soil in the past.

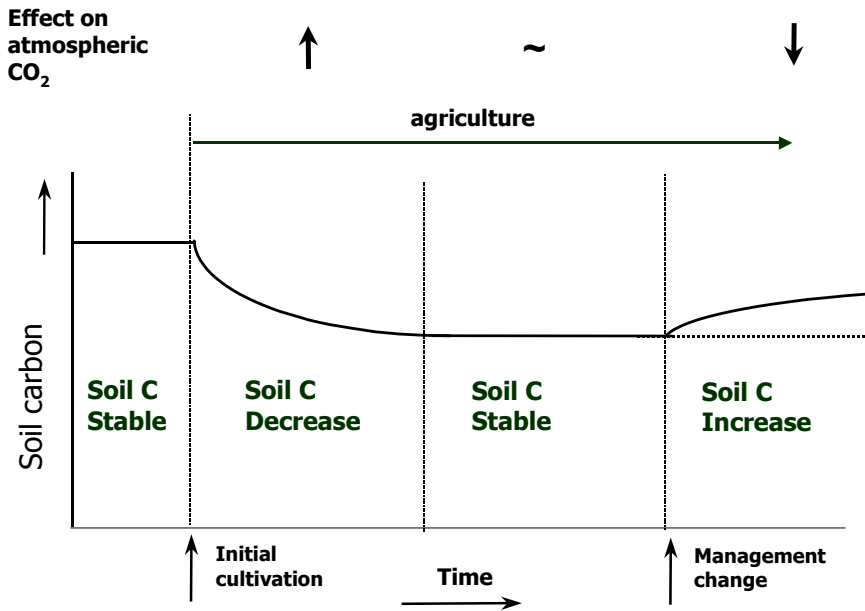


Figure 1. Change in soil organic carbon from breaking of native grass, attainment of new steady state, and then adoption of carbon sequestering practice (hypothetical example).

### What are the sources of the greenhouse gases from agriculture?

The role of soil organic matter on CO<sub>2</sub> balance was discussed above. Briefly, through photosynthesis, plants convert atmospheric CO<sub>2</sub> into organic materials that become soil organic matter. Therefore, an increase in soil organic matter represents a net removal (sink) of CO<sub>2</sub> from the atmosphere and a decrease in soil organic matter represents a net emission of CO<sub>2</sub> to the atmosphere.

Methane is produced when organic material decomposes under conditions where there is not enough oxygen for completion conversion of the carbon to CO<sub>2</sub>. Such conditions occur in the rumen of cattle and some other livestock, and in manure stored with poor aeration (e.g., some forms of wet storage).

Nitrous oxide is produced during the cycling of nitrogen. Predicting the amount of N<sub>2</sub>O emissions is difficult, so it is currently estimated simply as a proportion of nitrogen in stored manure and of nitrogen applied to the soil. For soil emissions, all forms of nitrogen (fertilizer, manure, decomposing crop residues, and nitrogen-fixing legume crops) are considered equal. Direct soil N<sub>2</sub>O emissions occur where the nitrogen was applied; indirect soil N<sub>2</sub>O emissions come from nitrogen lost from the field through leaching or release in gaseous form (indirect emissions result from agricultural nitrogen but do not necessarily occur on agricultural land).

### How important is agriculture as an emitter of greenhouse gases?

Table 3 compares greenhouse gas emissions for 1990 and 2001 for Canada and the Prairie Provinces. In 2001, primary agriculture produced 8.3% of Canada's total greenhouse gas emissions so it is an important contributor relative to its direct contribution to the Canadian

economy (2.2% of GDP in 1996, Can. Fed. Agric.). More than one-half of greenhouse gas emission from primary agriculture is N<sub>2</sub>O and about a third is CH<sub>4</sub>. Importantly, current estimates suggest that CO<sub>2</sub> has gone from a net source in 1990 of 7.6 Mt CO<sub>2</sub> to a net sink of 0.3 Mt CO<sub>2</sub> in 2001. Therefore, despite increasing N<sub>2</sub>O and CH<sub>4</sub> emissions, estimated net emissions from primary agriculture have remained relatively constant from 1990 to 2001.

Table 3. Greenhouse gas emissions in Canada and the Prairie Provinces in 1999 and 2001.

Greenhouse Gas	Greenhouse Gas Emission (Mt CO <sub>2</sub> equivalent)							
	1990				2001			
	Canada	MB	SK	AB	Canada	MB	SK	AB
Total	608.0	20.3	47.0	171.0	720	20.4	61.8	224.0
Total Agriculture	59.2	6.8	11.1	17.4	60.0	6.8	10.0	19.7
Total Agricultural N <sub>2</sub> O	31.0	4.0	6.2	8.4	24.3	4.8	9.0	10.0
Total Agricultural CH <sub>4</sub>	20.6	1.7	2.7	5.8	36.0	2.3	3.6	8.0
Total Net Agricultural Soil CO <sub>2</sub>	7.6	1.1	2.2	3.2	-0.3*	-0.3*	-2.6*	1.7

\*sink

Source: Environment Canada ([http://www2.ec.gc.ca/pdb/ghg/ghg\\_home\\_e.cfm](http://www2.ec.gc.ca/pdb/ghg/ghg_home_e.cfm))

### What exactly is soil organic matter and is the carbon sink permanent?

Soil organic matter is a catchall term to describe organic residues from plants and soil microbes in various states of decomposition. Once residues from above- and below-ground portions of the plant are added to the soil, soil microbes immediately start decomposing those residues. Over time and through transformations by many types of soil microbes, chemical combinations of well-decomposed organic materials are produced that are quite resistant to further degradation. These resistant organic materials, often called humus, represent the majority of soil organic matter in prairie soils. We know that the average age of the humus is more than a thousand years old. Humus plays an important role in providing structure to the soil that is necessary for good plant growth and water infiltration. However, because it is not readily acted upon by soil microbes, humus does not play a large role in nutrient cycling. The less decomposed organic materials from soil microbes and plant residues represent 20-50% of soil organic matter. This portion of the soil organic matter is a major source of plant nutrients such as nitrogen, phosphorus, and sulfur. These nutrients are released as by-products of decomposition because the microbes are using the carbon for energy and releasing it as CO<sub>2</sub>. The N, P, and S in the soil organic matter that is surplus to the needs of the microbes is left as “waste” products that plants can take up. After the adoption of an improved soil management practice like direct seeding, most of the increase in soil organic matter occurs in these more active portions of the soil organic matter that can still be decomposed. For this reason, if direct seeding is discontinued, the newly sequestered carbon may be readily lost (see Figure 3). Since most of the carbon from the plants is added to the surface, almost all the changes in carbon sequestration occur in the upper 10 to 20 cm of soil.

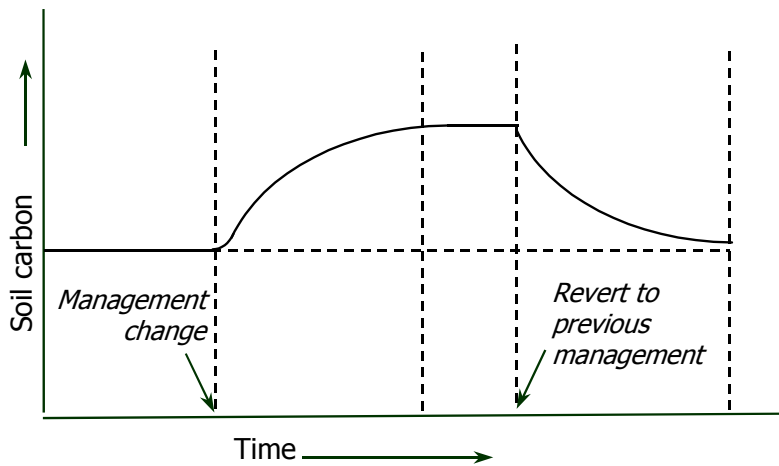


Figure 2. Hypothetical example showing that carbon sequestration is a reversible.

### How do farming practices affect the soil carbon source-sink balance?

Changing to new management practices that increase carbon inputs into the soil will produce a soil sink while the soil organic matter is increasing. Ways to increase carbon inputs includes changing to managements that produce more crop residue (such as better fertilization, irrigation, better moisture conservation, addition of manure, stopping burning residues, cropping instead of fallowing) or changing to managements that reduce net soil organic matter decomposition (such as reducing soil disturbance, perennial instead of annual crops, cropping instead of fallowing).

The actual rate of soil organic change depends on many factors. Generally, moister areas have greater rates of soil organic matter change. The farther the soil organic matter content is from the steady-state condition, the greater the rate of soil organic matter change. Fine-textured soils (clayey soils) may gain carbon at greater rates than coarse-textured soils (sandy soils). Typical rates of soil organic carbon sink for adopting low-disturbance direct seeding, eliminating fallow, or converting from annual to perennial crops are about 0.1 to 0.5 t C ha<sup>-1</sup> yr<sup>-1</sup> (0.16 to 0.8 ton CO<sub>2</sub> per acre per year) over a period of about 20 yr. The rate of soil organic carbon sink can be limited by available nitrogen. Soil organic matter maintains a fairly constant ratio of C to N of about 10:1 by mass. Therefore, to sustain the above C sink rates requires immobilizing up to 50 kg N/ha (44 lb/ac) in organic matter. Although that N can act as an effective N buffer by releasing N when the soil is warm and moist (when plant demand for N is greatest) and immobilizing N when soil is dry and cool (when plant demand for N is least), over the long term that sequestered N is not available to crops without losing the sequestered C.

### What is the source of N<sub>2</sub>O emitted from Prairie farms?

Nitrification, the oxidation of ammonium (NH<sub>4</sub><sup>+</sup>) to nitrate (NO<sub>3</sub><sup>-</sup>), and denitrification, the reduction of NO<sub>3</sub><sup>-</sup> or NO<sub>2</sub><sup>-</sup> to dinitrogen (N<sub>2</sub>) or N<sub>2</sub>O, are the major pathways of N<sub>2</sub>O emissions from prairie farms. Nitrous oxide may also be emitted from various chemical reactions,

collectively known as chemodenitrification, involving nitrite ( $\text{NO}_2^-$ ) and organic matter or exchangeable cations.

### **What controls the amount of $\text{N}_2\text{O}$ produced?**

Over any given period of time, the amount of  $\text{N}_2\text{O}$  emitted from an agro-ecosystem is a reflection of the amount of N nitrified and denitrified, and the fraction of that N released as  $\text{N}_2\text{O}$ . Nitrification rates are favoured by adequate levels of  $\text{NH}_4^+$ , and oxygen. Denitrification rates are favoured by adequate levels of soluble C,  $\text{NO}_3^-$ , and water. Soil-water content strongly influences oxygen status, the availability of nutrients, other microbial activity, and soil temperature. Consequently, soil-water content is the most important factor regulating  $\text{N}_2\text{O}$  emissions at the field scale.

### **When do most $\text{N}_2\text{O}$ emissions occur?**

$\text{N}_2\text{O}$  emissions during the growing season are episodic, and are usually associated with periods of high soil-water content after rainfall or irrigation. Emissions can be particularly intense after wetting of a dry soil. Spring snow melt also creates conditions strongly favouring high  $\text{N}_2\text{O}$  emissions. In western Canada, as much as 80% of total annual  $\text{N}_2\text{O}$  loss can occur during the spring thaw (Lemke et al. 1998).

### **Where do most $\text{N}_2\text{O}$ emissions occur?**

Considering that  $\text{N}_2\text{O}$  emissions are associated with high soil-water contents, site-specific regulators of soil-water status, such as slope position, soil texture, and drainage strongly influence  $\text{N}_2\text{O}$  emissions. Workers in Saskatchewan and Alberta have found that minimal amounts of  $\text{N}_2\text{O}$  are emitted from upper slope positions, while substantial losses occur in the lower slope and depressional areas (Corre et al. 1996).  $\text{N}_2\text{O}$  emissions are often higher in clay soils than on sandy soils.

### **Do farming practices affect the amount of $\text{N}_2\text{O}$ produced?**

N fertilizers: The direct contribution of  $\text{N}_2\text{O}$  from N fertilizers, calculated as the difference in  $\text{N}_2\text{O}$  emission between plots with and without N fertilizer additions, usually ranges from 0-3% of added N, although losses as high as 24% have been reported. While most studies have reported some increase in  $\text{N}_2\text{O}$  emission as a result of fertilizer N, the relationship between fertilizer rate and  $\text{N}_2\text{O}$  emission is not necessarily linear. Nitrous oxide production and emission is governed by a complex interaction between environmental conditions, soil properties, as well as the form, placement, and timing of the fertilizer N application.

Crop residues: The mineralization of organic N bound in crop residues provides inorganic N for nitrification and denitrification. Legume residues, in particular, can stimulate  $\text{N}_2\text{O}$  emissions as they generally have high concentrations of both N and available C. If the N released from crop residues results in a ready supply of inorganic N when available soil-water contents are high, significant losses of  $\text{N}_2\text{O}$  may occur. For example, Lemke (1997) observed greater losses of  $\text{N}_2\text{O}$  during spring thaw following fall-incorporation of alfalfa than from wheat stubble, apparently because of increased  $\text{NO}_3^-$  on the alfalfa plots.

Manure application: Applying manure to soil can lead to enhanced  $\text{N}_2\text{O}$  emission. Manure usually contains high concentrations of inorganic N and supplies easily decomposable organic C. Chang et al. (1998) have demonstrated that land-application of feedlot manure has a cumulative effect. In plots that had received 21 annual applications of feedlot manure at rates from 0 to 180  $\text{Mg ha}^{-1}$ ,  $\text{N}_2\text{O}$  rates ranged from less than 1  $\text{kg N ha}^{-1}$  to 56  $\text{kg N ha}^{-1}$ , respectively. In particular,

application of manure in the fall could induce large N<sub>2</sub>O emissions during the following spring thaw.

Soil Management: Tillage influences the N cycle by affecting soil aeration, temperature and humidity, by modifying soil structure, and by re-distributing fertilizer, crop residues and organic amendments in the soil profile. There is much research currently underway in Canada to determine the impact on no-tillage on N<sub>2</sub>O emissions. That research is showing N<sub>2</sub>O emissions for no-till are equal to lower than those for conventional-tillage systems.

Summerfallow: The increased soil-moisture and accumulation of soil NO<sub>3</sub><sup>-</sup> that occurs during a fallow period would be expected to increase N<sub>2</sub>O production and emission. In Saskatchewan, Aulakh et al. (1982) reported significantly higher N<sub>2</sub>O emissions from fallow compared to fertilized spring-wheat treatments during the growing season. In the Parkland region of Alberta, Lemke et al. (1999) reported lower losses from fallow than from fertilized spring-wheat treatments during the growing season, but losses were often higher during the following spring thaw.

### **How does fertilizer management affect N<sub>2</sub>O emissions?**

A recently completed study that included field experiments at four Saskatchewan locations, Swift Current, Scott, Indian Head and Star City, investigated four main questions concerning fertilizer-N management under a No Till regime: 1) How much N from fertilizer is lost directly as N<sub>2</sub>O under western Canadian conditions? 2) Does fertilizer-N source (anhydrous ammonia vs. urea) influence direct losses of N<sub>2</sub>O? 3) Does application time (spring vs. fall) influence direct losses of N<sub>2</sub>O? and, 4) Does fertilizer placement (mid-row vs. side-row banding) influence direct losses of N<sub>2</sub>O?

The results indicate very little difference in total N<sub>2</sub>O emissions from the N application systems compared. Emissions tended to be higher from mid-row compared to side-row banded N, although differences were only statistically significant at two of the four sites. Applying N in the fall tended to increase the risk of N<sub>2</sub>O emissions during the following spring thaw, but total annual N<sub>2</sub>O emissions were generally not significantly affected. It should be noted that winter snow cover was limited during the study, which would have reduced the risk of N<sub>2</sub>O production during spring thaw. Consequently, the results of the spring versus fall applied N comparison may not apply directly to more typical conditions..

Results from this study confirm that fertilizer-N applications increase N<sub>2</sub>O emissions, but also showed that emissions from all sites were consistently low. Over the three years of the project (May 2000 – April 2003), between 0.1 and 0.4 % of the fertilizer-N applied was lost as N<sub>2</sub>O (Table 3). National greenhouse gas inventories currently assume that 1.25 % of fertilizer-N is lost as N<sub>2</sub>O. This suggests that under western Canadian conditions, and under comparable management systems, N<sub>2</sub>O emissions associated with fertilizer-N use may be considerably lower than currently estimated.

Emissions from plots receiving N as anhydrous ammonia (AA) tended to be slightly higher than those receiving N as urea; however the differences were only statistically significant at Star City. More energy is required and more CO<sub>2</sub> is released during the manufacture of urea compare to AA (Table 4) (Nagy, C., 2000). Table 4 also compares the combined CO<sub>2</sub> equivalents from the manufacturing process and our measured N<sub>2</sub>O emissions (converted to CO<sub>2</sub> equivalents) from

urea and AA treatments for two different situations. At Star City in 2000, N<sub>2</sub>O emissions were higher from AA compared to urea treatments. However, when the CO<sub>2</sub> equivalents from manufacturing are included, total CO<sub>2</sub> equivalents turn out to be very similar. At Swift Current in 2000, N<sub>2</sub>O emissions were similar from AA compared to urea; therefore total CO<sub>2</sub> equivalents are substantially higher from urea compared to AA after CO<sub>2</sub> equivalents from manufacturing have been included. The latter situation was the more typical result in this study. While N<sub>2</sub>O emissions were similar or slightly higher from AA compared to urea, total CO<sub>2</sub> equivalents were generally lower from AA compared to urea.

**Table 3.** Percent of fertilizer N lost as N<sub>2</sub>O (3-yr total) at four Saskatchewan sites.

N management	Swift Current	Scott	Star City	Indian Head
	%			
Anhydrous Ammonia				
Fall banded	0.2	0.2	0.3	0.1
Side-row (spring banded)	0.2	0.1	0.1	0.1
Mid-row (spring banded)	0.3	0.3	0.2	0.1
Urea				
Fall band	0.4	0.2	0.2	0.1
Side-row (spring banded)	0.1	0.1	0.1	0.1
Mid-row (spring banded)	<u>0.3</u>	<u>0.1</u>	<u>0.1</u>	<u>0.1</u>
Mean	0.2	0.2	0.2	0.1

**Table 4.** Energy inputs and CO<sub>2</sub> equivalents for urea and AA applied at the recommended rates on wheat at Star City and Swift Current in 2000.

N-form	Energy Input (MJ ha <sup>-1</sup> )	N <sub>2</sub> O (kg CO <sub>2</sub> E) <sup>Z</sup>	EI + N <sub>2</sub> O (kg CO <sub>2</sub> E ha <sup>-1</sup> )	Grain/CO <sub>2</sub> E (kg kg <sup>-1</sup> )
<u>Star City</u>				
AA	7730	290	496 <sup>Y</sup>	4.8
Urea	9628	156	484	4.9
<u>Swift Current</u>				
AA	6040	155	309	10.4
Urea	7590	164	410	9.8

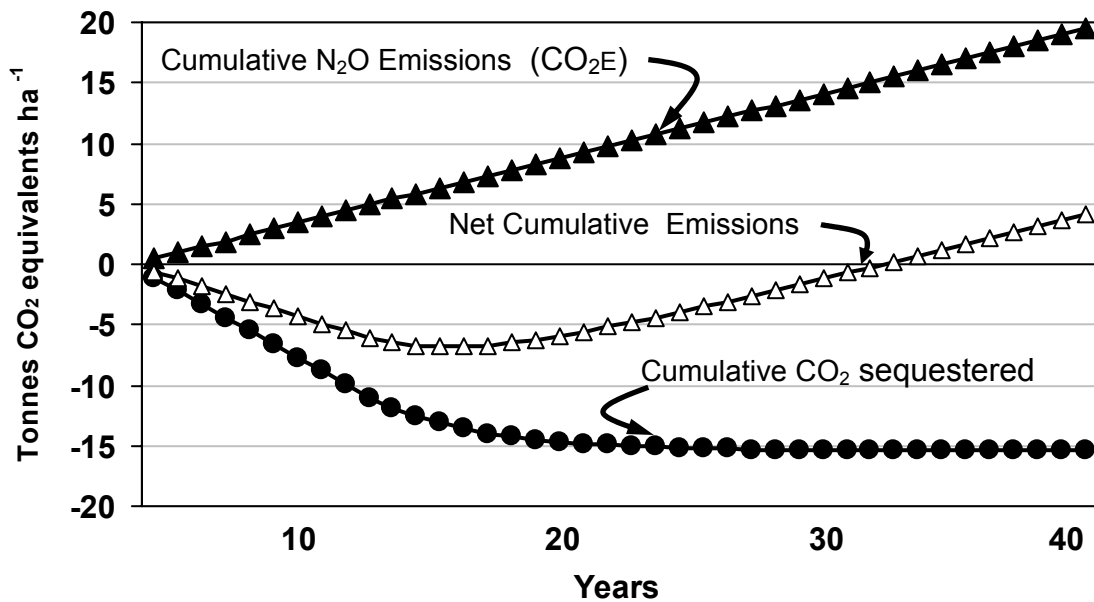
<sup>Z</sup> CO<sub>2</sub>E = CO<sub>2</sub> equivalents (Global warming potential of N<sub>2</sub>O is 310 times that of CO<sub>2</sub>)

<sup>Y</sup> CO<sub>2</sub> emission coefficients for fertilizer-N presented in Nagy 2000.

### Why should N<sub>2</sub>O and CO<sub>2</sub> be considered together?

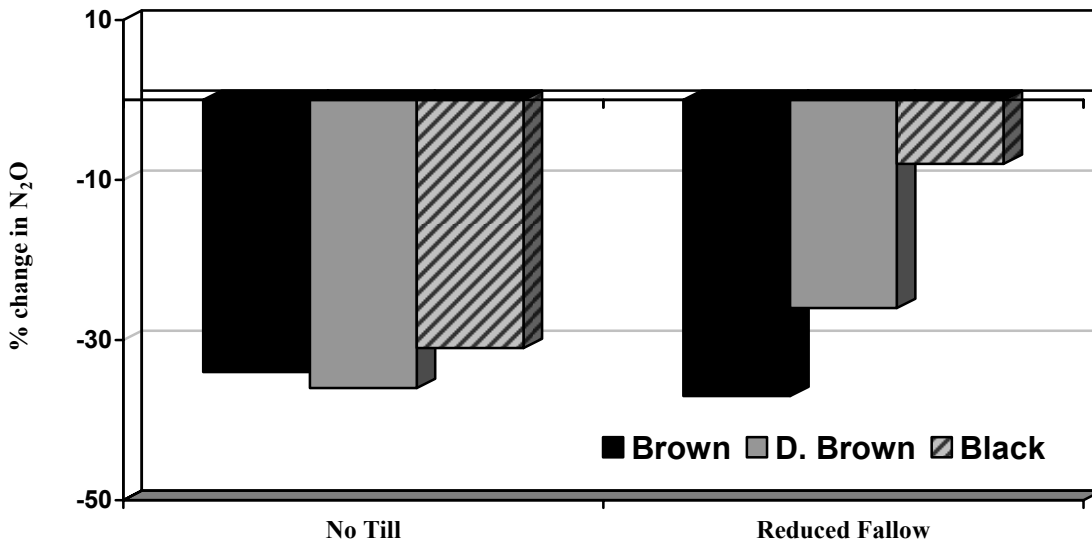
Carbon and nitrogen are inextricably linked in agricultural soils. Any management that changes organic carbon will affect nitrogen cycling and thereby N<sub>2</sub>O emissions. Similarly, any management that affects soil nitrogen will affect carbon cycling and thereby the soil C source-sink balance.

While the soil sink stops eventually, the N<sub>2</sub>O emissions continue indefinitely. Therefore, if the change in management accomplishes a soil sink at the expense of higher N<sub>2</sub>O emissions, then, eventually, the new management will be represent a net increase in greenhouse gas emissions. This is illustrated in Figure 3.



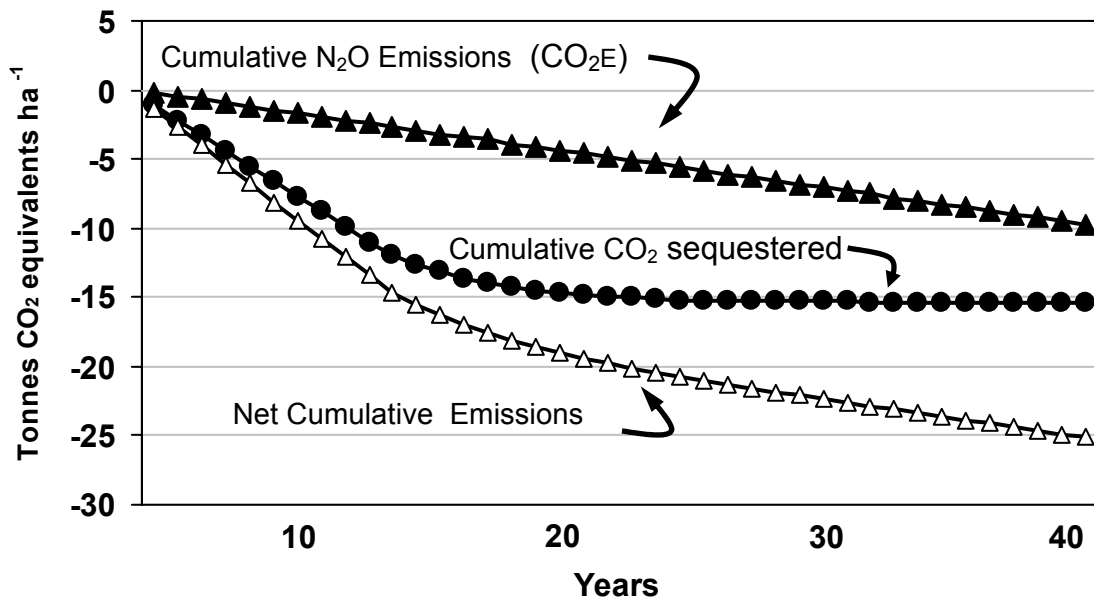
**Figure 3.** Scenario showing the net result of adopting a C sequestering practice that also increases N<sub>2</sub>O emissions. Assumes 300 kg ha<sup>-1</sup> yr<sup>-1</sup> of C sequestered for 10 years, decreasing by 20% in each subsequent year, with a concurrent increase of 1.0 kg N<sub>2</sub>O-N ha yr<sup>-1</sup>. Positive values represent a contribution to the atmosphere; negative values represent a withdrawal from the atmosphere.

While our confidence in the simulation models is still rather limited, the results from both a simulation study (Lemke et al. 2001) and comparisons based on field measurements indicate that N<sub>2</sub>O emissions may not increase for particular practices that produce a soil sink, including reductions in tillage intensity and fallow frequency (Figure 4).



**Figure 4.** Percent change in N<sub>2</sub>O emissions after adopting No Till or reducing fallow frequency for three soil zones in western Canada based on simulation model predictions.

Figure 5 presents another simple scenario. We make the same assumptions about SOC as in the first scenario, but this time we assume that N<sub>2</sub>O emissions decrease by 30% (the percent change reported in our modeling study). Average “base-line” N<sub>2</sub>O emission in the modelling study was 1.5 kg N ha<sup>-1</sup> yr<sup>-1</sup>, thus a 30% decrease would be about 0.5 kg N ha<sup>-1</sup> yr<sup>-1</sup>. The benefits of the C sequestered again levels off, but the decrease in N<sub>2</sub>O emissions do not, therefore the net benefit in greenhouse gas reduction continues to accrue. While the numbers used in these scenarios are for illustration only, our research results suggest that the trend depicted in the second scenario (Figure 5) is more likely than the trend depicted in the first scenario (Figure 3).



**Figure 5.** Scenario showing the net result of adopting a C sequestering practice that also decreases N<sub>2</sub>O emissions. Assumes 300 kg ha<sup>-1</sup> yr<sup>-1</sup> of C sequestered for 10 years, decreasing by 20% in each subsequent year, with a concurrent decrease of 0.5 kg N<sub>2</sub>O-N ha yr<sup>-1</sup>. Positive values represent a contribution to the atmosphere; negative values represent a withdrawal from the atmosphere.

### Will C sinks and N<sub>2</sub>O emission reductions be tradable?

The Canadian government has proposed that offset credits from C sinks and emission reductions from agriculture will be tradable with large industrial emitters of greenhouse gases. The large industrial emitters would use these credits to offset some of their emissions. However, the exact mechanisms for that trading and determining what will be traded are under discussion. In June 2003, there were a series of workshops involving sellers of C sinks and emission reductions, buyers (large industrial emitters), and the Canadian government to discuss trading mechanisms. The government discussion paper on offset trading and a summary report for these workshops can be found at <http://www.climatechange.gc.ca/english/publications/offsets/index.html>. The Saskatchewan Soil Conservation Association (SSCA) has been actively involved in these discussions. Position papers on offset trading by the SSCA can be found on the SSCA web site ([www.scca.ca](http://www.scca.ca)).

### How will C sinks and N<sub>2</sub>O emissions be quantified?

The emissions of N<sub>2</sub>O and net CO<sub>2</sub> from agriculture are diffuse and temporally and spatially variable thereby defying low-cost measurement. The methods now in place are based on general rates of soil C change and N<sub>2</sub>O emissions that are considered representative for large areas of agricultural land over many years. Any specific portion of a field in any one year may have vastly different rates of C change and N<sub>2</sub>O emissions than those general representative rates. However, when thousands of fields are considered over many years, these differences should average out to the representative rates. For offset credit trading, the same general quantification methods will likely be used. Therefore, it will not be feasible to determine the exact C sink and

N<sub>2</sub>O emissions for an individual farm. The C sink and N<sub>2</sub>O emissions can only be practically quantified for a large number of farms using similar practices. For example, the C sink and N<sub>2</sub>O emission reductions for adoption of direct seeding could only be practically quantified by considering many farms together that are using direct seeding.

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