Estimated N_2O Emissions as Influenced by Agricultural Practices in Canada

Smith, W.N.**,** ***Desjardins, R.L.*****,** ***Grant, B.*** and ***Lemke, R.***

Agriculture Agri-Food Canada, Research Branch, KW Neatby Bldg., 930 Carling Avenue
Ottawa Ontario, Canada. K1A OC5
Tel: 613-759-1522, Fax: 759-1515 E-mail:desjardins@em.agr.ca

Abstract: The Denitrification-Decompostion (DNDC) model was used to estimate the influence a change in management practices might have on N_2O emissions in seven major soil groups in Canada, for the period 1970 to 2030. Conversion of cultivated land to permanent cover would result in the least emissions of N_2O, particularly in eastern Canada where the model estimated about 60% less emissions for this conversion. About 33% less N_2O emissions were predicted for a change from conventional tillage to no-tillage in western Canada, however, a slight increase in N_2O emissions was predicted for eastern Canada. Greater emissions in eastern Canada due to adoption of no-tillage was attributed to higher soil moisture causing denitrification, whereas the lower emissions in western Canada was attributed to less decomposition of soil organic matter than in the conventionally tilled soil. Reduction in summer fallow resulted in a 9% decrease in N_2O emissions, with substantial emissions occurring during the wetter fallow years when N had accumulated. Increasing fertilizer application rates by 50% increased average emissions by 32%, while a 50% decrease of fertilizer application decreased emissions by 16%. A small increase in emissions was predicted when fertilizer was applied in the fall rather than in the spring. Inclusion of a pulse crop in rotations had little impact on emissions. The results from this work indicate that a shift to permanent cover and no-tillage management could substantially decrease N_2O emissions. This is encouraging because these practices are considered important for increasing soil carbon sequestration in agricultural soils.

1 Introduction

With the signing of the Kyoto protocol, Canada has promised to reduce its greenhouse gas emissions by 6% below 1990 levels by the year 2010. The agriculture sector is responsible for about 10-15 % of Canada’s greenhouse gas emissions (Desjardins and Riznek, 2000). Because it is intensively managed, this sector is an excellent candidate for helping Canada meet part’s of its commitment. The most viable implementation strategy for reducing GHG emissions is through the use of improved management practices. Many of these management practices have already been identified (Lal and Bruce, 1999; Smith *et al*., 2001). Practices such as adoption of no-tillage, reduction of bare fallow and conversion of croplands to permanent grasslands have frequently been identified as potential management practices to reduce greenhouse gas emissions. However, many of these practices have only been ranked based on their ability to either reduce CO_2 emissions or increase carbon sequestration. While carbon sequestration in agricultural soils may be beneficial to the environment as well as to crop production, other greenhouse gases must be considered when assessing the effects of management strategies. For example, N_2O which has a global warming potential 310 times more than CO_2 must be considered (IPCC, 1996). As well, emissions of methane from manure and livestock can substantially affect the GHG budget (Desjardins *et al*., 2001). Only after having considered the total net change of N_2O, CO_2 , and CH_4 emissions for each management practice will we be able to make accurate recommendations of how to reduce the net greenhouse gas emissions. In this paper we focus on N_2O emissions.

Emissions of N_2O are influenced by environmental factors such as temperature, rainfall, snowmelt, freezing and thawing, as well as by management practices, such as nutrient application via manure and fertilizer, summer fallowing, incorporation of crops or crop residues, and tillage. The temporal and spatial variability of N_2O emissions in response to climate and soil conditions make it very difficult to quantify emissions from agricultural sources. Chamber measurements of N_2O emissions provide satisfactory data at a point; however, because of the diversity in soil, climate, and crop, as well as soil and crop management, it is difficult to extrapolate these data to a larger scale. Emissions of N_2O within a field have been found to have a coefficient of variation of > 150% (Manuela *et al.*, 1999) and even greater variability can be expected between fields. Drivers of N_2O emissions are 1) substrate supply, 2) N additions and mineralization-nitrification of organic N, 3) soil water content and 4) temperature (Skiba and Smith, 2000). Each driver can have a large influence on emissions. Accurate estimates of annual N_2O emissions at the field, regional and country-wide scale are required in order to compare the impact of management strategies and identify management practices that will lead to lower GHG emissions. The objectives of this study are to estimate N_2O emissions coefficients and to quantify changes in N_2O emissions upon implementation of various mitigation practices.

2 Methodology

The DNDC model was used to analyze a wide variety of cropping systems across Canada in order to assess the impact of changes in agricultural management on N_2O emissions. The DNDC model developed by Li *et al.* (1992a,b, 1994, 2000) is a process-based model which can be used to predict carbon and nitrogen dynamics in soils over a long time period. It uses readily available input data. The model consists of four interacting submodels: thermal/hydraulic, crop growth, decomposition and denitrification. It can be used to estimate the impacts of agricultural practices on N_2O emissions for many crops.

Base (control) runs of the model, in which conventional tillage was used with various crop rotations within a soil group, were carried out for the period from 1970 to 2029. Simulations were also carried out in which the management practices were changed in the year 2000. Where applicable, the following changes in management were simulated: (1) Addition of forage/pasture in a rotation; (2) Conversion of croplands to grasslands; (3) Reduction in summerfallow; (4) Change in amount of fertilizer applied (50% and 150% of normal fertilizer application rate); (5) Changing time of fertilizer addition (fall rather than spring), and (6) Change from conventional tillage to either no-tillage or minimum-tillage.

Simulations were carried out for three soil textures (sandy loam, loam, and clay loam) in each of the seven dominant/major soil groups in Canada. The soil groups investigated were the Brown Chernozem, Dark Brown Chernozem, Black Chernozem, Dark Gray Chernozem , Gray Brown Luvisol, Gray Luvisol, and Gleysolic. Average soil properties such as bulk density, particle size distribution, pH, and initial organic carbon were obtained from the Soil Landscape of Canada (SLC) polygon database. All simulations were carried out for two to four commonly used crop rotations in each soil group. Representative climate data was chosen for each soil group using one that had near average yearly precipitation and temperature within the respective soil group. Daily temperature and precipitation were inputted into the model for a 30year simulation period from 1970 to 1999. The same weather was repeated for the years 2000 to 2030. Due to the large interannual variations in N_2O emissions , it was necessary to simulate emissions over 30 years to encompass a reasonable range of estimates.

Current fertilizer application rates for each crop rotation were taken from Smith *et al.* (2000). Fertilizer was applied at 1/3 current rates from 1970 to 1979 and 3/4 current rate from 1980 to 1989, in accordance with Canadian fertilizer consumption records (Korol and Girard, 1996). Thirty percent more fertilizer was applied on the no-tillage rotations than on conventional tillage systems.

Coefficients of N_2O emission for the period 2000 to 2030 were estimated as the average yearly difference in emissions between the new management practice and the control. Emissions were scaled up for the soil groups by weighting emissions by percent of crop rotation and area of soil texture within the soil groups as follows:

$$N_{Group} = \sum_{l}^{t} F_t \left(\sum_{l}^{r} F_r R_r \right)$$

where N_{Group} = N coefficient for a soil group, t = number of soil textures, F_t = fraction of area covered by soil texture, r = number of crop rotations, F_r = fraction of area covered by crop rotation, and R_r is the N coefficient for a particular crop within a soil texture and soil group.

3 Results & discussion

The DNDC model was used to estimate the impact on N_2O emissions for changes in management practices in Canada beyond the year 2000. Average N_2O emissions coefficients for various soil groups, soil textures, and appropriate crop rotations due to changes in management practices are presented for the period between 2000 to 2030 (Table 1). The average base or control N_2O emissions for the 2000—2030 period was about 1.49 kg N_2O-N $ha^{-1} \bullet y^{-1}$. Gleysolic and Gray Brown Luvisol soil groups are expected to have the greatest emissions. These soil groups are located in eastern Canada where they receive more precipitation and more nutrients via fertilizer and manure. Due to less rainfall, and cooler temperatures, N_2O emissions in western Canada were generally less than in eastern Canada. The results in Figure 1 show a typical response of DNDC to western prairie (panel A) and eastern (panel B) climates. Most of the changes in management practices (except increasing N fertilizer and adding N fertilizer in the fall) that were examined resulted in less overall N_2O emissions than did the control (Table 1). These practices include reduced tillage, reduction of summerfallow, reduction in fertilizer application, addition of fertilizer in the fall rather than in the spring, and conversion from croplands to grasslands.

Change of management from conventional to no-tillage in 2000 resulted in 17 % less emissions, on a weighted average in Canada, over 30 years (Table 2). The results from DNDC indicated that soil groups in western Canada emitted less N_2O upon introduction of no-tillage agriculture, whereas most of the simulations in the east showed a small increase in emissions (Figures 1a and 1b). We expect higher moisture in soils that are under no-tillage management and thus more denitrification and production of N_2O. However, depending on the redox potential in the soil, denitrification can occur with little of no N_2O being emitted to the atmosphere (Lemke *et al.*, 2001). Also temperatures are generally cooler in soil that is under no tillage management. Tilling soil disturbs structure, aerates the soil, and more substrates are released for decomposition. In the drier western soils the increased decomposition of organic matter may result in more nitrification and thus more N_2O emissions. If this is the case then no-tillage should have greater benefit in the dryer soil zones since it increases soil carbon sequestration, reduces fossil fuel use, conserve soil structure, reduce erosion risk, and conserve more soil moisture. Ball *et al.*, (1999) found that reduced gas diffusivity and air-filled porosity, caused by heavy rainfall resulted in periods of low CO_2 fluxes and high N_2O fluxes.

Reduction of summer fallow in the year 2000 resulted in 9% less emissions of N_2O when compared to the control DNDC simulations. Our first hypothesis was that more intensive cropping should result in greater emissions of N_2O because of greater additions of fertilizer. However, in the dryer western soils fertilizer N rates are low, thus the predicted emissions of N_2O are quite low with more frequent cropping. The crop generally uses most of the available N. In fallow years, N accumulates through mineralization of organic matter and the soil moisture increases. In these soils greater N_2O emissions are sometimes observed. In subhumid soils in Saskatchewan, Lemke *et al.*, 2001 reported variable emissions between wheat-wheat and wheat-fallow rotations with more emissions sometimes occurring from the wheat-fallow plots than from the wheat-wheat plots. Most fallowing now occurs in the Brown and Dark Brown soil zones where use of fallow is only really needed to suppress disease and weed infestations (Campbell *et al.*, 2002).

Emissions of N_2O from the western prairie soils were on average 34% more when fertilizer was applied n the fall rather than in the spring. The greatest influence of fall fertilization was found in the Dark Gray Chernozem with 60 % more emissions than when fertilizer was applied in the cropping season. The dryer Brown and Dark Brown Chernozems showed 10 and 18 percent change from the control, respectively. Nitrogen leached out of the system is not accounted for in DNDC, though the amount leached from these dryer western soil groups is small, particularly if the fertilizer is applied late in the fall at a time when the soil surface is most often frozen. Nitrogen leached to groundwater and drainage ditches can later become available for denitrification and production of N_2O.

Our simulations suggested that addition of 50% more fertilizer in the year 2000 would result in 22 to 47% more emissions of N_2O across Canada with a weighted average of 32% more emissions with emissions increasing with soil moisture. Likewise reduction by 50% fertilizer application resulted in 5 to 27% less emissions with an average of 16% less emissions. The greatest changes occurred in the continuously cropped areas where more fertilizer was applied. Up to 1.49 kg N_2O-N $ha^{-1} \bullet y^{-1}$ more emissions of N_2O occurred after addition of 50% more fertilizer to the maize-maize-barley-barley rotation of the eastern Gray Brown Luvisol (Table 1). A large percentage increase was predicted for continuous wheat in western Canada. In the western soil groups the crops use less fertilizer due to moisture deficiencies. Such constraints are less limiting in the warmer/wetter eastern soil groups.

Inclusion of pulse crops in the rotations had little effect on N_2O emissions (Table 1). Less emission occurred when soybeans replaced barley in the maize-maize-barley-barley rotation and when the wheat-fallow rotations were replaced by wheat-pea (Table 1). Fallow rotations generated substantial emissions due to frequent tillage. When the barley-non-legume hay rotation was changed to barley-legume hay in the year 2000 it was estimated that emissions in the eastern soil groups increased by as much as 0.79 kg N_2O-N $ha^{-1} \bullet y^{-1}$. This can be expected since minimal emissions come from non-legume hay rotations. However, large emissions of N_2O are common when legumes are plowed under (Wagner-Riddle and Thurtell, 1998).

As expected, management change to permanent cover in the year 2000 resulted in lower N_2O emissions in all soil groups. Emissions were reduced more in the more frequently fallowed systems because cover crop reduces soil water available for mineralization/nitrification and denitrification. The emissions were considerably less in eastern Canada where more fertilizer is applied to crops, and where more precipitation occurs. Emissions on the Gray Brown Luvisol, Gray Luvisol, and Gleysolic soil groups are reduced to about 40% of the emissions prior to the management change.

4 Summary

Emissions of N_2O from agricultural soils are extremely variable due to the diverse soil properties, climate, and agricultural management practices that occur in Canada. Accurate estimates of annual N_2O emissions at the field, regional and country wide scale are required to compare current management strategies and identify better management practices. The DNDC model, which was calibrated using experimental data collected across Canada was used to estimate the change in N_2O emissions for the period between 2000 to 2030 due to changes in management practices.

In comparison to the control simulations, conversion to permanent cover in the year 2000 resulted in the greatest reduction in N_2O emissions of any mitigation strategy assessed, with emissions particularly being less in eastern Canada. Emissions from no-tillage in western Canada were found to be 33% less than under conventional tillage. Some field research in western Canada shows less emission in no-tillage than in conventional tillage but the model may, however, be slightly exaggerating the difference. The lower emissions in western Canada were attributed to more availability of substrates for decomposition through physical disturbance and aeration. Emissions associated with no-tillage in eastern Canada were a bit higher than under conventional tillage. Much more precipitation occurs in Eastern Canada and no-tillage promotes higher soil moisture. Greater soil moisture can shift the denitrification pathway to N_2O, rather than N_2 or NO.

Addition of 50% more fertilizer increased N_2O emissions by 32% whereas 50% less fertlizer decreased emissions by 16%. Little overall change was found from inclusion of a pulse in rotations. About 34 % more emissions of N_2O occurred after applying fertilizer in the fall rather than in the cropping season.

The N_2O emission coefficients generated in this paper will be useful in making policy recommendations. When developing policies with respect to reducing greenhouse gas emissions it is of importance to examine the combined emissions of N_2O, CH_4 and CO_2.

References

Ball, B.C., Scott, A. and J.P. Parker. 1999. Field N_2O, CO_2, and CH_4 fluxes in relation to tillage, compaction and soil quality in Scotland. Soil and Tillage Research. 53, 29-39.

Campbell, C.A., Zentner, R.P., Gameda, S., Blomert, B. and Wall D.D. 2002. Production of annual crops on the Canadian prairies: Trends during 1976-1998. Can. J. Soil Sci. (In Press).

Desjardins, R.L. and R. Riznek. 2000**.** Agricultural greenhouse gas budget. In: Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. McRae, T., C.A.S. Smith and L.J. Gregorich (eds.) Catalogue No. A22-201/2000E. Agriculture and Agri-Food Canada, Ottawa, Ont., pp. 133-142.

Desjardins, R.L., S.N. Kulshreshtha, B. Junkins, W. Smith, B. Grant and M. Boehm. 2001. Canadian greenhouse gas mitigation options in agriculture. Nutrient Cycling in Agroecosystems 60:317-326.

IPCC. 1996. Climate Change 1995. Impacts, Adaptations and mitigation of climate change: Scientific-Technical Analyses. Cambridge University Press, New York, 879 pp.

Korol, M. and L. Girard. 1996. Canadian Fertilizer Consumption, Shipments and Trade 1994/95. Farm Income Policy and Programs Directorate, Agriculture and Agri-Food Canada, Ottawa, Ont.

Lal, R, and J.P. Bruce. 1999. The potential of world cropland soils to sequester C and mitigate the greenhouse effect. Environmental Science and Policy. 2:177-186.

Li, C., S. Frolking, and T.A. Frolking. 1992a. A model of nitrous oxide evolution from soil driven by rainfall events: 1. Model structure and sensitivity. J. Geophys. R. 97:9759-9776.

Li, C., S. Frolking, and T.A. Frolking. 1992b. A model of nitrous oxide evolution from soil driven by rainfall events: 2. Model applications. J. Geophys. R. 97.

Li, C., S. Frolking, and R. Harris. 1994. Modeling carbon biogeochemistry in agricultural soils, Global Biogeochemical Cycles. 8:237-254.

Lemke, R.L., McConkey, B.G., Izaurralde, R.C., Goddard, T.W., Selles, F., Campbell, C.A., Boehm, M., and Lindwall, C.W. 2001. Reduced tillage: Can it help conserve soils and reduce greenhouse gas emissions from western Canadian agriculture? p.p. 302-306 (session 3: Resources and Environment). *In* Wei *et al.* (eds.) Promoting Global Innovation of Agricultural Science & Technology and Sustainable Agricultural Development, proceedings of the International Conference on Agricultural Science and Technology. Nov. 7-9, Beijing, China.

Manuela, R., Heinemeyers, O., Munch, J.C., and Kaiser, E.A. 1999. Spatial heterogeneity within the plough layer: high variability of N_2O emission rates. Soil Biology and Biochemistry. 31,167-173.

Skiba, U. and K.A. Smith. 2000. The control of nitrous oxide emissions from agricultural and natural soils. Chemosphere- Global Change Science. 2, 379-386.

Smith W., Desjardins R.L. and E. Pattey. 2000. The net flux of carbon from agricultural soils in Canada 1970-2010. Global Change Biol. **6**, 1-12.

Smith, W.N., R.L. Desjardins and B. Grant. 2001. Estimated changes in soil carbon associated with agricultural practices in Canada. Can. J. of Soil Sci. 81: 221-227.

Wagner-Riddle, C. and G.W. Thurtell. 1998. Nitrous oxide emissions from agricultural fields during winter and spring thaw as affected by management practices. Nutr. Cycl. Agroecosys. 52:151-163.

Zhang, Y., Li, C., Zhou, X., and B. Moore III. 2002. A simulation model linking crop growth and soil biogeochemistry for sustainable agriculture. Ecological Modelling. (in press).

Table 1 Average simulated N_2O emissions coefficients for various soil groups and crop rotations, due to changes in management practices for the period between 2000 to 2030

	Change in N_2O emissions (coefficient)								
	Crop rotation	Control*	No-till	Reduced Fallow	150% Fert	50% fert	Fall fert	Add pulse	Perm cover
		-------------------------------------(kg N_2O-N/(ha • y))--------------------------------							
Brown	WF	0.86	–0.50	–0.39	0.10	–0.02	0.03	–0.27	–0.37
Chernozem	WWF	0.62	–0.23	–0.17	0.20	–0.05	0.07	–0.06	–0.16
	W	0.47	0.02		0.39	–0.07	0.18	0.11	0.02
	WP	0.68	–0.03		0.11	–0.02	0.04		–0.14
	Average	0.68	–0.23	–0.25	0.17	–0.04	0.07	–0.10	–0.19
Dark Brown	WF	1.25	–0.67	–0.47	0.08	–0.03	0.09	–0.35	–0.58
Chernozem	WWF	1.01	–0.36	–0.2	0.26	–0.05	0.18	–0.07	–0.30
	W	0.87	–0.23		0.58	–0.21	0.47	0.12	–0.16
	WP	1.10	–0.19		0.13	–0.04	0.06		–0.28
	Average	1.16	–0.41	–0.3	0.28	–0.08	0.21	–0.11	–0.37
Black	WF	1.40	–0.73	–0.49	0.27	–0.03	0.09	-0.37	–0.64
Chernozem	WWF	1.09	–0.33	–0.12	0.35	–0.10	0.46	0.05	–0.25
	W	1.10	–0.40		0.84	–0.36	0.77	0.10	–0.25
	WP	1.35	–0.26		0.40	–0.15	0.20		–0.33
	Average	1.16	–0.36	–0.09	0.55	–0.21	0.51	0.04	–0.29
Dark Gray	WF	2.00	–1.15	–0.8	0.11	–0.02	0.21	–0.31	–0.96
Chernozem	WWF	1.50	–0.55	–0.31	0.35	–0.08	0.61	0.35	–0.32
	W	1.30	–0.51		0.88	–0.33	1.54	0.56	–0.15
	WP	2.19	–0.61		0.30	–0.13	0.52		–0.69
	Average	1.58	–0.58	–0.21	0.54	–0.18	0.94	0.40	–0.36
Gray Brown	BBHHH	1.75	0.06		0.33	–0.17		0.59	–1.08
Luvisol	MMBB	3.22	0.86		1.49	–1.28		–0.78	–2.29
	BP	2.20	-0.06		0.34	–0.35			–1.22
	Average	2.43	0.36		0.80	–0.65		–0.10	–1.59
Gray	BBHHH	1.43	0.24		0.24	–0.18		0.51	–0.78
Luvisol	WWF	2.05	–0.36	0.64	0.54	–0.40		–0.51	–1.39
	Average	1.74	–0.06	0.64	0.39	–0.29		0.00	–1.08
Gleysolic	BBHHH	2.25	–0.04		0.27	–0.19		0.79	–1.33
	MMBB	3.59	0.60		1.47	–1.23		–0.49	–2.37
	BP	2.67	–0.25		0.47	–0.30			–1.32
	Average	2.87	0.18		0.79	–0.63		0.15	–1.74
Coefficient for Canada			–0.26	–0.13	0.48	–0.23	0.42	0.03	–0.56
Control Emis. Rate		1.49							

- base simulation with conventional tillage for the period between 1970 to 2030
- negative values indicate less emissions and positive indicate more emissions
- reduced fallow is relative to W
- increase and decrease in fertilizer only represents N-fertilizer application
- addition of pulse indicates that the rotation converts to WP in 2000
- w, wheat; h, hay; b, barley; f, fallow; m, maize; p, soybean

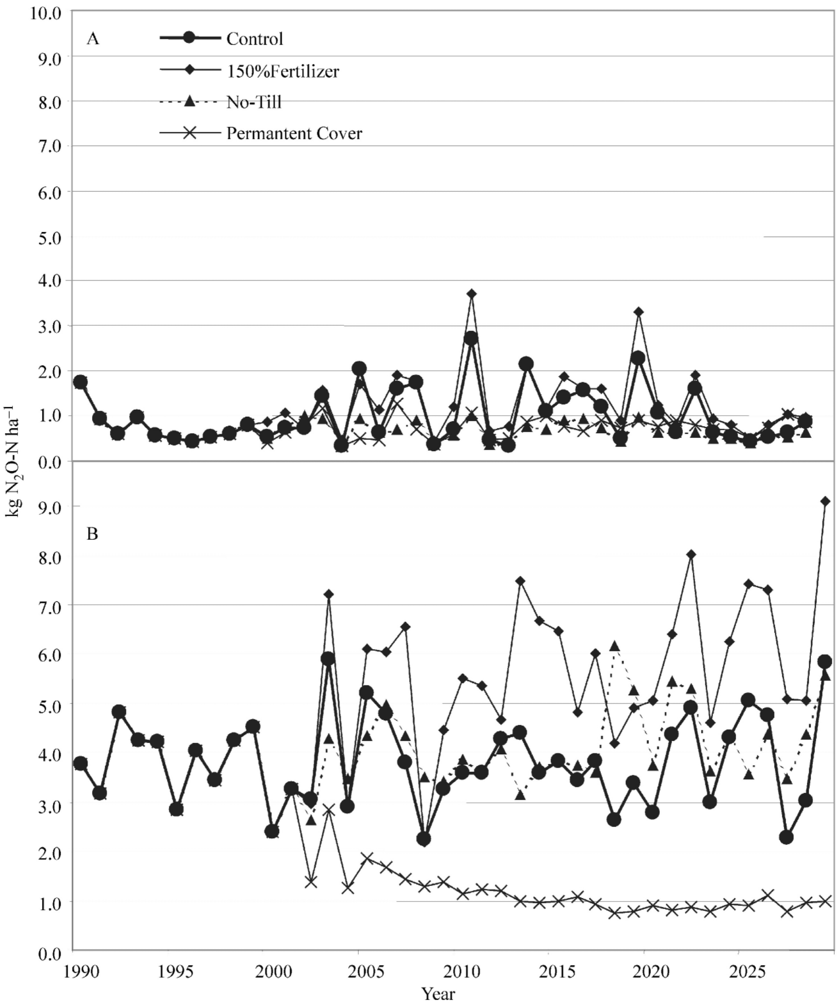

Fig.1 Model estimates of the influence of management changes implemented in the year 2000 on N_2O-N emissions for a Western (A) and Eastern (B) soil (1990—2030)

Table 2 Percent change in N_2O emissions from the control due to changes in management ractices

	Control	No-till	Reduced fallow	150% fert	50% fert	Fall Fert	Add pulse	Perm cover
Brown Chern.	0.68	–34	–37	25	–5	10	–15	–28
Dark Brown Chern.	1.16	–36	–26	24	–7	18	–10	–32
Black Chern.	1.16	–31	–8	47	–18	44	4	–25
Dark Gray Chern.	1.58	–36	–13	34	–12	60	25	–23
Gray Brown Luv.	2.43	15		33	–27		–4	–65
Gray Luv.	1.74	–3	37	22	–17		0	–62
Gleysolic	2.87	6		28	–22		5	–61
		–17	–9	32	–16	34	2	–38

Canada Positive indicates an increase in GHG emissions and negative means a decrease